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Department of **Water**

Avon Basin hydrological and nutrient modelling appendices

Securing Western Australia's water future

Water*Science*
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Avon Basin hydrological and nutrient modelling: Appendices A–I

A. Nutrient sampling summaries

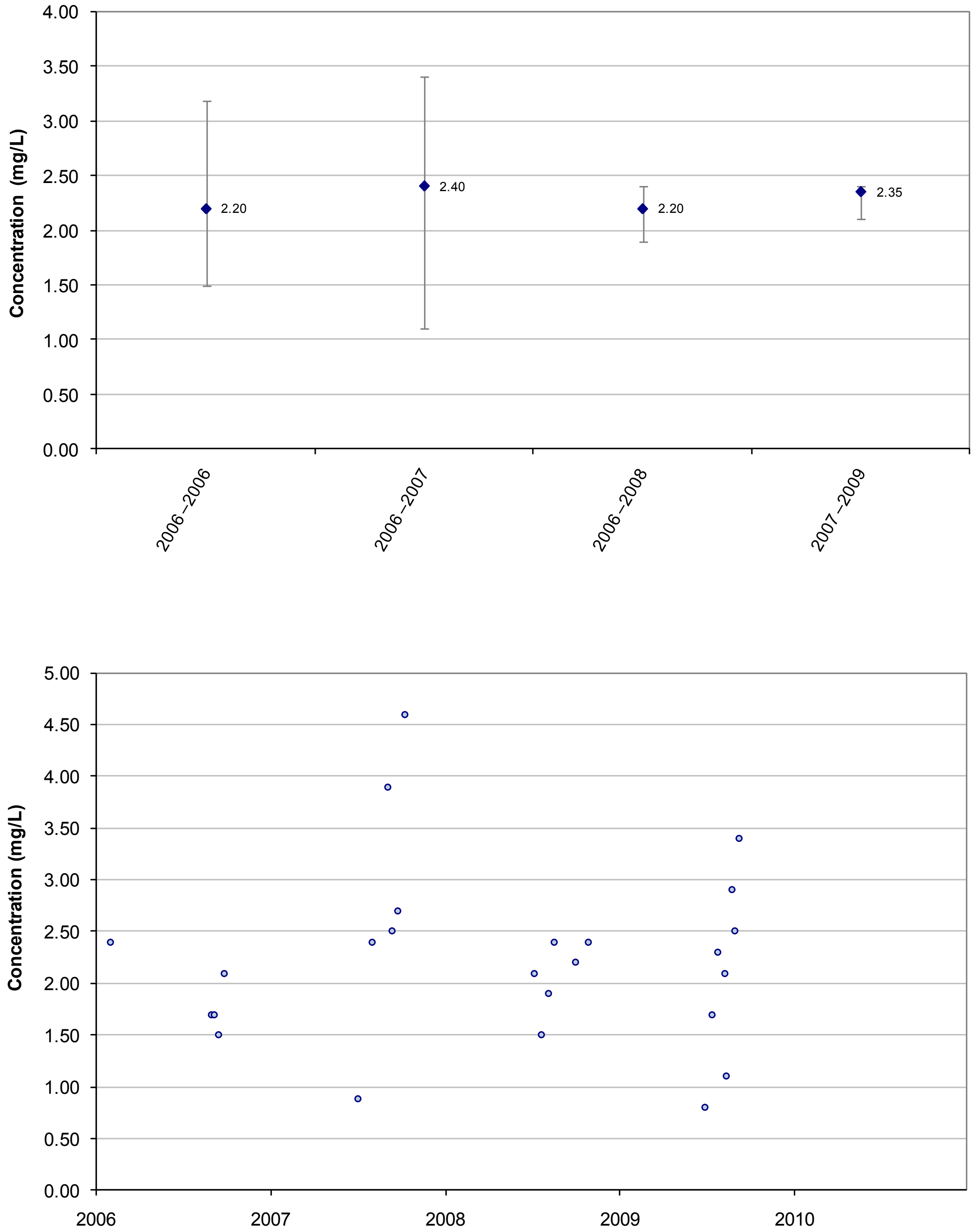
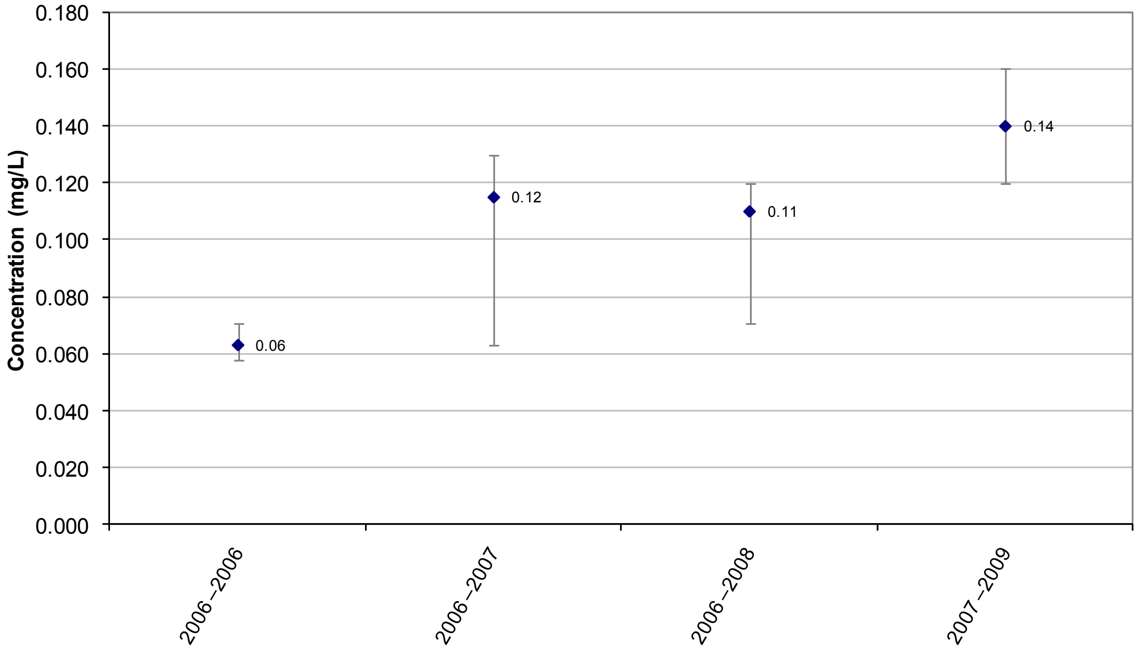


Figure A-1*: Total nitrogen at sampling location Mooranoppin Creek, Mooranoppin Rock (615011) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



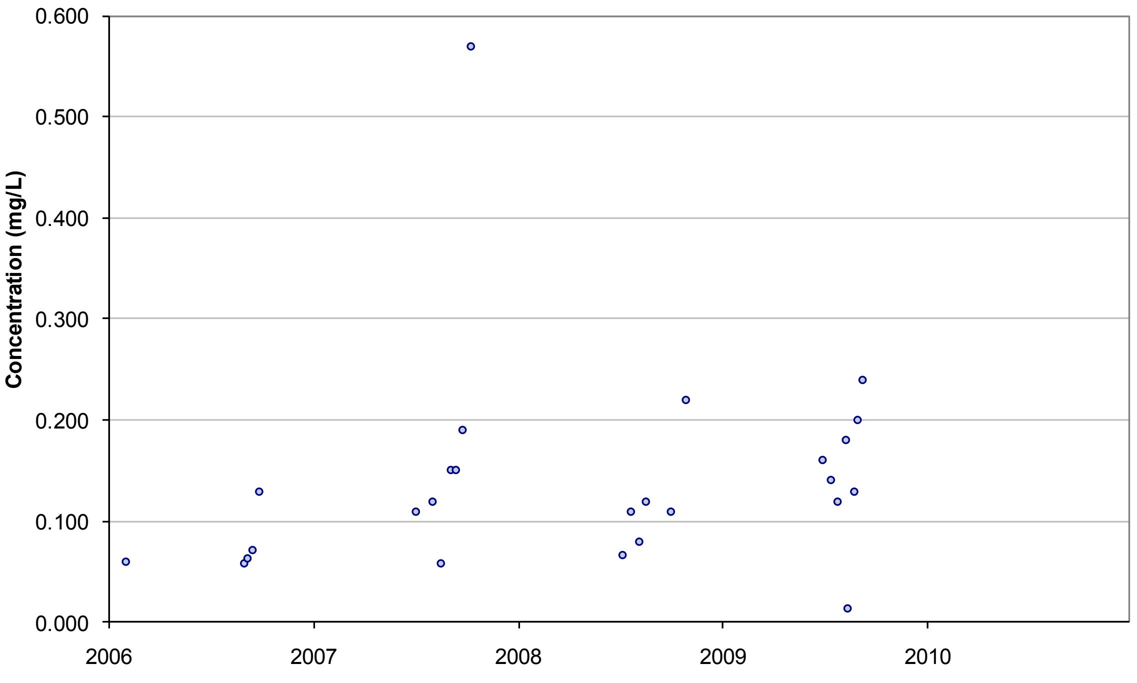
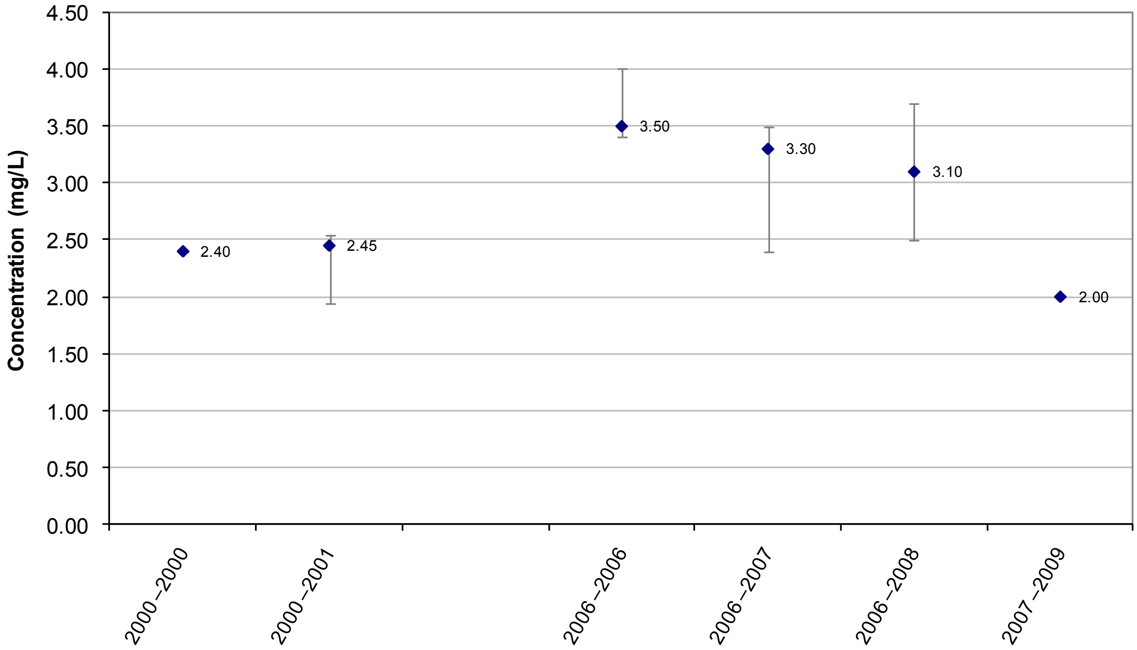


