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

Water quality management in urban catchments of the Swan Coastal Plain

Analysis of the Bartram Road catchment

Looking after all our water needs

Water*Science*
technical series

Report no. WST 22
August 2010

Water quality management in urban catchments of the Swan Coastal Plain

Analysis of the Bartram Road catchment

Department of Water

Water Science Technical Series

Report no. 22

August 2010

Department of Water
168 St Georges Terrace
Perth Western Australia 6000
Telephone +61 8 6364 7600
Facsimile +61 8 6364 7601
www.water.wa.gov.au

August 2010

ISBN 978-1-921675-45-4 (print)
ISBN 978-1-921675-46-1 (online)

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

Disclaimer

Acknowledgements

This project was funded by the Drainage and Waterways Branch of the Department of Water. The Department of Water would like to thank the Water Corporation for providing data for the project. For editing, review and technical advice the Department of Water would like to thank Belinda Quinton, Mischa Cousins and Malcolm Robb, Water Science Branch, Department of Water, Western Australia.

Reference details

The recommended reference for this publication is: Hall, J 2010, *Water quality management in urban catchments of the Swan Coastal Plain: analysis of the Bartram Road catchment*, Water Science Technical Series, report no. 22, Department of Water, Western Australia.

For more information about this report, contact Joel Hall, Water Science Branch, Department of Water.

Cover photograph: View south along Windchime Terrace in the Bartram Road catchment, J Hall (May 2009)

Contents

Appendices

Tables

Figures

Summary

This study investigates and analyses flow and nutrient runoff from the Bartram Road catchment, Western Australia. This catchment was developed using the principle of 'detention and water quality treatment of minor events', as defined in *Australian rainfall and runoff* (I.E.Aust. 1987) During the past decade, the Department of Water has further developed the principle of retaining or detaining 1-in-1 year average recurrence interval (ARI) events within urban catchments.

The study draws from the large dataset associated with the Bartram Road catchment's environmental management plans, which include surface water quality and flow, and groundwater quality and levels collected during the past 16 years. During the 1990s and 2000s, land use in the Bartram Road catchment changed from mostly agriculture and lifestyle blocks to medium-density urban residential blocks (~600 m^2).

The aims of the study were to:

- determine the changes in flow volumes and timing due to urban development
- determine the changes in water quality of discharge
- compare the Bartram Road catchment with a traditionally-drained urban catchment.

Nutrient concentrations – total nitrogen (TN) and total phosphorus (TP) – at the catchment's outlet were generally high to very high, according to classifications taken from the *Statewide river water quality assessment* webpage on the Department of Water's website <www.water.wa.gov.au/idelve/srwqa/>. However, changes in nutrient concentration were evident, due to the changes in land use. For most nutrient species the concentration decreased, but increased nutrient loads were evident post-urbanisation. Phosphorus exported from the catchment was mostly in soluble form due to the low phosphorus retention indices of the soils. Nitrogen consisted mostly of dissolved organic nitrogen and nitrate with relatively small amounts of ammonia.

Approximately 70% of the flow at the Bartram Road buffer lake inflow gauging station (AWRC reference 616083) was baseflow. Flow generally increased over the period studied, and the coefficient of runoff increased, despite a decrease in rainfall. The increases were likely to be a result of the urbanisation of the catchment. There was a general increase in catchment load for nitrogen and phosphorus, despite decreases in concentration and rainfall.

High rates of groundwater flow and associated nutrient loads (approximately 17% of the TP load and 39% of the TN load) highlights the importance of managing groundwater quality as well as surface water quality on the Swan Coastal Plain. This becomes particularly relevant in modern urban catchments, where surface water export is minimised, and larger proportions of the flow are from groundwater than in traditionally-drained urban catchments.

To assess the impact of 'flow rate and volume' management up to the 1-in-1 year ARI event, the Bartram Road catchment's hydrology, as well as nutrient loads and concentrations, were compared with a traditionally-drained urban catchment (South Belmont) which had similar size, rainfall, topography, soil type and nutrient inputs.

Annual catchment water yield for South Belmont was 231 mm, compared with 43 mm for Bartram Road. The Bartram Road catchment exports approximately 30% less load (TN and TP) per unit input load than the South Belmont catchment, despite having much higher export concentrations. The Bartram Road TP concentrations are approximately 3.5 times greater and the TN concentrations approximately twice those of South Belmont.

Comparing the Bartram Road and South Belmont catchments showed that ‘flow rate and volume’ management practices reduced the coefficient of runoff in the Bartram Road catchment and increased nutrient uptake due to the increased detention time for the water. However, the nutrient concentrations exported from the Bartram Road catchment were higher than those from the South Belmont catchment.

The 1-in-1 year ARI event design criterion is effective in reducing catchment loads by managing catchment flows. In addition, due to the timing of loads in ‘new’ urban catchments (minimal export in summer), flows from those catchments are likely to be less degrading to receiving waterbodies than traditionally-drained catchments.

The problem of elevated nutrient concentrations will persist and continue to cause management issues, particularly in local waterways. Further actions are required to address excessive nutrient concentrations in urban waterways.

1 Introduction

This study investigates and analyses flow and nutrient runoff from the Bartram Road catchment, approximately 20 km south of Perth. During the 1990s and 2000s, land use in the Bartram Road catchment changed from mostly agriculture and lifestyle blocks to medium-density urban residential blocks (~600 m^2).

Stormwater management in Western Australia has traditionally focused on flood prevention and control of groundwater levels. Using underground pipes and linear ‘engineered’ overland flow-paths, traditional stormwater systems efficiently convey runoff and groundwater from developed areas to receiving waterbodies. These systems were designed with little consideration of the impacts on those waterbodies. In traditionally-drained built environments, natural water storage in the catchment reduces when floodplains and natural wetlands are filled to allow development. At the same time, paved surfaces deliver water much more quickly to receiving waterbodies or to groundwater stores, and groundwater recharge increases with urban development. Traditional urban drainage results in increased peak discharges, increased runoff volumes and velocities, and decreased response times – all of which can result in more frequent and severe flooding compared with pre-development conditions.

In the late 1980s the concept of water sensitive urban design (WSUD) emerged. For urban planning and design, WSUD provides a framework to address stormwater-related issues including water quality, quantity and conservation. WSUD focuses on stormwater as a valuable resource and its impacts on receiving waterbodies. The concept represents a major shift in drainage design and philosophy, compared with traditionally-designed systems.

WSUD drainage aims to maintain existing hydrological regimes; that is, retain existing natural drainage lines, response times, peak discharges, runoff volumes and runoff velocities. The Department of Water has designed a stormwater management regime around smaller rainfall events, because these represent most of the water managed in a stormwater system. ‘Flow rate and volume’ will be managed up to the 1-in-1 year average recurrence interval (ARI) event, with the following criterion being introduced for assessing urban developments:

> *For the critical 1-year average recurrence interval (ARI) event, the post-development discharge volume and peak flow rates shall be maintained relative to pre-development conditions in all parts of the catchment.*

This criterion is simplified at a local scale: it requires all runoff from constructed impervious surfaces (e.g. roofs or pavements) during rainfall events up to the 1-year 1-hour ARI event to be retained or detained at the first outlet point. This effectively leads to distributed retention/detention (e.g. at or near source infiltration) of small to moderate events throughout the catchment to manage the quantity of urban stormwater before it reaches receiving waterbodies. The Bartram Road catchment was designed to detain up to the one year ARI events in ‘infiltration/treatment’ basins. Although this was consistent with WSUD best practice at the time, during the past decade these principles have been developed further – see the *Stormwater management manual* (DoW 2007).

The traditional conveyance stormwater-drainage system was designed on the assumption that stormwater – as it passed through the urban catchment – would remain 'benign' in nature. However, the built environment has many sources of nutrients (and also non-nutrients) that can contaminate the runoff as it passes through the catchment. Increased flow volumes, peak discharges and velocities usually associated with traditional stormwater conveyance results in significant mobilisation of nutrients and their consequent accumulation in receiving waterbodies (Kelsey et al 2010a).

Nutrient runoff is the main contributor to poor water quality in many natural and artificial waterways in Western Australia (Welker 1995). The problem has been the focus of three Australian Government Coastal Catchment Initiative (CCI) projects on the Swan Coastal Plain: in the Geographe Bay catchment (DoW 2009), the Swan-Canning coastal catchment (SRT 2009) and the Peel-Harvey catchment (EPA 2007). The aim of the CCI projects was to reduce nitrogen and phosphorus in the receiving waterbodies, and to guide investment by identifying cost-effective management actions to limit the transport of nitrogen and phosphorus from the catchment to the estuary and coastal waters. All the CCI projects identified urban land use as a large contributor of nutrient load per unit area – much greater than low-intensity agricultural land uses such as cattle grazing, cropping or mixed grazing (cattle, sheep and/or horses). The reason for the large nutrient load export per unit area was linked to large runoff volumes, high rates of fertilisation and, in many cases, septic tanks. However, most of the urban areas modelled and analysed as part of the CCI projects were traditionally-designed urban systems (WSUD developments are a relatively new phenomena).

This study's purpose is to analyse a catchment that was designed using the Department of Water's WSUD criteria addressing flow-rate and volume (DoW 2007). The analysis involves comparing the catchment's flow and quality of runoff with:

- pre-existing land conditions
- traditional conveyance stormwater-drainage systems for urban developments.

1.1 Project description

The Bartram Road catchment is in the South Jandakot region of the Swan Coastal Plain, and has been part of the South Jandakot Drainage Scheme since 1988. This urban drainage scheme was subject to a number of environmental constraints, and thus a detailed flow and water quality monitoring program was established in the early 1990s. This has resulted in the provision of a continuous high-quality surface water hydrograph between the years 1995 and 2008, weekly surface water sampling and – with the establishment of four groundwater bores – quarterly water level and water quality measurements. All of these data are associated with the environmental management plans that were set for the South Jandakot Drainage Scheme.

1.2 Study objectives

The objectives of this study are to:

- Describe the existing hydrology and water quality of the Bartram Road catchment.
- Determine the changes in flow volumes and timing due to urban development in the Bartram Road catchment. In particular, determine the catchment coefficient of runoff for pre- and post-development land uses. This will involve looking at the various stages of development and how these have changed over time.
- Determine changes in the quality of discharge from the Bartram Road catchment, and compare it with traditionally-drained urban catchments.

1.3 Scope

The scope of this study includes the following tasks:

- undertake literature review of previous studies to understand the monitoring scheme's operation and the site's history
- derive land-use coverages for the period of interest (from pre-development to 2008) through interpretation of aerial photographs
- collate surface water flow and water quality data
- collate groundwater data – groundwater levels and quality
- conduct statistical analysis of groundwater and surface water quality data to determine status, trends and loads
- analyse groundwater levels to determine changes due to urbanisation
- derive catchment coefficient of runoff, pre- and post-urban development
- compare catchment flow and nutrient exports with traditionally-drained urban catchments
- comment on current modelling conceptualisations and possible improvements to future urban design.

1.4 Methodology

Past reports for the monitoring programs and management plans were reviewed. Land-use coverages were determined using the Water Science Branch's land-use coverage data for the years 2000, 2003 and 2007. The land-use categories were assigned nutrient input rates (which were derived from local surveys and literature). Septic tanks were linked to the land-use coverages using the Water Corporation's deep sewer and sewerage infill dataset.

The Water Corporation provided surface water quality data for the Bartram Road buffer lake inflow gauging station (AWRC ref. 616083). The data were placed in a common database alongside flow measurements, and visual analysis of time-series and nutrient concentration was initially undertaken. The analytes of interest were total phosphorus (TP), total nitrogen

(TN), soluble reactive phosphorus (SRP), nitrate/nitrite (NO_x), dissolved organic nitrogen (DON), total Kjeldahl nitrogen (TKN) and ammonia/ammonium (NH_4/NH_3).

Statistical status and trend analysis of data from the Bartram Road buffer lake inflow gauging station includes the analysis of flow and concentration data for 1993 to 2008. A three-year median analysis was performed on the concentration data, and the nutrient status of TN and TP was compared for each of the three-year periods using the *Statewide river water quality assessment* classifications <www.water.wa.gov.au/idelve/srwqa/>. Trends were performed using non-parametric trend tests, and four statistical trend tests were performed for each analyte:

- Mann-Kendall trend test on raw nutrient concentration data
- Mann-Kendall trend test on flow-adjusted nutrient concentration data
- Seasonal-Kendall trend test on raw nutrient concentration data
- Seasonal-Kendall trend test on flow-adjusted nutrient concentration data.

Trend statistics were presented and interpreted. Annual loads were calculated for all nutrient species collected at the Bartram Road buffer lake inflow gauging station using three different load calculation techniques to infill the concentration for days when measurements were not taken:

- locally estimated scatterplot smoothing (LOESS) algorithm
- three-year median concentration
- most-recent sample concentration.

The coefficient of runoff (*CR*) was determined using adjacent rainfall information, and by using LiDAR analysis to determine the catchment boundary. *CR* was determined annually for the period 1996 – 2007, and trends in *CR* were analysed.

Groundwater levels and nutrients were collected at the four groundwater monitoring bores within the Bartram Road catchment. The analytes of interest were TP, TN, soluble reactive phosphorus (SRP), nitrate/nitrite (NO_x), dissolved organic nitrogen (DON) and ammonia/ammonium (NH_4/NH_3). Trends in groundwater levels were identified.

Groundwater levels and nutrient time-series were analysed for trends and for patterns relating to land-use changes. Darcy's equation was applied to determine approximate groundwater load and flow from the catchment. Trends in annual groundwater loads were analysed, and the groundwater loads compared with surface water loads at the Bartram Road buffer lake inflow gauging station.

The Bartram Road catchment was compared with an appropriate traditionally-drained urban catchment on the Swan Coastal Plain (South Belmont catchment). Parameters for comparison included *CR*, input nutrient loads, export nutrient loads per unit input load, and median nutrient concentrations.

2 Why manage for nutrients?

The Swan-Canning, Peel-Harvey and Leschenault estuaries and the Hardy Inlet are vitally important natural resources of the surrounding metropolitan and major regional centres. They are the scenic and recreational hearts of these areas. However, the estuaries have been showing signs of decline during recent decades, with symptoms of eutrophication such as fish deaths, macroalgal and harmful (blue-green) algal blooms and accumulation of organic matter in the bottom sediments. The most notable sign of the decline in health is the increasing frequency and extent of low oxygen or anoxic events.

Algal blooms, which generally occur in the upper reaches of the estuaries, are driven either by the nutrients in catchment inflows, or nutrients that have built up in the sediments and re-mobilised under anoxic conditions. Nitrogen and phosphorus are the most important nutrients for plant and algal growth yet are often limited naturally. Other major nutrients, such as carbon and sulfur, are usually in plentiful natural supply.

2.1 Nutrient export from catchments

Nitrogen and phosphorus exported from catchments to rivers and estuaries occur in both soluble and particulate form (adhered to soil particles) and may be transported in either surface runoff or groundwater discharge. Nitrogen occurs in the environment in several forms, including nitrogen gas, organic nitrogen, ammonium, nitrate and nitrite. Chemical processes cause transformations between these forms. Denitrification is important because it provides a pathway for excess nitrogen in soils to be released into the atmosphere. Studies indicate that soils with high levels of dissolved organic carbon, pH range of 5 to 7 and low redox potential, generally promote denitrification. Bassendean sands, which are prevalent on the Swan Coastal Plain (and in the Bartram Road catchment) have these characteristics and are generally observed to have low levels of nitrate. The plant-preferred form of nitrogen is generally nitrate, which is highly soluble and thus readily leached from the soil profile by water.

In contrast to nitrogen, the phosphorus cycle in soils is relatively simple. Phosphorus occurs as (ortho-) phosphate in soils and is generally strongly bound to soil particles, except in sandy soils (in particular quartz sands such as the Bassendean sands). Phosphorus is lost from the soils in particulate form by surface erosion, and is leached in soluble form.

Large point sources of nutrients, such as discharge from sewerage treatment plants or industry, are generally easy to locate and quantify. Diffuse sources, such as nutrient export from broadscale agriculture or urban areas, are more difficult to quantify.

2.2 Nutrient loads and concentrations and the effect of seasonality

A proportion of the nutrients applied to a catchment will be transported to its receiving waterbody. The mass of the nutrients delivered to a receiving waterbody is referred to as the nutrient export load. In south-west Western Australia, most of the nutrients are delivered to receiving waterbodies during winter, when most of the rainfall occurs.

The nutrient export load delivered to receiving waterbodies in winter does not usually result in immediate algal blooms – the lack of sunlight and cooler temperatures inhibit algal growth. The loads delivered in winter are generally either flushed out to sea, remain in the waterbody, or settle to the bottom sediments. The loads in the sediment can build up over time.

During summer, increased light availability and temperatures and little turbulence can result in ideal growth conditions for phytoplankton. In addition, saline stratification can occur in the estuaries, which can result in de-oxygenation of the lower part of the water column. De-oxygenation leads to the release of nutrients from the bottom sediments, and can lead to algal blooms and fish deaths.

Given the suitable physical conditions described above, nutrient enrichment will promote excessive phytoplankton growth, with higher nutrient concentrations resulting in faster and more severe phytoplankton growth. In summer, the runoff to the estuaries from natural and agricultural catchments is small, with most coming from urban catchments (traditionally-drained). As conditions are often favourable for algal growth in summer, inflows from urban areas at this time of year have the potential to promote algal activity.

To manage waterways for nutrients, total loads and summer concentrations should be minimised. In winter, it is more important to manage catchment loads than concentrations, because the receiving waterbodies are unlikely to respond to nutrient concentrations. Reduction of winter (and total) loads would reduce the amount of nutrients in the sediments and their concentrations in receiving waterbodies when the warmer months begin (summer and autumn). If most summer events are captured, the hydrology would be similar to the natural state with little summer discharge to receiving waterbodies, thus reducing the impacts of these high-concentration inflows.

3 Catchment description

3.1 Setting

The Bartram Road catchment is approximately 20 km south of Perth, on the Swan Coastal Plain, 8 km east of Cockburn Sound. The catchment's location is shown in Figure 3.1 with a 2008 aerial photograph. The land is found within a topographic catchment that sheds naturally to a chain of lakes that form a major part of the Beeliar wetlands system. Specifically, Bartram Road catchment drains naturally to Thomson Lake, which is an environmentally significant wetland, and is protected under the Ramsar convention (DEC 2007). Urban development (mainly residential) has occurred in the catchment since the early 1990s, and is now the dominant land use. The progression of urban development from 2000 to 2008 can be observed through aerial photograph analysis (see Appendix A).

The Bartram Road catchment is relatively flat, with an elevation ranging from 20 – 45 mAHD. The land generally slopes from west to east, and is characterised by small sand dunes and low-lying inter-dunal depressions. The catchment has a high watertable, and contains a number of wetlands that are seasonally inundated.

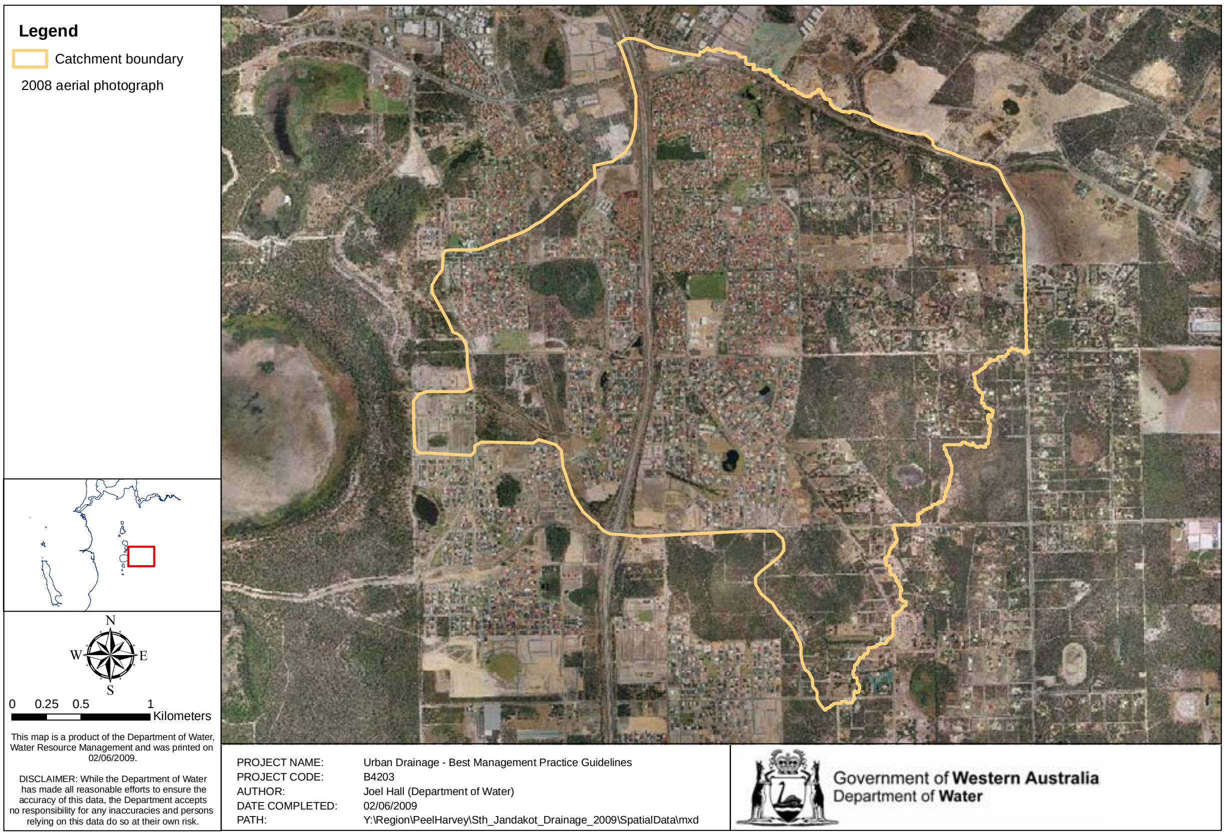


Figure 3-1: *Catchment boundary and location of the Bartram Road catchment*

3.2 Drainage

Details of the drainage design are outlined in the *South Jandakot drainage management plan* (Hill 1990). The drainage plan was designed to meet environmental objectives for the Beeliar wetlands (maintain water levels and quality in the receiving lakes), while addressing flood prevention for urban areas. The topography and drainage (including constructed and natural wetlands for internal drainage) are shown in Figure 3-2. The drainage in Figure 3-2 includes that outlined in the drainage plan (Hill 1990) and that of the local government authority (City of Cockburn). The urban developments are generally drained using subsurface drainage, which is conveyed to a variety of internal waterbodies. The subsurface drains are not mapped in Figure 3-2 and accurate mapping of subsurface drainage is generally not available.

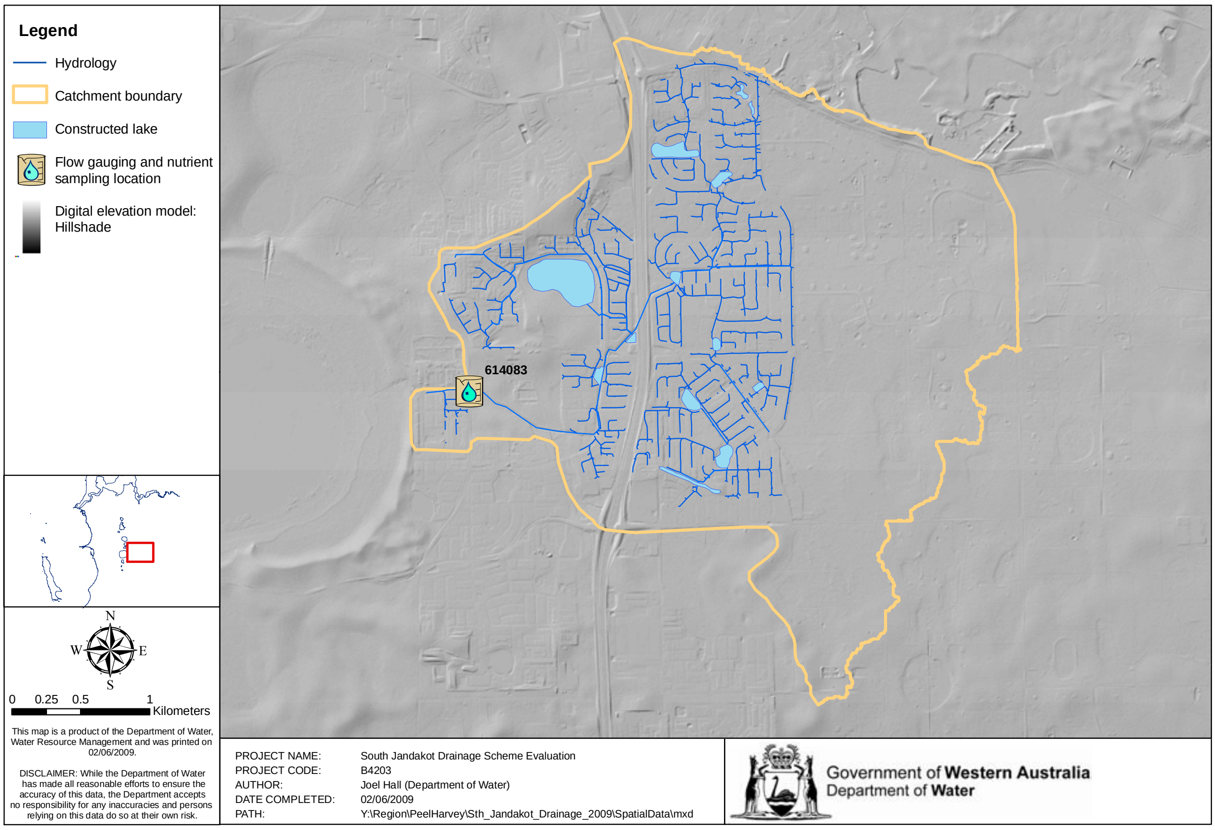


Figure 3-2: *Drainage network and topography of the Bartram Road catchment*

Waterbodies that capture most of the drainage from the urban runoff include constructed lakes surrounded by concrete walls (Figure 3-3); constructed lakes that maintain natural fringing vegetation and parklands, and function partly as natural wetlands (Figure 3-4); constructed lakes that form a drainage sump in low-lying regions of parklands (Figure 3-5); and natural wetlands (which generally dry out in summer) with maintained vegetation and board-walks and picnic areas around them (Figure 3-6).

Figure 3-3*: Constructed lake in public open space, with features including concrete-lined walls and aeration fountain*

Figure 3-4*: Constructed lake with remnant wetland features (reeds and vegetation), combined with parkland and public open space*

Figure 3-5: *Constructed lake in the catchment's north-east which is effectively a large drainage sump in a low-lying region of a park*

Figure 3-6: *Remnant wetland used as a drainage waterbody, complete with remnant vegetation, board-walks and picnic areas*

Figure 3-2 shows the connectivity of all drainage areas within the Bartram Road catchment. However, surface water will only connect during large rainfall events. During regular events (less than 1-in-1 year) the surface runoff from most regions of the catchment will drain to the constructed lakes/wetlands. The catchment is hydrologically connected throughout winter by way of groundwater. It is evident from the hydrograph at the Bartram Road buffer lake inflow gauging station that most of the flow exiting the catchment is groundwater flow (see Section 5.3 for details).

3.3 Land use and vegetation

Land use in the Bartram Road catchment has changed dramatically during the past decade. It shifted from mostly rural and lifestyle blocks to medium-density residential blocks after the Kwinana Freeway was constructed through the catchment's centre. Little change has occurred on the catchment's eastern fringe, while its north-east comprises lifestyle blocks approximately 2 ha in size.

Land use for the years 2007, 2003 and 2000 has been mapped using cadastral parcels and aerial photographs, and is shown in figures 3-7, 3-8 and 3-9 respectively.

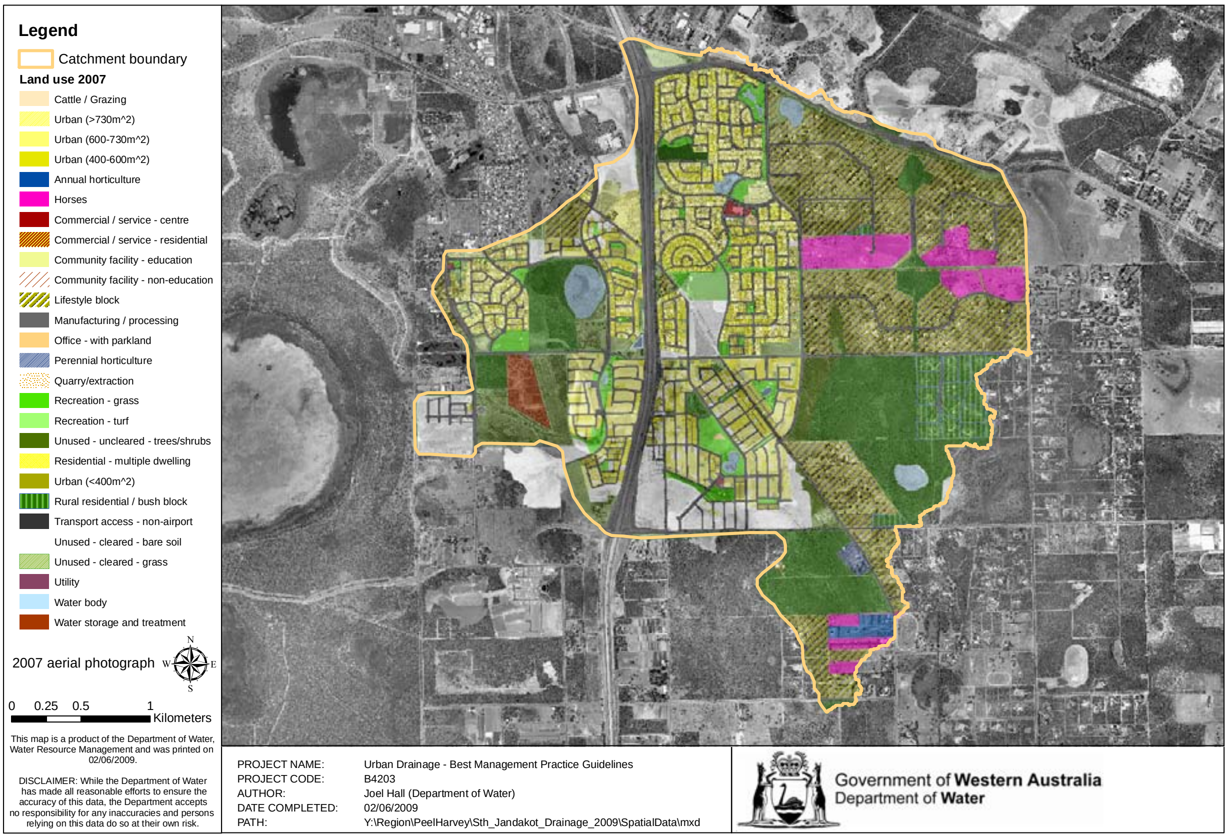


Figure 3-7: *2007 land use in the Bartram Road catchment*

Many of the lifestyle blocks support small-scale agricultural/horticultural activities or are used for horses. The catchment's western and central portion is primarily zoned urban residential (mostly R20, but ranges between R5 to R160). Analysis of the 2000 and 2003 land-use maps shows the southern residential zone was used for agricultural purposes until urban development began between 2000 and 2003. A portion of the catchment in the south-west, near the gauging station, was historically used for horticulture and horse stables, but this has also undergone urban development in recent years.

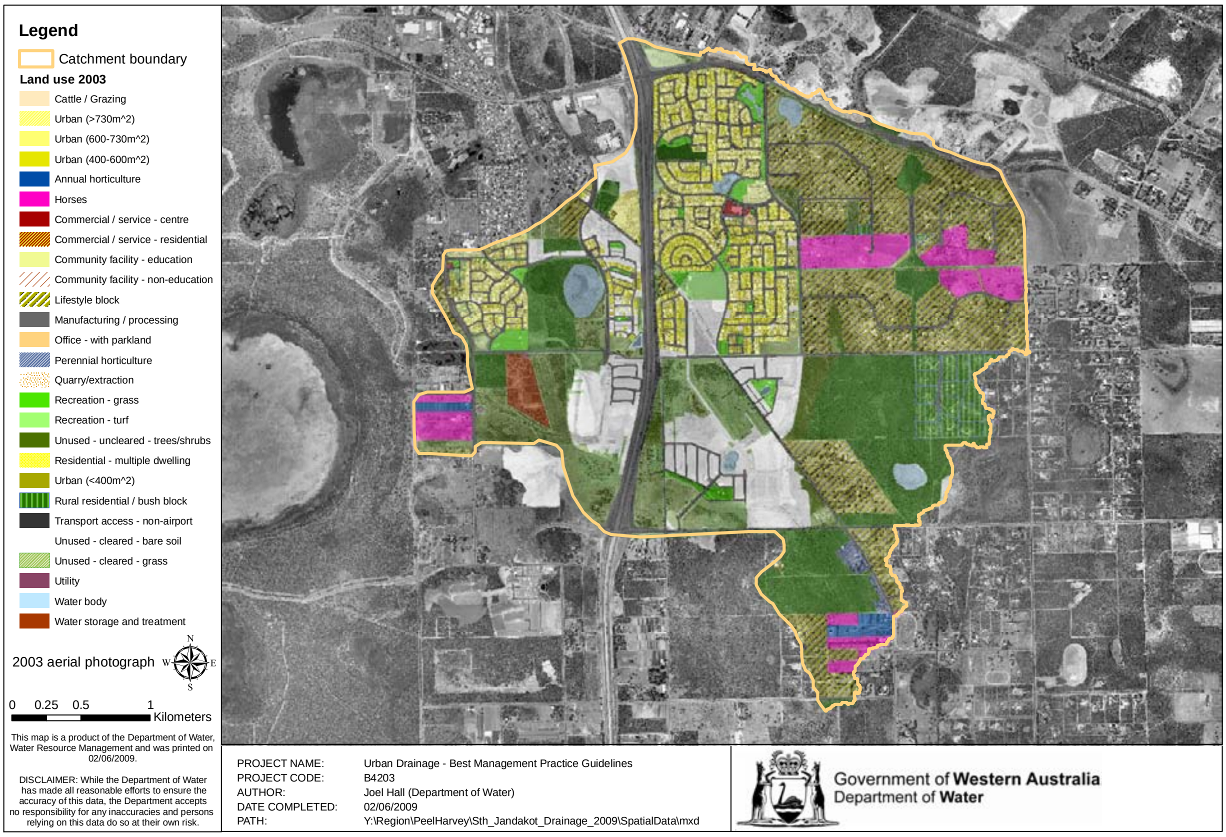


***Figure 3-8**: 2003 land use in the Bartram Road catchment*

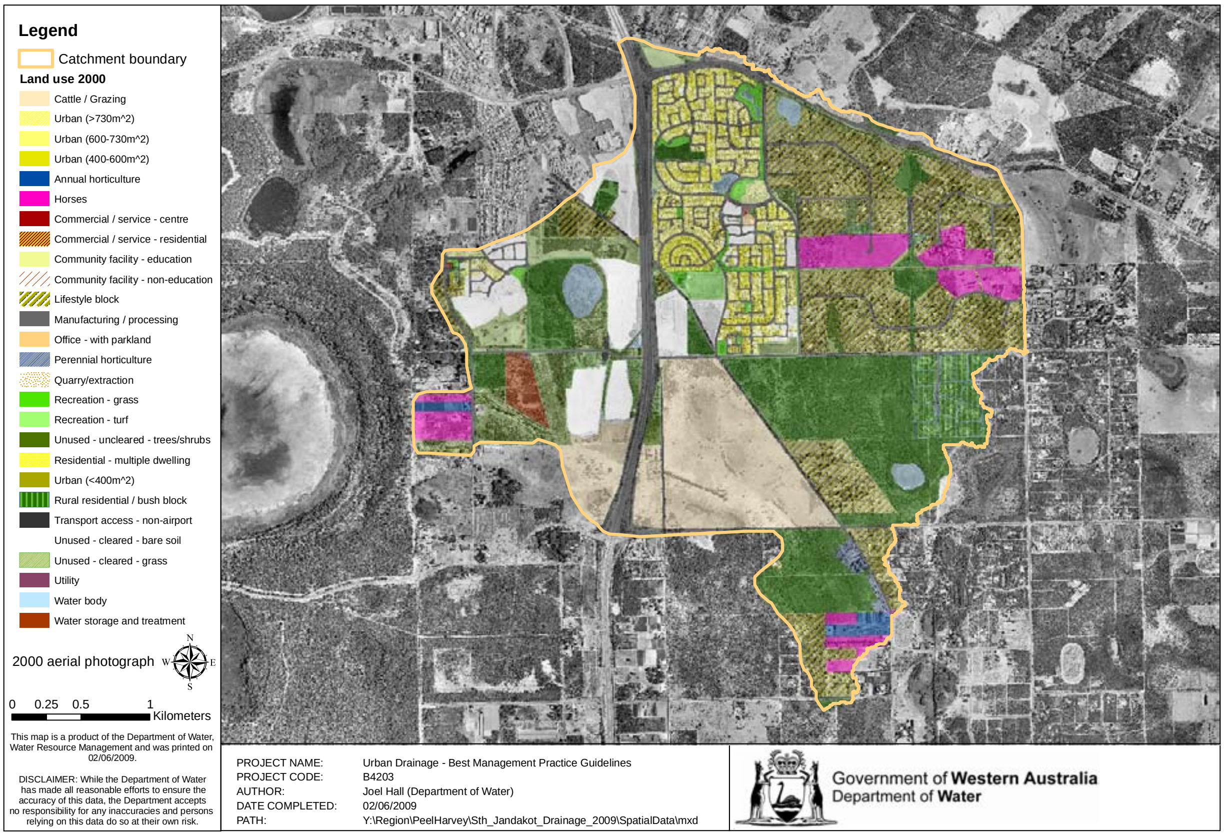


***Figure 3-9**: 2000 land use in the Bartram Road catchment*

The rate of urban expansion in the catchment has been rapid: within two decades most of it has been transformed from agricultural activities and lifestyle blocks to urban residential land uses.