***Figure A-2**: Total phosphorus at sampling location Mooranoppin Creek, Mooranoppin Rock (615011) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



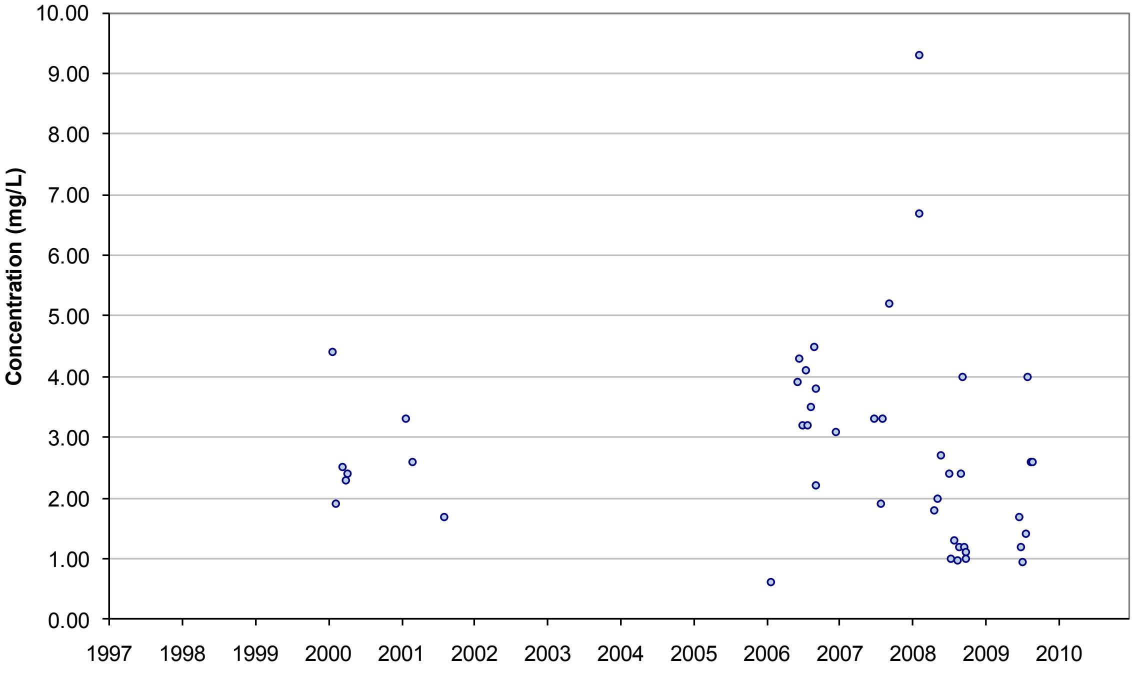
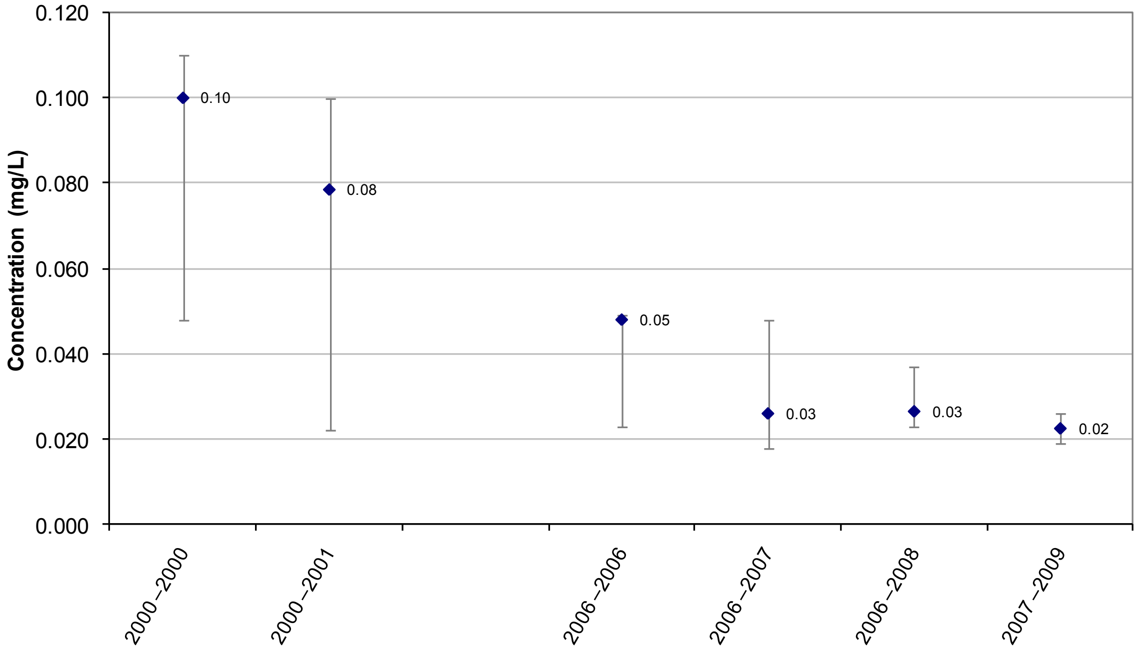


Figure A-3*: Total nitrogen at sampling location Lockhart River, Kwolyn Hill (615012) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