Figure 3-10 shows where septic tanks are found in the Bartram Road catchment, and where deep sewerage is connected, according to the Water Corporation's deep sewer and sewerage infill dataset. All new residential blocks are connected to deep sewerage, and septic tanks are limited to lifestyle blocks. One hundred and sixty septic tanks were identified in the catchment, mostly associated with lifestyle blocks in the catchment's east; as such, this amount of septic input has remained relatively constant during the past two decades.

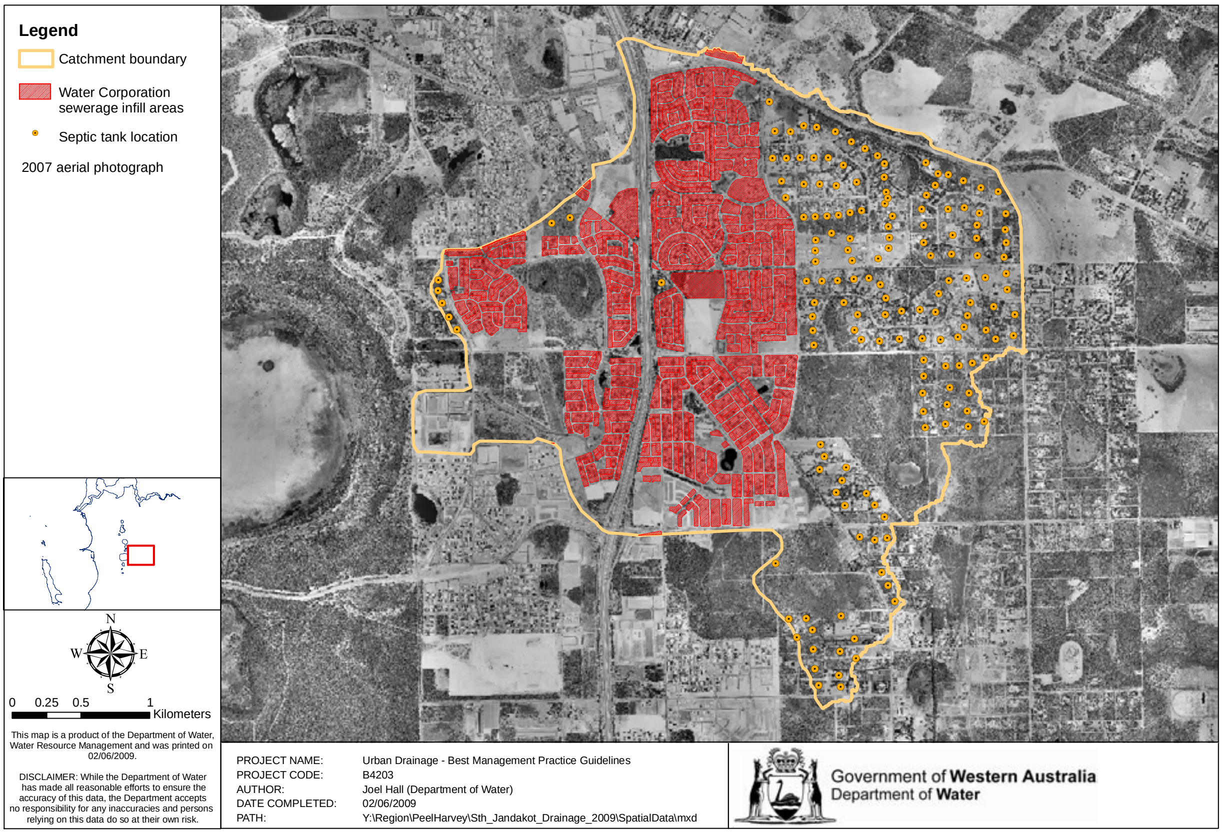


Figure 3-10: *Septic tank locations and regions connected to deep sewerage in the Bartram Road catchment*

3.4 Soil type

The Bartram Road catchment lies entirely on Bassendean sands. Bassendean sands are pale grey to white, moderately sorted, fine- to medium-grained quartz sands with traces of heavy minerals (Deeney 1989). The grains tend to be sub-rounded to rounded quartz that commonly has an upward fining progression in grain size (Davidson & Yu 2008). A layer of friable, mostly weakly limonite cemented sand known as 'coffee rock' is commonly present at or near the watertable.

Quartz sands, such as the Bassendean sands, have a very low ability to adsorb phosphorus, and hence are generally associated with very low phosphorus retention indices (PRI). As such, soluble phosphorus such as superphosphate, or phosphates associated with septic leaching or many non-organic garden fertilisers, will move freely through the soil matrix and into the groundwater. Figure 3-11 displays the surface geology (soils) for the Bartram Road catchment.

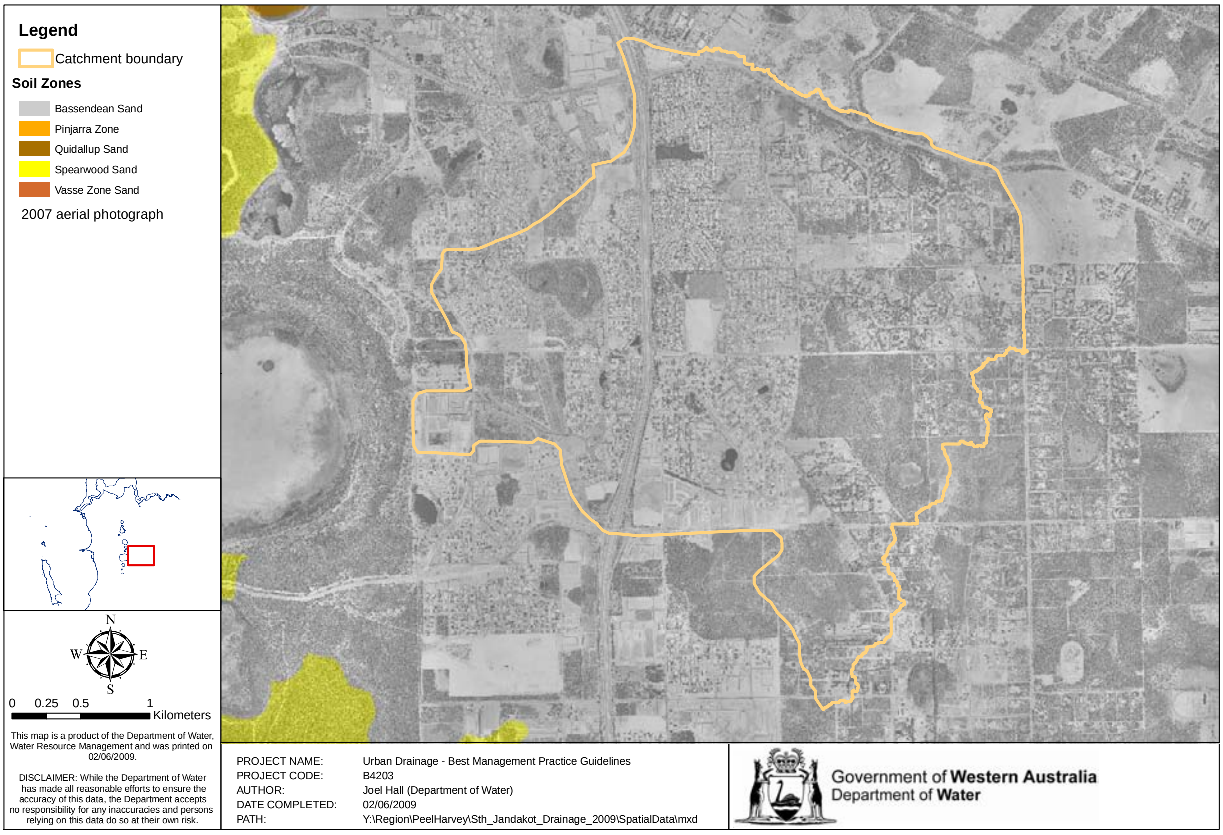


Figure 3-11: *Surface soil map of the Bartram Road catchment, showing Bassendean sands as the dominant soil type*

Figure 3-12 shows the PRI for the surface soils of the Bartram Road catchment. The PRI map is not completely consistent with the Bassendean sands soil map – there is not a single PRI value for all Bassendean sands. This is due to some regions of Bassendean sands within the Bartram Road catchment containing swamp deposits, or low-lying depressions that collect more clays and organic particles than the dunal ridges. The higher dune systems are generally coarse-grained and well-sorted sands and are more likely to have a lower PRI.

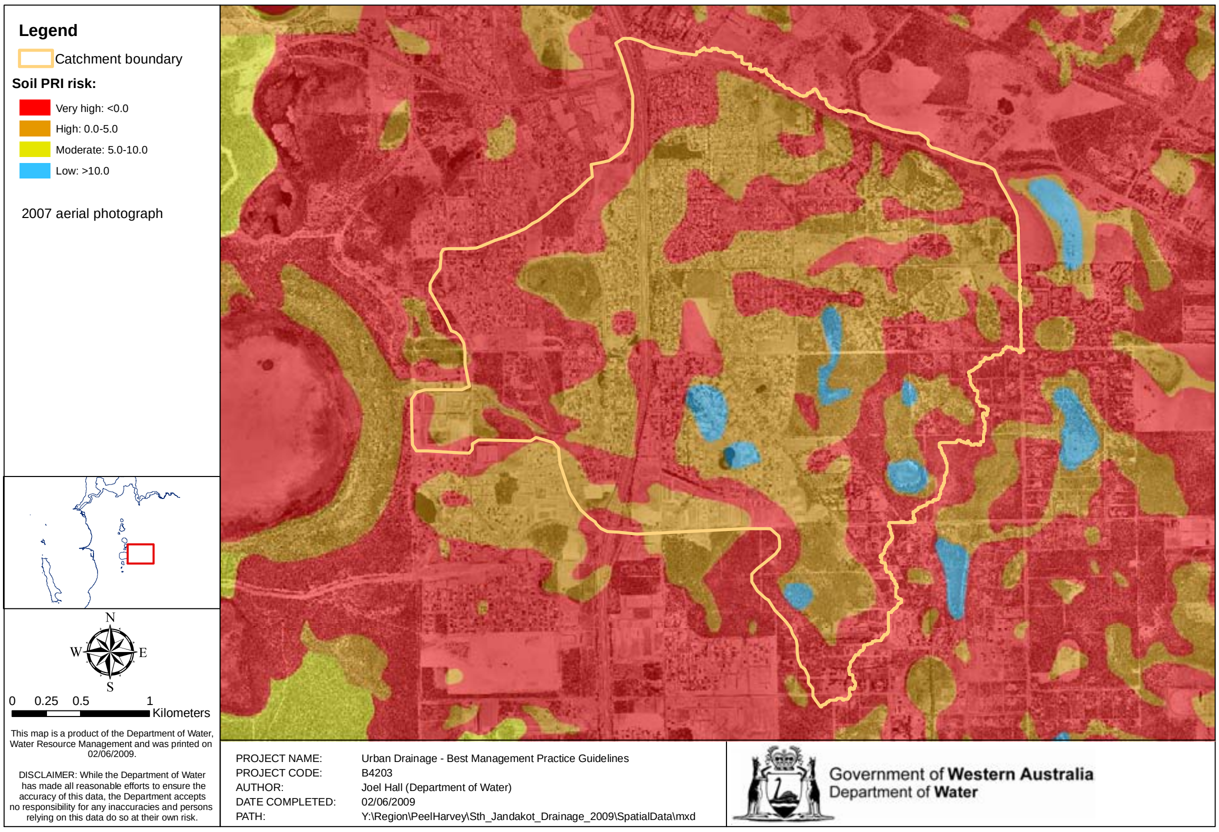


Figure 3-12: *Soil phosphorus retention index (PRI) map of the Bartram Road catchment*

3.5 Flow gauging and nutrient sampling

The rationale for monitoring of the South Jandakot Drainage Scheme is outlined in the environmental management program (EMP) (Hill 1991). Since 1993 the Water Corporation has implemented a monitoring program in accordance with the EMP. The EMP stated that all surface and subsurface drainage from the proposed development would be routed though buffer lakes (natural and constructed wetlands). The performance of the buffer lakes was to be monitored to determine nutrient/pollutant loads in the discharged drainage water and to assess the acceptability for discharge to Thomson Lake. The buffer lake monitoring program was designed to be undertaken at Bartram Road, with sampling conducted weekly for seven to 10 years. Gauging station 616083 was installed at the Bartram catchment's outlet to monitor and measure the performance of the buffer lake immediately downstream; hence the name of the gauging station is 'Bartram Road buffer lake inflow' (Figure 3-2). However, for the purpose of this report, the station was used to monitor the flow and nutrient loads exported from the Bartram Road catchment (the buffer lake's performance not being the focus). The gauging station consists of a v-notch weir and float-well to measure stage height (Figure 3-13). The construction of the station and relatively large head drop between the upstream and downstream levels of the weir means the flow readings are likely to be reliable.

Figure 3-13: *Bartram Road buffer lake inflow gauging station (616083)*

Groundwater levels and quality were monitored as part of the EMP, and a groundwater monitoring program for the South Jandakot Drainage Scheme has been in place since 1993. Groundwater levels and nutrients were collected at the four groundwater monitoring bores within the Bartram Road catchment (Figure 3-14). Groundwater was monitored quarterly or monthly, with the analytes of interest being TP, TN, soluble reactive phosphorus (SRP), nitrate/nitrite (NO_x), dissolved organic nitrogen (DON) and ammonia/ammonium (NH_4/NH_3).

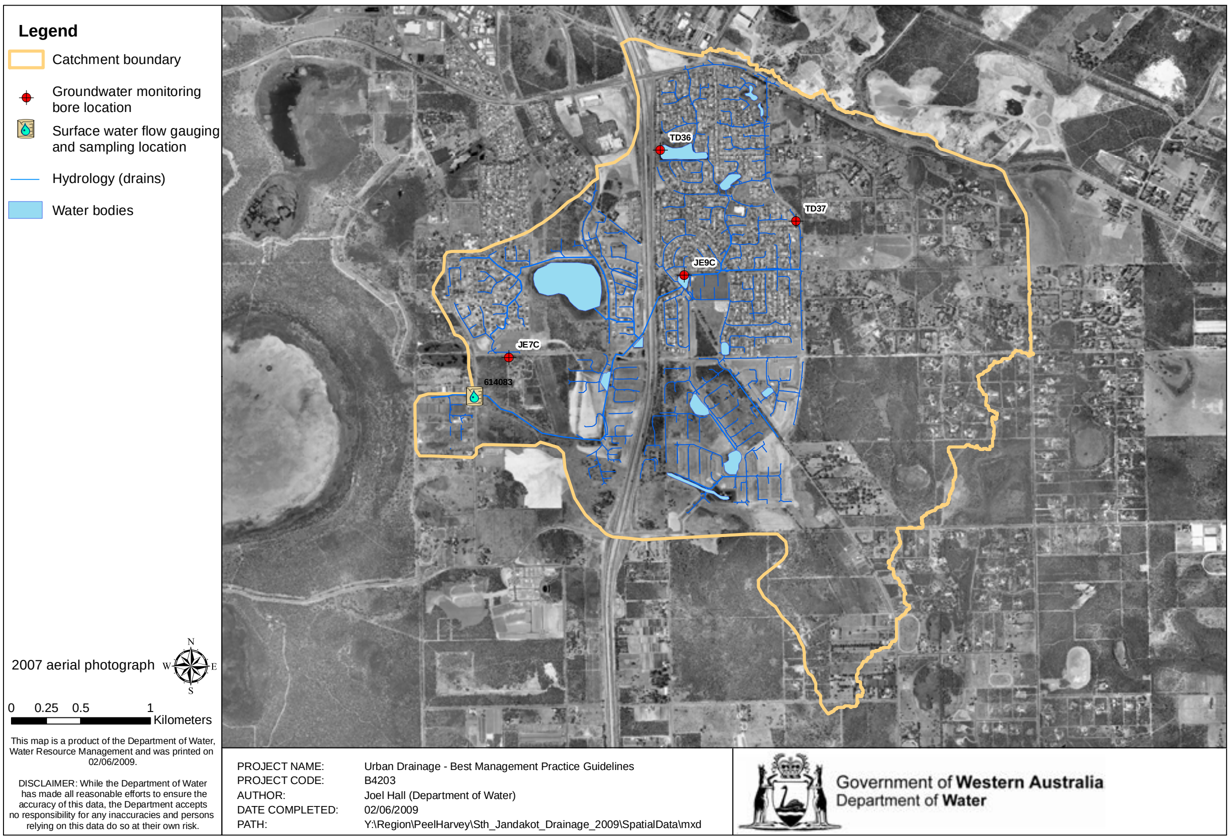


Figure 3-14: *Groundwater monitoring bore locations and the surface water flow gauging and nutrient sampling location in the Bartram Road catchment*

4 Literature review

The Bartram Road catchment is a subset of the South Jandakot Drainage Scheme. The scheme was developed in response to a 1998 Western Australian Planning Commission (WAPC) proposal to rezone land in the South Jandakot area for urban development and a parks and recreation reserve. Development in the area was approved by the then Minister for Environment subject to a number of conditions placed on the WAPC.

A drainage management plan and an environmental management plan were completed in 1990–91 and reviewed in 1992–93. In subsequent years monitoring reports were completed by various consultancy agencies on behalf of the Water Corporation. Reports detailing the data collection, analysis or review of the program were completed for the years 1993, 1994–95, 1998, 1999, 2001, 2003 and 2004.

A chronological review of the above-mentioned reports, which range from the 1998 water quality monitoring program report to the 2004 development compliance report, is presented below. Key aspects of the reports are highlighted, with respect only to the Bartram Road catchment:

***Thomsons Lake water quality monitoring program*, 1988 LeProvst, Semeniuc and Chalmer, Environmental Consultants** (LeProvst et al. 1988)

Key aspects: Review of existing information in the catchment including management and recommendations. Summary of the proposed drainage, sumpage and pumpage, and report on the desirable environmental conditions. Completion of a rationale for monitoring, including sites, times and parameters.

Key conclusions: Concerns about the effects of nutrients and a rise in water level in Thomson Lake were raised by the Environmental Protection Authority (EPA) before development. No flow or groundwater data is available in the Bartram Road catchment at this date, and six monitoring bores are monitored monthly for water level in the entire South Jandakot area. Limited water quality data is collected in Thomson Lake, and none from the Bartram Road catchment.

***South Jandakot drainage management plan,* 1990, GB Hill & Partners Pty Ltd** (GB Hill & Partners 1990)

Key aspects: Overview of the drainage plan, urban drainage requirements, and protection plans for the wetlands, including water level and quality management. The staging of the urban development and drainage scheme is proposed, and impacts on water resources reviewed.

Key conclusions: The study concludes that the area can be adequately drained for urban development, stating that '*the quality of the water entering the wetlands will be improved as a result of the proposed urban development'*, and that the drainage system will meet the environmental objectives of controlling lake water levels and water quality. The study recommends the development of the Bartram Road buffer lake and diversion of the Hammond Road drain. The staging of the development and drainage is outlined.

***Environmental management program of the South Jandakot Drainage Scheme*, 1991, GB Hill & Partners Pty Ltd** (GB Hill & Partners 1991)

Key aspects: Monitoring program design for surface water, groundwater and flow is established. Monitoring costs are calculated and subsoil drainage recommendations included. Wetland monitoring was proposed, as well as intensive buffer lake monitoring.

Key conclusions: Design of the monitoring program for the Bartram Road buffer lake inflow was determined, as well as the monitoring program for the groundwater bores within the Bartram Road catchment. The establishment of the weekly monitoring program at the Bartram Road buffer lake was the beginning of the dataset used in the analysis for the current study. Collected samples at Bartram Road buffer lake inflow included filterable reactive phosphorus, TP, total Kjeldahl nitrogen, nitrate plus nitrite as nitrogen, and ammonia.

***South Jandakot drainage management scheme: report by the Technical Review Committee*, 1993, Environmental Protection Authority** (EPA 1993)

Key aspects: Reports on construction of the Bartram Road buffer lake in 1993, establishment of the bores in the area in 1993, load and concentration calculations and comparisons with previous levels.

Key conclusions: Hydrographs indicate that flow to the Bartram Road buffer lake is dominated by the groundwater entering the drain rather than surface water. TP concentrations are similar to those previous and very high (between 0.348 and 0.517 mg/L). TP load was estimated to be 189 kg of phosphorus for July to October 1993, and TN load was estimated to be 1136 kg for the same period (with concentrations generally between 2.25 and 3 mg/L). A report was required at the end of 1995, which was to include a full review of the effectiveness of the EMP. Groundwater levels and surface flow rates were considerably lower than the previous year, reflecting the low rainfall year of 1993.

***Bartram Road inflow nutrient source monitoring*, 1994, Asset Monitoring Services, South Perth Region** (Asset Monitoring Services 1994)

Key aspects: The objective was to determine the source of the nutrients to Bartram Road buffer lake by means of surface water sampling. Six surface water sites were outlined for measurement in the Bartram Road catchment.

Key conclusions: TP concentrations at the Bartram Road buffer lake ranged from 0.466 – 0.558 mg/L over the period, and TN ranged from 2.48 – 2.83 mg/L. The report was fairly inconclusive due to the lack of flow at five proposed surface water sampling sites. The only flowing tributary site measured recorded high nutrient-concentration values, 0.305 – 0.627 mg/L for TP and 2.0 – 2.3 mg/L for TN.

***Stormwater runoff study for catchments of the Southern Beeliar Lakes,* 1993, GB Hill & Partners Pty Ltd.** (GB Hill & Partners 1993)

Key aspects: The report reviewed the catchment's rainfall and drainage hierarchy and modelled its drainage, including surface runoff, subsurface drainage and detention basins. The study was undertaken to estimate drainage flows.

Key conclusions: The report gives average rainfall intensities for durations up to 72 hours. For a 24-hour period, the 1-in-1 year event is 1.9 mm/hr, the 1-in-5 years is 3.29 mm/hr and 1-in-100 years is 5.82 mm/hr. Estimates of drainage flows for extreme events were determined to enable preliminary design of the major features of the catchment's drainage system.

South Jandakot EMP monitoring – annual data report, 1995, Asset Monitoring Services (Asset Monitoring Services 1996)

Key aspects: Data collection report only, giving the data collection tables; no interpretation or load calculations.

South Jandakot Drainage Scheme – scheme monitoring report for 1998, 2000, **Acacia Springs Environmental** (Deeley 2000)

Key aspects: Outline of the monitoring program for surface water and groundwater, presentation of the results for 1998, comparison with past results.

Key conclusions: Bartram Road buffer lake has attenuated flows and nutrient loads, with reductions of 15% for TN and TP in the outflow compared with inflow loads. Inflow loads were calculated to be 300 kg for TN and 55 kg for TP. TN concentrations were highest at the end of July, decreasing through to September. For TP, the highest concentrations were observed from July to August. In most cases, soluble phosphorus accounted for more than 70% of TP at the Bartram Road site.

Southern lakes drainage scheme, report on emergency relief, **1999, GHD Pty Ltd** (Norrish 1999)

Key aspects: Report plans for an emergency relief from Yangebup Lake to Kogolup Lake under extreme events (1-in-100 year), with the aim to prevent flooding of houses.

Key conclusions: A formal piped emergency relief is required to reinstate the natural overflow that occurred from Yangebup Lake to Kogolup Lake. The relief pipe is requested to be included in the works scheduled for construction in 1999–2000.

South Jandakot Drainage Scheme – review of the current monitoring program, 2001, Acacia Springs Environmental (Deeley 2001)

Key aspects: Reviews aims and actions of the monitoring program, proposes alterations, addresses gaps in what has been reported or monitored, and looks at the adequacy of the plan. Also comments on a performance assessment of the South Jandakot Drainage Scheme and recommends changes to the monitoring plan.

Key conclusions: Collection and storage of data is satisfactory. Flaws in the plan include a failure to account for groundwater volumes and nutrient loads, or plans to reduce groundwater throughflow. For the Bartram Road buffer lake inflow site, it is proposed that grab samples be taken during storm events.

South Jandakot Drainage Scheme monitoring program – monitoring report, 2003, Glenwood Nominees Pty Ltd (Glenwood Nominees 2005a)

Key aspects: Report analyses the data collected for 2003 and whether the process was in accordance with the EMP. Compares data from previous years and identifies emerging trends.

Key conclusions: The Bartram Road buffer lake failed performance requirements, although the report stated it surpassed them when using daily export figures for 2003, which is a questionable analysis. Nutrient concentrations in surface water in the Bartram Road buffer lake remain relatively stable when corrected for flow. The monitoring program was sufficiently implemented to enable the calculation of nutrient loads and provide a good indication of water quality and trends. The report recommended the groundwater monitoring program be reviewed and updated.

***Development compliance report for the South Jandakot Drainage Scheme environmental management program*, 2004, Glenwood Nominees Pty Ltd** (Glenwood Nominees 2005b)

Key aspects: Summarises the data collected in 2004 and concludes the level of compliance with monitoring commitments and infrastructure development outlined in the EMP. Analyses data in conjunction with results reported in previous annual reports and identifies significant trends. Determines whether performance criteria are being met and comments on the statistical significance of results or trends.

Key conclusions: The Bartram Road buffer lake surpassed the requirement of 20% phosphorus attenuation and 50% reduction in nitrogen. Water quality characteristics in groundwater bore TD38 are closer to the buffer lake than they are to JE7C, indicating that the lake may be recharging the local watertable. Long-term trends indicate an overall reduction in the concentration of nutrients in the shallow groundwater.

5 Data analysis

5.1 Nutrient status

The TN and TP concentrations at the Bartram Road buffer lake inflow gauging station (616083) are described in terms of the nutrient classifications shown in Table 5-1, which are from the *Statewide river water quality assessment* webpage on the Department of Water's website <www.water.wa.gov.au/idelve/srwqa/>.

Table 5-1: *Classifications used to assess the status of TN and TP concentrations in monitored waterways*

Status	Total nitrogen (mg/L)	Total phosphorus (mg/L)
Very high	> 2.0	> 0.20
High	1.2 - 2.0	0.08 - 0.20
Moderate	0.75 - 1.2	0.02 - 0.08
Low	< 0.75	< 0.02

Depending on trends, chance sampling and sources of natural variation, the nutrient concentrations sampled from a monitored site will change. The nutrient status for a waterway is initially assigned using the median nutrient concentration for the first year of sampling. Subsequent status periods are assessed using the median and 90% confidence interval. If the median or all or part of the confidence interval remains in the earlier classification band, then there is no change in status. Status only changes once both the median and entire 90% confidence interval move to a different classification band.

Figure 5-1 shows how TP status at Mayfields Main Drain (in the Peel-Harvey catchment) was originally classified as high (the median was between 1.2 and 2.0 mg/L). By the 1992–94 period, the median had decreased and fallen within the moderate classification band (0.75–1.2 mg/L); however, part of the 90% confidence interval was still in the high classification band and so the status remained high. In the 1994–96 period, both the median and 90% confidence interval fell below the high classification and hence the status changed to moderate. During the 1996–98 period the median once again dropped to a lower classification band (<0.75 mg/L); however, it wasn't until the 1998–2000 period that the actual classification status changed to low.

In summary, the nutrient status for a waterway is assigned by using the median of nutrient concentration over a three-year period. The three-year period is used to diminish the influence of natural variation between years. Change in status requires the median and whole 90% confidence interval to be within the new status concentration range. For the Bartram Road buffer lake inflow (616083), the most recent period of analysis (2006, 2007 and 2008) was used to determine current nutrient status, based on the technique outlined above.

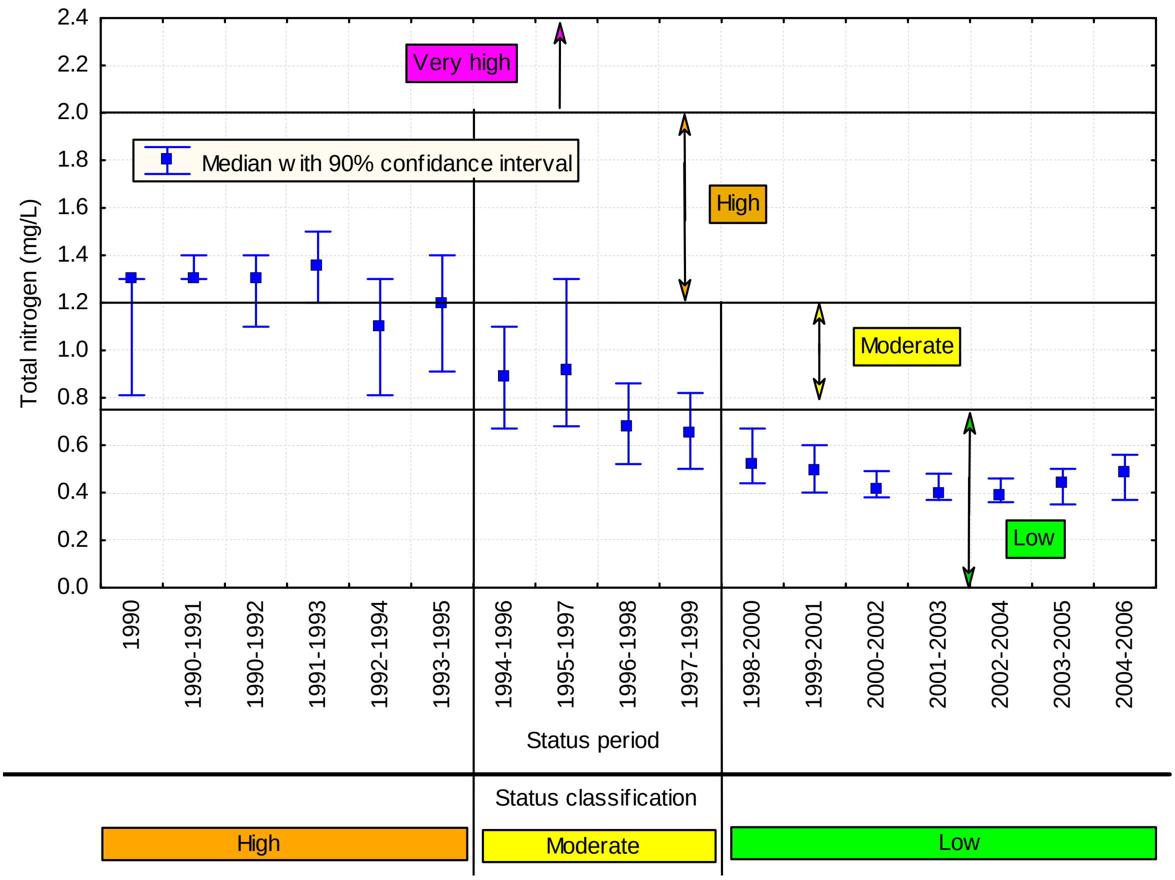


Figure 5-1*: Total phosphorus status classification for Mayfields Main Drain (AWRC 613031)*

5.1.1 Nutrient run-down

There is a lag between nutrient applied to the land being expressed in the waterways, which is due to the buffering of soil and vegetation stores. Applied nutrients (from fertilisation, animal waste or septic leachate) may also be assimilated into the soil profile or, in the case of nitrogen, lost to the atmosphere. The Bartram Road catchment is relatively small (11 km^2) with sandy soils and a high watertable, and the time for applied nutrients to reach the waterways is likely to be about five to 10 years (R. Summers, pers. comm. 2008).

Thus, the nutrients measured in the catchment's waterways are associated with the land uses of the previous five to 10 years, so a polluting land use from 1995 is still likely to be contributing nutrients in the waterways in 2000. Nutrient run-down makes it very difficult to attribute waterway nutrient loads to a particular land use for a particular year. However, it is likely that the fertiliser applied in the catchment in 1990 is not being expressed post-2000, so the pre-urbanisation rural land uses in the Bartram Road catchment are not likely to have a significant effect on the nutrient concentrations and loads measured in recent years.

When relating nutrient load or concentration measurements from a surface waterbody to the associated land use in the catchment, nutrient run-down and hence previous years' land uses in the catchment must be considered.

5.1.2 Total phosphorus (TP)

The three-year median concentrations and observed values for TP are shown in Figure 5-2. According to classes taken from the *Statewide river water quality assessment* webpage, TP concentrations are classified for three-year status periods from 1993 to 2008. The values of the three-year medians vary from 0.32 mg/L in 2002–04, 2003–05 and 2006–08, to 0.58 mg/L in 1996–98. Between the years 1997 to 2008 the annual three-year medians appear to be quite stable. The much higher values in the years 1993 to 1998 are likely to be reflecting the pre-urbanisation land conditions.

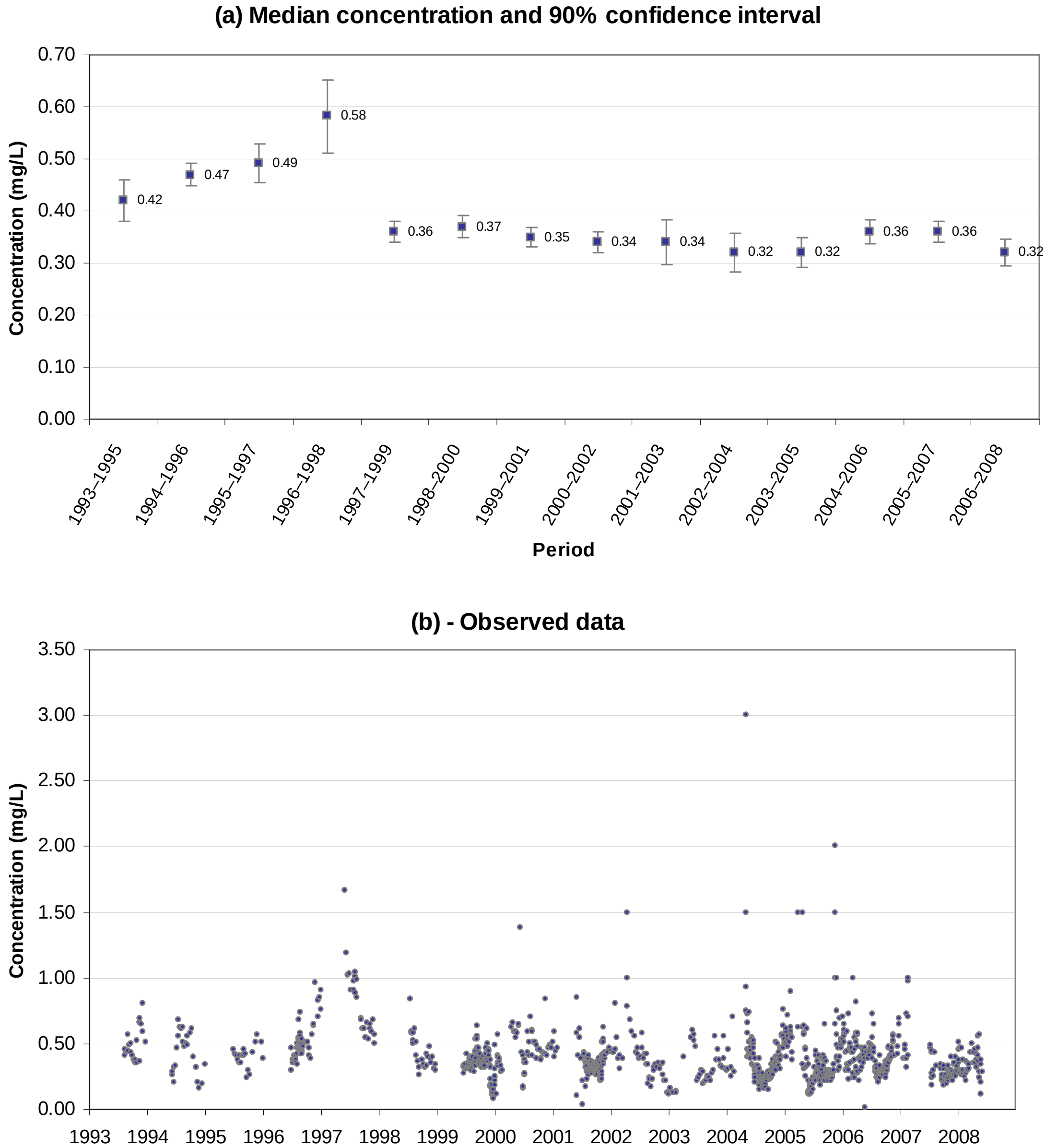


Figure 5-2: *Three-year median total phosphorus concentrations and 90% confidence intervals (a), and observed total phosphorus concentration data (b)*

5.1.3 Soluble reactive phosphorus (SRP)

The three-year median concentrations and observed values for SRP concentration samples are shown in Figure 5-3. The values of the three-year medians vary from 0.22 mg/L in 2003–05 to 0.55 mg/L in 1996–98. The trends in the SRP concentrations are closely related to the TP trends, as greater than 60% of the TP is composed of SRP. This is reflective of the soil type, which has a very poor ability to adsorb soluble phosphorus. As with TP, there are higher values during the years 1993–98 for SRP, which is likely to be reflecting the pre-urbanisation land conditions.