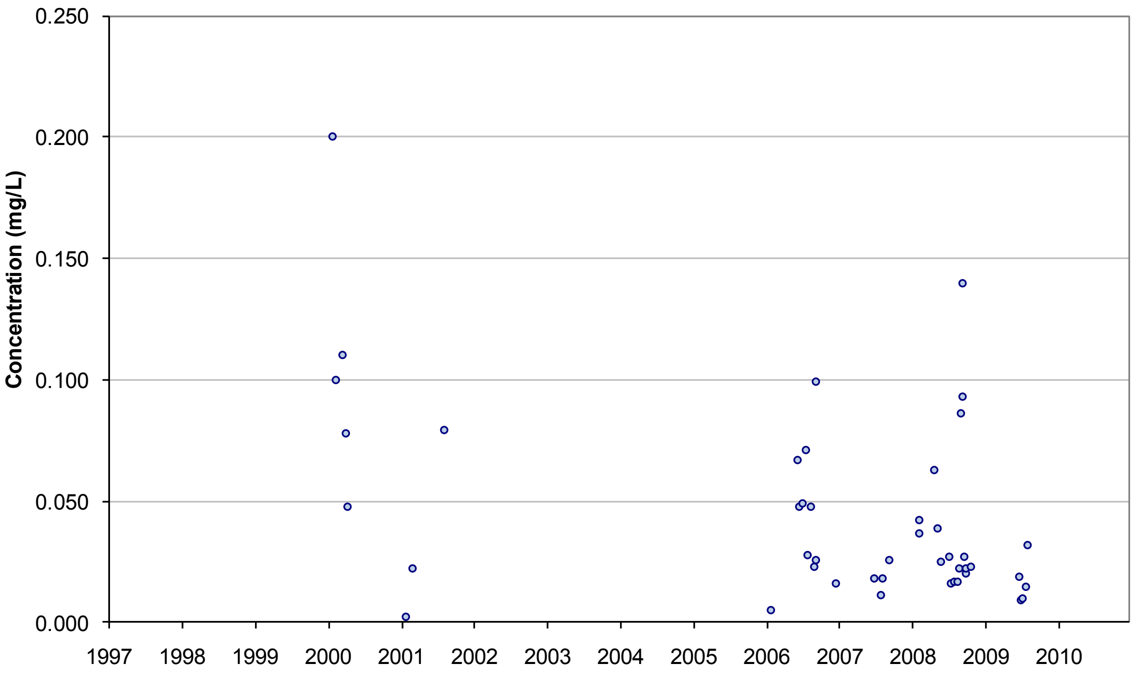
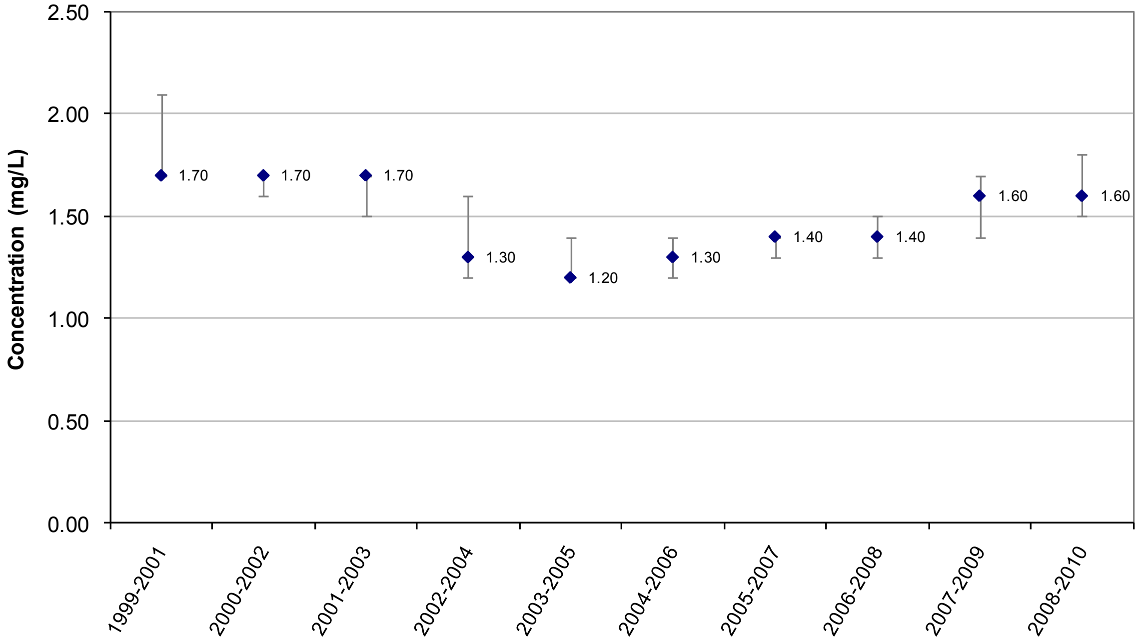


***Figure A-4**: Total phosphorus at sampling location Lockhart River, Kwolyn Hill (615012) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



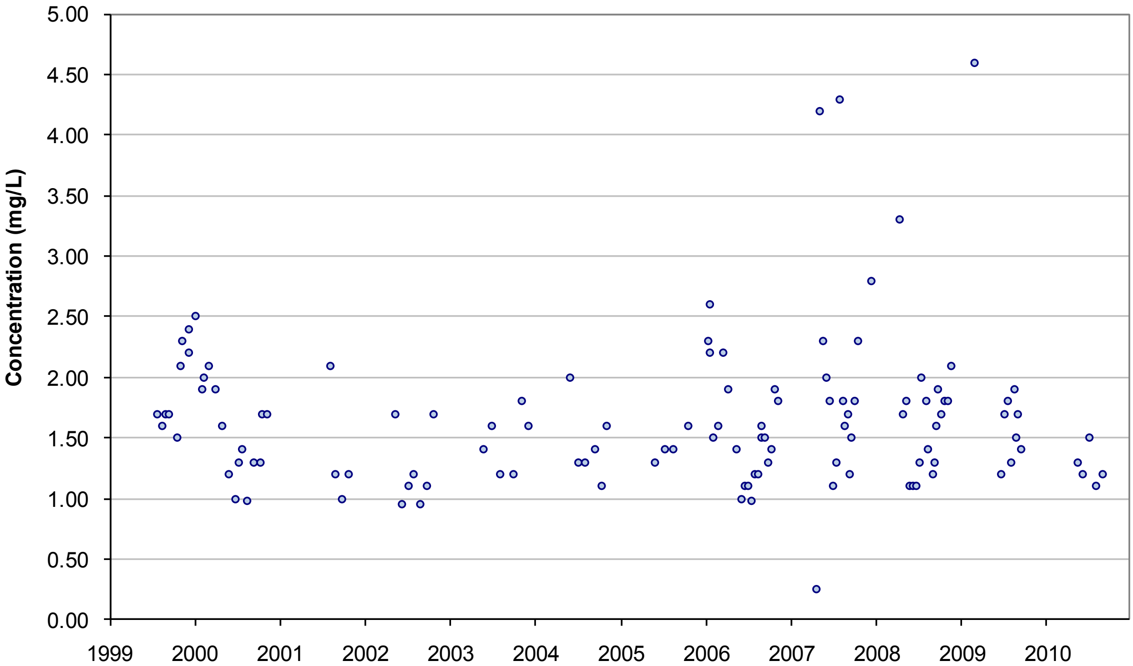
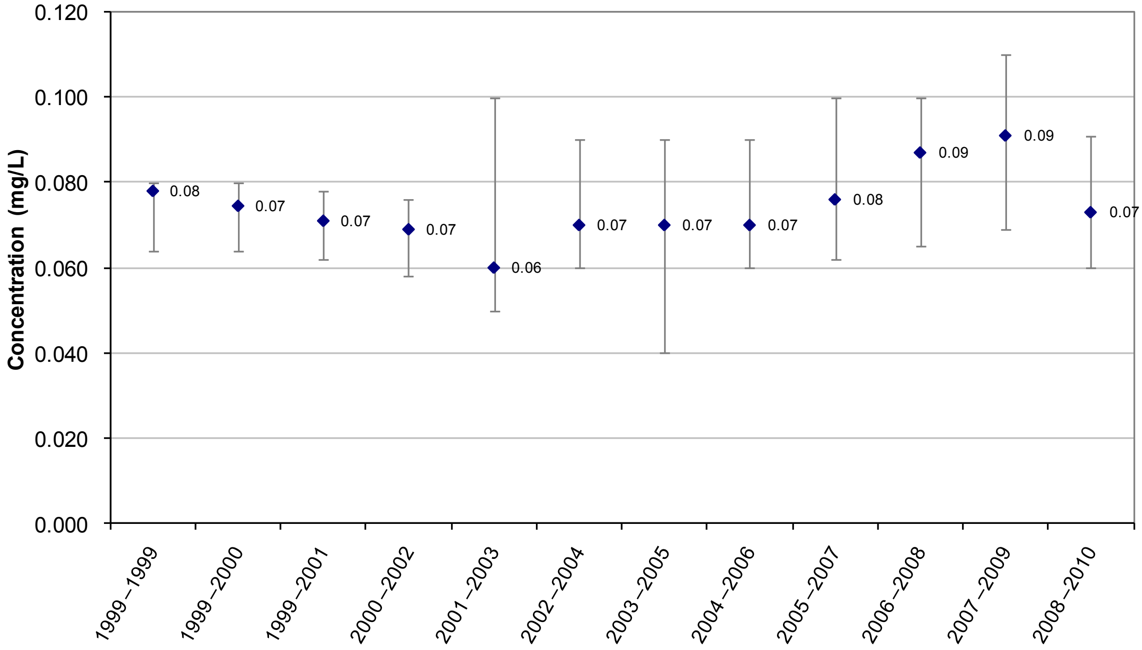


Figure A-5*: Total nitrogen at sampling location Mortlock River North Branch, Frenches (615013) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



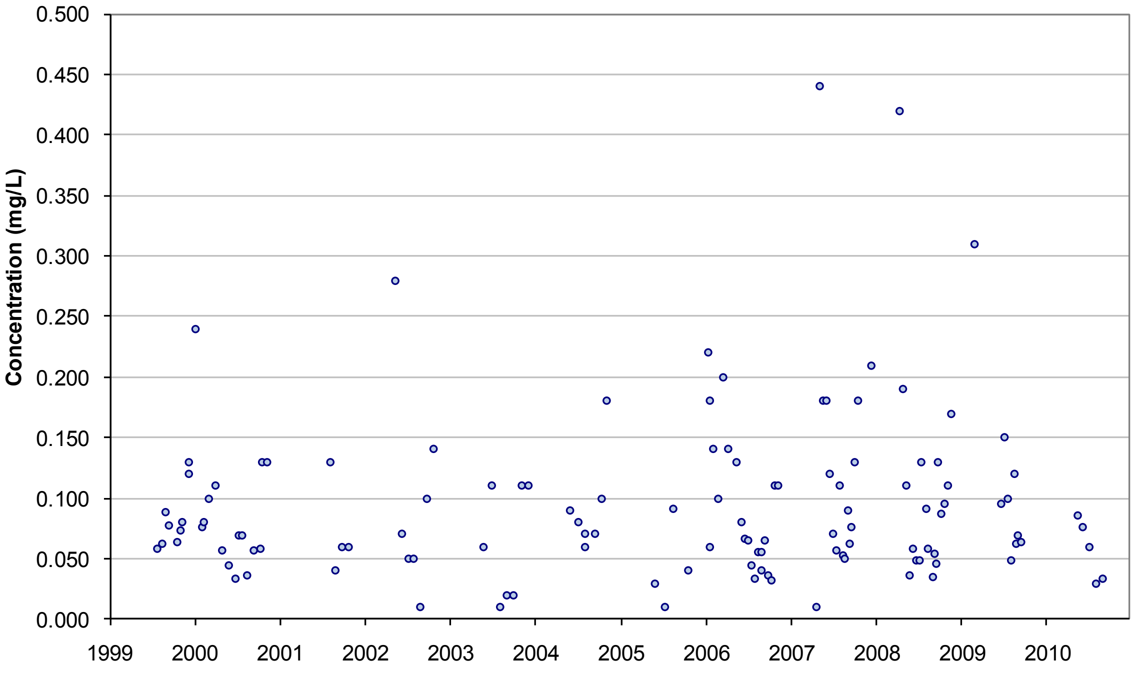
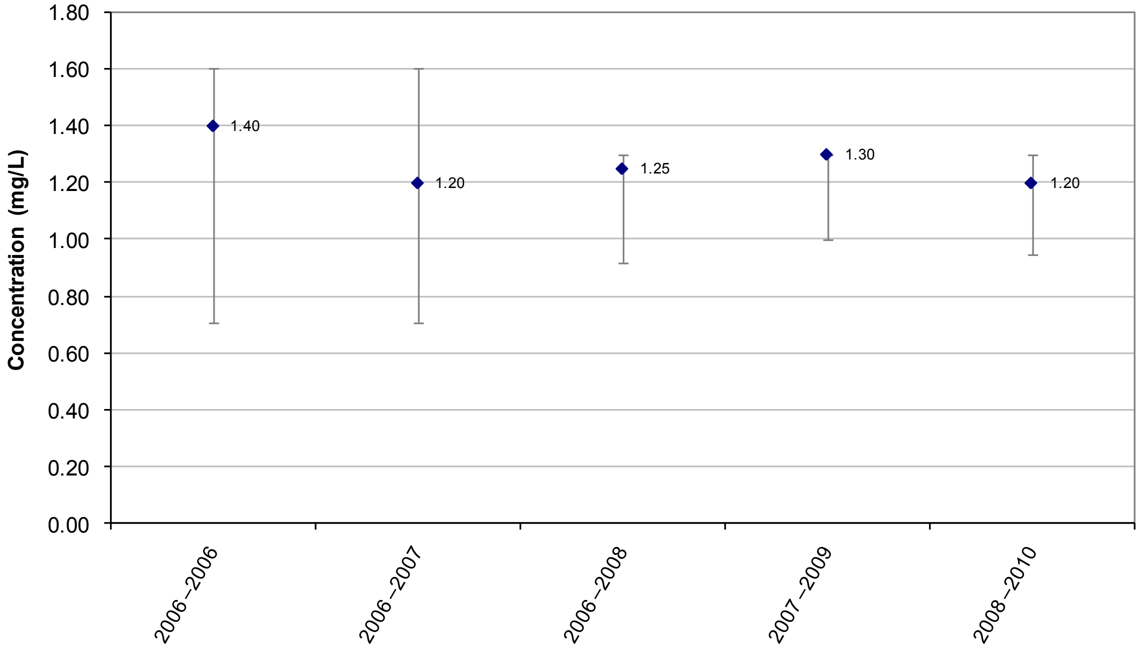


Figure A-6*: Total phosphorus at sampling location Mortlock River North Branch, Frenches (615013) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



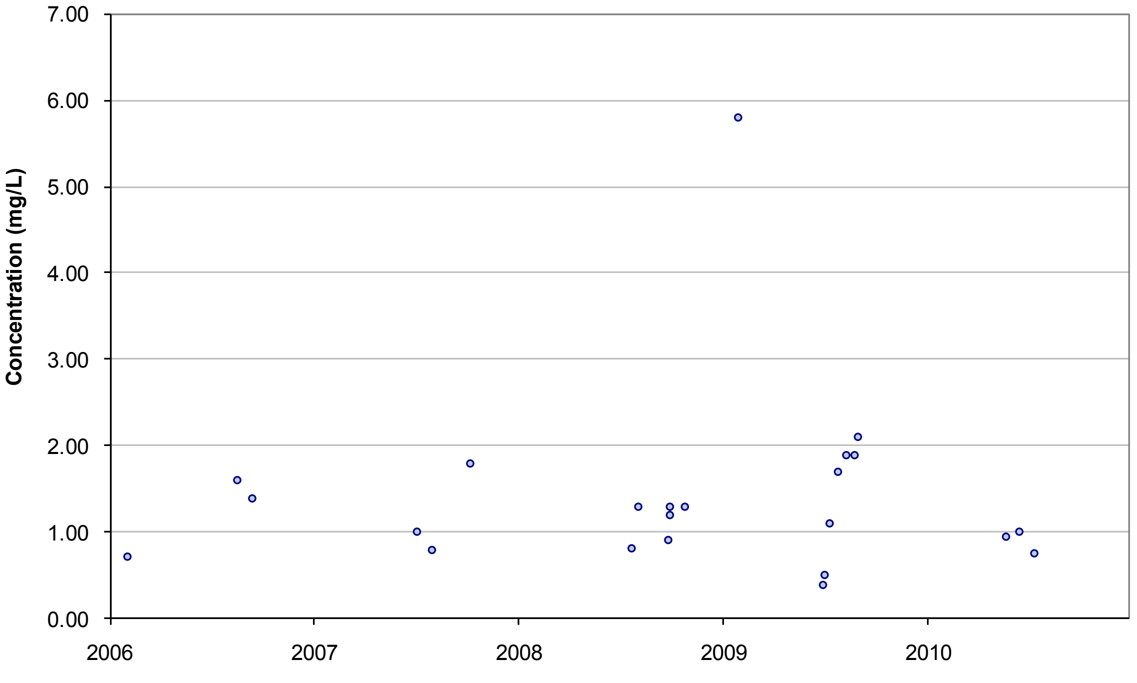
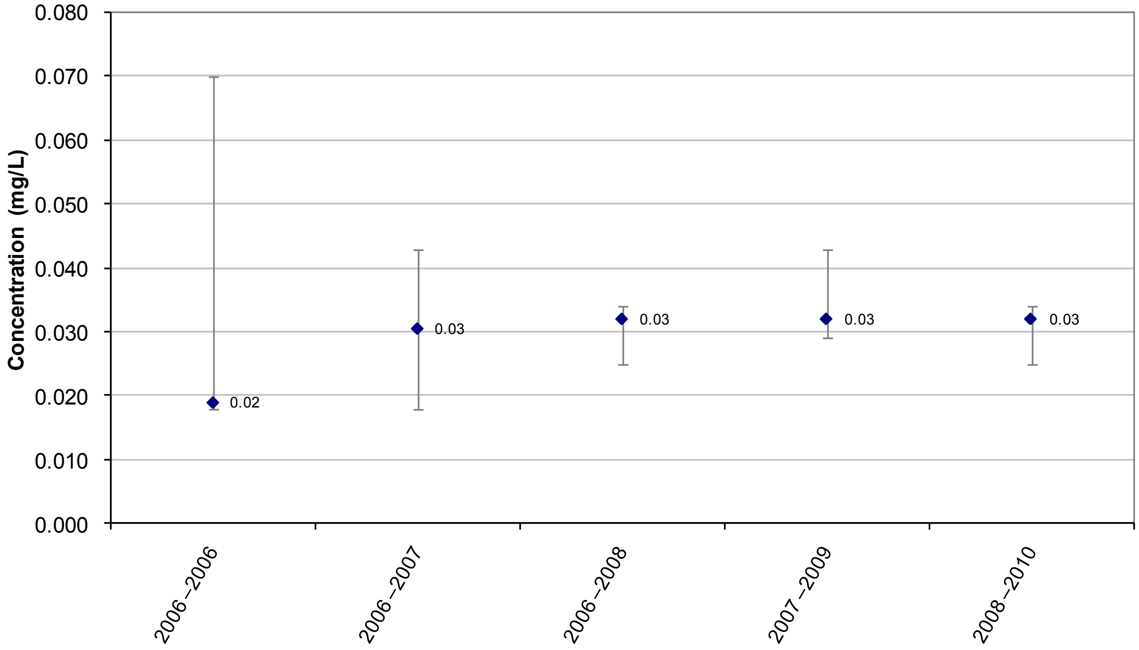


***Figure A-7**: Total nitrogen at sampling location Yilgarn River Gairdners Crossing (615015) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