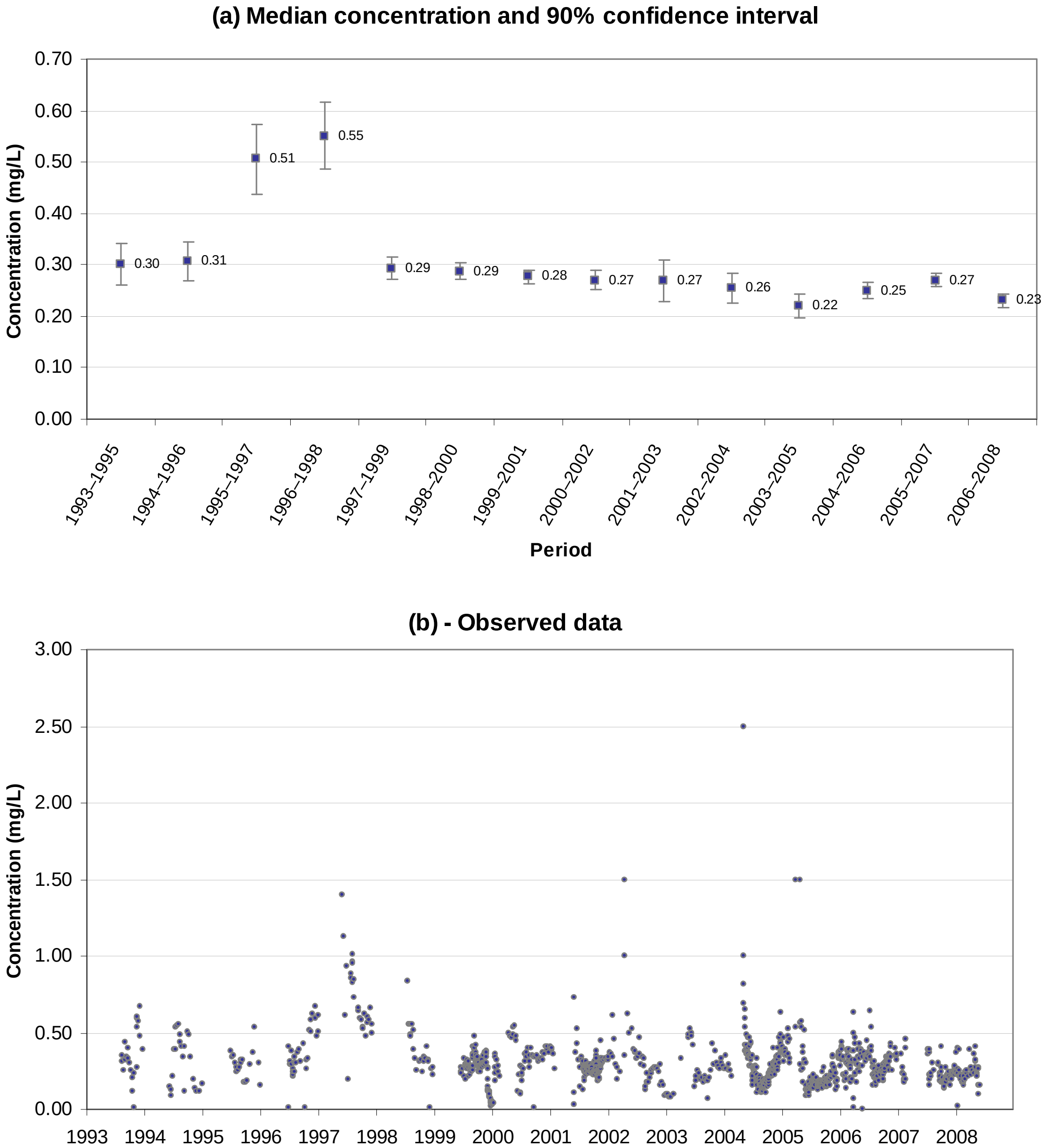
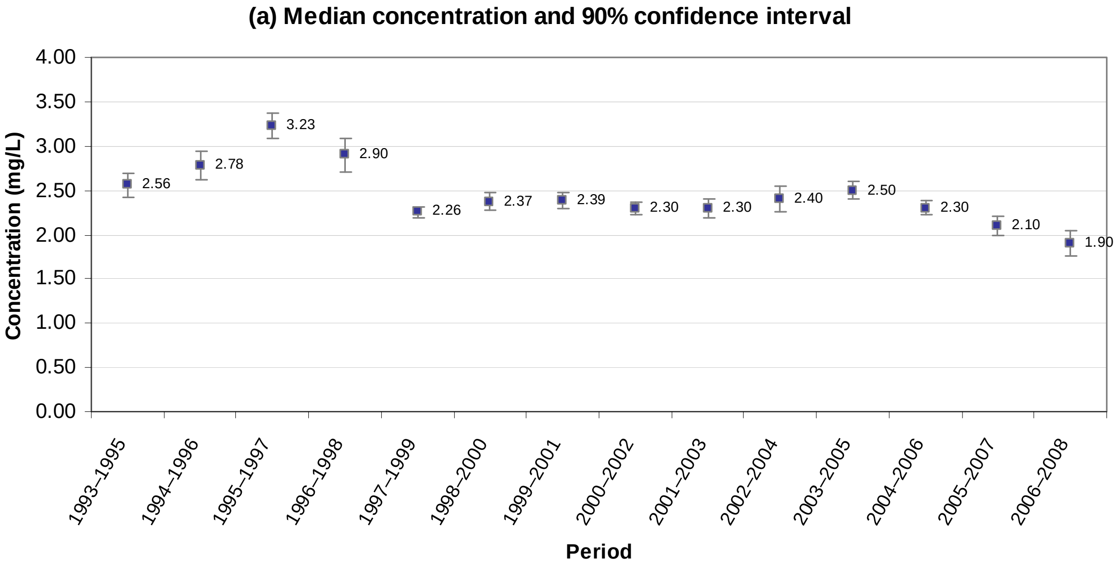


***Figure 5-3:** Three-year median SRP concentrations and 90% confidence intervals (a), and observed SRP concentration data (b)*

5.1.4 Total nitrogen (TN)

The three-year median concentrations and observed values for TN concentration samples are shown in Figure 5-4. According to classes taken from the *Statewide river water quality assessment* webpage, TN concentrations were classified as very high. The values of the three-year medians vary from 1.9 mg/L in 2006–08 to 3.23 mg/L in 1995–97. TN concentrations tend to be much higher pre-urbanisation, with steady to decreasing TN values post-1997. As with TP, there are much higher values during the years 1993–98 for TN, probably reflecting the pre-urbanisation land conditions.



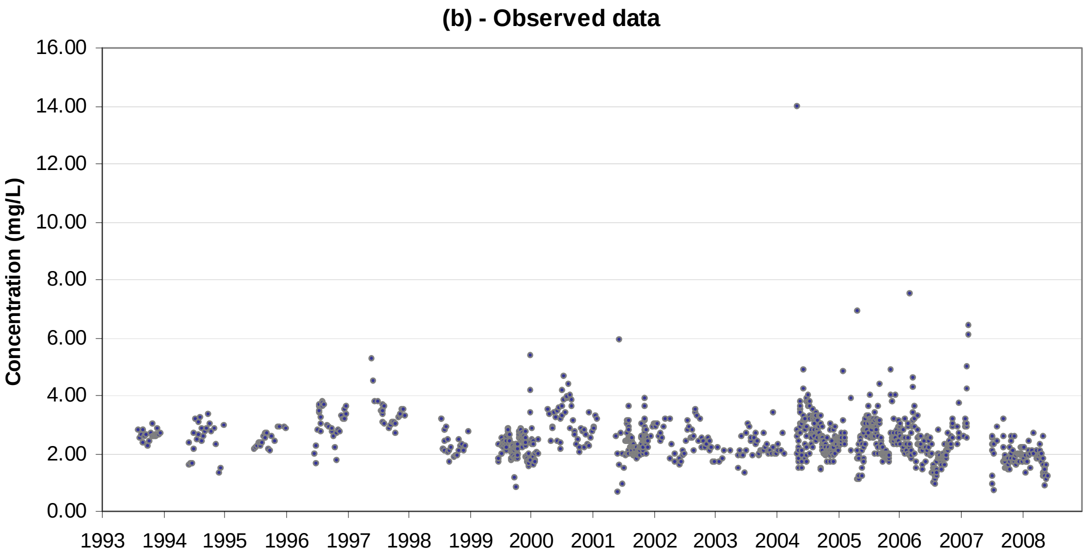
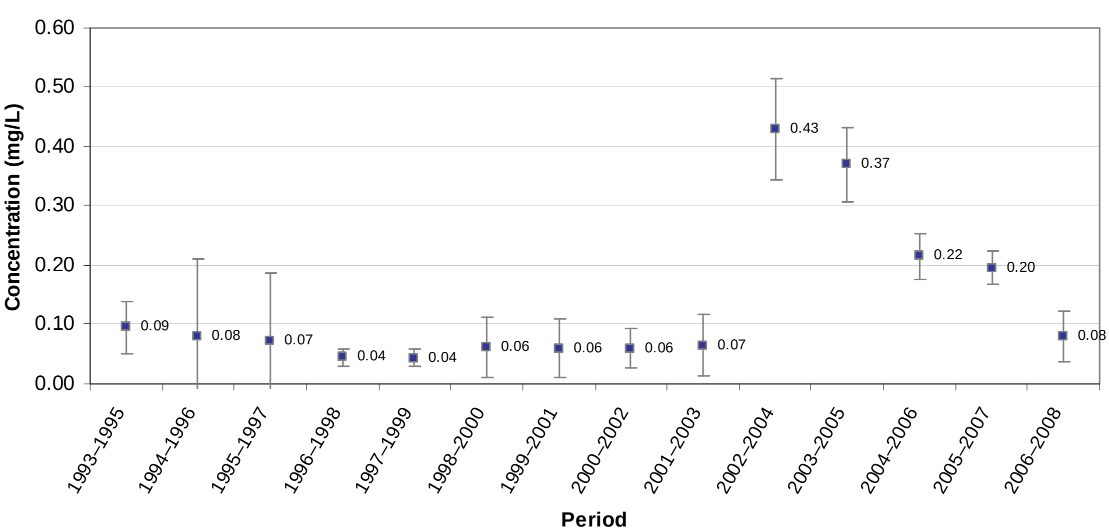


Figure 5-4: *Three-year median TN concentrations and 90% confidence intervals (a), and observed TN concentration data (b)*

5.1.5 Total oxidised nitrogen (NO_x)

The three-year median concentrations and observed values for NO_x concentration samples are shown in Figure 5-5. NO_x concentrations were generally low until the year 2003, when there was a sharp increase in the NO_x concentration. This may be a response to urbanisation or drainage changes in the catchment. It may also be a result of reduced de-nitrification. Although the NO_x concentrations are high after 2003, there is a strong decreasing trend. There is a strong seasonal trend in the NO_x data.



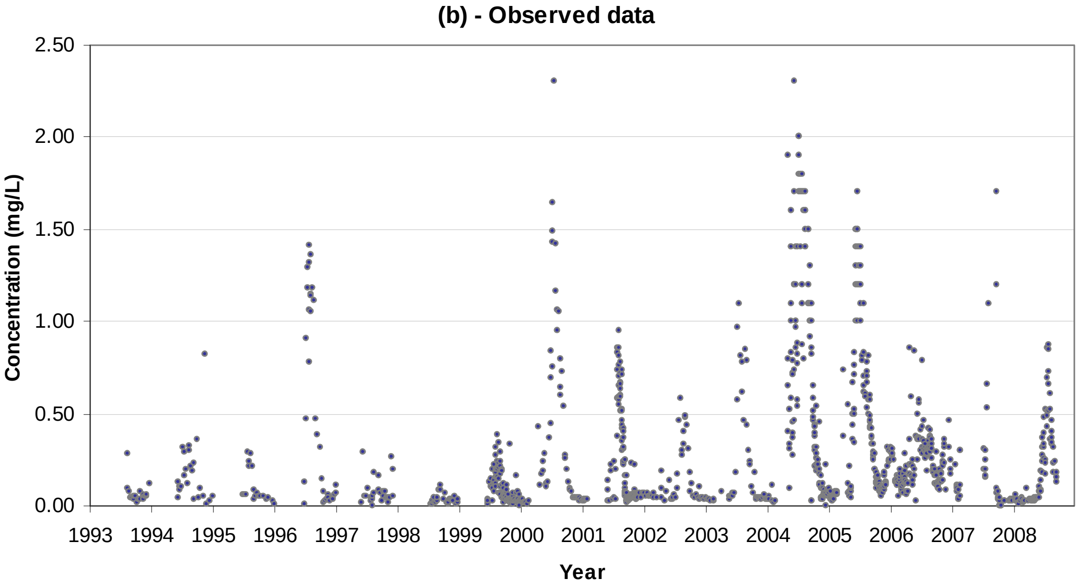


Figure 5-5: *Three-year median NO_x concentrations and 90% confidence intervals (a), and observed NO_x concentration data (b)*

5.1.6 Ammonia/Ammonium (NH_4/NH_3)

The three-year median concentrations and observed values for NH_4 concentration samples are shown in Figure 5-6. NH_4 concentrations are generally low and exhibit a strong decreasing trend. The decreasing trend has a lower gradient after 2001, which may be a response to urbanisation or drainage changes in the catchment. NH_4 generally makes up only a very small portion (<5%) of TN in the surface water.

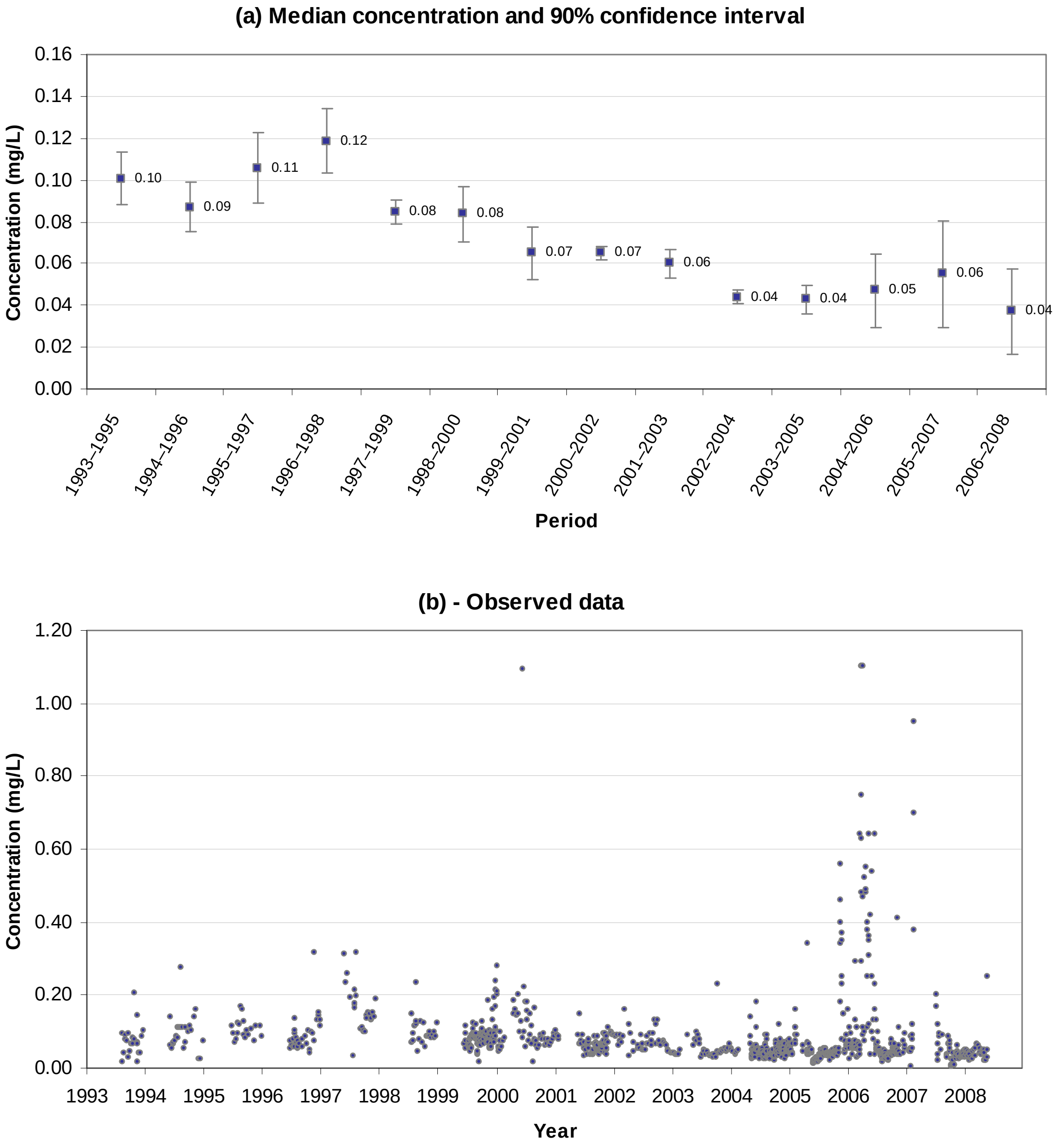


Figure 5-6: *Three-year median NH_4/NH_3 concentrations and 90% confidence intervals (a), and observed NH_4/NH_3 concentration data (b)*

5.1.7 Total Kjeldahl nitrogen (TKN)

Total Kjeldahl nitrogen (TKN) is the sum of ammonia and dissolved organic nitrogen. The three-year median concentrations and observed values for TKN concentration samples are shown in Figure 5-7. TKN concentrations are generally high, indicating that TN is composed mostly of dissolved organic nitrogen. The TKN values appear to exhibit a slight decreasing trend after 1997, which is likely to be due to land-use changes.

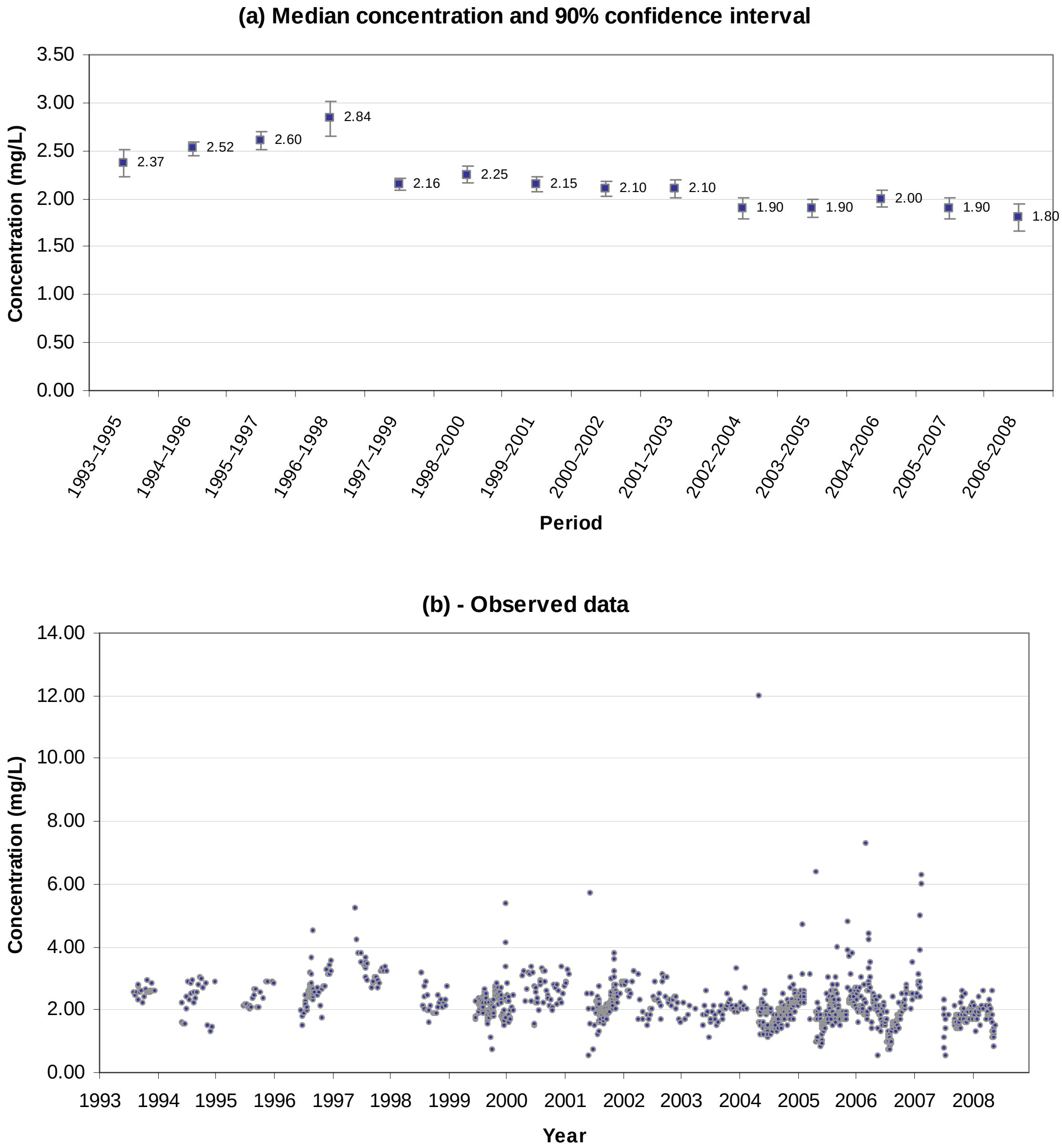


Figure 5-7: *Three-year median TKN concentrations and 90% confidence intervals (a), and observed TKN concentration data (b)*

5.2 Nutrient trends analysis

Nutrient concentrations in waterways vary due to:

- changes in flow
- seasonal variations
- trends related to land use or climate changes
- random components.

Changes brought about by human activity will usually be superimposed on natural sources of variation. Before trends are analysed (for this report), the influence of flow and seasonal variation are examined and corrected for. Thus the observed trends in nutrient concentration are (more than likely) linked to human intervention or influences within the catchment.

This report uses non-parametric tests to identify statistically-significant trends in the nutrient data series. Non-parametric techniques are used because they are not affected by a non-normal distribution of data, and they are not sensitive to outliers, or affected by missing or censured data (Loftis et al. 1991). An assumption of the trend tests is that the trends are monotonically increasing or decreasing (Helsel & Hirsch 1992). If concentrations vary non-monotonically over the period being analysed, the results of linear tests for trend may be misleading (Robson & Neal 1996). Another assumption of the trend tests is that measurements in the data series are independent. If the data are not independent (i.e. they exhibit auto-correlation) the risk of falsely detecting a trend is increased (Esterby 1996). A correlated data series contains surplus data and ultimately results in little or no net information gain. As a rule, the level of serial correlation in a data series increases as the frequency of sampling increases. The maximum sampling frequency possible without encountering serial correlation can be thought of as the point of information saturation. Further explanation of and the equations for the methodology used in the non-parametric trend results are shown in Appendix B.

5.2.1 Trend results

The results of the statistical trends analysis are shown in Table 5-2. Flow adjusted curves were determined using locally-weighted scatterplot smoothing (LOWESS) analysis, and the LOWESS curves are shown in Appendix C. The period of monotonic change in concentration for the nutrient species was identified from charts in figures 5-2 to 5-7. Monotonic change occurred between 1997 and 2008, and was generally decreasing (with the exception of nitrate). Trend statistics were calculated over this period.

Table 5-2: *Statistical trend results for nutrient concentrations at 616083*

Parameter	Period	Series	Test	Trend	Z	p	n	n*	n#	Trend results
TP	1997-2008	Obs.	MK	-0.01	-23.15	<0.05	1024	620	131	Decreasing trend
TP	1997-2008	Obs.	SK	-0.015	-6.59	<0.05	1024	929	90	Decreasing trend
TP	1997-2008	FAC	MK	-0.01	-8.30	<0.05	1023	117	100	Decreasing trend
TP	1997-2008	FAC	SK	-0.011	-9.74	<0.05	1023	116	79	Decreasing trend
NOx	1997-2008	Obs.	MK	0.008	6.96	<0.05	1024	104	295	Emerging increasing
NOx	1997-2008	Obs.	SK	0.013	10.47	<0.05	1024	101	100	Increasing trend
NOx	1997-2008	FAC	MK	0.01	7.72	<0.05	1023	107	158	Emerging increasing
NOx	1997-2008	FAC	SK	0.011	6.95	<0.05	1023	105	132	Emerging increasing
NH3	1997-2008	Obs.	MK	-0.005	-14.74	<0.05	996	154	66	Decreasing trend
NH3	1997-2008	Obs.	SK	-0.006	-17.94	<0.05	996	224	49	Decreasing trend
NH3	1997-2008	FAC	MK	-0.005	-14.94	<0.05	995	155	62	Decreasing trend
NH3	1997-2008	FAC	SK	-0.005	-15.67	<0.05	995	224	69	Decreasing trend
SRP	1997-2008	Obs.	MK	-0.009	-7.45	<0.05	1024	111	87	Decreasing trend
SRP	1997-2008	Obs.	SK	-0.016	-14.82	<0.05	1024	106	24	Decreasing trend
SRP	1997-2008	FAC	MK	-0.011	-11.35	<0.05	1023	106	52	Decreasing trend
SRP	1997-2008	FAC	SK	-0.011	-12.32	<0.05	1023	101	47	Decreasing trend
TN	1997-2008	Obs.	MK	-0.043	-6.80	<0.05	1020	138	54	Decreasing trend
TN	1997-2008	Obs.	SK	-0.046	-6.70	<0.05	1020	130	45	Decreasing trend
TN	1997-2008	FAC	MK	-0.053	-8.58	<0.05	1019	141	49	Decreasing trend
TN	1997-2008	FAC	SK	-0.05	-7.84	<0.05	1019	150	39	Decreasing trend
TKN	1997-2008	Obs.	MK	-0.049	-9.25	<0.05	1024	154	35	Decreasing trend
TKN	1997-2008	Obs.	SK	-0.072	-13.84	<0.05	1024	159	16	Decreasing trend
TKN	1997-2008	FAC	MK	-0.058	-11.41	<0.05	1023	151	24	Decreasing trend
TKN	1997-2008	FAC	SK	-0.066	-12.76	<0.05	1023	143	19	Decreasing trend

Statistically significant decreasing nutrient concentration trends between 1997 and 2008 were observed for all analytes apart from NO_x. It is likely the decreasing trend in concentration (and increasing trend for NO_x) is related the changes in land use during this period.

5.3 Flow status and coefficient of runoff

The Water Corporation has provided flow data from the Bartram Road buffer lake inflow gauging station (616083) for the years 1995 – 2008. The baseflow and surface flow components of the daily hydrograph were extracted using a baseflow separation technique (Eckhart 2005). Baseflow (groundwater flow that expresses itself in a drain) accounts for approximately 71% of the total flow (Figure 5-8). The ratio of surface flow to baseflow does not appear to change over the period, indicating that the urban development in the catchment has not drastically altered the hydrological regime (although increases in flow are evident). Catchment flow begins in autumn, and peaks in July/August. Baseflow peaks in September/October, and continues to through to January the following year.

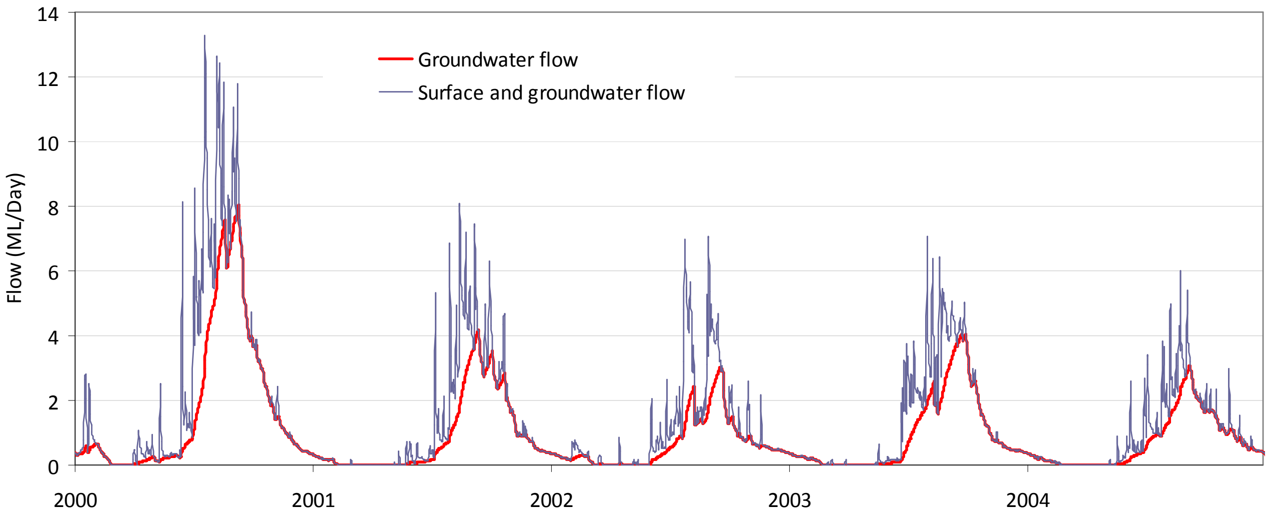


***Figure 5-8**: Baseflow separation results for the daily streamflow for Bartram Road buffer lake inflow gauging station (616083) for the years 2000 to 2004*

The monthly flow is shown in Figure 5-9 and annual flow is shown in Figure 5-10. Monthly flow varies from year to year, and a high-flow year (such as 2005) will have over five times as much flow as a dry year (2006). Although not statistically significant, there appears to be an increasing trend in flow between the years 1995 and 2008, which is evident in both the monthly and annual flow charts. The summer of 2005–06 shows the most significant summer flows for the entire period sampled.

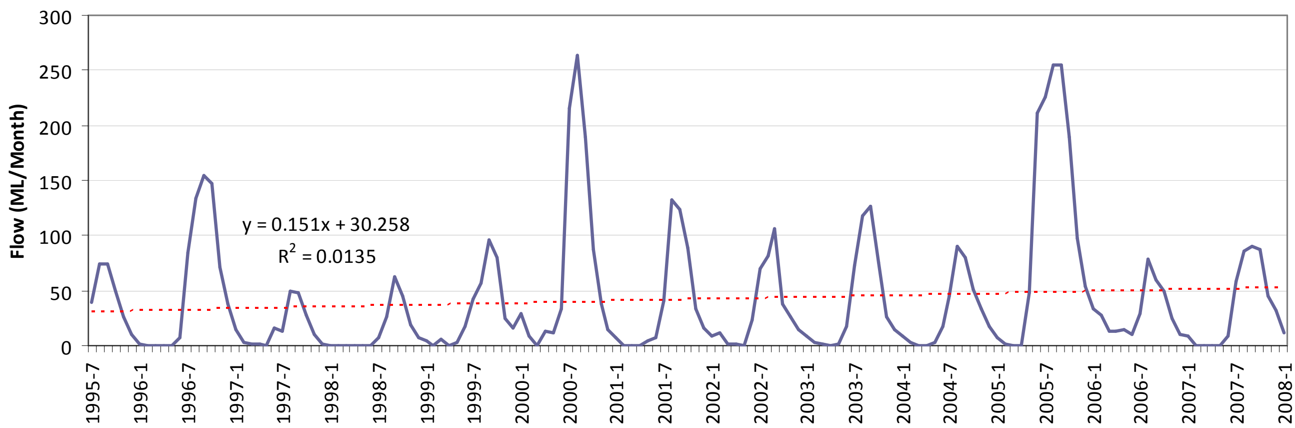


***Figure 5-9**: Monthly flow rates and trend for the period 1995 to 2008 at Bartram Road buffer lake inflow gauging station (616083)*

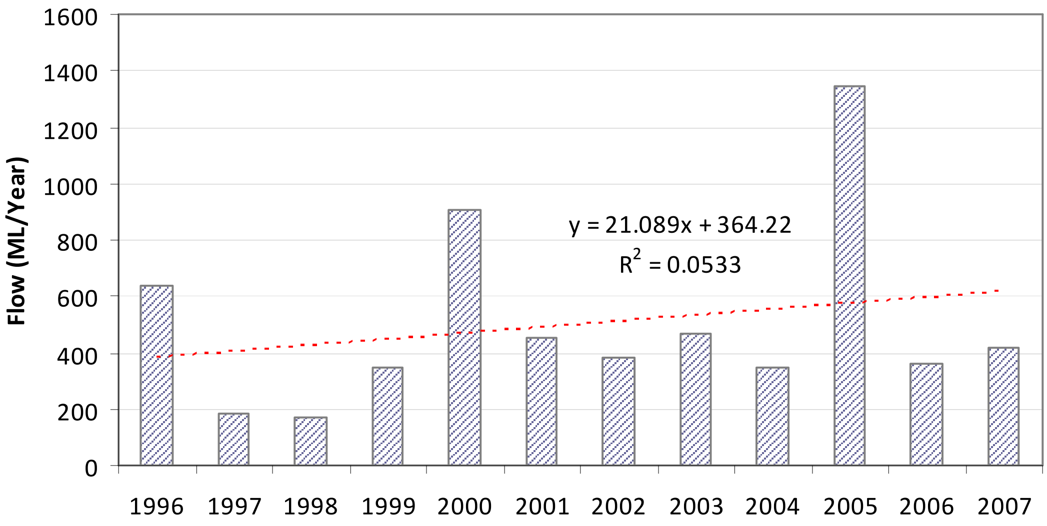


Figure 5-10: *Annual flow and trend for the period 1996 to 2007 at Bartram Road gauging station (616083)*

The annual coefficient of runoff (*CR*) is the amount of annual runoff as a percentage of annual rainfall. Annual values for runoff, rainfall, and *CR* are shown in Table 5-3. Figure 5-11 shows the *CR* and the annual rainfall. It is evident from Figure 5-11 that an increasing trend in *CR* is occurring, whereas the rainfall appears to be decreasing. The increase in *CR* is likely to be due to the hydrological changes in the catchment between the years 1996 and 2007. More precisely, the increase in runoff is likely to be due to urbanisation in the catchment, despite the implementation of various WSUD measures. Urbanisation increases impervious areas (roofs and road surfaces), which discharge to soak-wells, in turn increasing groundwater recharge. The coverage of deep-rooted vegetation decreases because of land clearing for development. This leads to less evapotranspiration and higher recharge, which leads to higher baseflow runoff.

Table 5-3: *Annual flow, rainfall and coefficient of runoff for the Bartram Road catchment*

Year	Flow (ML)	Rainfall (mm)	*CR**
1996	637	922	5.9%
1997	185	698	2.3%
1998	168	787	1.8%
1999	347	891	3.3%
2000	905	900	8.6%
2001	454	693	5.6%
2002	381	745	4.4%
2003	466	916	4.4%
2004	346	708	4.2%
2005	1344	933	12.4%
2006	364	527	5.9%
2007	418	820	4.4%
Average	501	795	5.3%

* Assuming a catchment area of 11.65 km^2

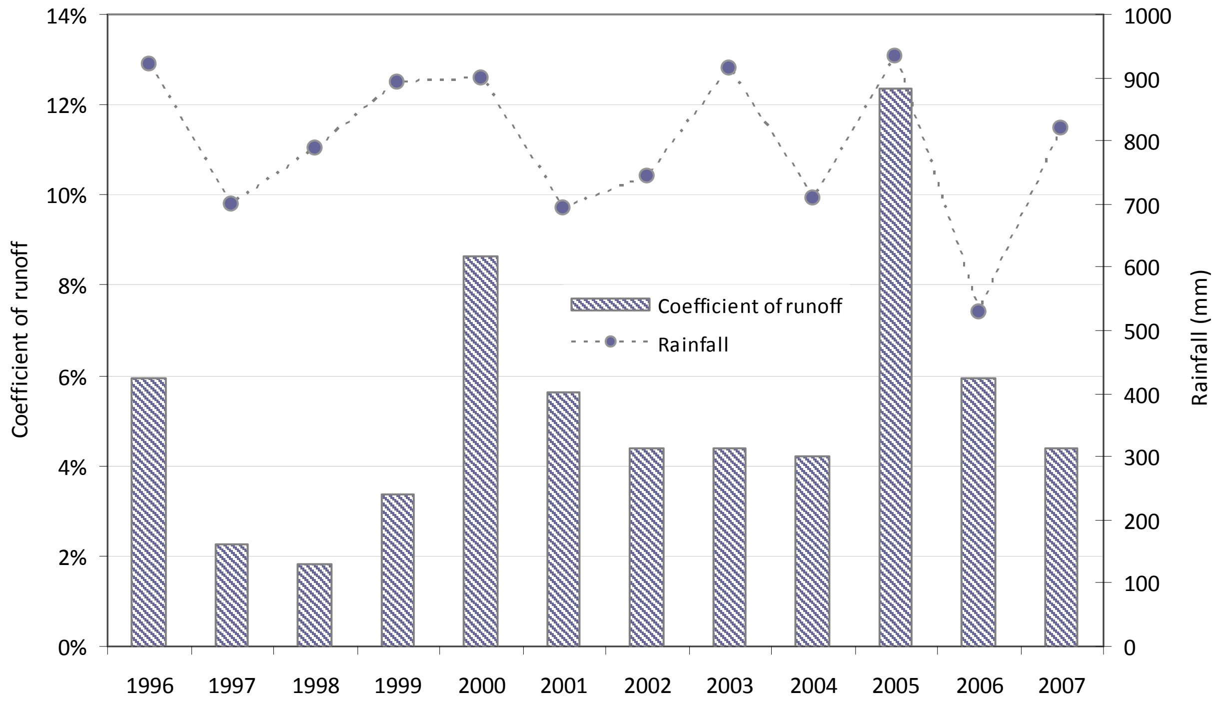


Figure 5-11: *Annual coefficient of runoff and rainfall for the Bartram Road catchment*

5.4 Nutrient loads

Annual loads are calculated by multiplying daily flow with daily nutrient concentration, and aggregating over the year. Daily flows are available between the years 1996 and 2007 inclusive. Daily concentration measurements are not available because samples were taken weekly at best, so daily concentration data needs to be in-filled to calculate loads. Annual loads were calculated for all nutrient species collected at the Bartram Road buffer lake inflow gauging station (616083) using three different load calculation techniques. These in-filled the concentration for days when concentration measurements were not collected. The techniques are as follows:

- **Locally estimated scatterplot smoothing (LOESS) algorithm (Cleveland 1979):** This is the most complex of the three methods. LOESS creates a flow-concentration curve by fitting a low-degree polynomial to a subset of the flow-concentration data to estimate the concentration for the flow at the centre point of the data subset. This is done for each flow value in the dataset. For days on which nutrient data were collected, daily loads are calculated from observed concentrations and flows. For days with no data, daily loads are calculated from the daily flow and the estimated concentration from the LOESS flow-concentration curve. The assumption of the LOESS algorithm is that there is a relationship between flow and concentration.
- **Three-year median concentration:** This is the most simple load calculation method: it takes the three-year median for any given year (e.g. for 2001 this is the median concentration from 2000, 2001 and 2002) and multiplies this value by the annual flow value. The assumption is that no relationship exists between flow and concentration.