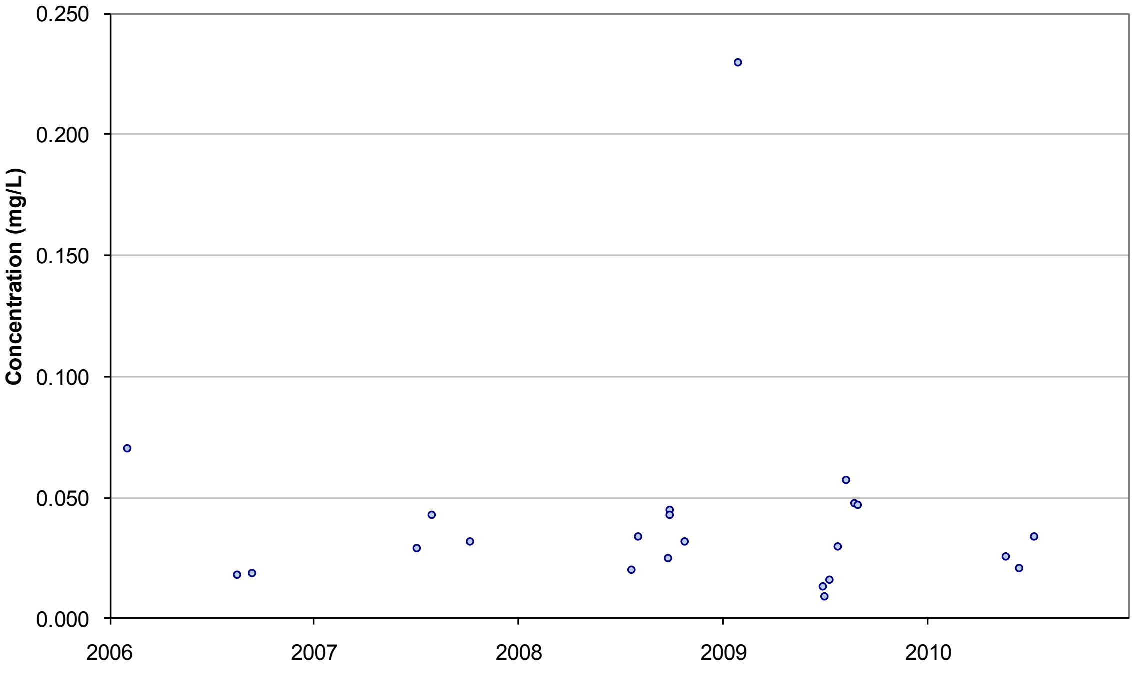
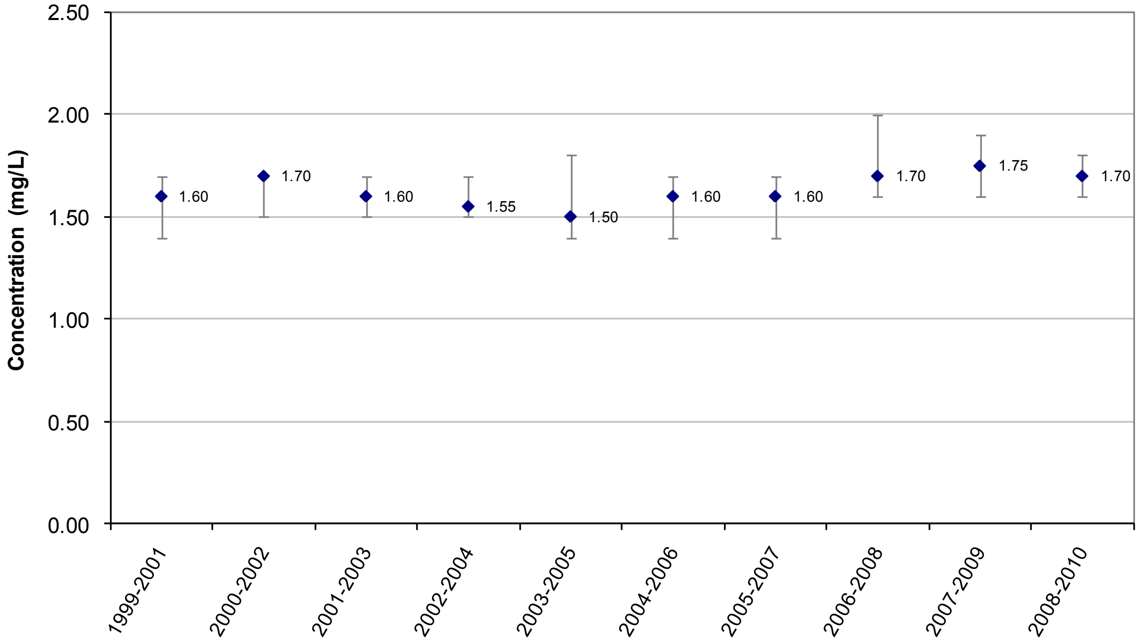


Figure A-8*: Total phosphorus at sampling location Yilgarn River Gairdners Crossing (615015) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



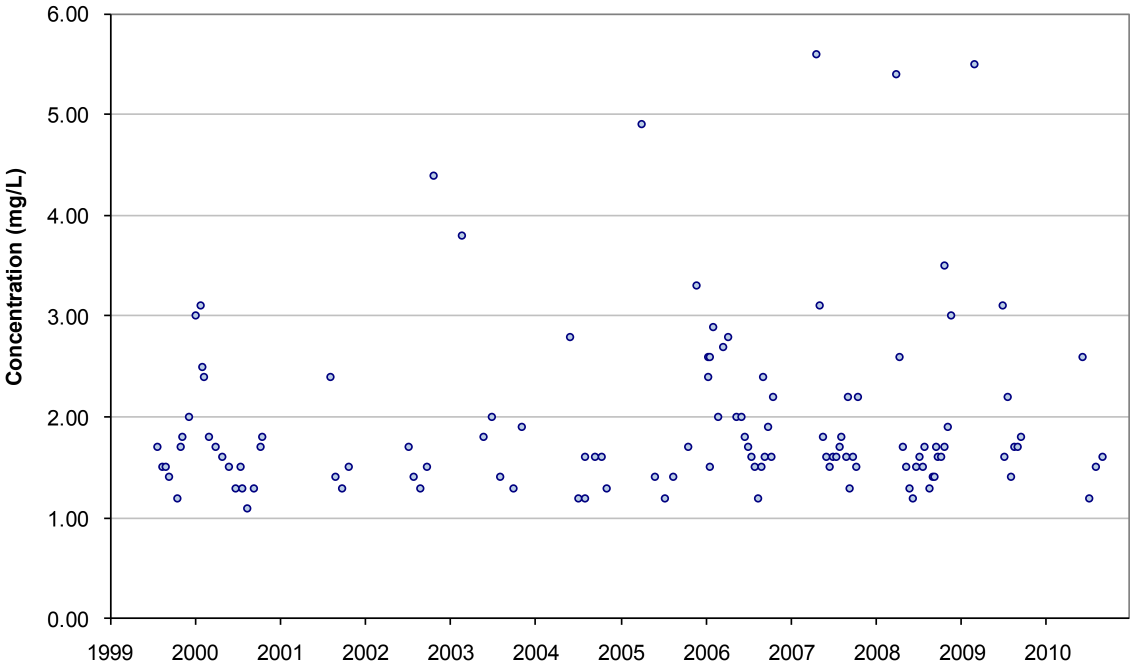
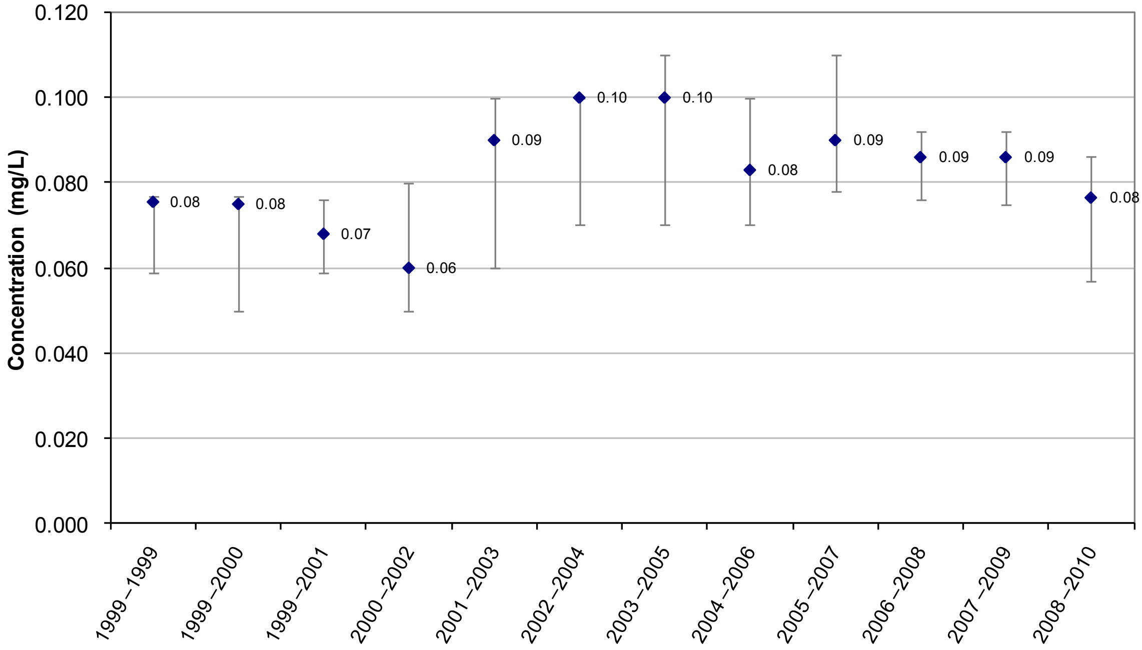


Figure A-9*: Total nitrogen at sampling location Mortlock River East Branch, O'Driscolls Farm (615020) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



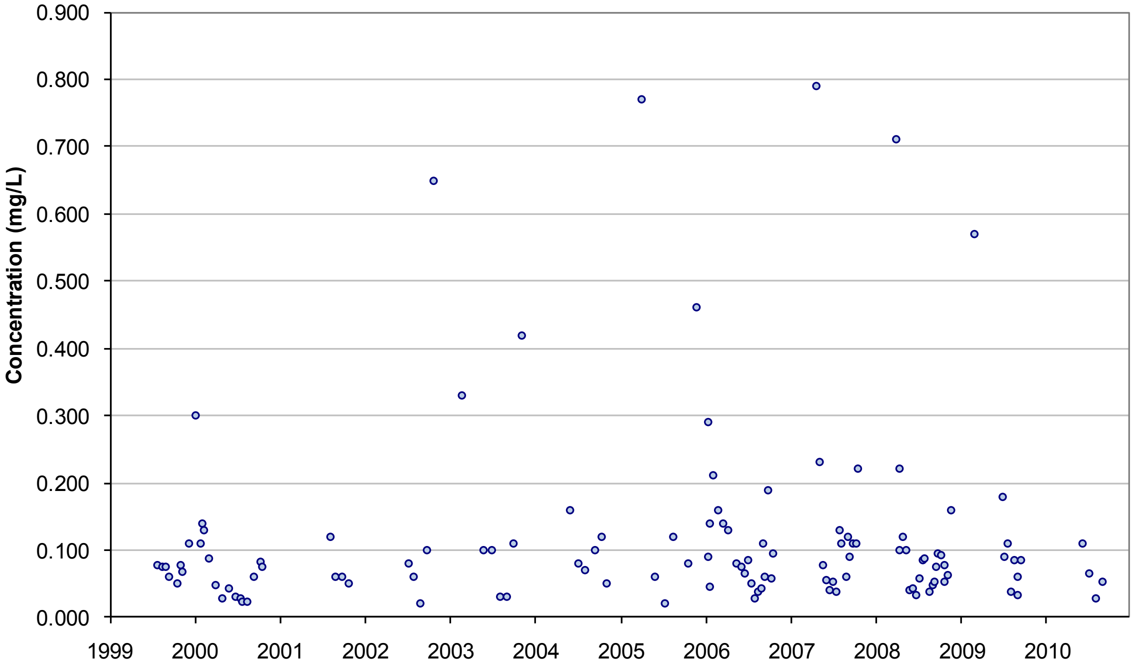
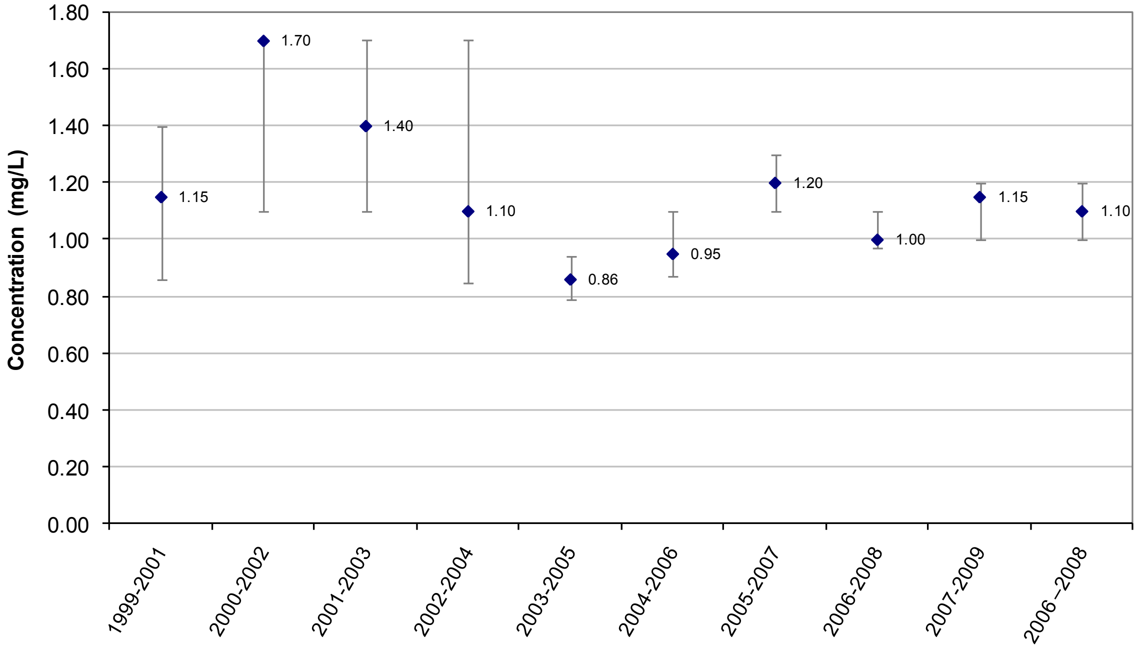


Figure A-10: *Total phosphorus at sampling location Mortlock River East Branch, O'Driscolls Farm (615020) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



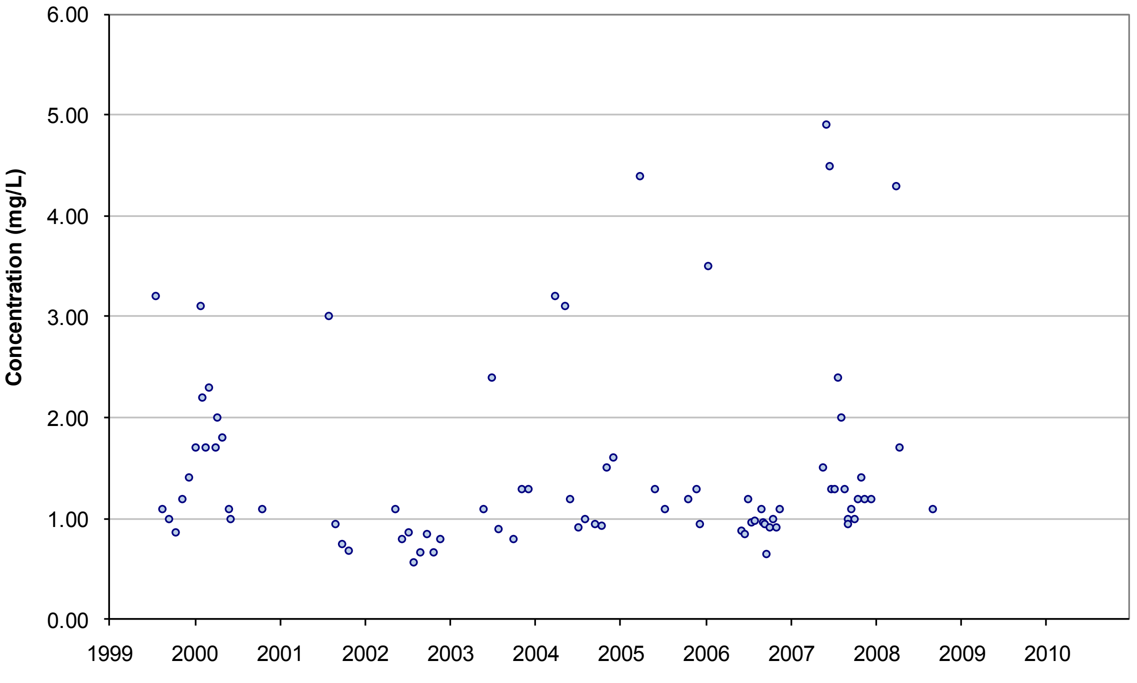
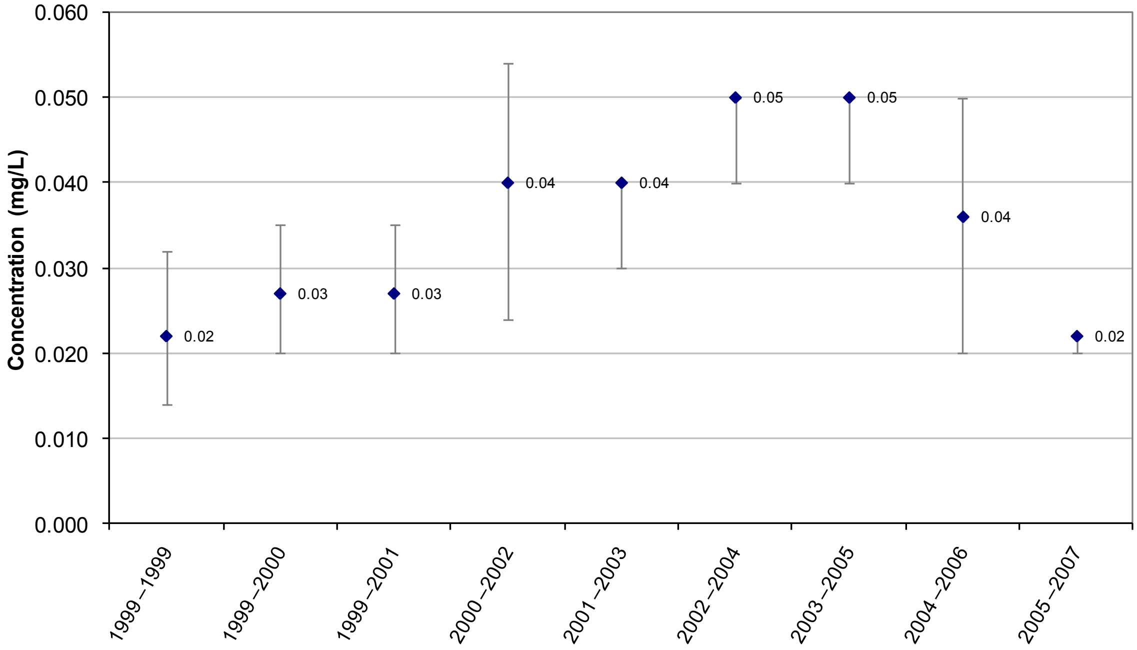


Figure A-11: *Total nitrogen at sampling location Avon River, Ballagong Street York (615024) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