- **Most-recent sample concentration:** The most-recent sample concentration takes the measured concentration and multiplies it by the daily flow for each day until a new measured concentration is sampled. This technique is similar to that used by Hydstra (provider of the flow database used by the Department of Water) for load calculation, and assumes that the concentration is a function of the time at which the sample was taken.

The three techniques produced similar results. There appeared to be a relationship between flow and concentration for most nutrient species. Appendix C displays the flow-concentration relationships and curves derived using the LOESS algorithm. Because the relationship exists, and because the LOESS technique mostly produced the least extreme results (generally between the three-year median and most-recent sample annual loads), LOESS loads are presented and discussed in this section (below). Annual load values and charts using the other techniques are shown in Appendix D.

Table 5-4 displays the annual load calculations using the LOESS algorithm, and also the rainfall and coefficient of runoff, assuming a catchment area of 11.65 km^2. The values for rainfall were determined using the five closest rainfall gauges to the centroid of the Bartram Road catchment that contained data for any given day between 1996 and 2007 (using the inverse distance-squared weighting technique).

Table 5-4: *Annual load calculations using the LOESS algorithm*

		LOESS annual loads (kg)							
Year	**Flow (ML)**	**NOx**	**TKN**	**TN**	**NH3**	**TP**	**SRP**	**Rainfall (mm)**	***CR****
1996	637	253	1326	1416	32	227	137	922	5.9%
1997	185	28	421	457	15	82	65	698	2.3%
1998	168	28	351	388	12	63	49	787	1.8%
1999	347	57	716	783	25	129	100	891	3.3%
2000	905	539	1883	2470	63	308	207	900	8.6%
2001	454	128	901	1030	20	150	122	693	5.6%
2002	381	107	797	920	24	134	102	745	4.4%
2003	466	155	919	1092	26	152	115	916	4.4%
2004	346	193	647	882	18	108	83	708	4.2%
2005	1344	775	2609	3483	62	388	253	933	12.4%
2006	364	76	694	772	27	133	102	527	5.9%
2007	418	98	792	908	23	134	103	820	4.4%

Figure 5-12 and Figure 5-13 show the annual loads for nitrogen and phosphorus species respectively, as well as the annual rainfall for the Bartram Road catchment. Generally, the magnitude of the load exported is highly dependent on the annual rainfall: low annual rainfall years can have annual loads up to one order of magnitude less than years with high annual rainfall.

There is a general increase in catchment load for all nutrient species, despite the decreasing trends in concentration. Load is directly related to flow, and the increase in load is due to the increase in flow, which overcompensates for the decrease in nutrient concentrations in the Bartram Road catchment. The increasing trend in load is evident despite a decreasing trend in rainfall for the same period. The trends are not significant, and conclusions about nutrient load trends over the sampling period cannot be easily made. However, it is interesting to note that while 1996 and 2005 had similar rainfalls (922 mm and 933 mm), in 2005 the TN and TP loads were respectively 2.5 times and 1.7 times greater than the corresponding 1996 loads.

The phosphorus in the catchment is mostly in soluble form due to the low PRI of soils in the superficial aquifer. Nitrogen consists mostly of dissolved organic nitrogen, with significant amounts of nitrate and relatively small quantities of ammonia.

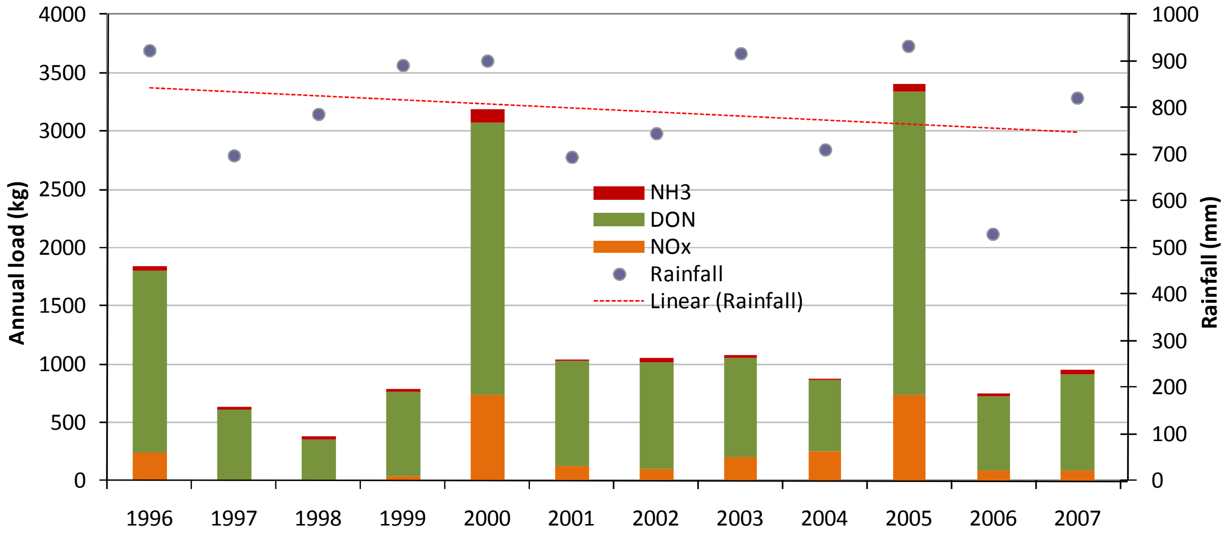


Figure 5-12: *Annual nitrogen loads and trends for the period 1995 – 2008 at Bartram Road buffer lake inflow gauging station (616083)*

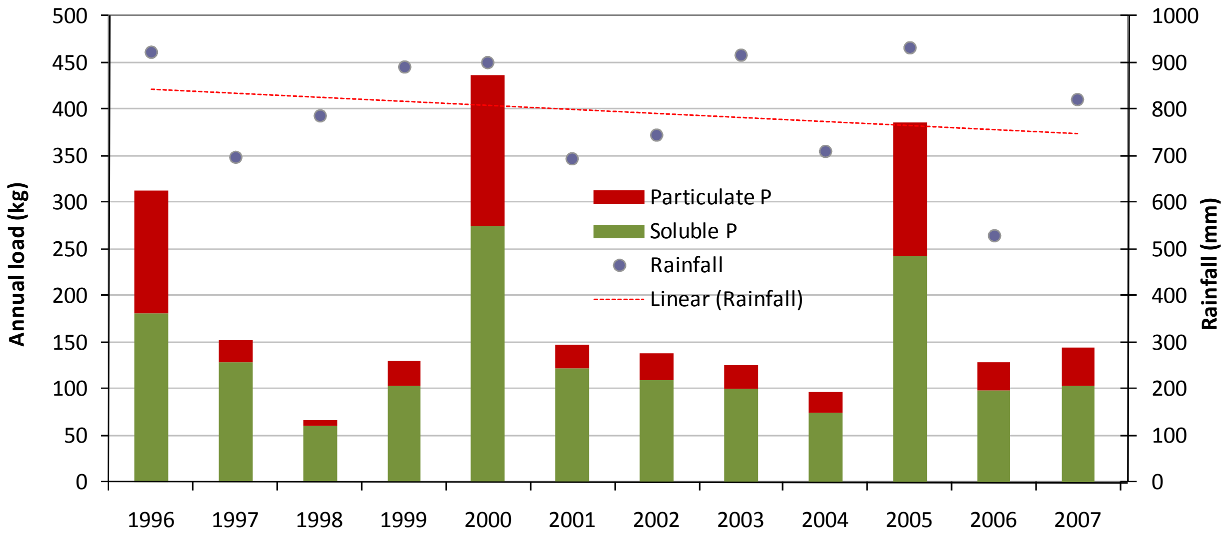


Figure 5-13: *Annual phosphorus loads and trends for the period 1995 – 2008 at Bartram Road buffer lake inflow gauging station (616083)*

5.5 Nutrient source analysis

The natural and human sources of nutrients in river catchments include:

- fertilisers from both rural and urban land use
- sewerage effluent
- animal faeces and urine
- nitrogen fixation by leguminous plants
- atmospheric deposition
- phosphorus from the weathering of rocks
- decaying plant and animal matter
- point sources (e.g. intensive animal production, abattoirs and the food industry).

Of the nutrient inputs above, the most important are fertilisers, septic tank effluent, animal inputs, and nitrogen fixation. Atmospheric deposition is a small contributor of nitrogen and an insignificant amount of phosphorus, and the Bartram road catchment does not contain naturally-occurring phosphorus-rich geology for weathering over time.

Total nutrient inputs for the Bartram Road catchment were determined from estimated nutrient input rates (kg/ha/year) and areas of land uses (ha). Data was gathered from the Department of Agriculture and Food's nutrient surveys of rural properties (Ecotones & Associates 2008) and the Department of Water's 2006 urban nutrient survey (Kelsey et al. 2010b). The 2008 nutrient surveys covered rural or semi-rural properties in the Ellen Brook, Geographe Bay and Peel-Harvey catchments, and accounted for nutrient input from fertilisers, fodder, grain and livestock, and from nitrogen fixation.

The 2006 urban nutrient study's aim was to determine the amount of nitrogen and phosphorus being applied in residential urban areas of the Swan Coastal Plain. Approximately 7000 questionnaires were sent to 17 suburbs in the Perth, Peel-Harvey and Geographe areas, which were chosen based on the following differences: location (Perth metropolitan and regional), dwelling type (house, unit, villa and canal), dwelling age (new: 0–2 years, recent: 3–5 years, established: 6–10 years and old: >11 years) and lot size.

Twelve-hundred people responded with information including lot size, areas of lawn, garden, pavement and roof, number and type of pets, plant types, water usage, fertiliser regimes and disposal of garden and pet waste. Fertiliser regimes were specified by fertiliser type, application amount, frequency and seasonality. Data from the surveys were analysed and fertiliser types were researched for phosphorus and nitrogen content, and a fertiliser rate in kg/ha for each urban residence was calculated.

Point sources of nutrient pollution include dairy milking sheds, cattle feedlots, landfills, wastewater treatment plants and industrial discharges. Various datasets were analysed to extract nutrient point-source information for the Bartram Road catchment, including the National Pollutant Inventory (NPI), the EPA's licensed premises and contaminated sites datasets, and the Hirschberg historic nutrient point-source dataset (Hirschberg 1991). The Hirschberg dataset identified three decommissioned piggeries in the catchment. However, the closure date, size and effluent quantity of the piggeries were unknown. Even though the piggeries were not likely to be affecting recent nutrient concentrations in the Bartram Road waterways, they may have had some influence on historical concentrations of nutrients exported from the catchment. Analysis of the other datasets did not identify other point sources of pollution in the Bartram Road catchment.

The septic-tank spatial coverage was developed by extracting all residential, industrial and commercial land parcels from the land-use spatial coverage, and assigning each parcel a septic tank if it did not fall within the Water Corporation infill or deep-sewerage coverage (Figure 3-10). Rates of occupancy were taken from Australian Bureau of Statistics data. Septic-tank export loads of 1.1 kg phosphorus/person/year and 5.5 kg nitrogen/person/year were taken from a Western Australian study by Whelan and Barrow (1984a, 1984b). Median fertilisation rates assigned to each land-use type are shown in Table 5-5.

Table 5-5: *Nutrient input rates for the land-use categories in the Bartram Road catchment*

Land-use	N (kg/ha/year)	P (kg/ha/year)
Annual horticulture	142.6	126.9
Commercial / service - centre	5.0	2.5
Commercial / service - residential	84.1	19.7
Community facility - education	42.1	9.8
Community facility - non-education	21.0	4.9
Horses	70.1	13.1
Lifestyle block	49.2	3.4
Manufacturing / processing	5.0	2.5
Office - with parkland	84.1	19.7
Office - without parkland	5.0	2.5
Perennial horticulture	27.2	12.3
Quarry/extraction	0.0	0.0
Recreation - grass	175.0	35.0
Recreation - turf	350.0	70.0
Recreation / conservation	2.0	0.0
Residential - aged person	42.0	9.9
Residential - multiple dwelling	42.0	9.8
Rural residential / bush block	2.0	0.0
Storage / distribution	0.0	0.0
Transport access - non-airport	5.0	2.5
Unused - cleared - bare soil	0.0	0.0
Unused - cleared - grass	0.0	0.0
Unused - uncleared - trees/shrubs	2.0	0.0
Urban (<400m^2)	23.4	6.9
Urban (>730m^2)	74.2	18.0
Urban (400-600m^2)	91.3	22.8
Urban (600-730m^2)	100.6	26.4
Utility	0.0	0.0
Waterbody	0.0	0.0
Water storage and treatment	0.0	0.0

Fertiliser input loads were determined by applying the rates from Table 5-5 to the land-use coverages determined for the catchment for the years 2000, 2003 and 2007 (figures 3-9, 3-8 and 3-7). The resultant input loads from each type of land use and the total input loads for nitrogen and phosphorus are shown in Table 5-6.

Table 5-6: *Nutrient input quantities for the land-use categories in the Bartram Road catchment for the years 2007, 2003 and 2000*

Land Use	Area (hectares)			Nitrogen input load (kg)			Phosphorus input load (kg)		
	2000	**2003**	**2007**	**2000**	**2003**	**2007**	**2000**	**2003**	**2007**
Annual horticulture	8.8	8.8	6.0	1261	1261	862	1122	1122	767
Cattle / grazing	138.0	0.0	0.0	11921	0	0	1747	0	0
Community facility - education	3.7	3.7	7.0	156	156	293	36	36	69
Horses	57.1	57.1	45.5	4006	4006	3191	751	751	598
Lifestyle block	239.3	235.2	242.7	11781	11579	11948	823	809	835
Manufacturing / processing	0.0	0.0	0.0	0	0	0	0	0	0
Perennial horticulture	4.7	4.7	3.2	128	128	86	58	58	39
Recreation - grass	12.0	20.9	32.8	2102	3662	5742	420	732	1148
Recreation - turf	6.0	6.0	6.0	2100	2100	2100	420	420	420
Recreation / conservation	193.8	163.4	157.6	388	327	315	2	2	2
Rural residential / bush block	31.9	31.9	33.4	64	64	67	0	0	0
Transport access - non-airport	145.2	170.6	202.6	726	853	1013	363	427	506
Urban residential	93.6	130.1	213.4	8494	11837	19246	2160	3011	4937
Septic tanks	-	-	-	2205	2205	2138	440	440	427
Input Load	1164.1	1164.1	1164.1	45472	38573	47421	8375	7896	9842

Both phosphorus and nitrogen input increases between the years 2000 and 2007: phosphorus increases approximately 15% (from 8.37 to 9.84 tonnes) and nitrogen increases approximately 4% (from 45.5 to 47.4 tonnes). However, 2003 has less nutrient input than both 2000 and 2007. This is because a large quantity of land used for cattle grazing in 2000 was sold for urban development; however, it was not developed by 2003, so there was no fertiliser being applied during that time. By 2007 much of this land was developed, and fertiliser was again being applied to the land.

5.6 Groundwater analysis

Groundwater is naturally very close to the ground surface for most locations on the Swan Coastal Plain. To enable urban development and prevent seasonal inundation when groundwater levels rise in winter, fill needs to be added to keep the development above the groundwater, and/or drains need to be installed to intercept and lower the peak groundwater table. Surface water and groundwater management is inseparable and techniques to minimise the risk of pollution from stormwater in areas of high watertable will be different to those used in areas where low groundwater levels allow stormwater infiltration.

Groundwater levels and nutrient concentrations were collected at the four groundwater monitoring bores within the Bartram Road catchment (Figure 3-14). Analytes sampled included TP, TN, soluble reactive phosphorus (SRP), nitrate/nitrite (NO_x), dissolved organic nitrogen (DON) and ammonia/ammonium (NH_4/NH_3). The time-series results of the groundwater samples and levels are shown in Appendix E.

Groundwater discharge from the Bartram Road catchment was approximated using Darcy's equation as follows:

$$Q_{Darcy} = KibL'$$

Where:

Q_{Darcy} = groundwater throughflow defined as the volume of water passing across a length of the aquifer (m^3/year)

L' = length of the aquifer across which groundwater discharges

b = saturated thickness of aquifer (containing nutrients)

K_h = horizontal hydraulic conductivity (m/d)

i = hydraulic gradient

The hydraulic gradient (i) was approximated using the regional groundwater contours from the Department of Water's Regional Groundwater GIS layer. This is an approximation, as the groundwater hydraulic gradient will vary throughout the year, according to the rainfall (intensity, duration and quantity), the soil type, vegetation and most importantly the drainage. However, to determine a more detailed value for the hydraulic gradient on a finer time-scale, a detailed modelling approach is required, which is outside of the scope of this study. The value for L' was taken as the average length of the Bartram Road catchment, perpendicular to the groundwater contours. The value for the hydraulic conductivity varies for Bassendean sands and is usually reported to be between 7 – 15 m/day. It is likely that the first metre of saturated soil overlies more poorly sorted sands, with a lower value for K_h. A value for K_h of 7 m/d was used in this analysis.

The value of b (thickness of aquifer containing nutrients) is the most difficult to estimate. Generally, nutrients reach the groundwater table by leaching from the ground surface and thus concentrate in the uppermost layers of the aquifer. The concentration gradient is quite steep, with high nutrient concentrations in the first 0.5 m of the aquifer, but very close to non-detectable concentrations within approximately 2 m. The bores in the Bartram Road catchment were drilled to a depth of 5 m bgl, and were screened from the bottom of the bore to above the surface of the watertable.

The annual nutrient load was calculated by averaging the median annual concentrations from each the four bore locations and multiplying by the annual flow. Results for the annual groundwater export loads for phosphorus and nitrogen are shown in tables 5-7 and 5-8 respectively.

Table 5-7: *Total phosphorus median annual groundwater concentrations and loads for the Bartram Road catchment*

Year	JE7C (mg/L)	JE9C (mg/L)	TD36 (mg/L)	TD37 (mg/L)	Average (mg/L)	Load (kg)	Surface water load (kg)	GW/total load
1994	0.01	0.13			0.07	16		
1995	0.01	0.18	0.04		0.08	17		
1996	0.01	0.19	0.10		0.10	22	313	6.6%
1997	0.01	0.19	0.30	0.50	0.25	56	108	34.0%
1998	0.02	0.18	0.29	0.50	0.25	54	60	47.3%
1999	0.02	0.14	0.12	0.39	0.16	36	128	22.1%
2000	0.02	0.11	0.12	0.25	0.12	27	317	7.9%
2001	0.01	0.07	0.08	0.24	0.10	22	154	12.5%
2002	0.01	0.08	0.10	0.17	0.09	20	130	13.2%
2003	0.02	0.06	0.09	0.13	0.07	16	149	9.8%
2004	0.02	0.09	0.16	0.10	0.09	20	111	15.4%
2005	0.02	0.07	0.17	0.10	0.09	19	484	3.9%
2006	0.01	0.08	0.22	0.10	0.10	22	131	14.6%
2007	0.01	0.08	0.19	0.08	0.09	20	134	13.0%
2008	0.01	0.07	0.19	0.12	0.10	22		
Average	**0.01**	**0.11**	**0.15**	**0.22**	**0.12**	**26**	**185**	**16.7%**

Table 5-8: *Total nitrogen median annual groundwater concentrations and loads for the Bartram Road catchment*

Year	JE7C (mg/L)	JE9C (mg/L)	TD36 (mg/L)	TD37 (mg/L)	Average (mg/L)	Load (kg)	Surface water load (kg)	GW/total load
1994	1.99	2.26			2.13	471		
1995	2.20	2.55	1.64		2.13	471		
1996	1.64	6.67	2.02		3.44	763	2056	27.1%
1997	2.54	3.25	3.57	3.62	3.24	718	538	57.2%
1998	1.83	2.80	3.57	3.62	2.95	654	379	63.3%
1999	2.37	2.27	2.56	3.00	2.55	564	823	40.7%
2000	3.80	2.18	2.56	3.50	3.01	666	2162	23.6%
2001	4.71	2.29	2.10	3.50	3.15	698	1045	40.0%
2002	4.20	2.10	2.75	3.50	3.14	695	877	44.2%
2003	2.85	2.30	2.50	3.10	2.69	595	1118	34.7%
2004	2.10	2.10	2.55	2.65	2.35	521	865	37.6%
2005	2.65	2.10	2.70	2.70	2.54	562	3091	15.4%
2006	2.00	1.70	3.45	2.80	2.49	551	764	41.9%
2007	1.50	2.20	3.95	2.80	2.61	579	794	42.2%
2008	4.50	2.00	5.00	2.80	3.58	792		
Average	**2.73**	**2.58**	**2.92**	**3.13**	**2.80**	**620**	**1209**	**39.0%**

Tables 5-7 and 5-8 compare the load exported from groundwater with the load exported from surface water in the Bartram Road catchment. According to the analysis, approximately 17% of the TP load and 39% of the TN load is exported by groundwater. It should be noted that large errors are likely to be associated with the groundwater loads when compared with the surface water loads, because much higher uncertainty is associated with the groundwater flow, the spatial distribution of the groundwater nutrient concentration and the vertical distribution of the nutrient concentration in the groundwater. Figures 5-14 and 5-15 show the three-year median and the catchment-wide average groundwater concentration from each of the bore locations (A), the calculated annual groundwater load (B) and the comparison between surface water and groundwater loads (C) for phosphorus and nitrogen respectively.

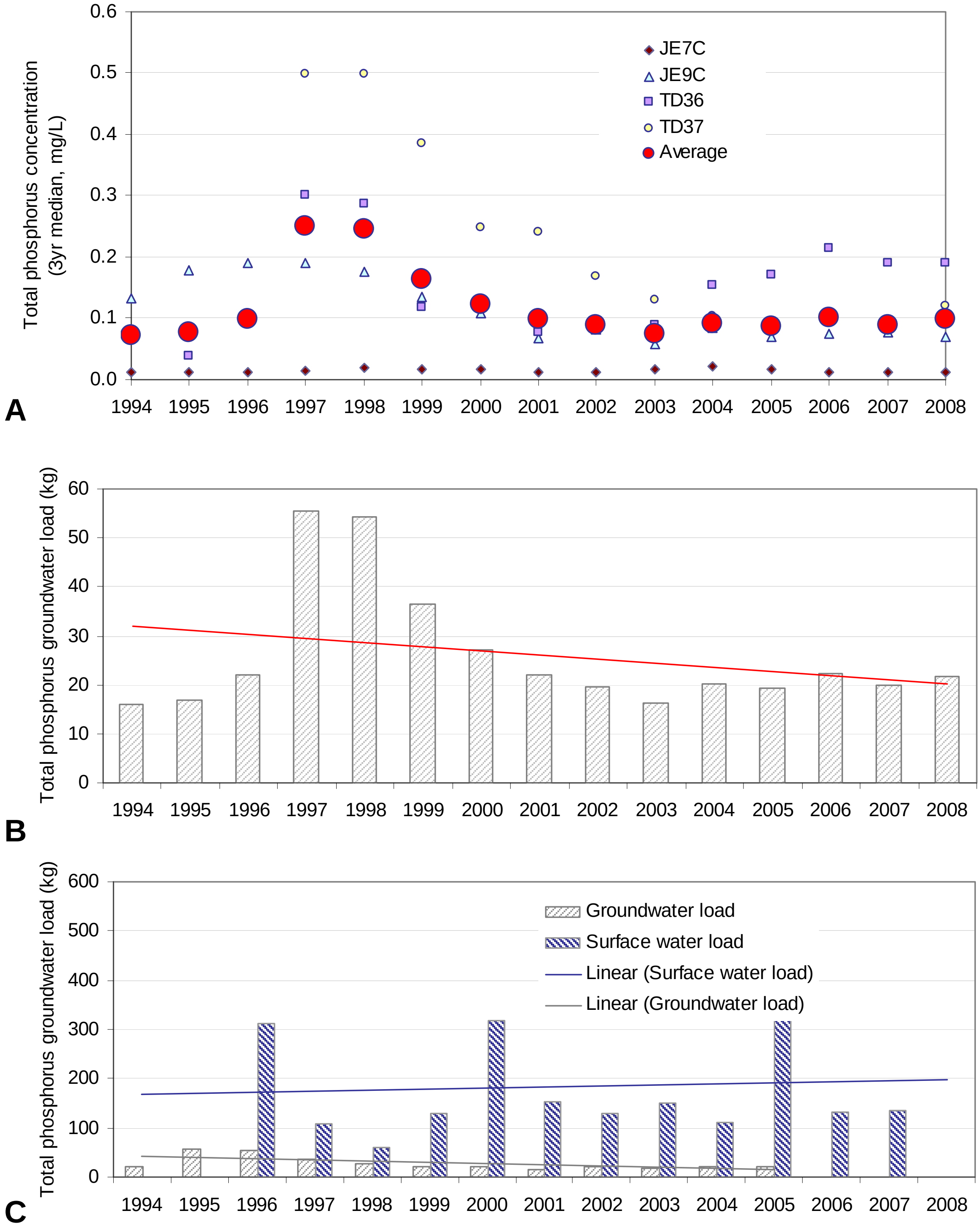


Figure 5-14: *Three-year median concentration from each of the bore locations (A), the calculated annual groundwater load (B) and the comparison between surface water and groundwater loads (C) for total phosphorus*

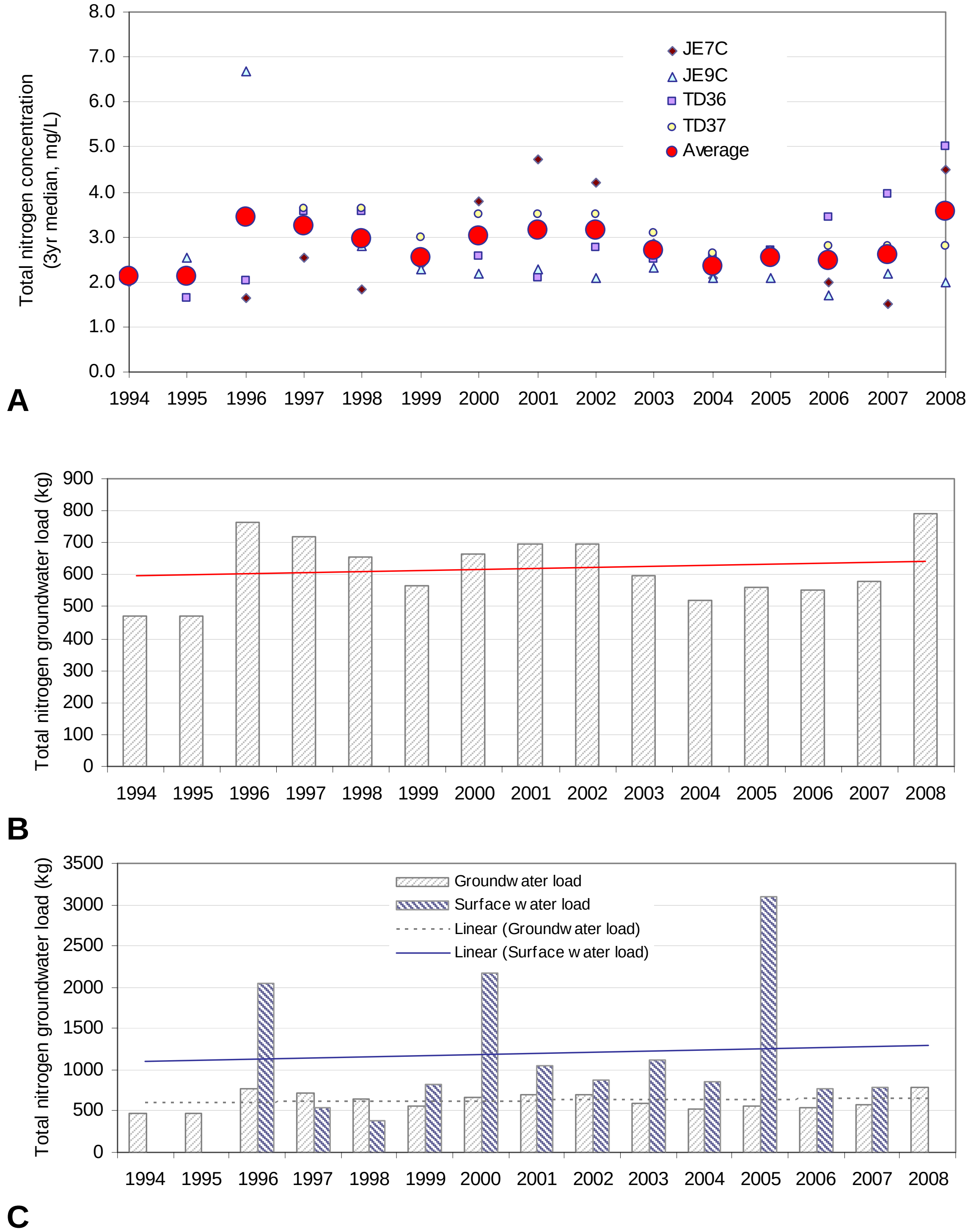


Figure 5-15: *Three-year median concentration from each of the bore locations (A), the calculated annual groundwater load (B) and the comparison between surface water and groundwater loads (C) for total nitrogen*

In dry years, such as 1997 and 1998 when the surface water runoff rates are relatively small, the nitrogen export load from groundwater is higher than from surface water. However, it is generally likely that much more nutrient export from surface water will occur. The relatively high proportion of export load from groundwater highlights the importance of managing groundwater quality as well as surface water quality on the Swan Coastal Plain. This becomes particularly relevant in WSUD catchments, where surface water export is minimised, and the ratio of groundwater export to surface water export load will increase when compared with traditionally-drained urban catchments.

6 Comparing ‘new’ and traditional urban drainage

To assess the relative impacts of WSUD drainage on the Bartram Road catchment, the hydrology and nutrient loads and concentrations were compared with those of a traditionally-drained urban catchment. A suitable catchment for comparison needed to satisfy the following criteria:

- traditional drainage (established urban for over 20 years)
- mostly urban land use, with similar nutrient inputs to Bartram Road catchment
- similar soil-type
- good record of flow and nutrient sampling at the catchment outlet
- similar catchment size to Bartram Road catchment.

The most suitable catchment on the Swan Coastal Plain was the South Belmont catchment, which is in Perth’s metropolitan area about 5 km east of the CBD, and approximately 20 km north of the Bartram Road catchment (Figure 6-1).

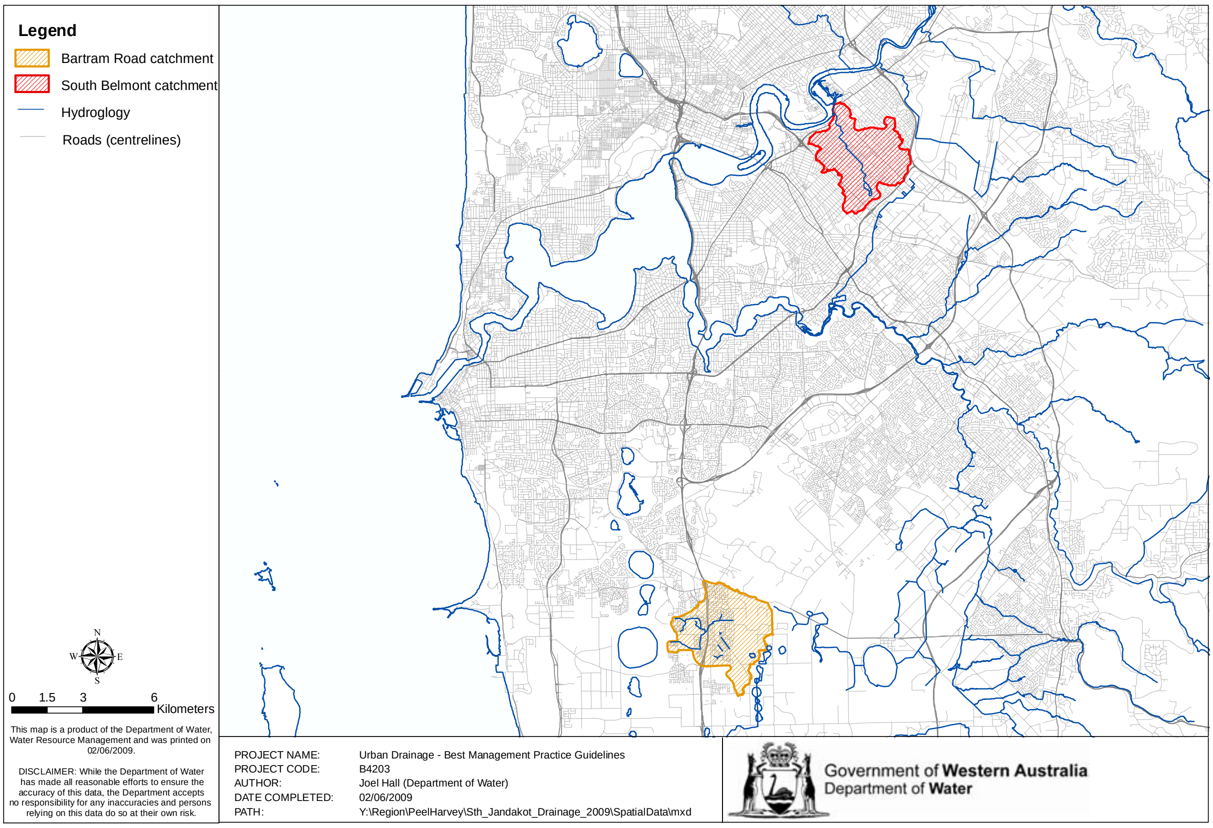


Figure 6-1: *Location of Bartram Road catchment and South Belmont catchment*

The South Belmont catchment's land use is primarily urban with patches of public open space and commercial use (Figure 6-2). The catchment has a linear drainage network consistent with traditionally-designed urban drains on the Swan Coastal Plain.

The South Belmont catchment contains a flow-gauging and nutrient-sampling site located approximately 200 m upstream of the catchment outlet into the Swan River, at Abernathy Road. The station has flow readings from 1988, and comprehensive water quality sampling data from 1996. The catchment's soil type is similar to Bartram Road catchment, which consists of Bassendean sands throughout. The area of the catchment is 10.55 km^2 compared with 11.65 km^2 for the Bartram Road catchment.

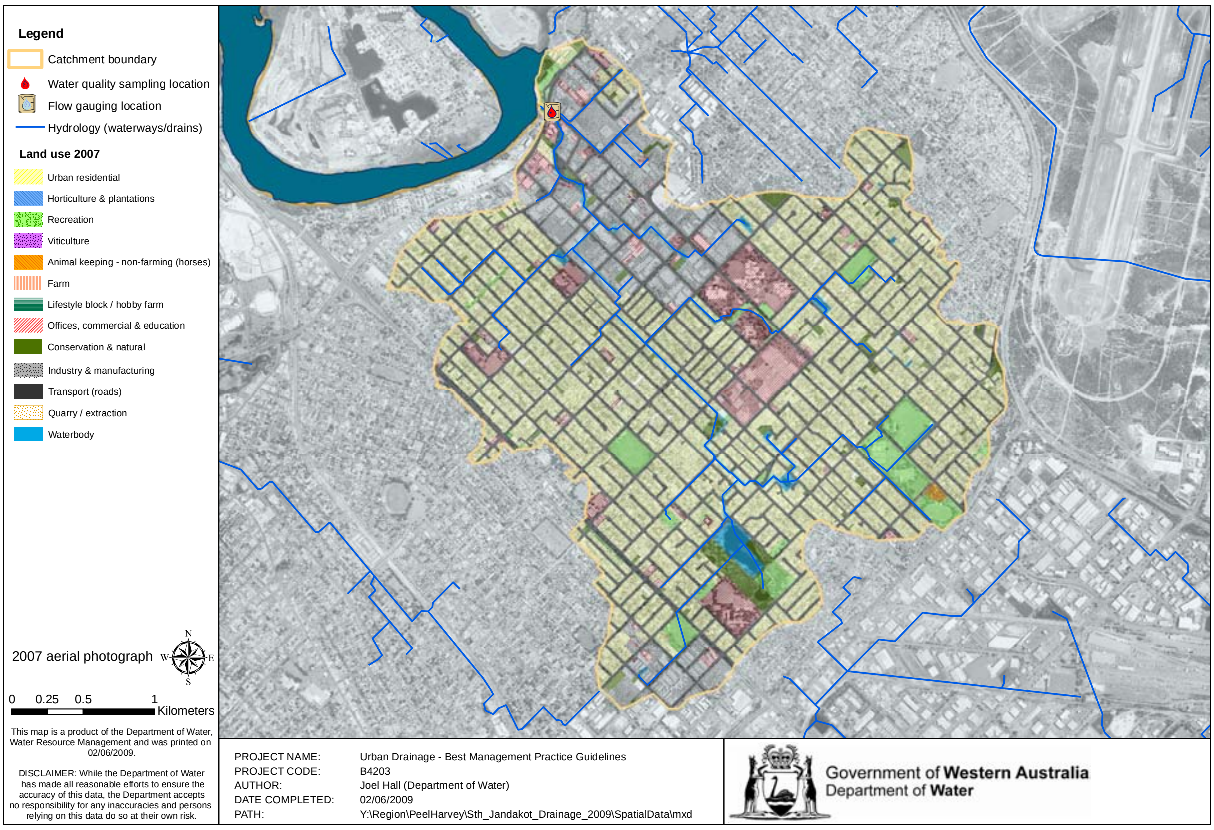


Figure 6-2: *Land use in the South Belmont catchment*

The Department of Water's Streamflow Quality Affecting Rivers and Estuaries (SQUARE) model was used to determine annual nitrogen and phosphorus loads exported from the South Belmont catchment (Kelsey et al. 2010a), using sampling and flow data from the South Belmont gauging station. Nutrient loads, flow, rainfall, coefficient of runoff, and winter median TN and TP concentrations for the Bartram Road and South Belmont catchments are shown in Table 6-1, for the years 1996 – 2007. Table 6-2 shows the input versus export loads for the Bartram Road and South Belmont catchments for the years 2000, 2003 and 2007.

***Table 6-1**: Results of catchment modelling in the Bartram Road and South Belmont catchments: flow, TN, TP and CR*

Year	Flow (ML)	TN load (kg)	TP load (kg)	Rainfall (mm)	*CR**	TN (mg/L)	TP (mg/L)
Bartram Road							
1996	637	2056	313	922	5.9%	3.23	0.49
1997	185	538	108	698	2.3%	2.90	0.58
1998	168	379	60	787	1.8%	2.26	0.36
1999	347	823	128	891	3.3%	2.37	0.37
2000	905	2162	317	900	8.6%	2.39	0.35
2001	454	1045	154	693	5.6%	2.30	0.34
2002	381	877	130	745	4.4%	2.30	0.34
2003	466	1118	149	916	4.4%	2.40	0.32
2004	346	865	111	708	4.2%	2.50	0.32
2005	1344	3091	484	933	12.4%	2.30	0.36
2006	364	764	131	527	5.9%	2.10	0.36
2007	418	794	134	820	4.4%	1.90	0.32
Average	501	1209	185	795	5.3%	2.41	0.38

Year	Flow (ML)	TN load (kg)	TP load (kg)	Rainfall (mm)	*CR**	TN (mg/L)	TP (mg/L)
South Belmont							
1996	2873	2356	292	903	27.3%	1.03	0.10
1997	2599	1766	256	669	33.4%	0.82	0.10
1998	2247	1871	247	703	27.4%	1.04	0.11
1999	2551	2118	275	805	27.2%	1.01	0.11
2000	2704	1881	260	771	30.1%	0.77	0.09
2001	2157	1572	214	686	27.0%	0.93	0.10
2002	2383	1735	250	694	29.5%	0.84	0.10
2003	2643	1859	266	824	27.5%	0.82	0.10
2004	2274	1461	223	640	30.5%	0.80	0.10
2005	2821	1815	263	865	28.0%	0.73	0.09
2006	1894	1110	186	520	31.3%	0.69	0.09
2007	2106	1620	217	669	27.0%	0.97	0.10
Average	2438	1764	246	729	28.9%	0.87	0.10

***Table 6-2**: Inputs vs export loads for the South Belmont and Bartram Road catchments*

Bartram Road	**2007**		**2003**		**2000**	
Land-use	**N load (tonnes)**	**P load (tonnes)**	**N load (tonnes)**	**P load (tonnes)**	**N load (tonnes)**	**P load (tonnes)**
Input load	47.4	9.84	38.6	7.90	45.5	8.37
Output loads	0.9	0.10	1.1	0.15	1.9	0.21
Output/input ratio	1.9%	1.0%	2.8%	1.9%	4.1%	2.5%
South Belmont	**2007**		**2003**		**2000**	
Land-use	**N load (tonnes)**	**P load (tonnes)**	**N load (tonnes)**	**P load (tonnes)**	**N load (tonnes)**	**P load (tonnes)**
Input load	59.1	14.38	59.1	14.38	59.1	14.38
Output loads	1.6	0.22	1.8	0.27	1.9	0.26
Output/Input ratio	2.7%	1.5%	3.1%	1.9%	3.2%	1.8%

6.1 Differences in flow

The quantity of flow exported from the Bartram Road and South Belmont catchments was vastly different. Both catchments had similar average annual rainfalls (795 mm in Bartram Road, 729 mm in South Belmont); however, the annual catchment yield (the quantity of runoff per unit area) in South Belmont was 231 mm, compared with 43 mm at Bartram Road. The average coefficients of runoff for the South Belmont and Bartram Road catchments are shown in Figure 6-3.

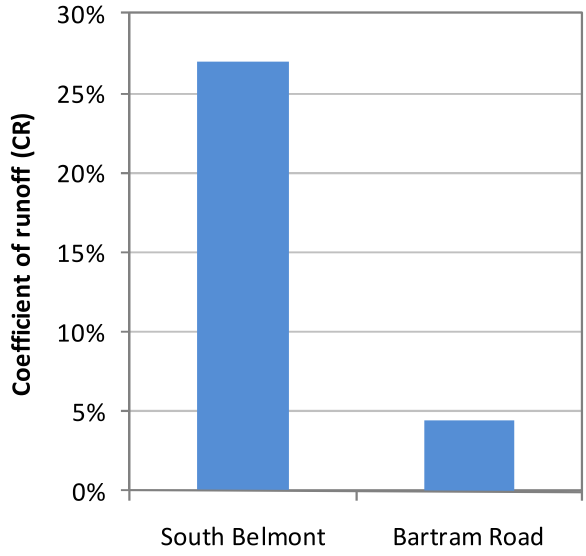


Figure 6-3: *Average CR for South Belmont and Bartram Road catchments for 1996 – 2007*

6.2 Differences in export loads

Export loads are highly related to flows, with the Bartram Road catchment exporting an average of 1209 kg/year of TN, compared with 1764 kg/year for South Belmont; and 185 kg/year of TP compared with 246 kg/year TP for South Belmont. However, there is slightly more input load in the South Belmont catchment, and for comparison the ratio of input/output loads should be reported to standardise for the total nutrient input of each of the catchments. The results of the export/input ratio for TN and TP in the Bartram Road and South Belmont catchments are shown in Figure 6-4. The Bartram Road catchment exports approximately 30 per cent less load (TN and TP) per unit input load than the South Belmont catchment, despite having much higher export concentrations.

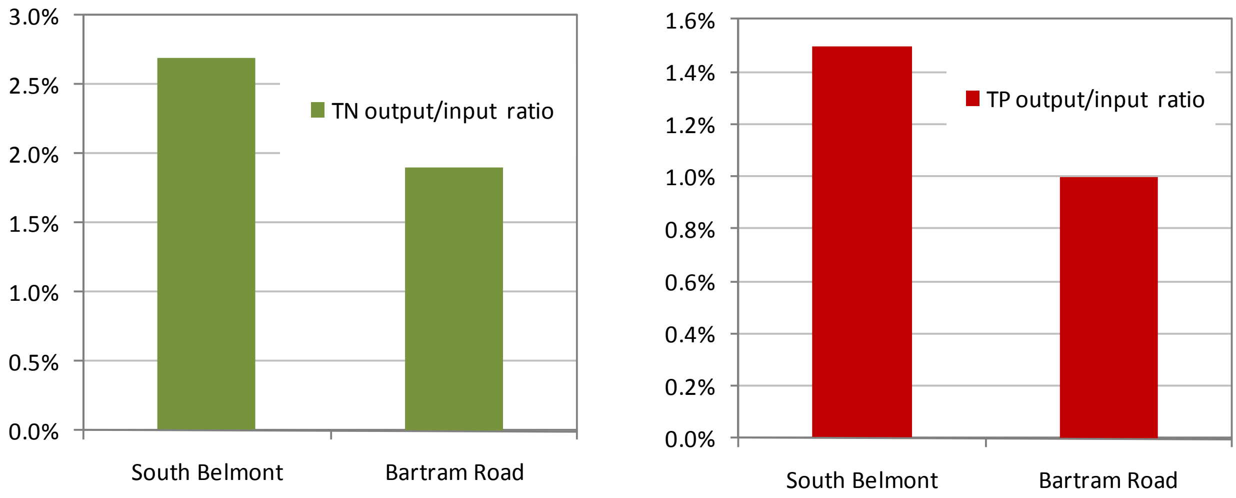


Figure 6-4: *Export/input ratios for TN and TP in the South Belmont and Bartram Road catchments*

6.3 Differences in export concentrations

The average winter median concentrations in the Bartram Road and South Belmont catchments are shown in Figure 6-5.

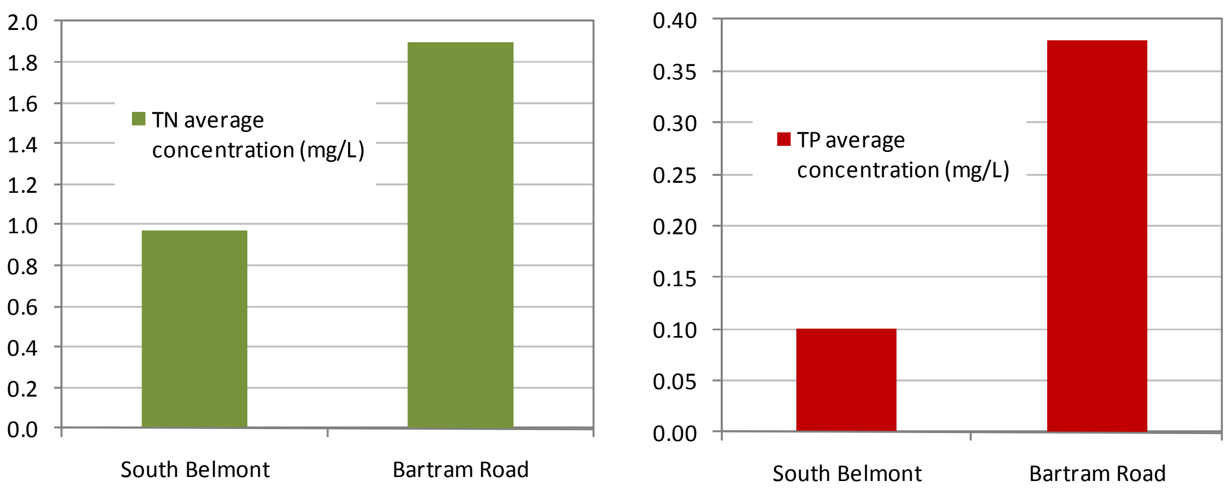


Figure 6-5: *Average winter median concentrations for TN and TP at the outlets of the Bartram Road and South Belmont catchments*

In the Bartram Road catchment, the TP concentration is approximately 3.5 times higher and the TN concentration twice as high as those of the South Belmont catchment. The concentrations for the South Belmont catchment are typical for traditionally-drained urban catchments in the Perth metropolitan area (Kelsey et al. 2010a). The concentrations for South Belmont are within the ANZECC guideline for aquatic ecosystems in lowland rivers of Western Australia (ANZECC & ARMCANZ 2000) for TN (1.2 mg/L) but exceed the guideline for TP (0.065 mg/L). Bartram Road's concentrations far exceed the ANZECC guidelines.

6.4 Mechanisms

The differences in coefficient of runoff are likely to be related to implementation of the design criterion for 'new' urban catchments; that is, 'flow rate and volume' management up to the 1-in-1 year ARI event. In the Bartram Road catchment, most rainfall events are drained internally – water therefore has the opportunity to evaporate and infiltrate from the large inland waterbodies. The South Belmont catchment's traditional drainage incorporates linear drains and small detention basins that remove water from the surface flows and groundwater and convey it to the catchment outlet quickly and efficiently. Some infiltration and evaporation from the detention basins occurs, but this will be small compared with the large constructed lakes in the Bartram Road catchment. The South Belmont catchment's coefficient of runoff is typical for urban catchments on the Swan Coastal Plain (Kelsey et al. 2010a).

In 'new' urban catchments, flow from 1-in-1 year rainfall events are captured and infiltrate or store on-site. Infiltration allows the water to be extracted via household bores for garden watering. Storage in constructed lakes and raingardens promotes evaporation and evapotranspiration. Thus capturing the 1-in-1 year flows on-site promotes evaporation, evapotranspiration and re-use, and as such reduces the outflows and the coefficient of runoff (Figure 6-6).

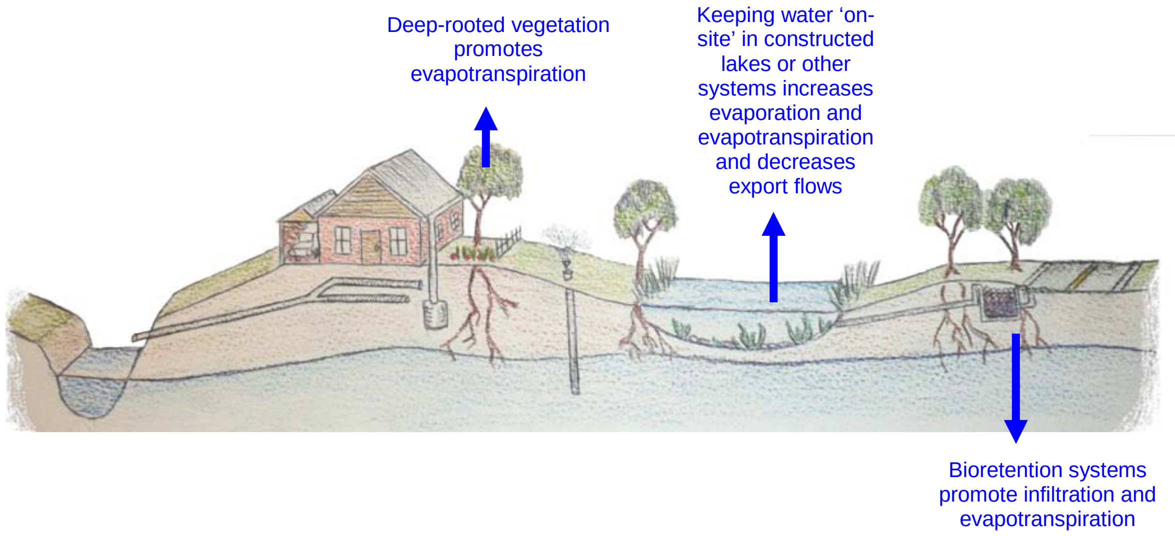


Figure 6-6: *Processes that reduce flow by means of infiltration and evaporation in WSUD catchments*

Nutrient fluxes generally follow hydrological fluxes. For traditionally-drained catchments, nutrients will move with the surface flows or subsurface drainage, through the linear drainage systems and to the receiving waterbodies. This conveyance-type drainage allows little opportunity for plant uptake of nutrients, or for the process of de-nitrification.

'New' urban catchments increase the time that water – and nutrients – remain in the catchment before being discharged to receiving waterbodies. The increased detention time provides plants with more time to adsorb nutrients and promotes denitrification. Extraction of water for backyard or public open space watering will also increase the uptake of nutrients, and infiltration will allow phosphorus more opportunity to adsorb to soil particles as it travels through the soil profile. All of the above processes will reduce the export load of nutrients from 'new' urban catchments (Figure 6-7).

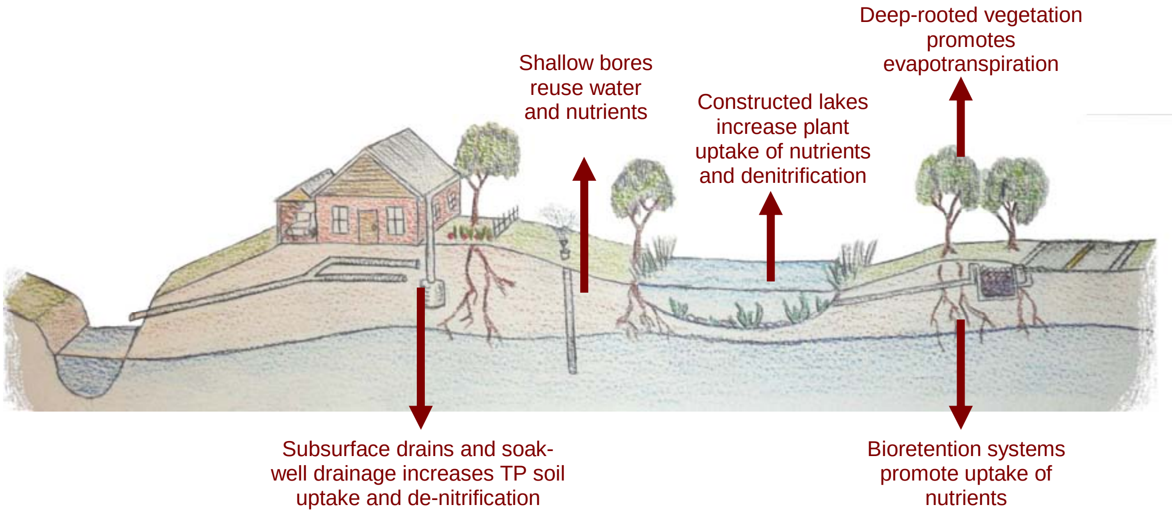


Figure 6-7: *Processes that reduce nutrients by means of infiltration and evaporation in 'new' catchments*

The hydrological and drainage features of the Bartram Road catchment drastically reduce its coefficient of runoff compared with the South Belmont catchment. The nutrient uptake is increased, but not by as much as the reduction in flow. Therefore, the nutrient concentrations exported from the Bartram Road catchment are higher.

7 Discussion

7.1 'New' urban development and nutrient management – is it effective?

7.1.1 Managing receiving waterbodies

The Bartram Road catchment exhibits reduced flow, reduced loads and increased nutrient concentrations when compared with the South Belmont catchment (traditionally-drained). Capturing the 1-in-1-year flows on-site promotes evaporation, evapotranspiration and re-use, and as such reduces outflows. Infiltration promotes soil adsorption of phosphorus, and increased detention time in the catchment gives plants more time to use nutrients, while promoting denitrification.

The Bartram Road catchment's waterways are ephemeral, with flows ceasing in summer. Most urban catchments in the Perth metropolitan region flow year-round. In winter, it is more important to manage catchment loads than concentrations, because the receiving waterbodies are unlikely to respond to nutrient concentrations. Conversely, it is important to manage flows and concentrations from urban catchments in summer, when conditions are favourable for algal growth. There is little or no flow from natural or agricultural catchments in summer, and most of the nutrients exported to receiving waterbodies during this period are from urban catchments (Kelsey et al. 2010a).

'New' urban catchments capture most summer events, and hence reduce the flow output in summer (the hydrology is more similar to the natural state). Also, the winter (and total) loads are reduced when compared with traditionally-drained catchments. The shift from traditionally-drained urban catchments to 'new' urban catchments is likely to lessen the impact of urban development on receiving waterbodies. The 1-in-1 year event design criterion is effective in reducing catchment loads by managing catchment flows.

When catchments capture 1-in-1 year events, little summer flow would be expected. In the Bartram Road catchment, however, some groundwater flow continues through December and into January each year. Baseflow will need to be managed even when the 1-in-1 year events are captured in WSUD catchments, particularly because baseflow nutrient concentrations are likely to be high to very high (see Section 5).

7.1.2 Managing constructed lakes

As mentioned previously, nutrient concentrations are elevated in 'new' urban catchments. On the Swan Coastal Plain, implementation of the 1-in-1 year event design criterion often involves the development of constructed lakes to manage stormwater. The lakes are generally a prominent feature within the residential development, and are highly valued by the community for their recreational and aesthetic function. Constructed lakes are subject to relatively high concentrations of nitrogen and phosphorus, due mostly to the high fertilisation rates of surrounding urban land uses. It is very difficult to create a constructed lake that will not be subject to nuisance algal blooms in summer if they receive high nutrient concentrations as an input. As such, most constructed lakes in the Perth metropolitan region are subject to regular phytoplankton blooms (Woodward 2008), a problem that dominates management issues for these features on the Swan Coastal Plain. While it is acknowledged that 'new' urban catchments are likely to be an improvement on traditionally-drained catchments when managing the water quality of receiving waterbodies, the problem of elevated nutrient concentrations persists and continues to cause management issues. Further actions are required to address excessive nutrient concentrations in urban waterways.

7.1.3 Bartram Road urban compared with pre-existing land uses

For all nutrient species with the exception of nitrate, decreasing trends in concentration are evident over the period of urbanisation. The pre-existing land use consisted mostly of grazing, horses and lifestyle blocks. There were also three piggeries in the catchment, which were decommissioned before urbanisation. It is very difficult to link catchment land use with nutrient export concentrations for various reasons: signals in catchment inputs versus exports are confused by nutrient run-down from pre-existing land uses, and often the pre-existing land uses are unknown; or pre-existing nutrient inputs are difficult to quantify (as in the case of the piggeries). It is possible the decreasing trends are a result of the piggeries being removed, but this is impossible to assess because the size and effluent quantity of the piggeries is unknown. There was an estimated decrease in nutrient input between the years 2000 and 2003, when the agricultural land had been taken out of production but urban gardens had not yet been established. It is also possible the decreasing trend over the period of urbanisation could be due to the decreasing trend in input over this period. Some evidence (Kelsey et al. 2010b) suggests that established residential land use has lower fertilisation rates than newer residential areas.

A slight increase in export loads occurred during the urbanisation period, which was not statistically significant, but evident despite a general decrease in rainfall over the same period. The increasing catchment loads are likely to be due to increased flows, as urbanisation increases impervious areas and infiltration, and decreases evapotranspiration from vegetation.

Analysis of the input loads indicates similar input loads pre- and post-urbanisation, with marginally higher input loads post-urbanisation (the piggery loads were not included). Large decreases in nutrient export loads post-urbanisation cannot be achieved without decreasing nutrient input loads significantly. Increased loads in urban catchments are likely to be linked with how the hydrology is managed. If a development is designed to effectively manage flows so that the coefficient of runoff does not increase, then management of the catchment loads will also be more effective.

7.1.4 Groundwater

A simple calculation of groundwater load exports from the Bartram Road catchment revealed that groundwater flow is likely to be a major source of nutrient load for developments on the Swan Coastal Plain. This is particularly important in 'new' urban developments, where surface water flows are minimised. The high proportion of load being delivered via groundwater is a consequence of the Swan Coastal Plain's sandy soils, where hydraulic conductivities are high and water moves relatively quickly through the soil profile. In addition, the soils generally have a very low PRI, so phosphorus does not bind to the soil matrix in many locations and will move freely through the groundwater and to the receiving waterbodies. Water quality management for 'new' urban developments must consider groundwater.

7.1.5 What does this mean for water quality targets?

Water quality targets are contentious at the best of times. Targets generally fall under three categories: 1) load targets, 2) concentration targets, and 3) load reduction targets. All three have problems both with implementation and assessment. The Swan River Trust generally uses concentration compliance targets (Kelsey et al. 2010a), whereas the Environmental Protection Authority may implement the condition of 'no net increase in load', effectively setting a load target.

As demonstrated in this report, load and concentration reductions can be mutually exclusive (Bartram Road catchment produces relatively lower loads but increased concentrations when compared with the South Belmont catchment). This outlines the importance of considering the environmental values being protected (i.e. the receiving waterbody) when setting targets, and the largest risks to these values. Seasonality and timing of exports should be considered, as should groundwater flows and exports. Water quality targets are influenced by environmental, social and economic considerations, which in most cases will be unique. Where possible, targets should have regard for the current condition and long-term trends in water quality. In summary, targets should take into account the catchment's hydrology, as well as the water quality.

7.1.6 What does this mean for predictive tools?

The current standard tool for urban water quality assessment used by developers and regulators in Australia is the Model for Urban Stormwater Improvement Conceptualisation (MUSIC). MUSIC is a modelling tool for designing conceptual stormwater management systems at scales ranging from a single residence to an entire catchment. It is not a detailed drainage design tool but rather a tool for evaluating the water quality treatment of stormwater. MUSIC is a product of the eWater Cooperative Research Centre. MUSIC is widely used in Australia's eastern states and is endorsed by regulators in Victoria and Queensland for demonstrating the compliance of proposed stormwater management plans with local planning requirements.

However, MUSIC is not widely used in Western Australia because it does not adequately address issues related to shallow groundwater, which are important on the Swan Coastal Plain. An underlying assumption of MUSIC is that most (more than 90%) of the water in a catchment is 'surface water' that may be intercepted and treated. For catchments on the Swan Coastal Plain this is not the case, because a large percentage of the flow is from groundwater. Seventy-one per cent of the flow in Bartram Road catchment is groundwater flow (Section 5.3). This means that much of the 'storm' water can infiltrate directly to groundwater without being intercepted by treatment devices. MUSIC does not currently account for these groundwater fluxes. The importance of groundwater as a major flux of nutrient export has been demonstrated in this report. Tools to assess water quality management will need to adequately address groundwater if they are to be used for urban catchments on the Swan Coastal Plain.

Furthermore, MUSIC models only sediment and TN and TP loads, and does not include other nutrient species and contaminants. For example, treatment systems will perform differently according to the fraction of dissolved and particulate phosphorus and even the form of dissolved phosphorus (organic or inorganic). It has been demonstrated in the Bartram Road catchment that most TP is in dissolved form. Structural controls that reduce phosphorus concentrations by means of sediment removal will not perform as well in these circumstances, and the change in performance due to the differences in ratios of soluble to particulate TP must be captured in an appropriate water quality assessment tool. A tool that allows different treatment efficiencies for different nutrient species is needed for Swan Coastal Plain catchments.

In addition, MUSIC does not currently address subsoil drains, soil amendment or the specific treatment efficiencies of structural best management practices in Western Australia, and consequently it is not currently endorsed by the Department of Water or local government authorities – indeed in some cases its use is opposed by regulators.

The Department of Water and the Urban Development Institute of Australia agree that an endorsed tool is needed to help developers design drainage systems that meet the urban water management objectives outlined in various policy documents, and to assist regulators evaluate compliance of the resulting drainage plans. It is suggested that MUSIC be modified so that regulators can endorse it for use in Western Australia.

7.2 Future directions

7.2.1 Source control

Source control refers to the management of nutrient inputs (sources) to the catchment. An analysis of nutrient inputs in the Bartram Road catchment showed similar input rates of nitrogen and phosphorus pre- and post-urbanisation. Structural controls used to treat water quality will only treat a certain percentage of the nutrient load; so without some form of source control, the management of loads and nutrient concentration of outflows will be difficult. In particular, the management of constructed lakes for eutrophication will be very difficult. Recent fertiliser surveys indicate that urban fertilisation rates are similar to or higher than some agricultural fertiliser rates (e.g. beef grazing, sheep, horses or mixed grazing).

It appears that little has been done to limit fertiliser inputs in the Bartram Road catchment. Figure 7-1 shows a typical street within the Bartram Road catchment (Bandee Drive). Large gardens containing predominantly turf, turf in the median strips, non-native tree species and high-fertiliser-use gardens (e.g. roses) are evident in most streets of the catchment.

The methodology for source control is outlined briefly in Chapter 7 of the Department of Water's *Stormwater management manual* (DoW 2007) and includes:

- maintenance of gardens and reserves with respect to plant selection, pest management, irrigation, lawn maintenance and nutrient management
- amendment of soils in the construction phase of urban developments to minimise the export of nutrients from gardens and lawns
- education campaigns on effective fertiliser use.

Figure 7-1: *Bandee Drive, Bartram Road catchment*

The *Fertiliser action plan* (JGFIWP 2007) has been invoked to reduce leaching of phosphorus from fertilisers to waterways, and is another effective method of source control for urban nutrients. The plan aims to phase out the use of highly water-soluble phosphorus fertilisers on the coastal plain's low PRI soils. Water-soluble phosphorus fertilisers (80 – 100% soluble) will be replaced by fertilisers with low water solubility (40% or less). The plan will mandate that the maximum highly water-soluble phosphorus content of non-bulk (bagged) fertilisers for urban use be 1% for lawn fertilisers and 2.5% for general garden fertilisers.

Planning controls that promote unfertilised native gardens in both residential lots and public open space should be strongly encouraged. This is an effective WSUD practice that limits fertiliser use and minimises water consumption. Some metropolitan developments have placed 'controls' on gardens (e.g. 'The Green' development at Brighton).

A change in fertiliser use requires a fundamental shift in the behaviour of urban landowners. The change from backyards with large areas of turf and high water- and fertiliser-use European-style gardens to native gardens with minimal turf areas is a challenge that all states of Australia currently face. Adoption of low-impact garden practices is necessary if the control of nutrients and water quality is to be successfully achieved in urban Western Australia.

7.2.2 Monitoring and modelling

Currently there is no suitable standard for urban catchment monitoring that allows accurate loads to be calculated. Accurate loads need to be assessed to enable target setting.

MUSIC is the Australian standard for urban catchment water quality modelling, but is not suitable for Western Australian coastal catchments. A modelling tool for urban developments in coastal Western Australia needs to include groundwater nutrient loads in the nutrient budget. If such a tool is to be developed it needs to be:

- scientifically rigorous
- simple for practitioners to use
- simple for regulators to assess.

The development of such a tool requires collaboration between regulators, practitioners and developers. It is recommended that the Department of Water and local government authorities endorse or develop a tool or tools for the design of stormwater management plans (and water quality assessments in particular) and that the department review what software is available and determine a suitable model applicable to the Swan Coastal Plain.

Furthermore, the Department of Water needs to inform local government authorities that the computer model MUSIC requires modifications to address the role of groundwater and, until it is modified or new software is adopted, it can only be used as an approximate guide to assess BMPs.

A large research gap also exists in BMP measurement in Western Australia. The design and assessment (by regulators) of treatment systems to meet water quality targets would be aided by the publication of endorsed treatment efficiencies. The determination and publication of these treatment efficiencies should be the responsibility of the Department of Water. The department needs to investigate treatment efficiencies for BMPs currently used in Western Australia and publish values for use in MUSIC and other models.

8 Conclusions

One of the main aims of WSUD is to maintain the pre-development catchment hydrology. To achieve this in Western Australia, the Department of Water has implemented a design criterion addressing 1-in-1 year ARI flow events, which are to be retained at- or near-source. This criterion is implemented in ‘new’ urban catchments: in the Bartram Road catchment in the form of a series of connected constructed and natural wetlands. This study examined the flow and nutrient data at the outflow of the catchment, and at four groundwater bores in the catchment for a 16-year period during which urbanisation occurred.

- Flow and the coefficient of runoff increased over the period of urbanisation, despite a decrease in rainfall. The increases are caused by less evapotranspiration due to decreased vegetated area and the use of subsurface drainage under the urban areas.
- The TN and TP concentrations were high to very high (according to the classifications from the *Statewide water quality assessment* webpage) for the period studied. However nutrient concentrations decreased slightly post-urbanisation.
- There was an increase in nutrient load post-urbanisation (increased flows + decreased concentrations → increase loads). That is, the increase in flow had relatively more impact on nutrient loads than the concentration decreases. This also might be due to greater nutrient inputs post-urbanisation.
- Groundwater nutrient loads were estimated to be approximately 17% of the TP load and 39% of the TN load. This highlights the importance of managing groundwater quality as well as surface water quality on the Swan Coastal Plain. This becomes particularly relevant in ‘new’ urban catchments, where surface water export is minimised, and larger proportions of the flow are from groundwater than in traditionally-drained urban catchments.
- Phosphorus exported from the catchment is mostly in soluble form due to the low PRI of the soils. Nitrogen consists mostly of dissolved organic nitrogen, with significant amounts of nitrate and relatively small amounts of ammonia.

To assess the relative benefits of ‘new’ urban drainage, the hydrological, nutrient load, and nutrient concentration outputs of the Bartram Road catchment were compared with those of South Belmont catchment, which is a traditionally-drained urban catchment of similar size, soil type and annual rainfall.

- Average catchment flow yield for South Belmont was over five times higher than Bartram Road (231 mm compared with 43 mm).
- Bartram Road exports approximately 30% less load (TN and TP) per unit input load than South Belmont, despite having much higher export concentrations. Nutrient uptake is relatively greater in Bartram Road than South Belmont.
- Bartram Road TP concentrations are approximately 3.5 times greater and the TN concentrations approximately twice those of South Belmont.

- ‘New’ urban catchments are likely to have less impact on receiving waterbodies than traditionally-drained urban catchments. The 1-in-1 year event design criterion reduces catchment loads by managing catchment flows. However, in most cases, the load reductions are not enough to protect receiving waterbodies and further measures such as nutrient stripping features or source controls are required.

- ‘New’ urban catchments are hydrologically more similar to agricultural and natural catchments than traditionally-drained catchments. They have much smaller summer flows than traditionally-drained catchments. Summer flows are important because receiving waterbodies (large rivers and estuaries) are prone to algal activity during this period.

Source control refers to the management of the nutrient inputs (sources) to the catchment. An analysis of the inputs of nutrients in the Bartram Road catchment showed similar input rates of nitrogen and phosphorus pre- and post-urbanisation. Without some form of source control, the management of loads and nutrient concentration of outflows will be difficult. In particular, the management of constructed lakes for eutrophication will be very difficult.

A change in fertiliser use requires a fundamental shift in the behaviour of urban landowners. Adoption of low-impact garden practices is necessary if the control of nutrients and water quality is to be successfully achieved in urban Western Australia.