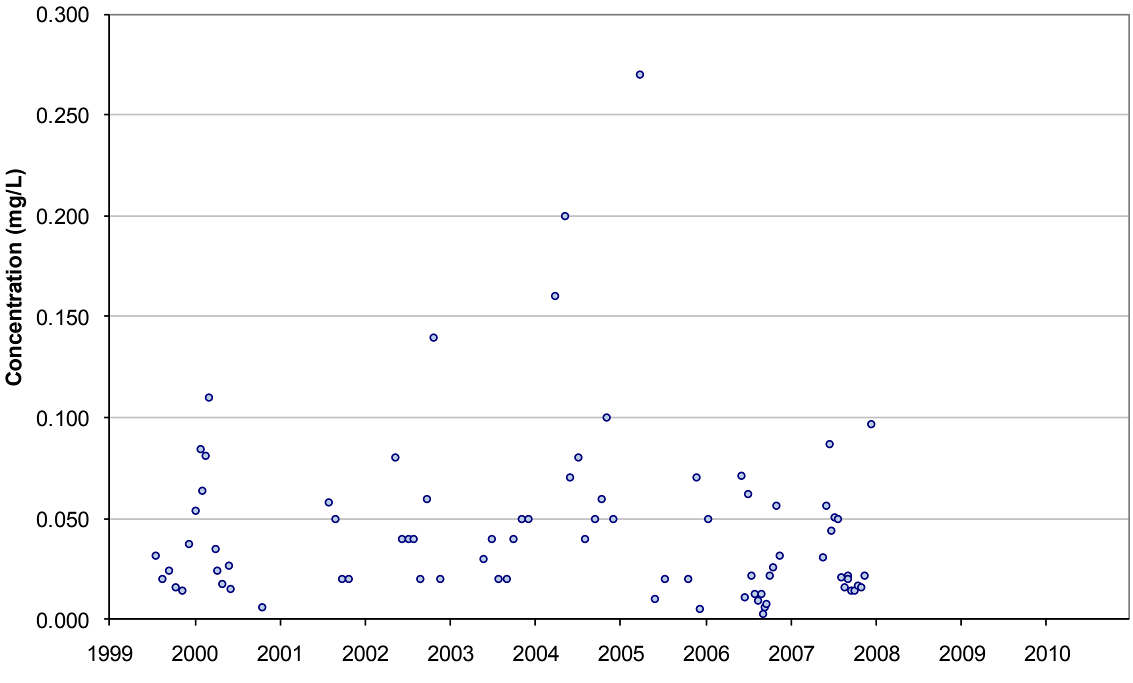
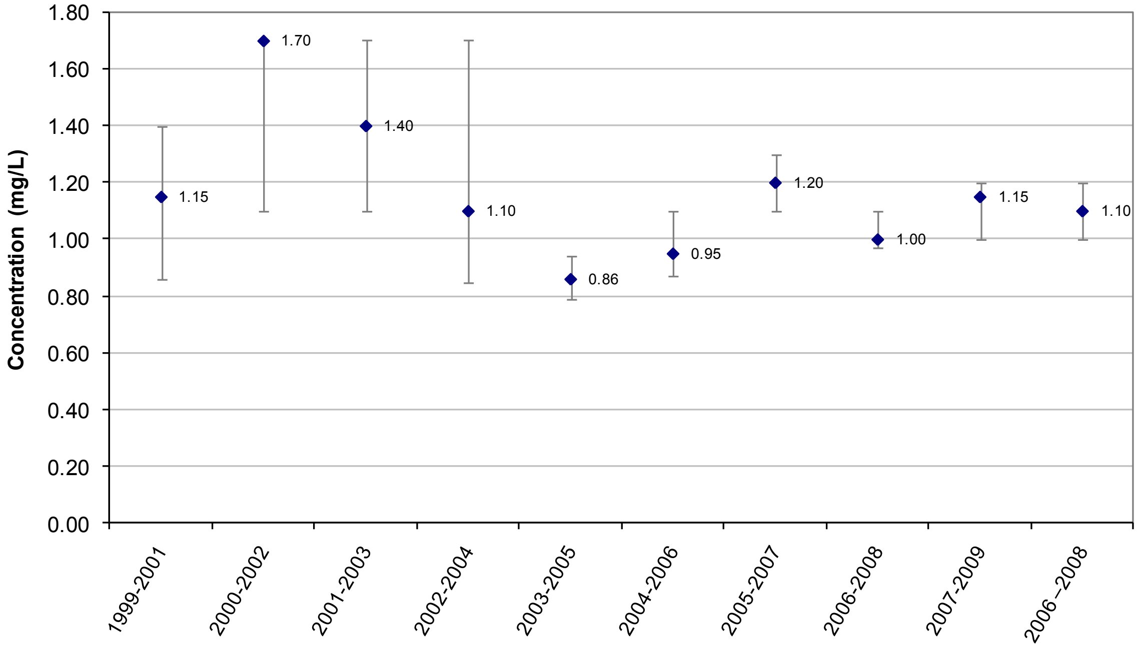


Figure A-12: *Total nitrogen at sampling location Avon River, Ballagong Street York (615024) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



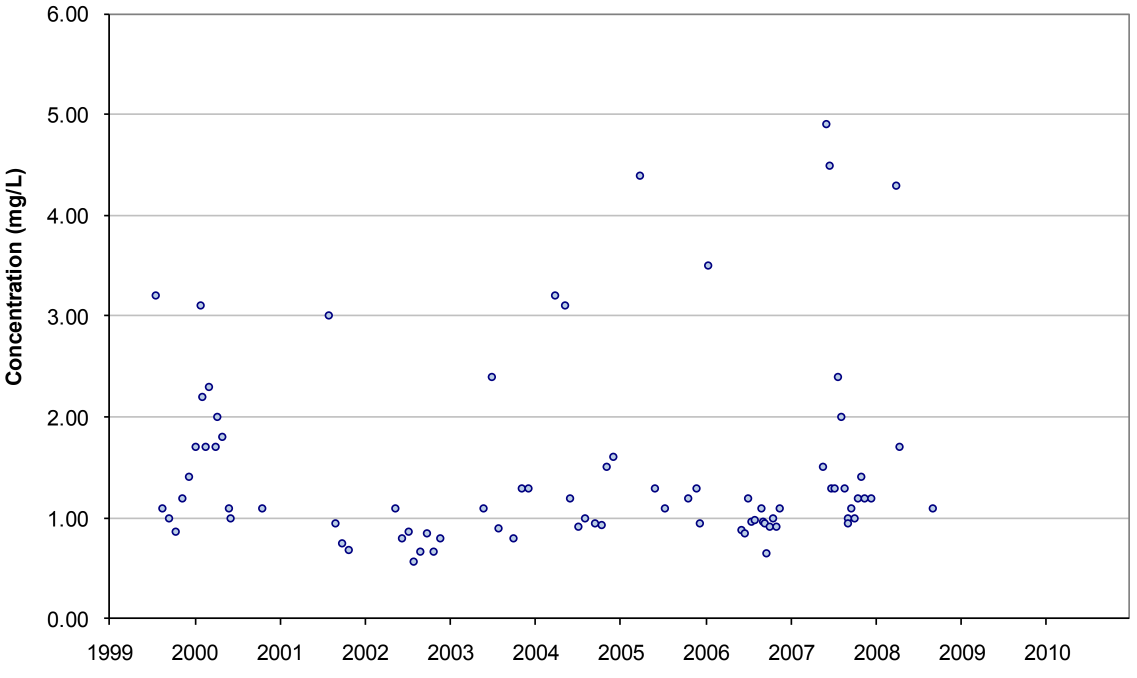
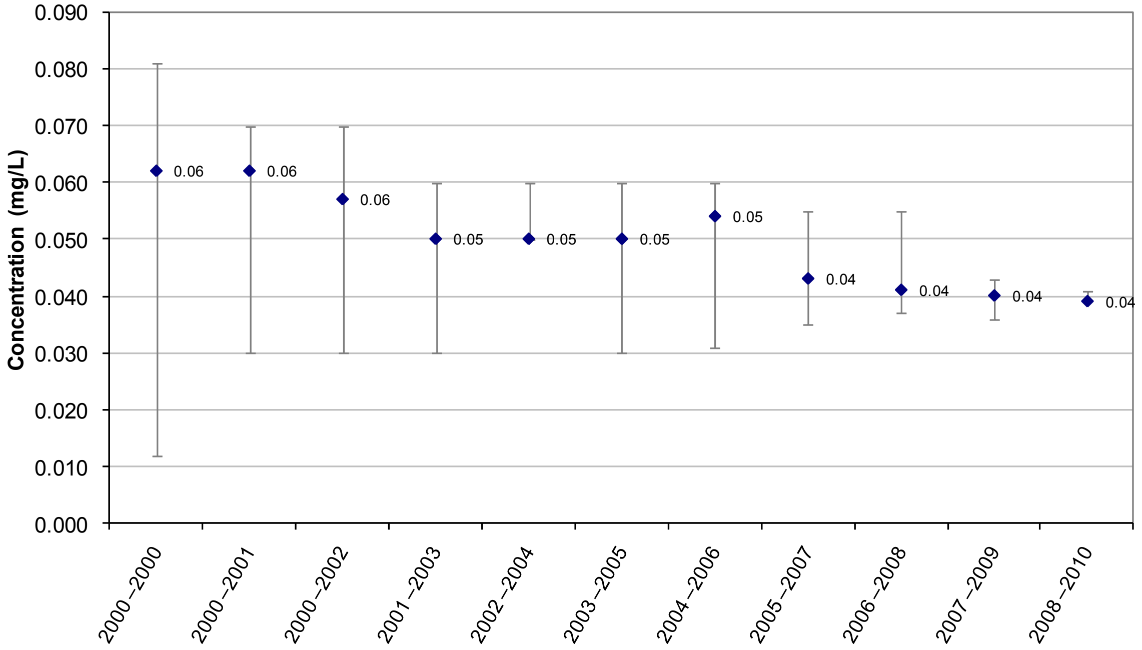