Appendix A: Historic aerial photographs (2000–07)

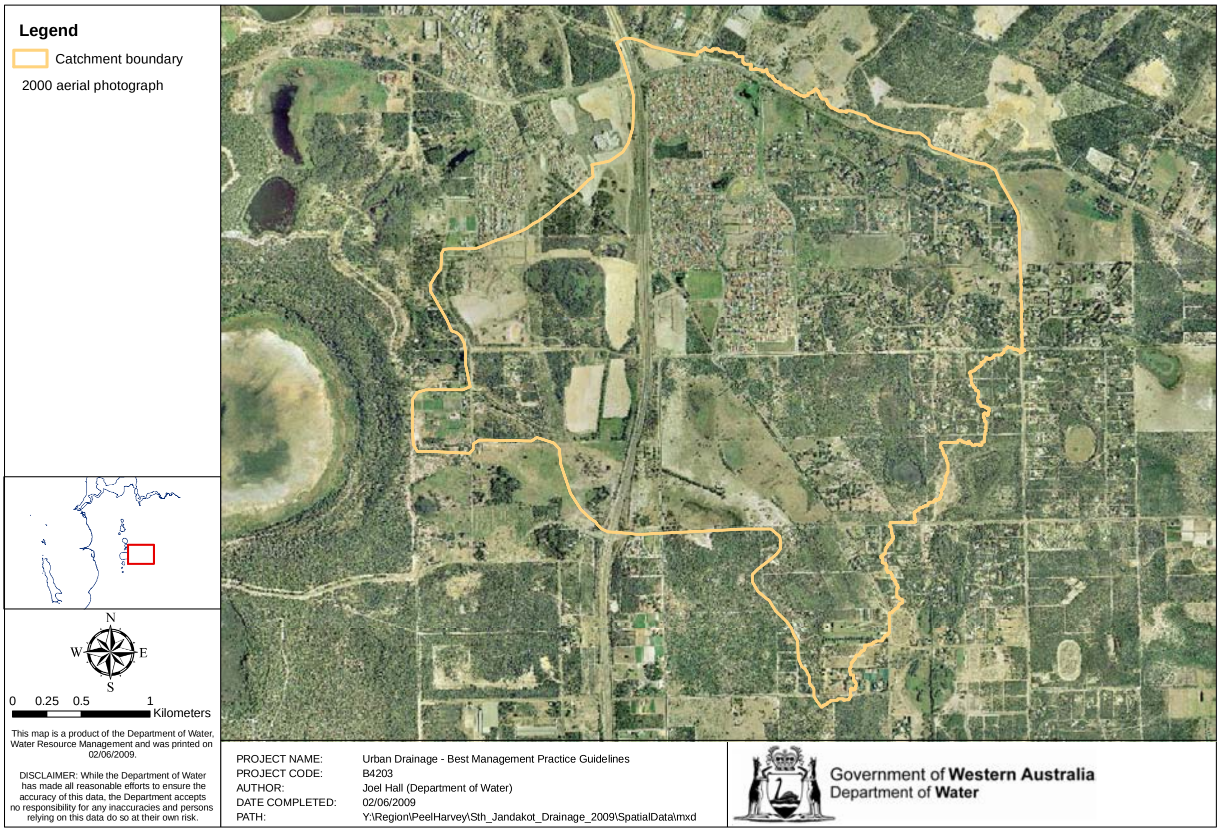


Figure A-1: *2000 aerial photograph of the Bartram Road catchment*

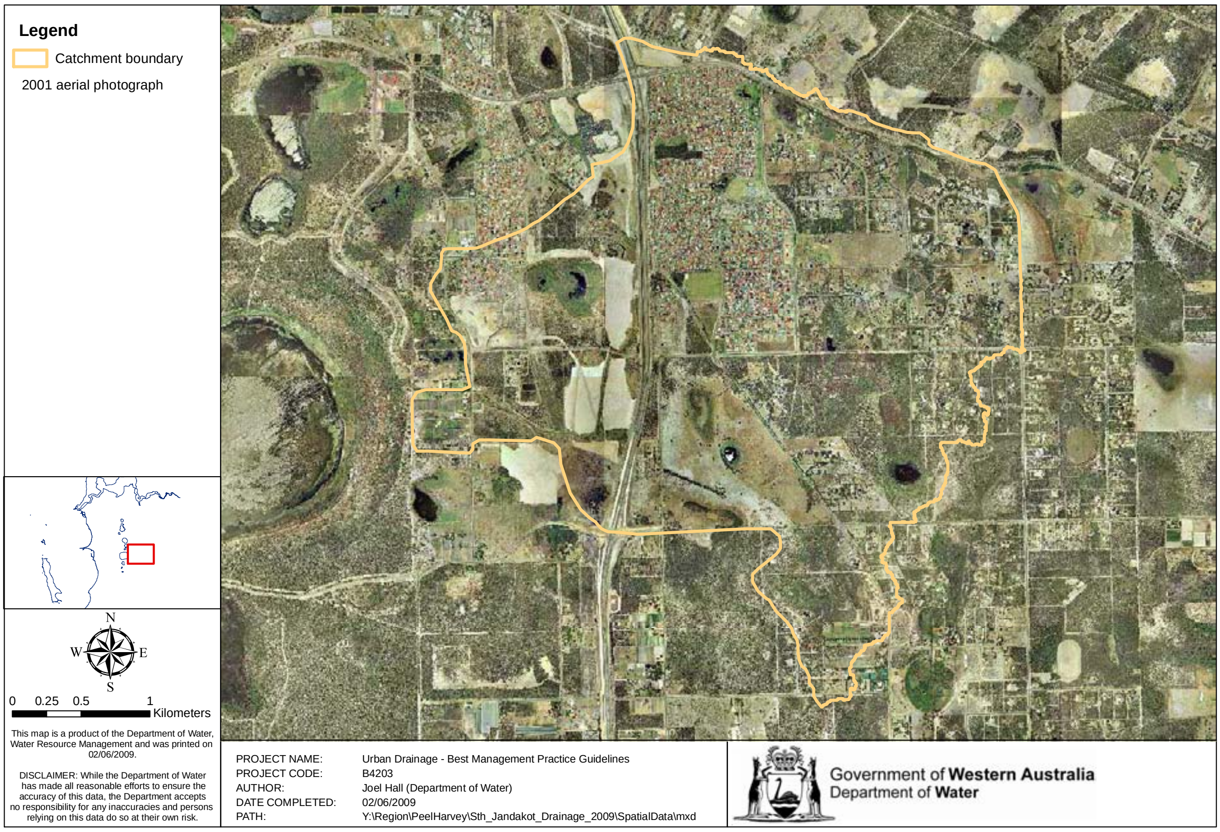


Figure A-2: *2001 aerial photograph of the Bartram Road catchment*

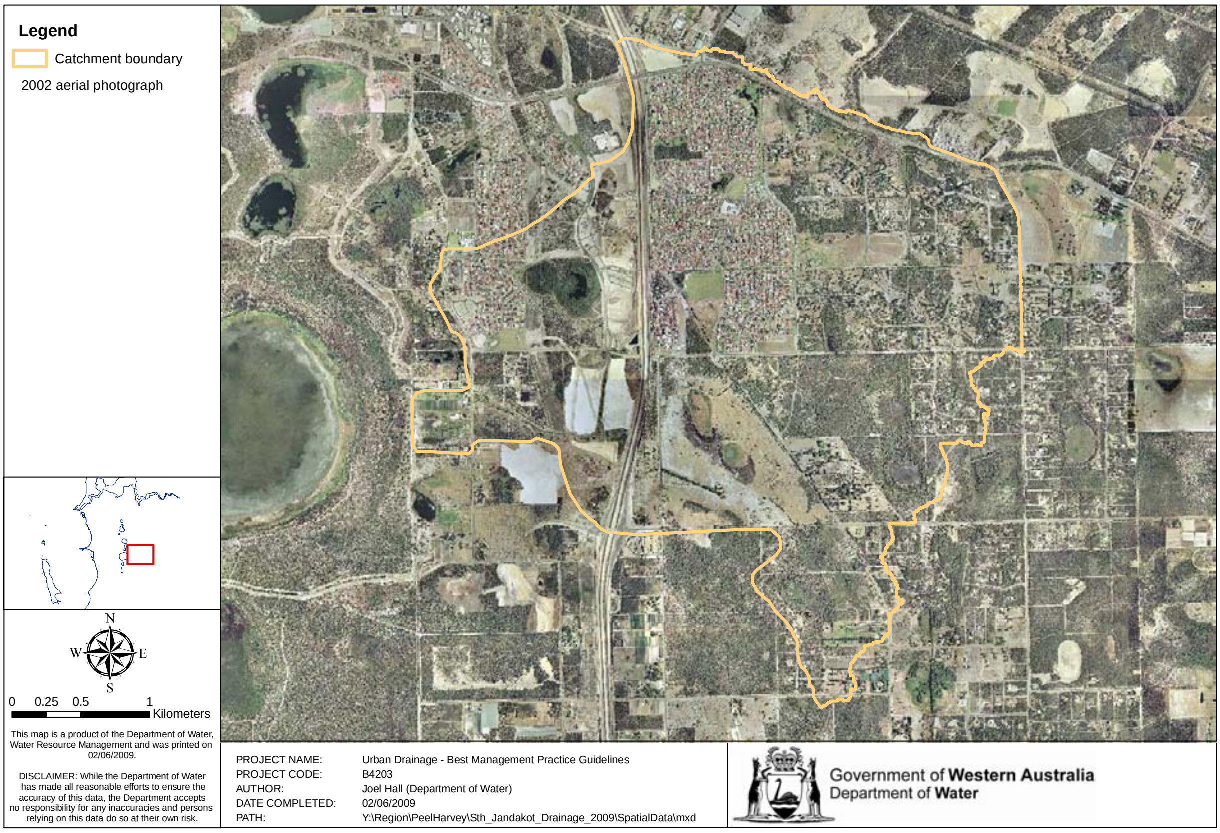


Figure A-3: *2002 aerial photograph of the Bartram Road catchment*

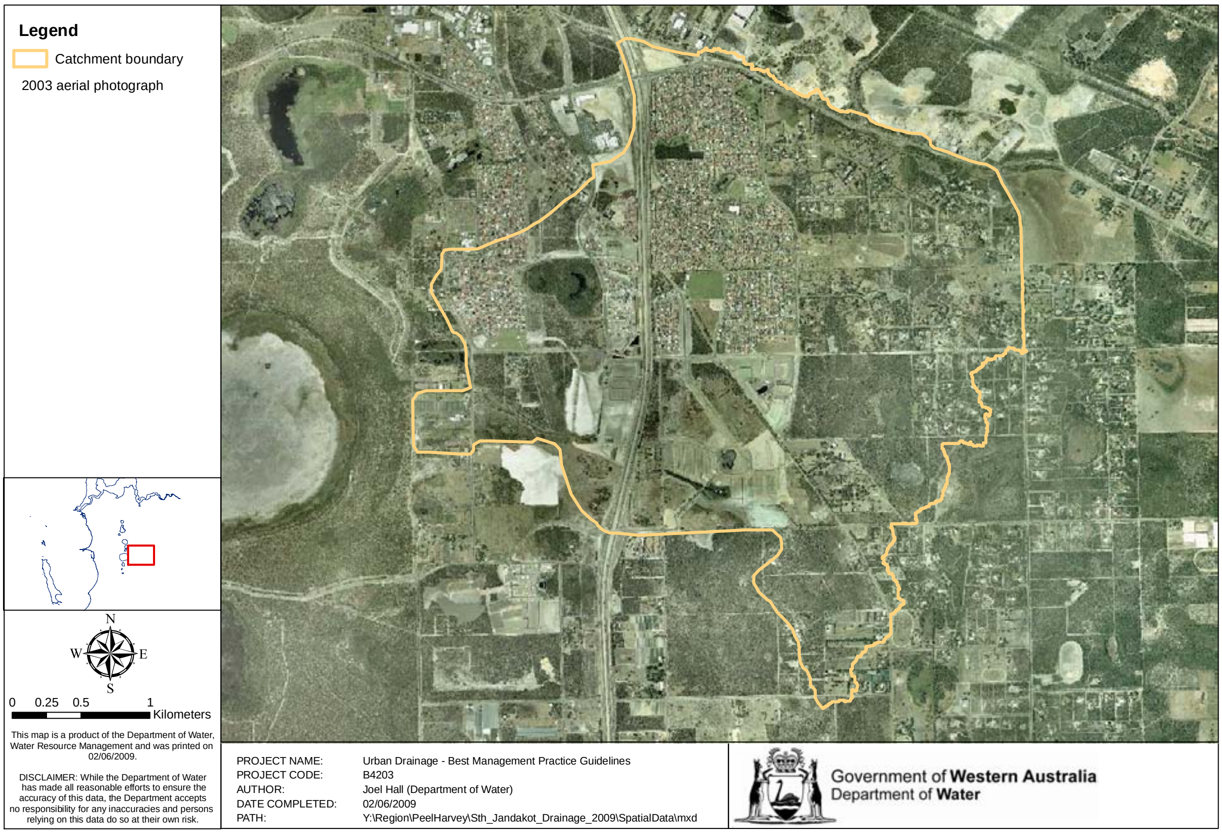


Figure A-4: *2003 aerial photograph of the Bartram Road catchment*

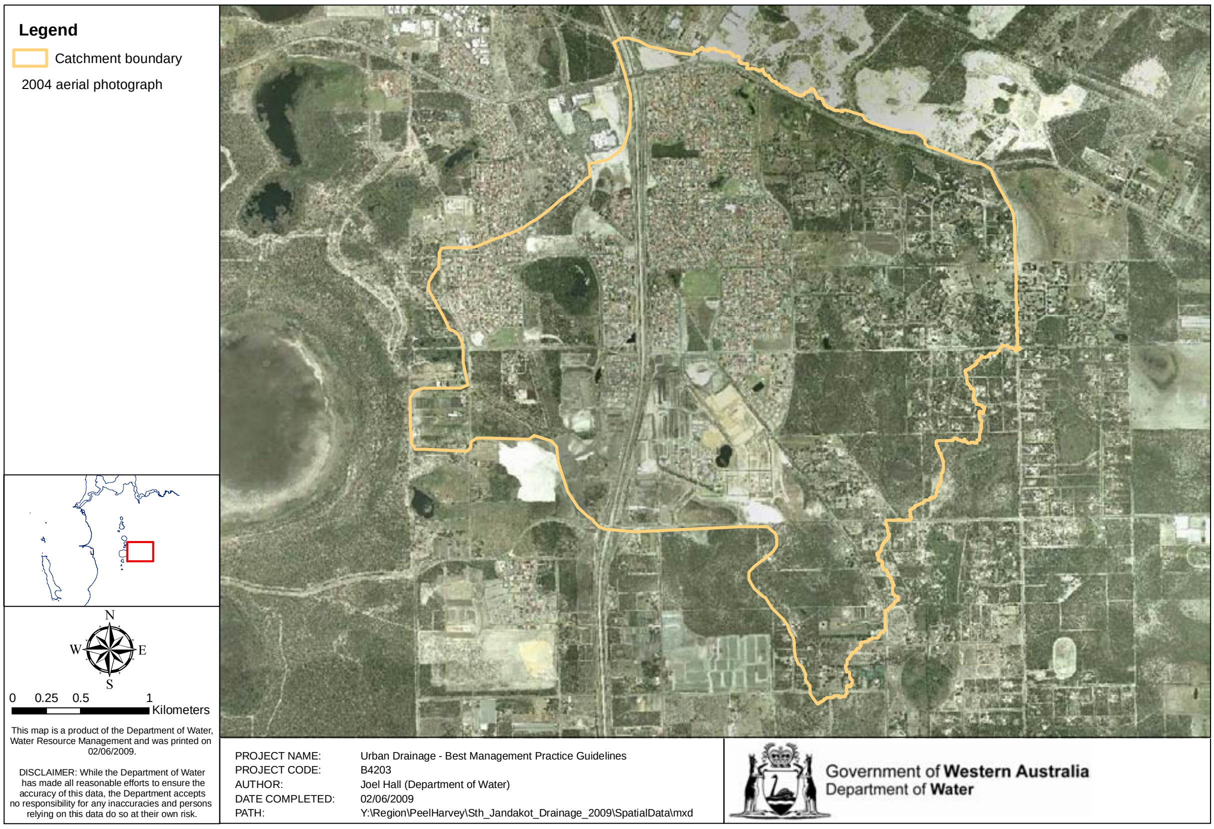


Figure A-5: *2004 aerial photograph of the Bartram Road catchment*

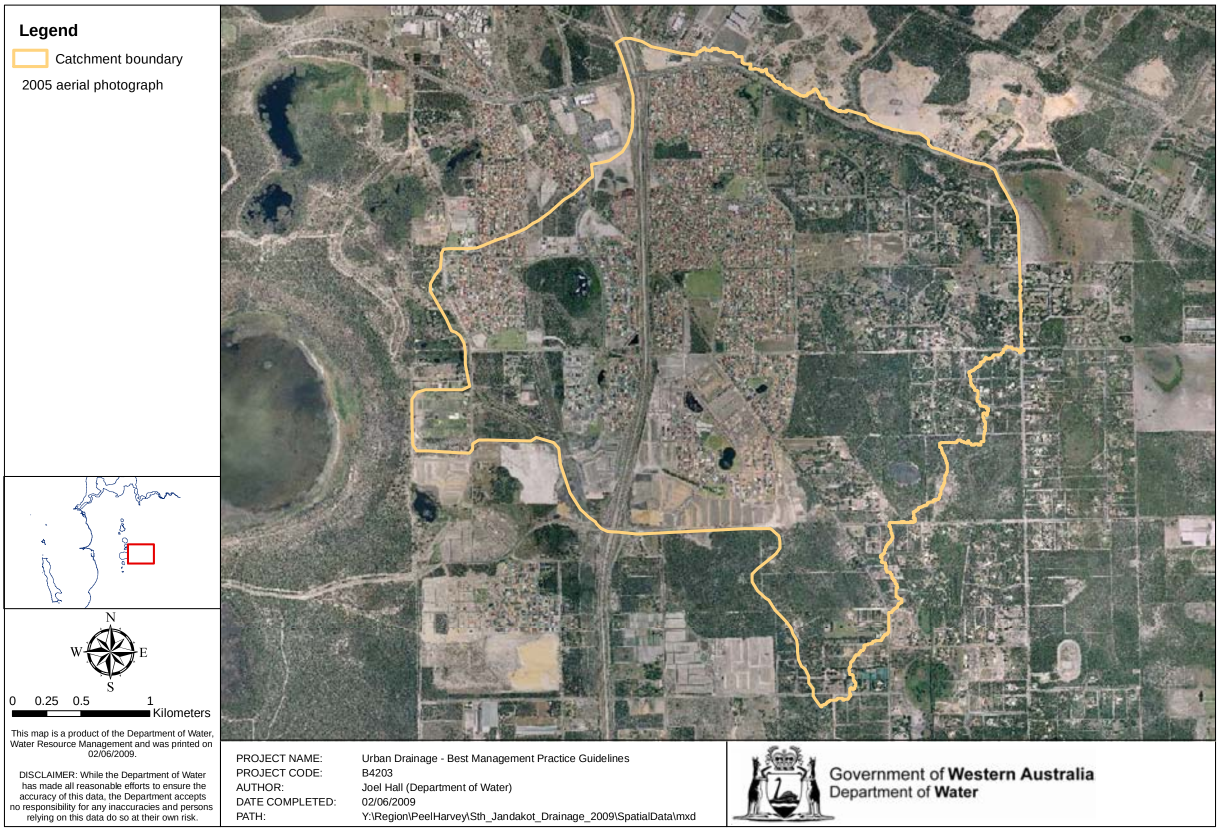


Figure A-6: *2005 aerial photograph of the Bartram Road catchment*

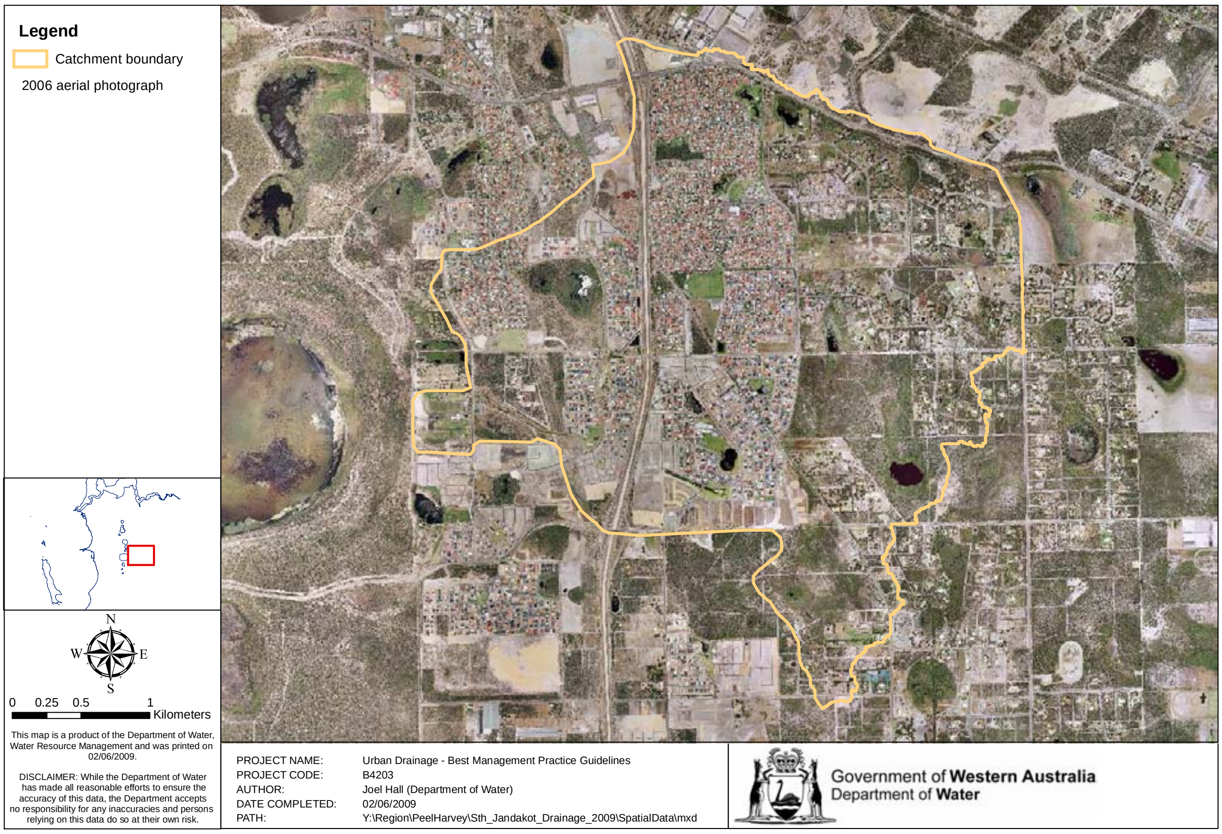


Figure A-7: *2006 aerial photograph of the Bartram Road catchment*

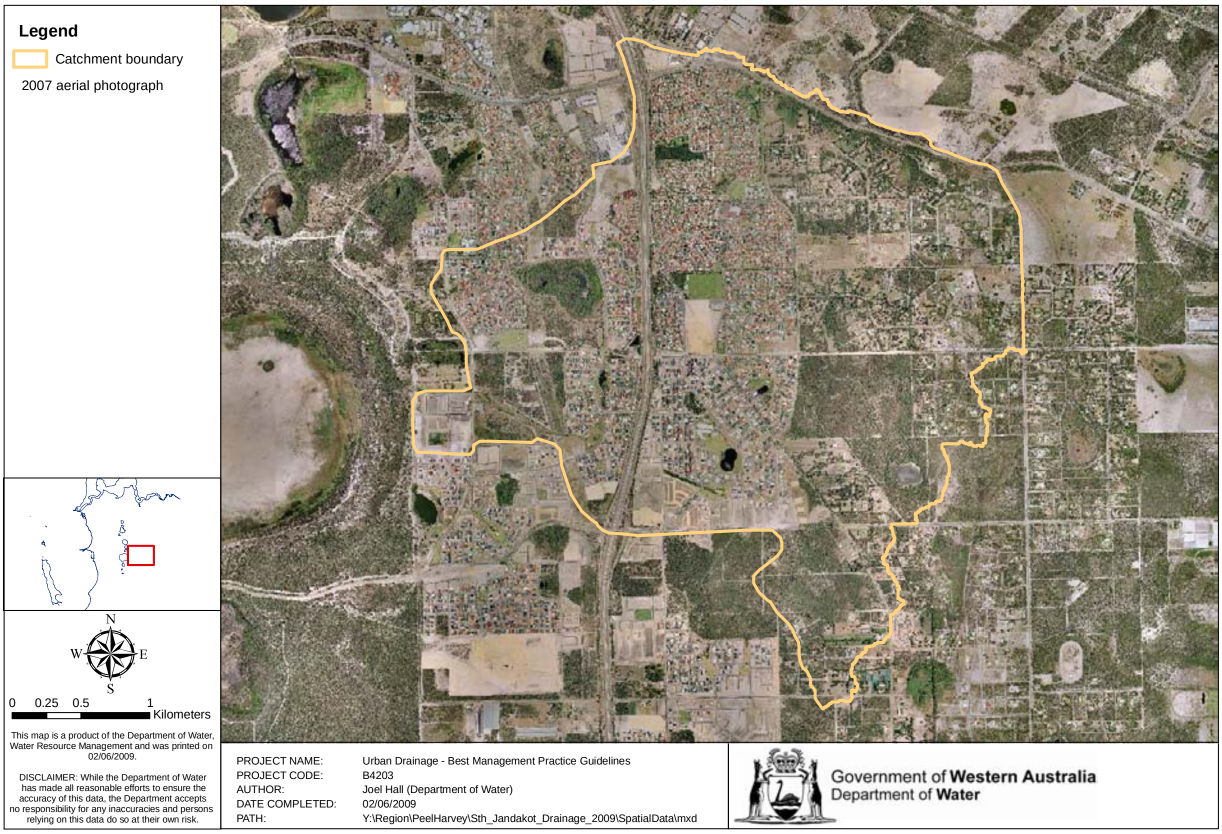


Figure A-8: *2007 aerial photograph of the Bartram Road catchment*

Appendix B: Statistical trend test methodology

Testing for statistically significant changes

The Mann-Kendall test is used to determine the statistical significance of the trends in water quality over time (Gilbert 1987). It is a non-parametric test and is only used when the data series exhibits independence (i.e. no correlation in the data series) (Figure B-1). The Mann-Kendall test works by calculating a statistic 'S' and testing the significance of this statistic. Each data pair is compared and assigned a plus or a minus depending on whether the later data point is higher than the earlier data point. 'S' is the overall number of pluses or minuses (where one plus cancels out one minus) for the whole dataset (Nelson 2004). The Z-statistic, from which the 'p-value' is derived, is calculated as follows:

$$Z = \frac{S-1}{[Var(S)]^{1/2}} \qquad \text{if } S > 0$$

$$Z = 0 \qquad \text{if } S = 0$$

$$Z = \frac{S+1}{[Var(S)]^{1/2}} \qquad \text{if } S < 0$$

Where *Var(S)* is the variance of the dataset used to derive 'S'. An increasing trend will have a large positive Z-statistic, while the Z statistic for a decreasing trend will be negative and have a large absolute value.

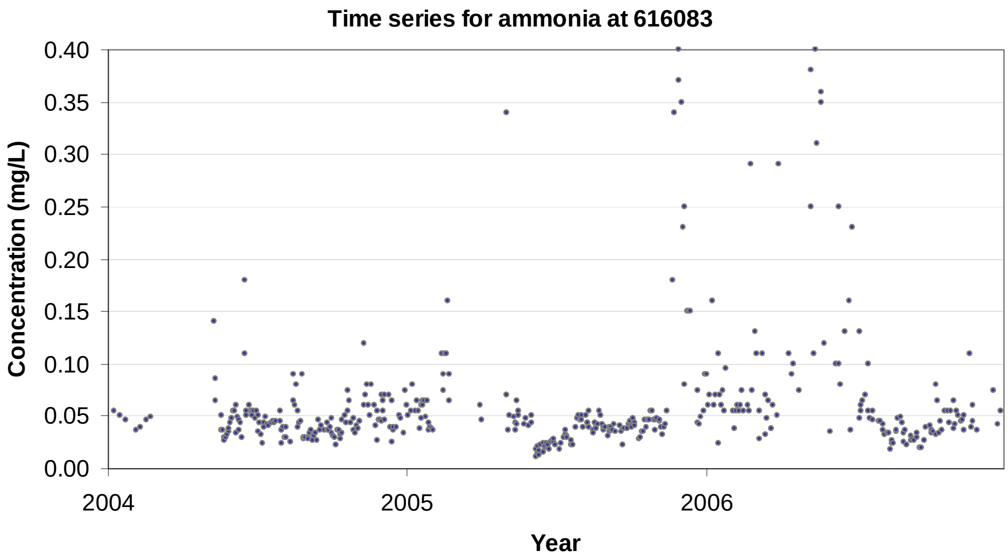


Figure B-1: *Example of a time-series with little evidence of a seasonal pattern in total phosphorus concentration, hence the Mann-Kendall test for trend is used*

Seasonal cycles in nutrient concentration are common in waterways and can be introduced by natural cycles in rainfall, runoff, tributary hydrology and seasonal variation in groundwater. When seasonal cycles are evident in a data series (Figure B-2), the Seasonal-Kendall test is used to test for trend. The Seasonal-Kendall test is a variant of the Mann-Kendall test that accounts for the presence of seasonal cycles in the data series (Gilbert 1987). The ‘S’ statistic is calculated slightly differently in the Seasonal-Kendall test. Rather than comparing all data pairs, only data points falling in the same ‘season’ are compared. For example, if a weekly season is used, data points from the first weeks of the year are only compared with data points from the first week of all other years.

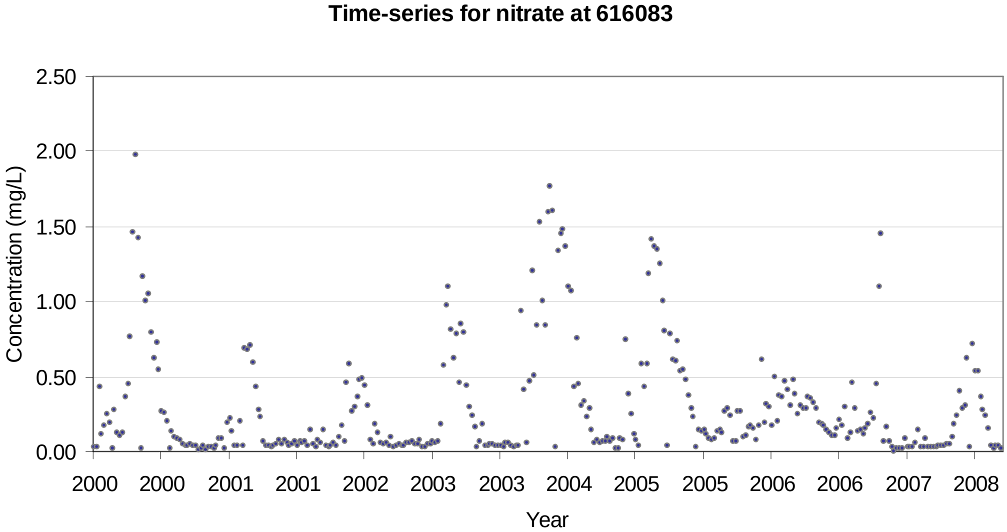


Figure B-2: *An example of a pronounced seasonal pattern in total phosphorus concentration*

Nutrient concentrations in waterways can also be affected by changes in flow. The relationship between nutrient concentration and flow is modelled using LOWESS fit between the concentration and flow (Helsel & Hirsch 1992). The difference of ‘residuals’ between the observed and LOWESS modelled concentration are termed flow-adjusted concentrations (FAC), as shown in Figure 5-9 (Hipel & McLeod 1994). Trend analyses may then be performed on the flow-adjusted concentrations. The flow-adjustment process often helps to remove seasonal variation (as shown by comparing Figures B-2 and B-3b), although some evidence of seasonal variation often remains in the flow-adjusted data series.

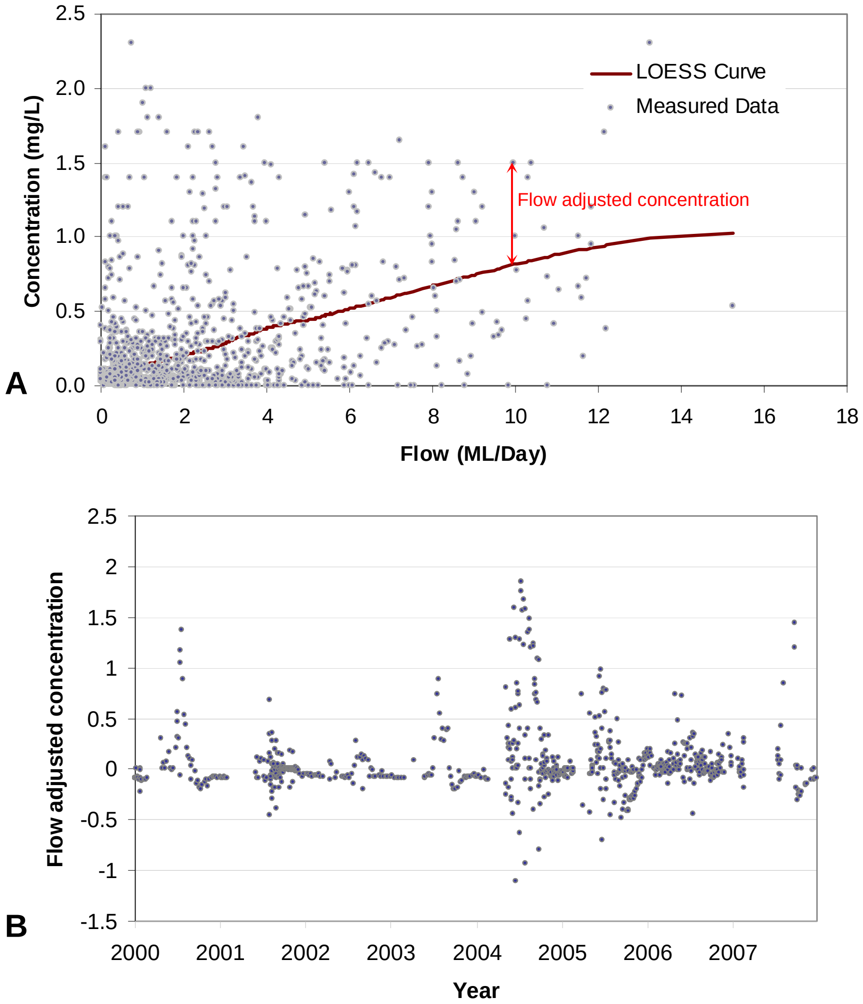


Figure B-3: *The flow response plot shows whether a relationship exists between discharge and nutrient concentration (A). The flow-adjusted concentrations (or residuals) are the difference between observed and modelled (LOWESS) concentrations (B)*

Estimating the rate of change

The Sen slope estimator is used to estimate the slope of the trend line (Gilbert 1987). The Sen estimate is calculated in a similar manner to the test statistic 'S' from the Mann-Kendall test. Rather than comparing each data pair from an increase or decrease over time, a slope is calculated using each data pair. The Sen slope estimator is taken as the median slope of all slopes calculated using all data pairs. In the presence of seasonal cycles the Seasonal-Kendall slope estimator is used. This is similar to the seasonal test 'S' in the Seasonal-Kendall test, in that slopes are only calculated for data pairs from the same season. The Sen slope estimator is the median of all these slopes. Figure B-4 shows an example of a slope estimated for a series showing seasonally.

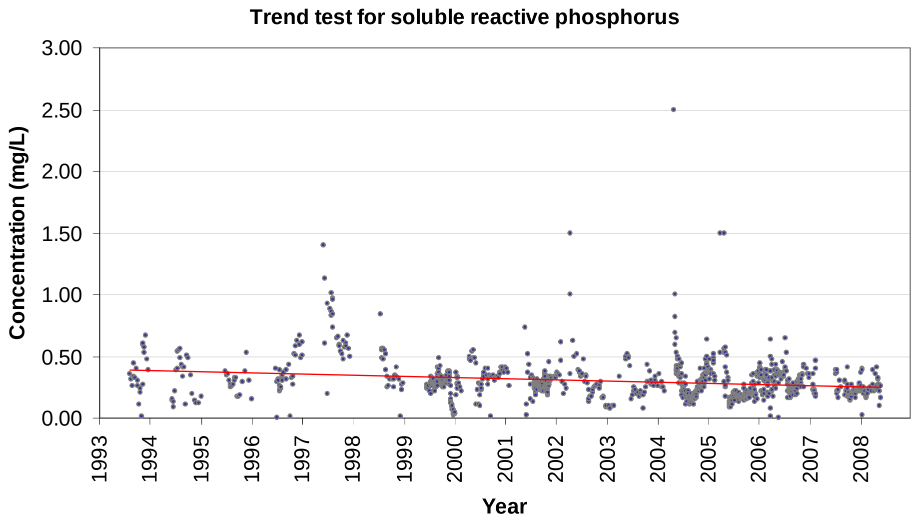


***Figure B-4:** An example of how the Seasonal Sen slope estimator represents the slope of the trend line in a seasonal nutrient data series*

Detecting the trend

A trend in the nutrient data series is significant only when two criteria are met. Firstly, the Mann-Kendall or Seasonal-Kendall test for trend and the data series must be statistically significant (i.e. $p<0.05$). Secondly, the number of independent measurements collected (n^*) has to be approximately equal to or exceed the 'estimated' number of independent measurements ($n^\#$) required to detect a trend.

The effective information content in the data series, that is the effective number of independent values, is estimated for each of the data series analysed for trend using the formula provided by Bayly and Hammersley (1946) (op cit Lettenmaier 1976; Lachance 1992; Close 1989; Zhou 1996).

$$n^* = \left[\frac{1}{n} + \frac{2}{n^2} \sum_{j=1}^{n-1} (n-j)\rho(jt) \right]^{-1}$$

Where:

n^* = effective number of independent observations

n = number of measurements

j = lag number

t = sampling interval

ρ = coefficient of correlation

Where seasonal cycles are found, the nutrient data series are de-trended and de-seasonalised (using seasonal medians) before calculating the number of independent measurements (n^*). The estimated number of measurements needed to detect a linear trend (in a variable distributed normally about the trend line) is estimate using the functions (Lettermair 1976; Ward et al. 1990):

$$n^{\#} = 12\sigma^2 \frac{\left[t_{\alpha/2,(n-2)} + t_{\beta,(n-2)}\right]^2}{\Delta^2}$$

Where:

$n^{\#}$ = estimated number of measurements needed to detect a trend

σ = the standard deviation of the de-trended series

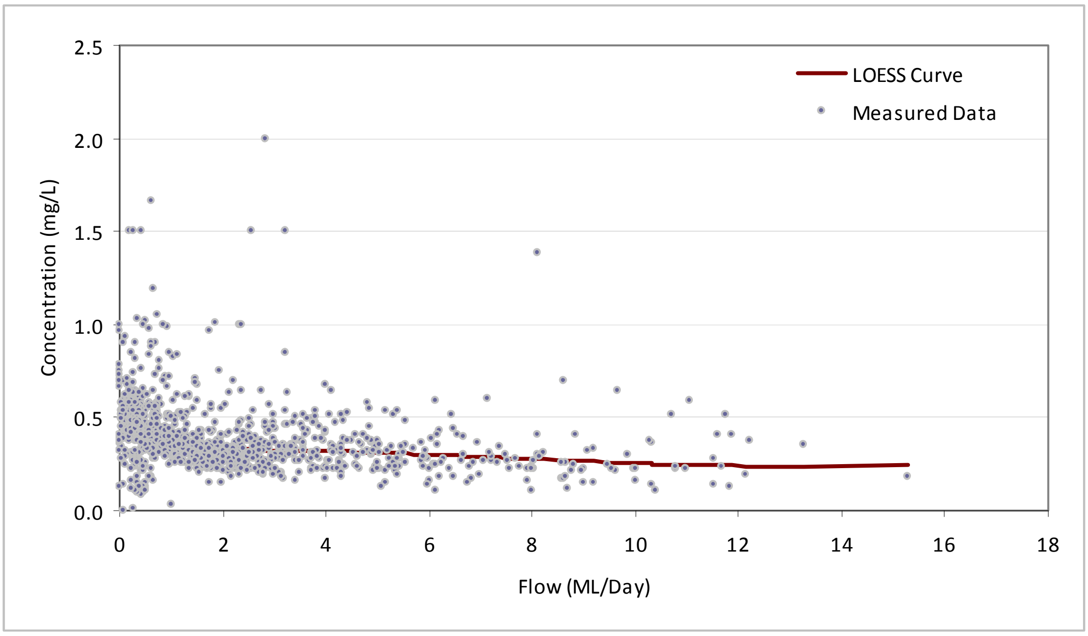
Δ = the magnitude of the trend

t = the critical values of the t-distribution where $\alpha = 0.05$ and $\beta = 0.1$

This function relies on probabilities predicted by the t-distribution and is therefore from the parametric family of statistical procedures. Data requirements for parametric and the equivalent non-parametric tests are similar, so the equation will approximate the sample size needed for non-parametric tests of significance (Ward et al. 1990).

Appendix C: LOESS curves

Total phosphorus (TP)



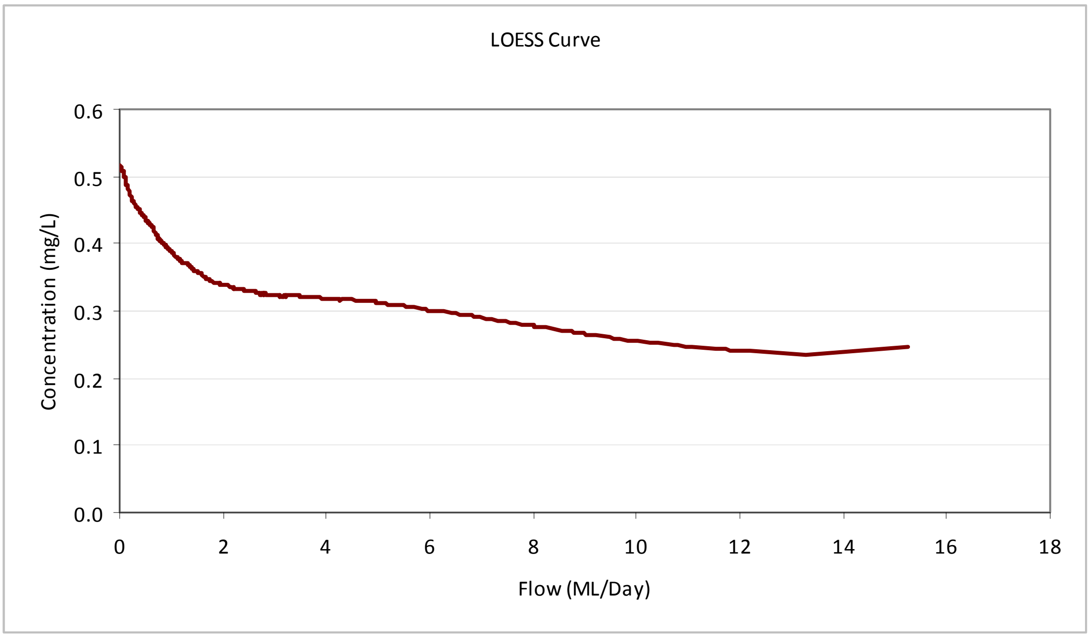
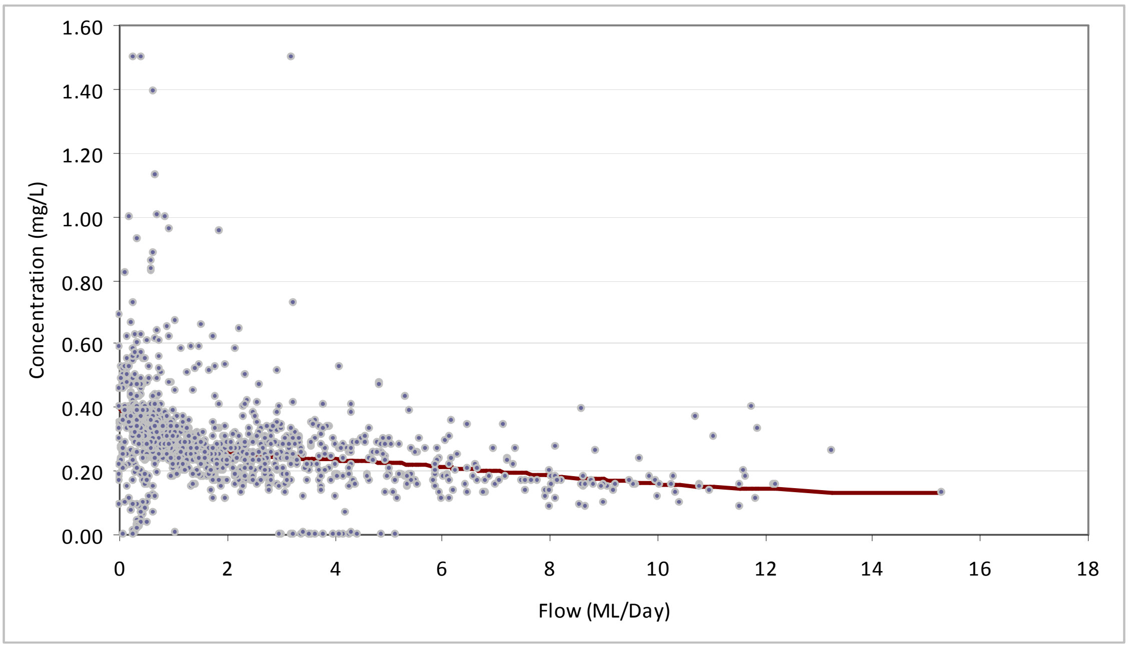


Figure C-1: *Total phosphorus LOESS curve with and without measured data*

Soluble reactive phosphorus (SRP)



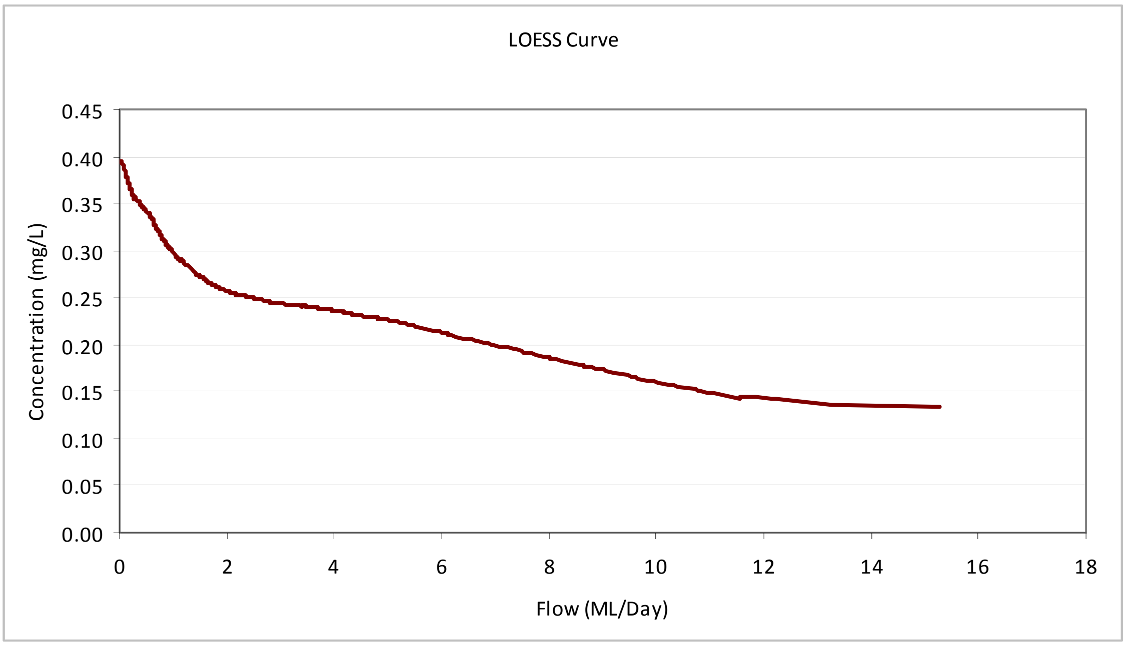
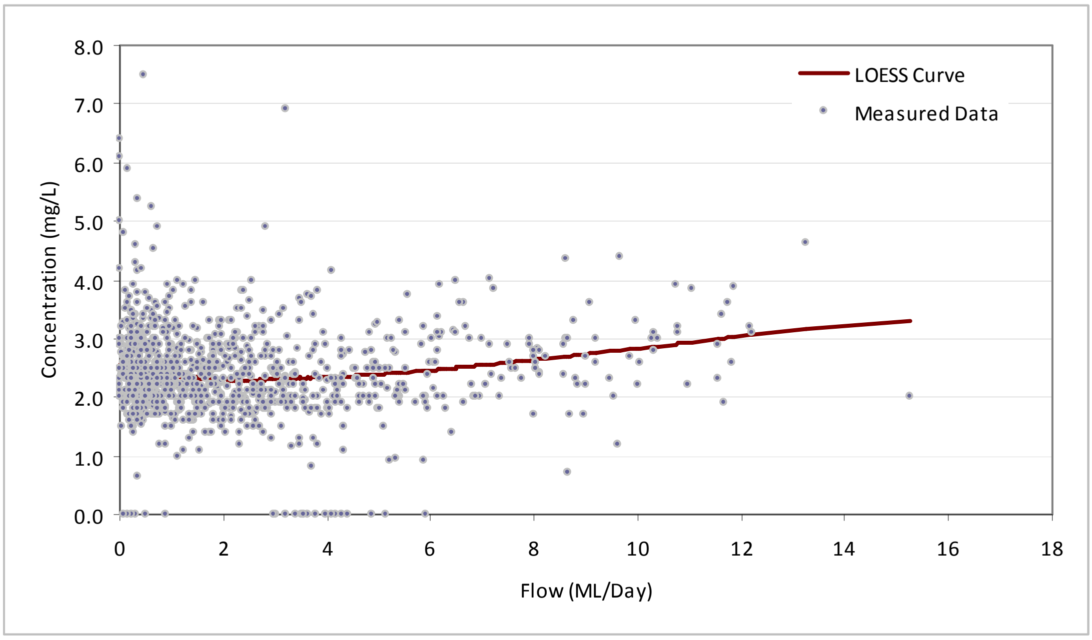


Figure C-2: *Soluble reactive phosphorus LOESS curve with and without measured data*

Total nitrogen (TN)



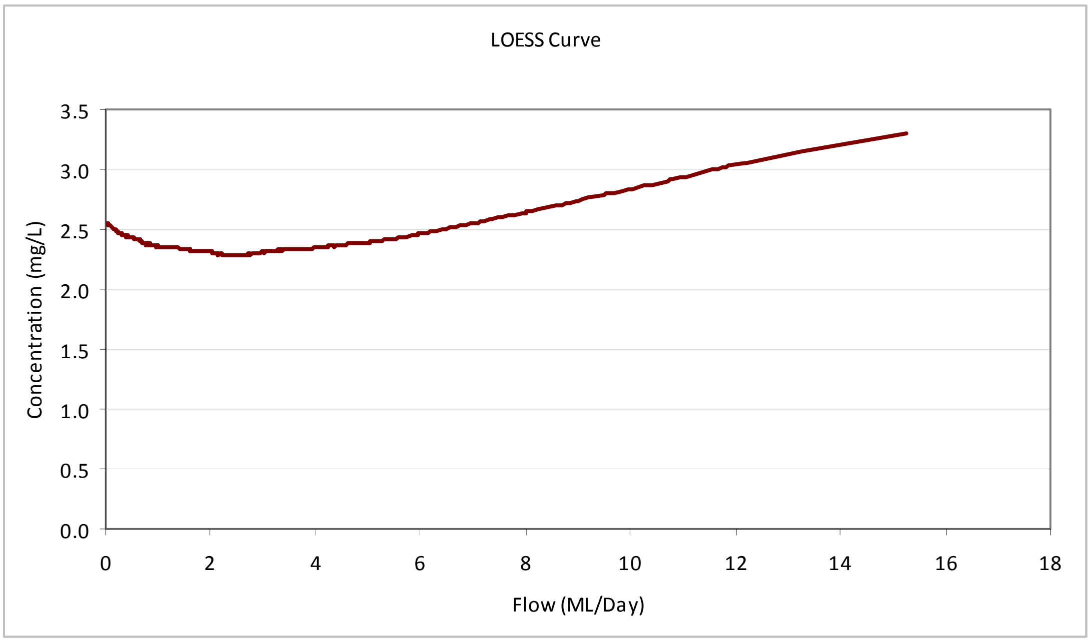


Figure C-3*: Total nitrogen LOESS curve with and without measured data*

Total oxidised nitrogen (TON)

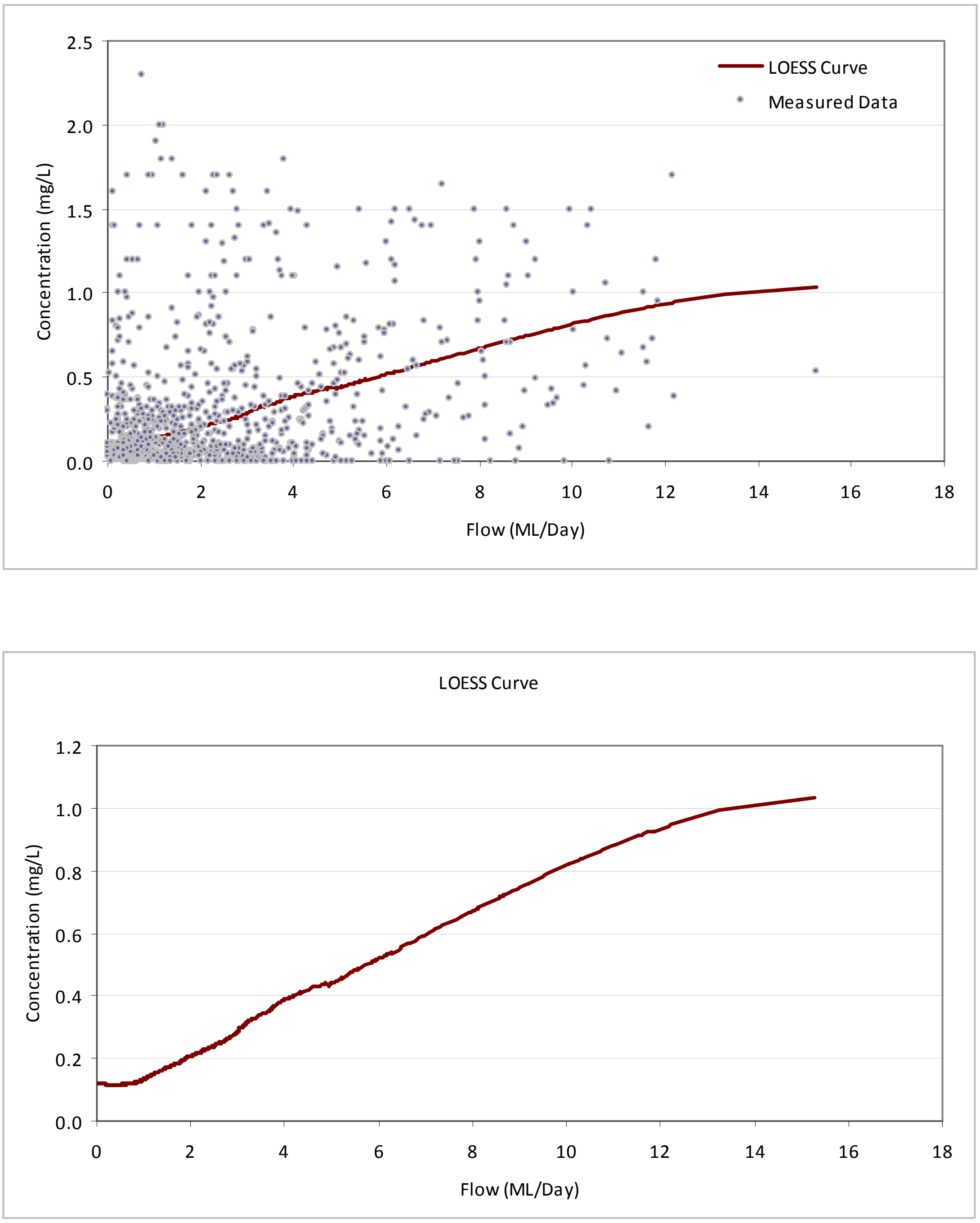
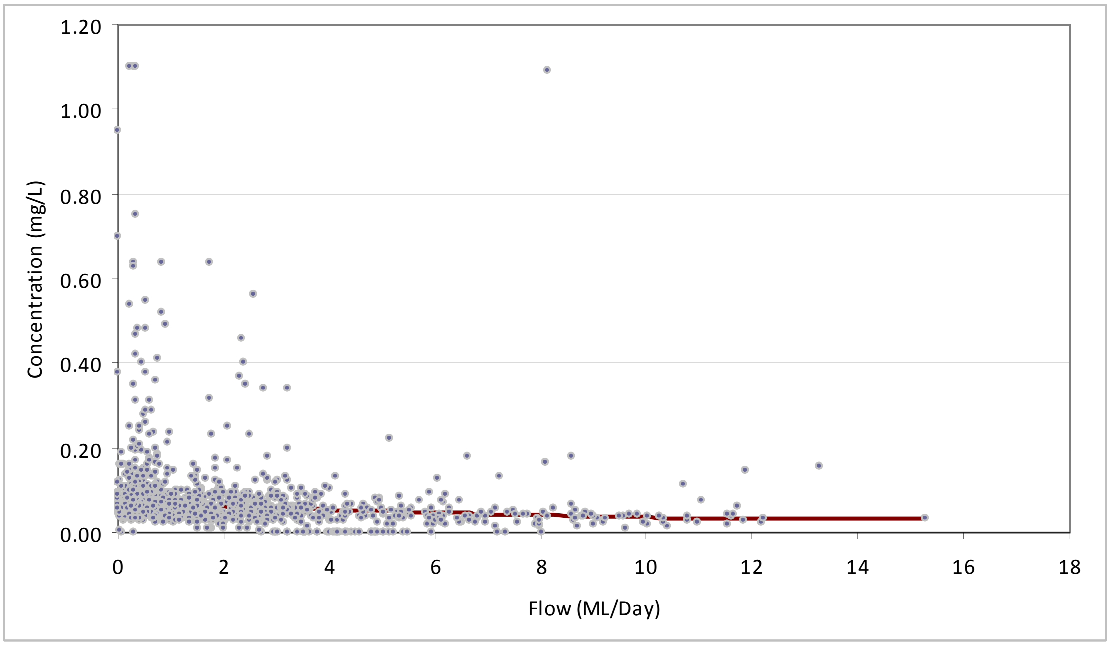


Figure C-4*: Total oxidised nitrogen LOESS curve with and without measured data*

Ammonia / ammonium (NH_3/NH_4)



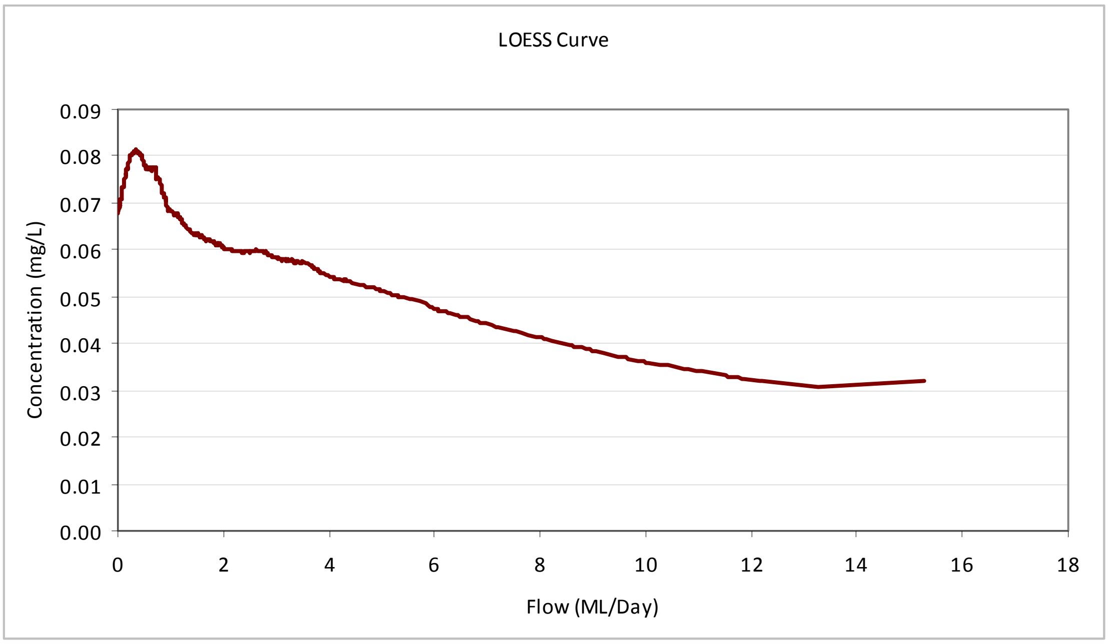
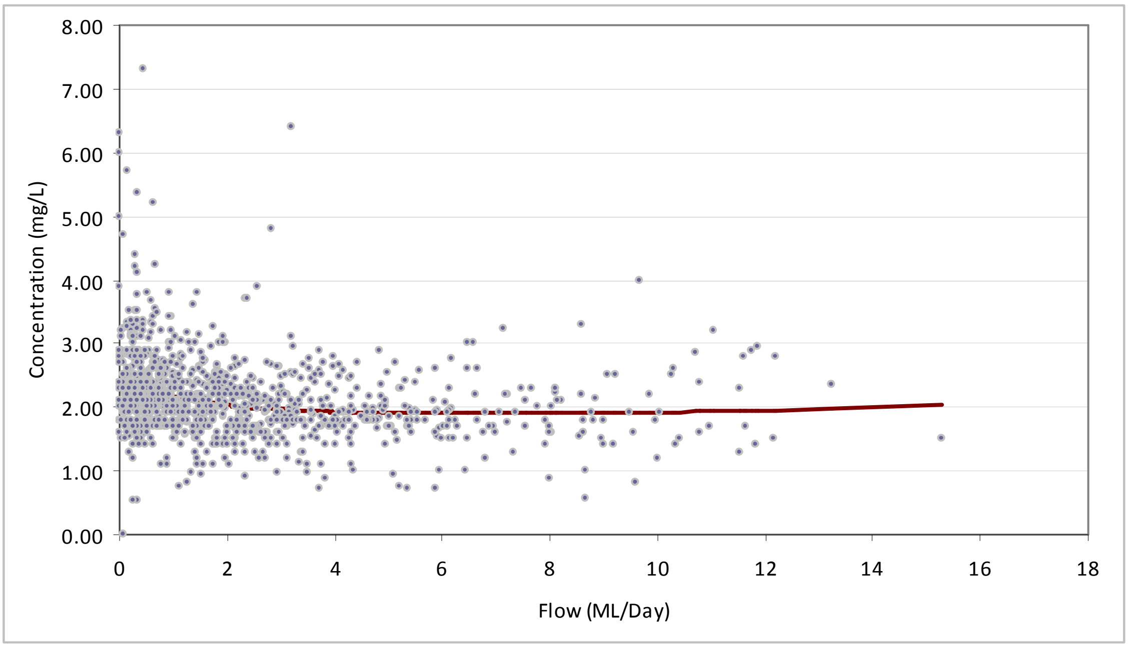


***Figure C-5**: Ammonia/ammonium LOESS curve with and without measured data*

Total Kjeldahl nitrogen (TKN)



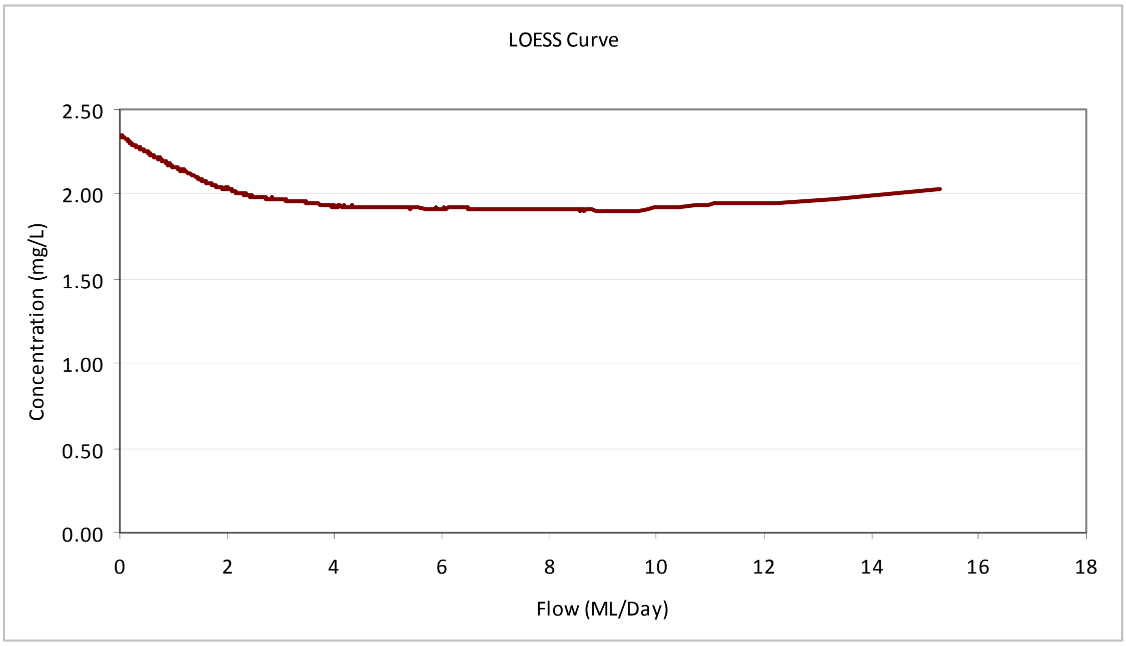
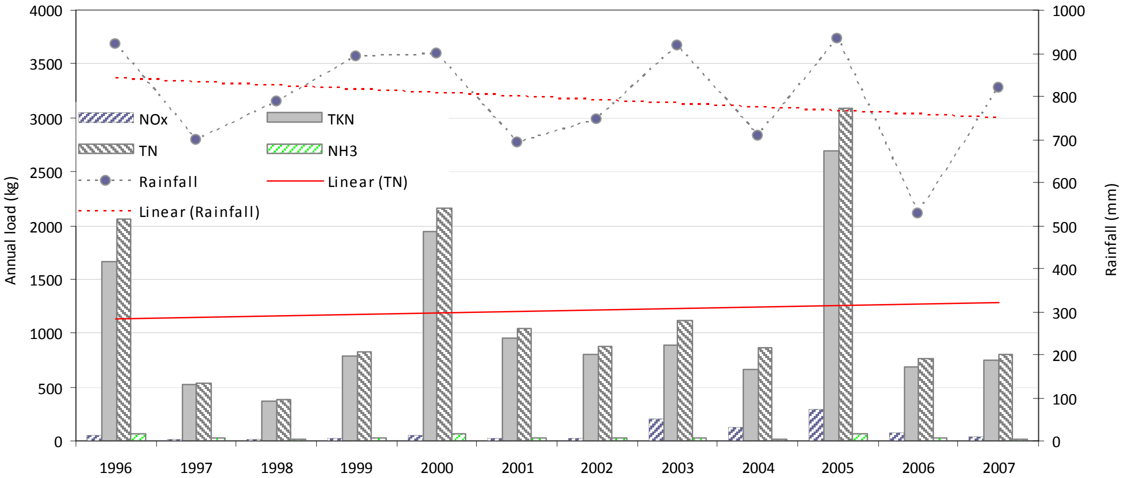


Figure C-6*: Total Kjeldahl nitrogen LOESS curve with and without measured data*

Appendix D: Alternative load calculations

		Three-year median annual loads (kg)							
Year	Flow (ML)	NOx	TKN	TN	NH3	TP	SRP	Rainfall mm)	*CR**
1996	637	46	1659	2056	67	313	322	922	5.9%
1997	185	8	526	538	22	108	102	698	2.3%
1998	168	7	362	379	14	60	49	787	1.8%
1999	347	21	782	823	29	128	100	891	3.3%
2000	905	54	1946	2162	59	317	251	900	8.6%
2001	454	27	954	1045	30	154	123	693	5.6%
2002	381	25	800	877	23	130	103	745	4.4%
2003	466	200	885	1118	21	149	119	916	4.4%
2004	346	128	657	865	15	111	76	708	4.2%
2005	1344	289	2688	3091	63	484	336	933	12.4%
2006	364	71	691	764	20	131	98	527	5.9%
2007	418	33	752	794	15	134	96	820	4.4%



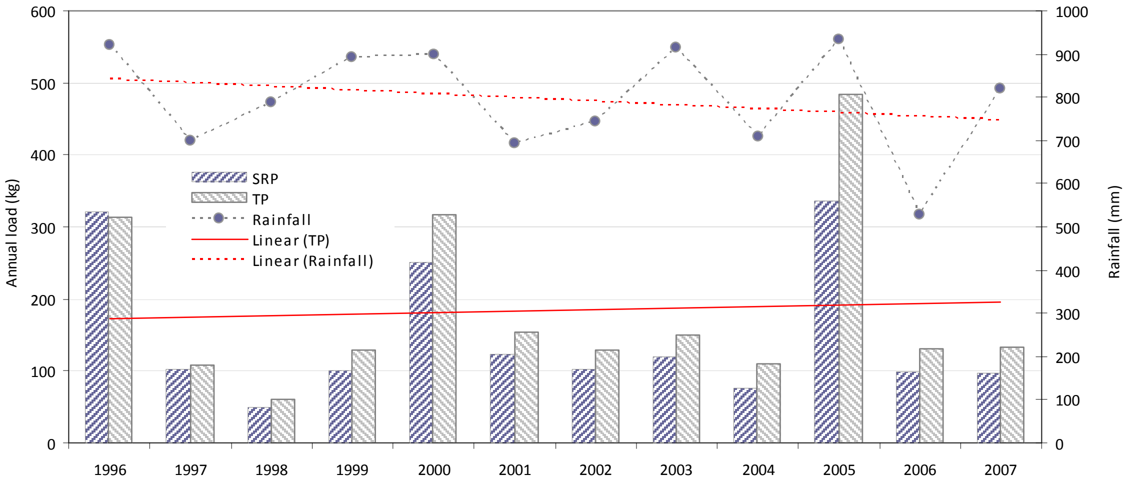
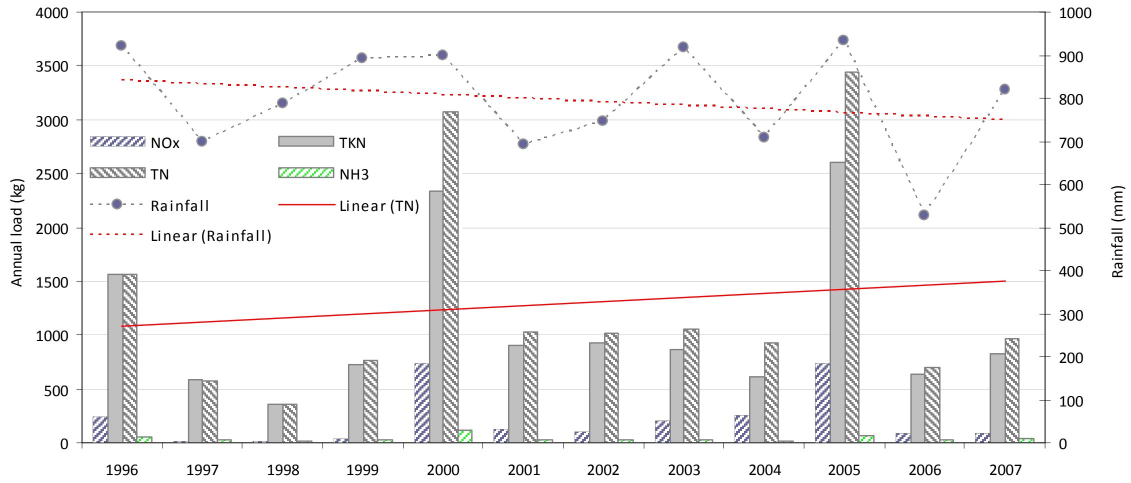


***Figure D-1**: Load calculations: three-year median concentration technique*

Year	Flow (ML)	NOx	TKN	TN	NH3	TP	SRP	Rainfall mm)	*CR**
			Previous concentration annual loads (kg)						
1996	637	240	1559	1568	47	313	180	922	5.9%
1997	185	14	589	569	28	153	129	698	2.3%
1998	168	9	352	357	16	66	60	787	1.8%
1999	347	36	728	764	29	131	102	891	3.3%
2000	905	738	2340	3078	110	436	275	900	8.6%
2001	454	126	901	1024	20	148	122	693	5.6%
2002	381	98	924	1022	29	138	110	745	4.4%
2003	466	200	858	1053	21	125	100	916	4.4%
2004	346	256	607	922	15	97	75	708	4.2%
2005	1344	734	2606	3446	65	386	242	933	12.4%
2006	364	88	631	695	30	128	98	527	5.9%
2007	418	83	831	971	43	144	103	820	4.4%

* Assuming a catchment area of 11.65 square km



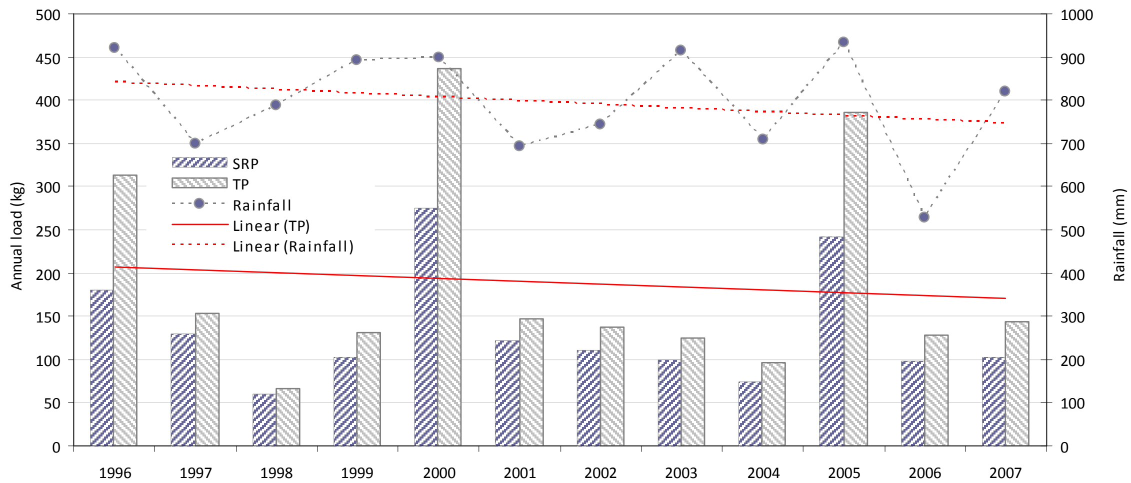


***Figure D-2:** Load calculations: latest concentration technique*

Appendix E: Groundwater levels and nutrient concentration time-series

61410224 (JE7C)

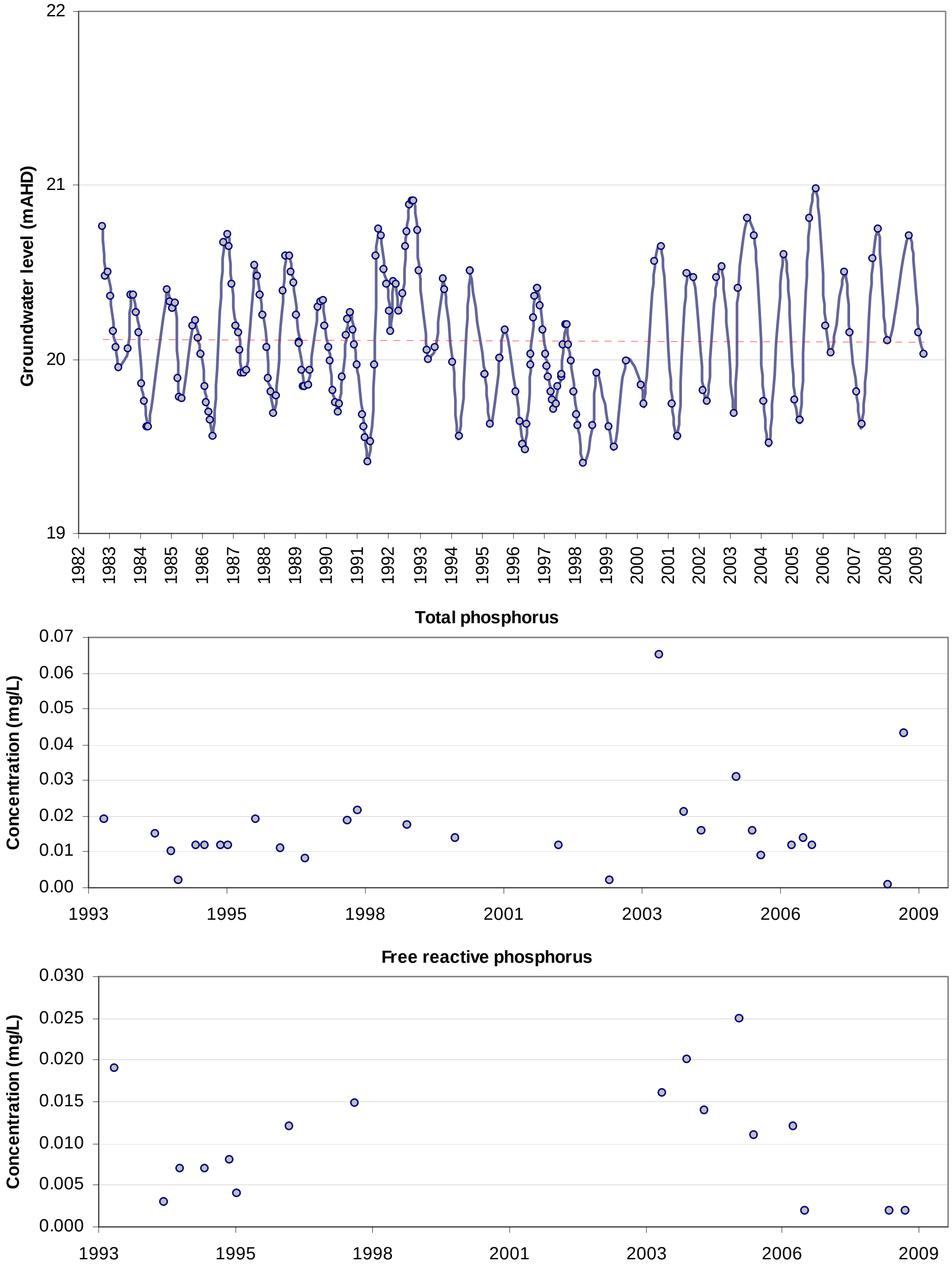


Figure E-1*: Water level, TP and SRP concentration time-series for JE7C*

61410224 (JE7C)

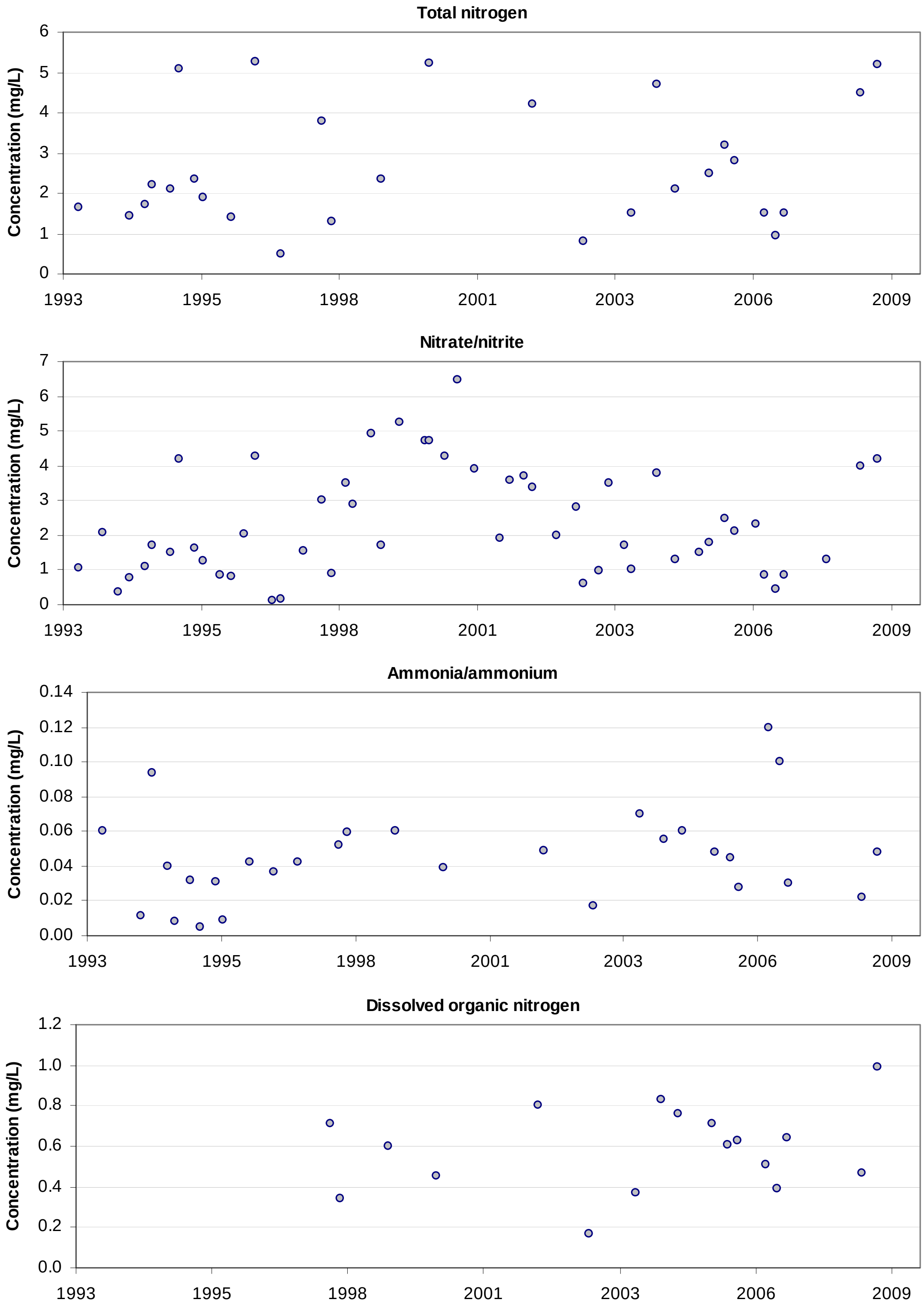


Figure E-2: *TN, DON, TON and ammonia concentration time-series for JE7C*

614103927 (JE9C)

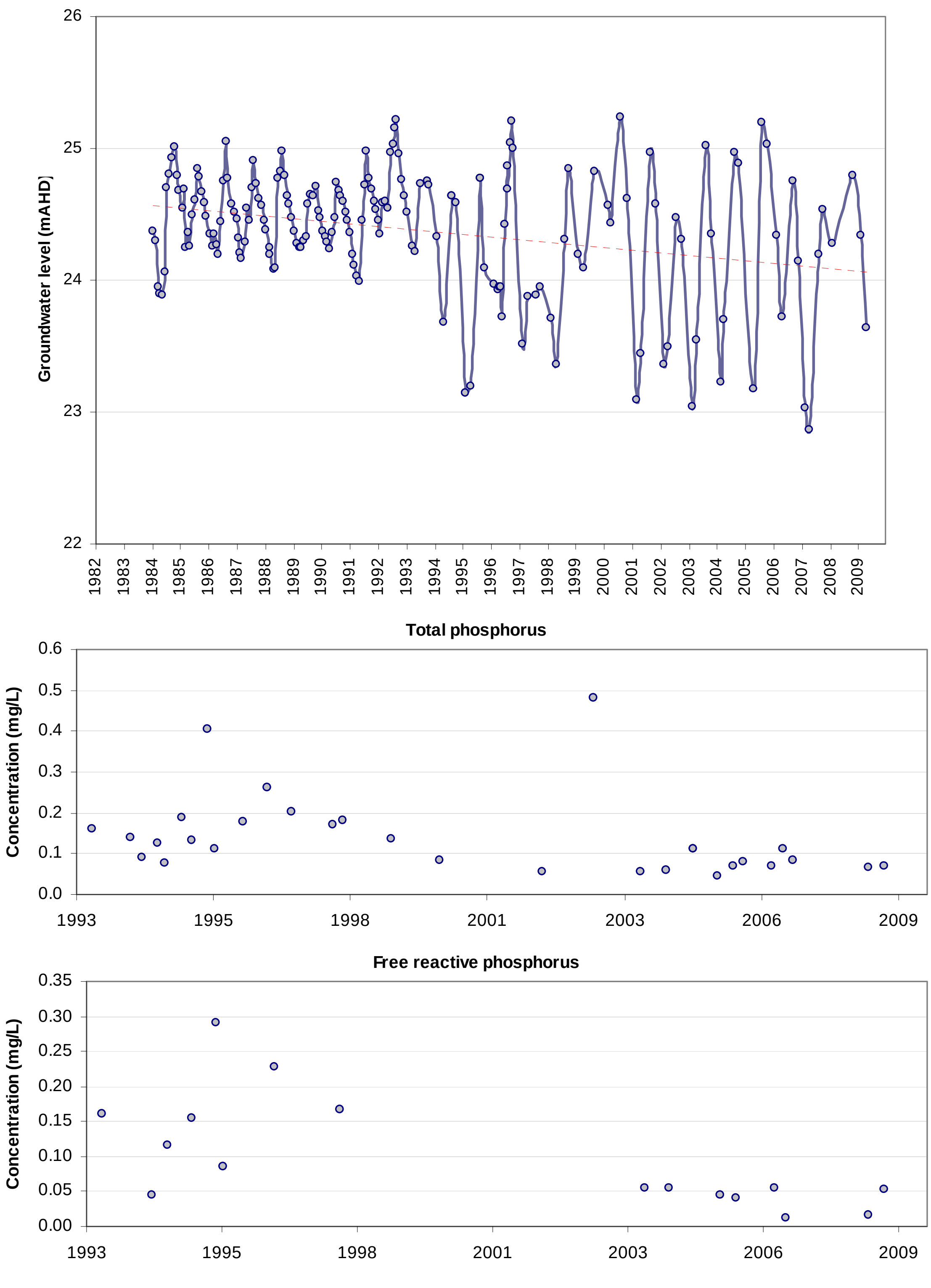


Figure E-3: *Water level, TP and SRP concentration time-series for JE9C*

61410229 (JE9C)

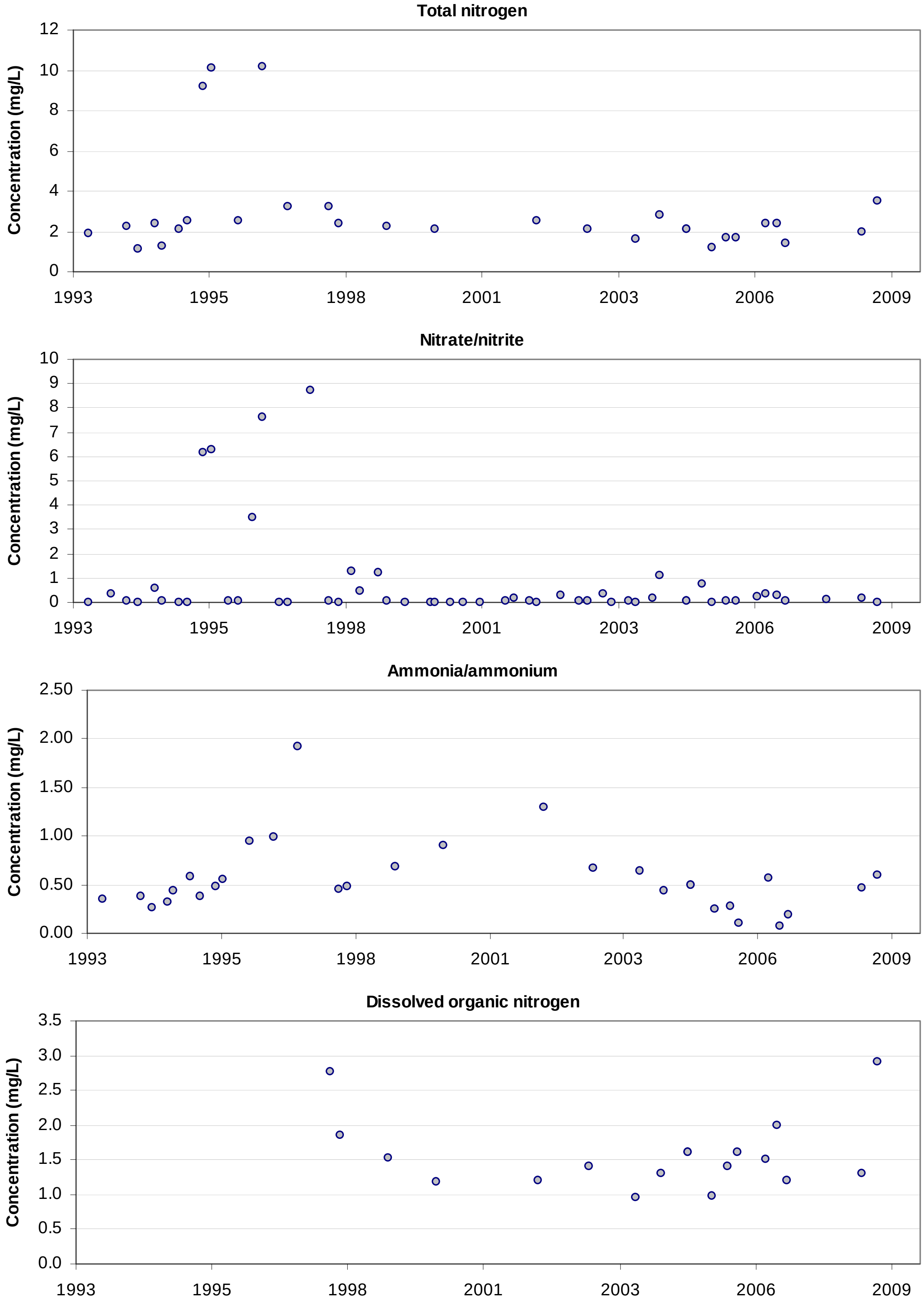
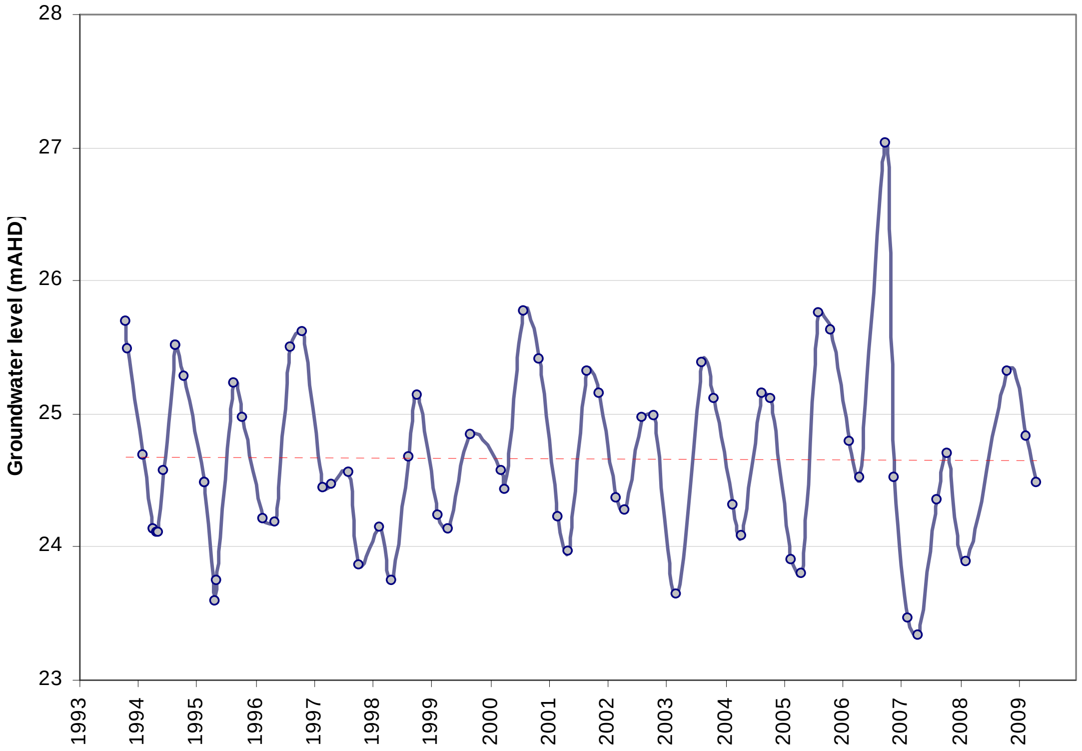
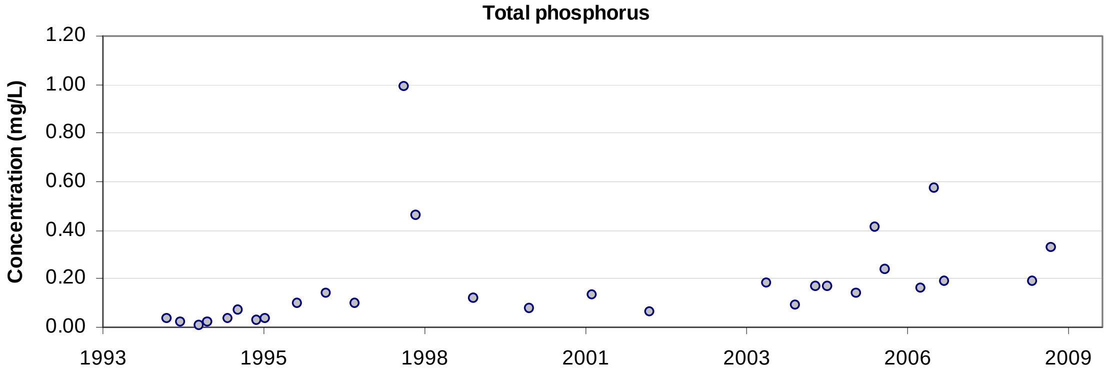


Figure E-4: *TN, DON, TON and ammonia concentration time-series for JE9C*

61410702 (TD36)





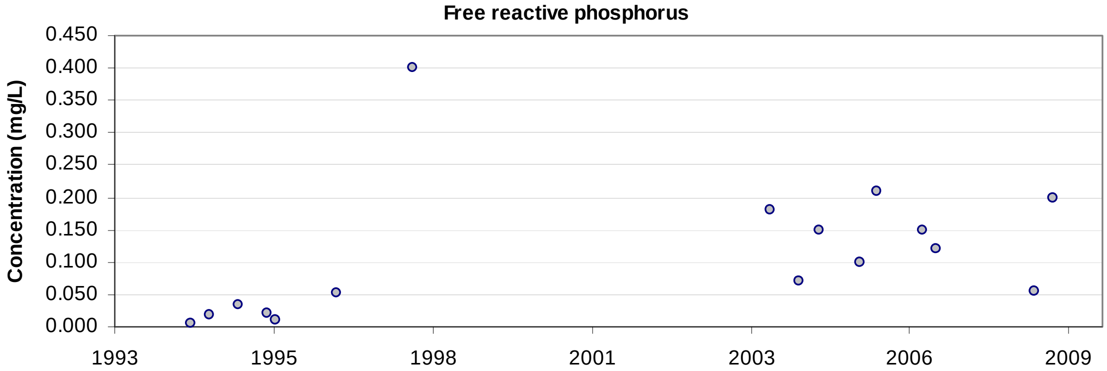


***Figure E-5**: Water level, TP and SRP concentration time-series for TD36*

61410702 (TD36)

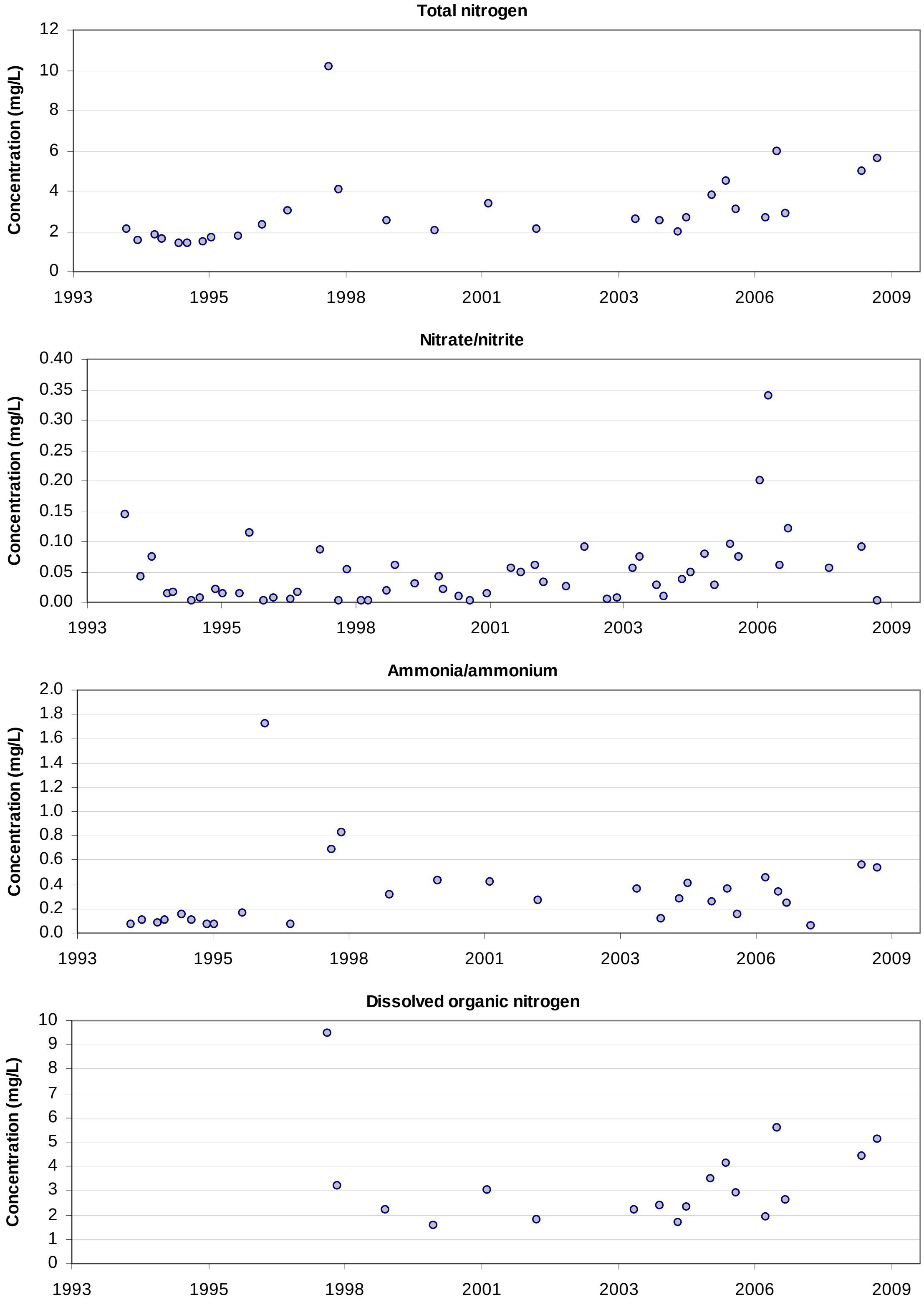


Figure E-6: *TN, DON, TON and ammonia concentration time-series for TD36*

61410710 (TD37)

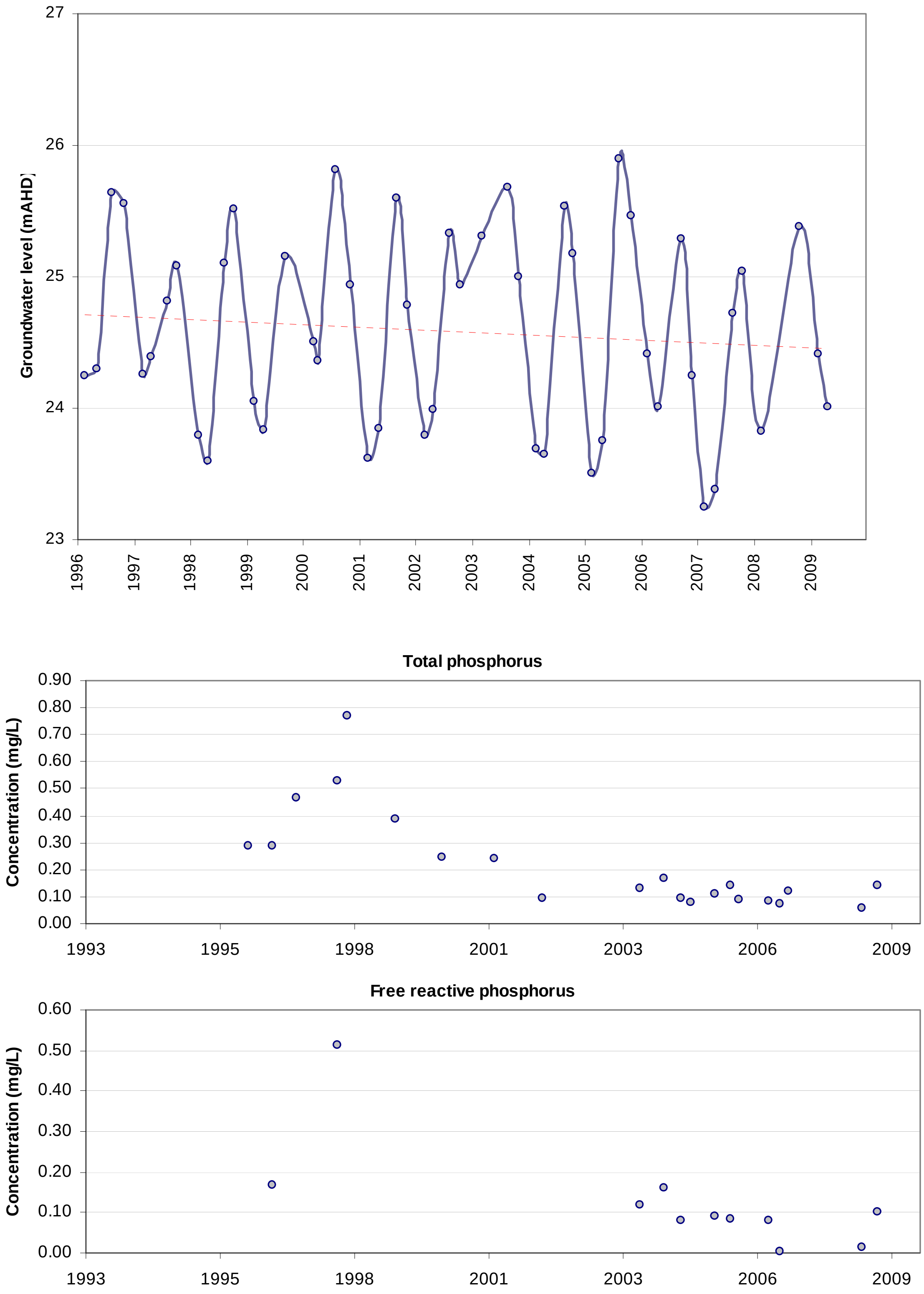


Figure E-7: *Water level, TP and SRP concentration time-series for TD37*

61410710 (TD37)

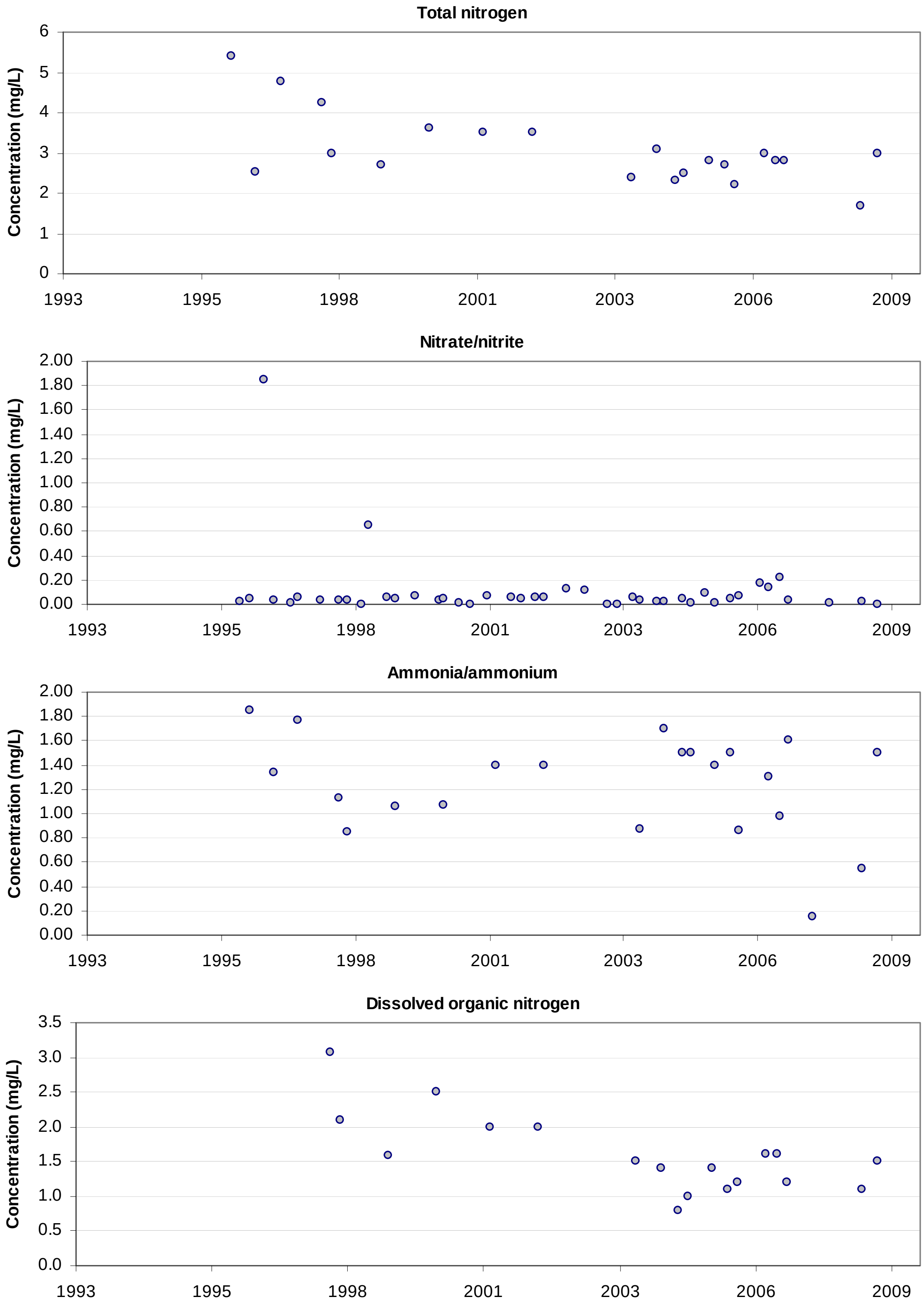


Figure E-8: *TN, DON, TON and ammonia concentration time-series for TD37*

Shortened forms

ANZECC & ARMCANZ	Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand
ARI	(Average Recurrence Interval) is defined as the average, or expected, time between exceedances of a given rainfall total accumulated over a given period. Thus, the ‘up to 1-in-1 ARI’ criterion refers to all events up to the largest event that occurs on average annually. This criterion generally includes 99% of the rainfall. The event duration depends on the source catchment. For instance, for house roofs the event duration would most likely be 1 hour, thus the criterion would be stated as 1-year 1-hour ARI. For further information, refer to *Australian rainfall and runoff* (Engineers Australia 2001) and the Bureau of Meteorology website via <www.bom.gov.au/hydro/has/ari_aep.shtml>.
AWRC	Australian Water Resources Council
CBD	central business district
CR	coefficient of runoff
DoW	Department of Water
EPA	Environmental Protection Authority
JGFIWP	Joint Government and Fertiliser Industry Working Party
LiDAR	light detection and ranging
LOESS	locally estimated scatterplot smoothing
LOWESS	locally-weighted estimated scatterplot smoothing
TN	total nitrogen
TP	total phosphorus
SRT	Swan River Trust
WAPC	Western Australian Planning Commission
WSUD	water sensitive urban design

References

ANZECC & ARMCANZ 2000, *Australian and New Zealand guidelines for fresh and marine water quality*, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand.

Asset Monitoring Services 1996, *South Jandakot EMP monitoring – annual data report 1994/95*, a report for the Water Corporation, WA.

Cleveland, WS 1979, ‘Robust locally weighted regression and smoothing scatterplots’, *Journal of the American Statistical Association*, Vol. 74, pp. 829-836.

Deeley, D 2000, *South Jandakot Drainage Scheme – scheme monitoring report for 1998*, Acacia Springs Environmental on behalf of the Water Corporation, WA.

— *South Jandakot Drainage Scheme – review of the current monitoring program*, Acacia Springs Environmental on behalf of the Water Corporation, WA.

Department of Environment 2004, ‘Aggregated emissions of total nitrogen and total phosphorus to the Vasse Wonnerup catchment, Western Australia’, a submission to the National Pollutant Inventory.

Department of Environment and Conservation 2007, *Ecological character of the Vasse Wonnerup wetlands Ramsar site in south-west Western Australia*, technical report produced by Wetland Research and Management for the Department of Environment and Conservation and Geographe Catchment Council.

DoW 2007, *Stormwater management manual for Western Australia,* Department of Water 2004–07. <www.water.wa.gov.au/Waterways+health/Stormwater+and+drainage/Stormwater+manmanagem+manual/default.aspx>.

— 2009, *Interim position statement: constructed lakes*, Drainage and Waterways Branch, Department of Water, WA, July 2007

Eckhardt, K 2005, ‘How to construct recursive digital filters for baseflow separation’, *Hydrological Processes*, 19, 507 – 515.

Ecotones & Associates 2008, *SSPND: the support system for phosphorus and nitrogen decisions – BMP scenarios for the Vasse Geographe catchment*, consulting report to the Department of Agriculture and Food: Vasse Geographe CCI project.

EPA 1993, *South Jandakot Drainage Management Scheme*, report by the Technical Review Committee for the period 1 November 1992 to 31 October 1993

— 2007, *Draft water quality improvement plan for the rivers and estuary of the Peel-Harvey system,* Environmental Protection Authority, Perth, WA.

Esterby, SR 1996, 'Review of methods for the detection and estimation of trends with emphasis on water quality applications', *Hydrological Processes,* 10 (2): 127-149.

Fuller, G & Deane, A 1994, *Bartram Road inflow nutrient source monitoring: data collection annual report 1993/1994*, Water Resource Measurement Services, a report for the Water Authority of Western Australia.

GB Hill & Partners Pty Ltd, 1990, *South Jandakot drainage management plan*, report for the Department of Planning and Urban Development, January 1990.

— 1991, *Environmental management program of the South Jandakot Drainage Scheme*, a report for the Environmental Protection Authority

— 1993, *Stormwater runoff study for catchments of the Southern Beeliar Lakes*, a report for the Water Authority of Western Australia, March 1993.

Gilbert, R 1987, *Statistical methods for environmental pollution monitoring*, Van Nostrand Reinhold, New York, 250 pp.

Glenwood Nominees Pty Ltd 2005, *South Jandakot Drainage Scheme monitoring program – monitoring report 2003*, a report for the Water Corporation, WA, March 2005.

— 2005, *Development compliance report for the South Jandakot Drainage Scheme environmental management program, volume 1: report on 2004 monitoring program*, a report for the Water Corporation, WA, February 2006.

Helshel, D & Hirsch, R 1992, *Statistical methods in water resources*, Elsevier, Amsterdam. 522 pp.

Hipel, K & McLeod, A 1994, *Time series modelling of environmental and water resources systems*, Elsevier, Amsterdam

Hirschberg, K 1991, 'Nutrient export in surface and groundwater under various land uses, in land development in areas of high water table', *Forum Proceedings, Institution of Engineers Australia in association with Urban Development Institute of Australia.*

I.E.Aust. 1987, 'Australian Rainfall and Runoff'. Published by the I.E.Aust, editor in chief, R.P. Canterford, 2 Vols., 1987

JGFIWP 2007, *Fertiliser action plan, phasing-out the use of highly water soluble phosphorus fertilisers in environmentally sensitive areas of south-west Western Australia*, a report to the Western Australian Minister for the Environment, 2 March 2007.

Kelsey, P, Hall, J, Kitsios, A, Quinton, B & Shakya, D 2010a, *Hydrological and nutrient modelling of the Swan-Canning coastal catchments*, Water Science Technical Series, report no. 14, Department of Water, Western Australia.

Kelsey, P, King, L & Kitsios, A 2010b, *Survey of urban nutrient inputs on the Swan Coastal Plain,* Water Science Technical Series, report no. 24, Department of Water, Western Australia.

LeProvst, Semeniuc & Chalmer 1988, *Thomsons Lake water quality monitoring program*, a report for Gold Estates of Australia (1903) Limited, Residential Sites Limited, Landbank of Western Australia, February 1988.

Lettenmaier, D 1976, 'Detection of trends in water quality from records with independent observations', *Water Resources Research*, 12 (5): 1037-1046

Loftis, JC, McBride, GB & Ellis, JC 1991, 'Considerations of scale in water quality monitoring and data analysis', *Water Resources Research*, 12 (5): 1037-1046.

Nelson, S 2004, *Planet (Version 5) user manual*, Water and Rivers Commission, Perth, Western Australia.

Norrish, A 1999, *Southern lakes drainage scheme: report on emergency relief*, GHD Pty LTD on behalf of the Water Corporation, WA, July 1999.

Robson, AJ & Neal, C 1996, 'Water quality trends at an upland site in Wales', *Hydrological Processes*, 10 (2): 183-203.

Ward, R, Loftis, J & McBride, G 1990, *Design of water quality monitoring systems*, Van Nostrand Reinhold, New York.

Whelan, B & Barrow, N 1984a, 'The movement of septic tank effluent through sandy soils near Perth 1: movement of nitrogen', *Australian Journal of Soil Research* 22: 283-292.

— 1984b, 'The movement of septic tank effluent through sandy soils near Perth 1: movement of phosphorus', *Australian Journal of Soil Research* 22: 293-302.

Woodward, B 2008, 'Constructed lakes in the Perth metropolitan area and south-west region: literature review and interview project', ENV Australia Pty Ltd for the Department of Water, WA, November 2008.

Water*Science*
technical series

Looking after all our water needs

Department of Water
168 St Georges Terrace, Perth, Western Australia
PO Box K822 Perth Western Australia 6842
Phone: (08) 6364 7600
Fax: (08) 6364 7601
www.water.wa.gov.au

072010