Figure A-13: *Total nitrogen at sampling location Avon River, Beverley Bridge (615025) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



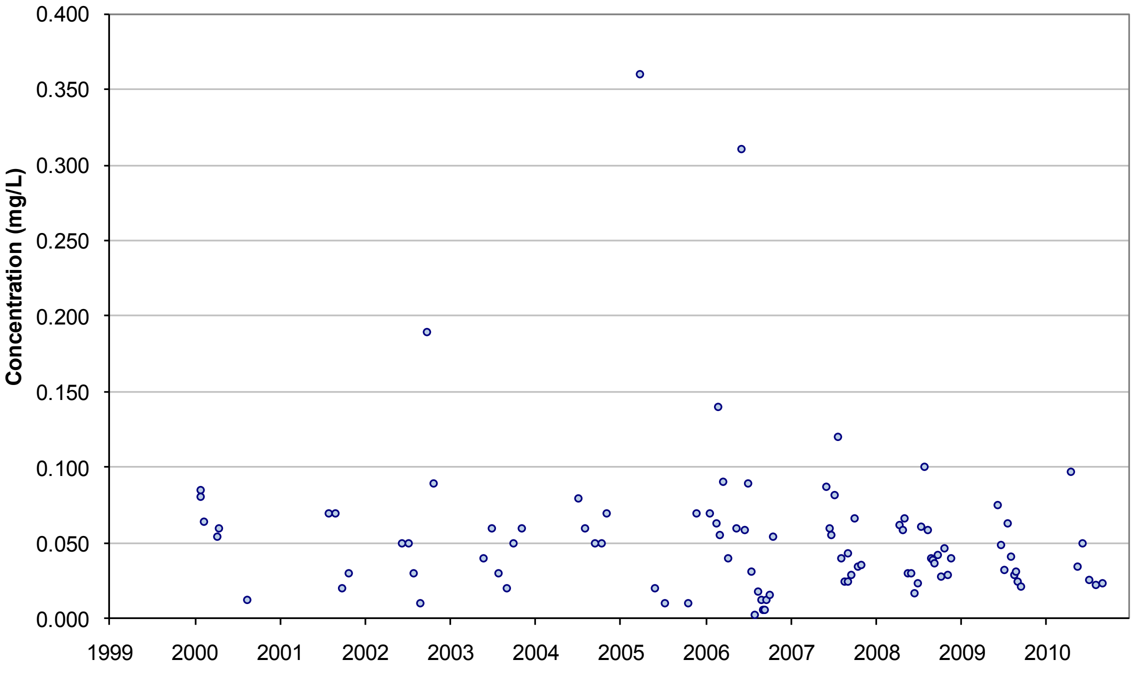


***Figure A-14**: Total phosphorus at sampling location Avon River, Beverley Bridge (615025) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*

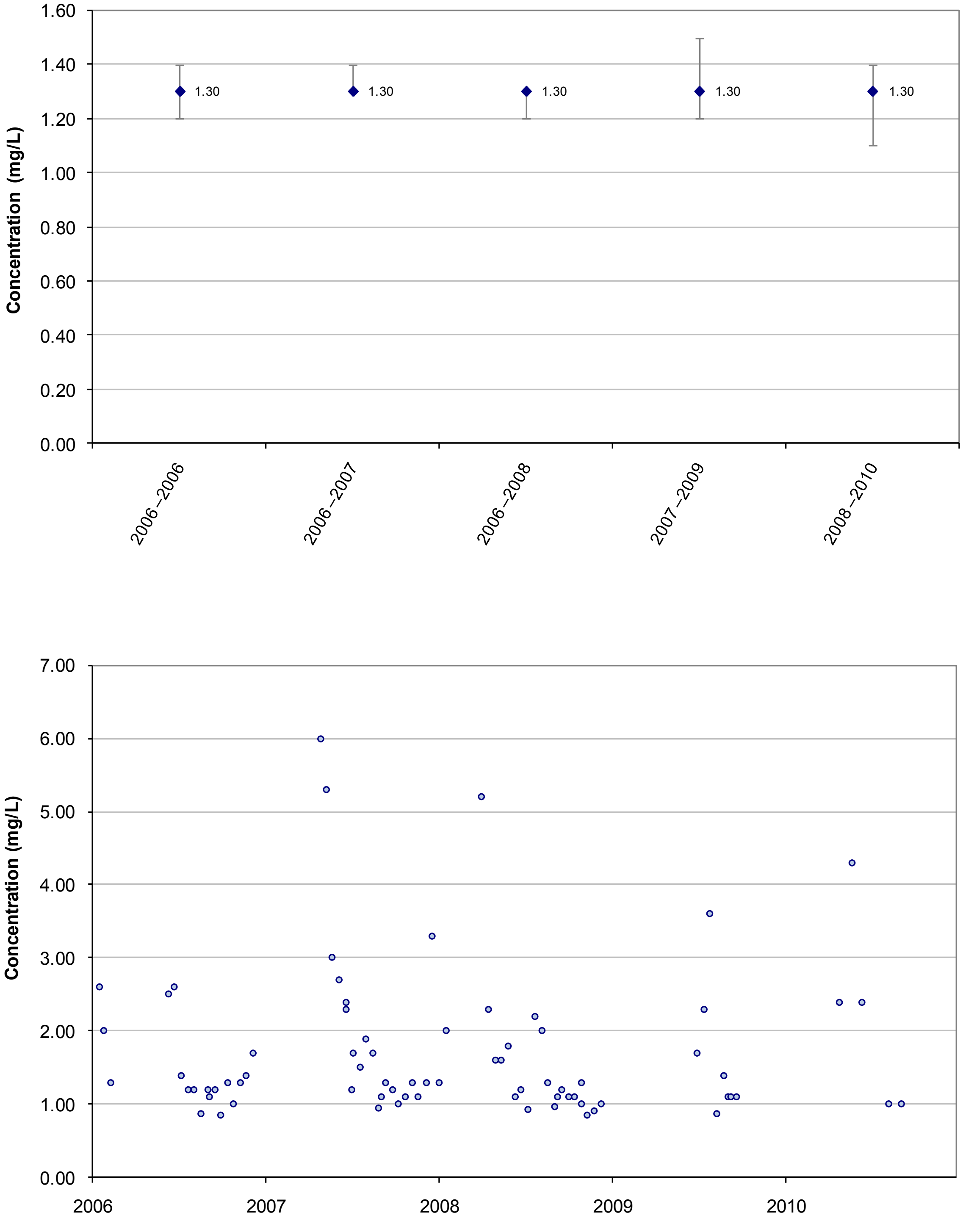
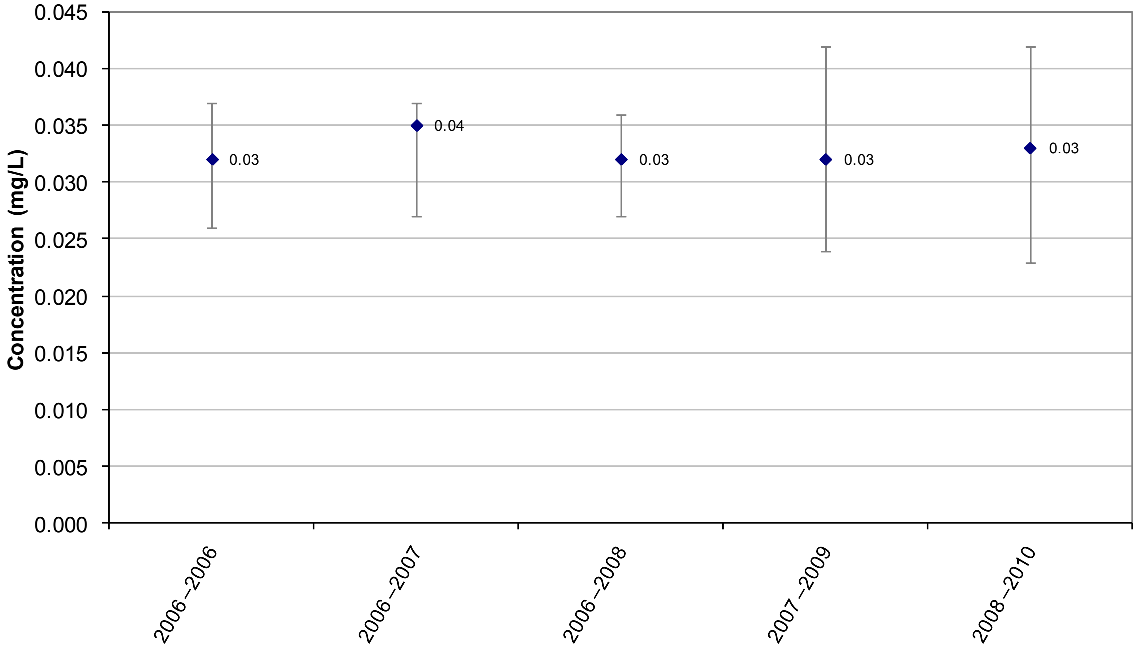


Figure A-15: *Total nitrogen at sampling location Avon River, Stirling Terrace Toodyay (615026) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



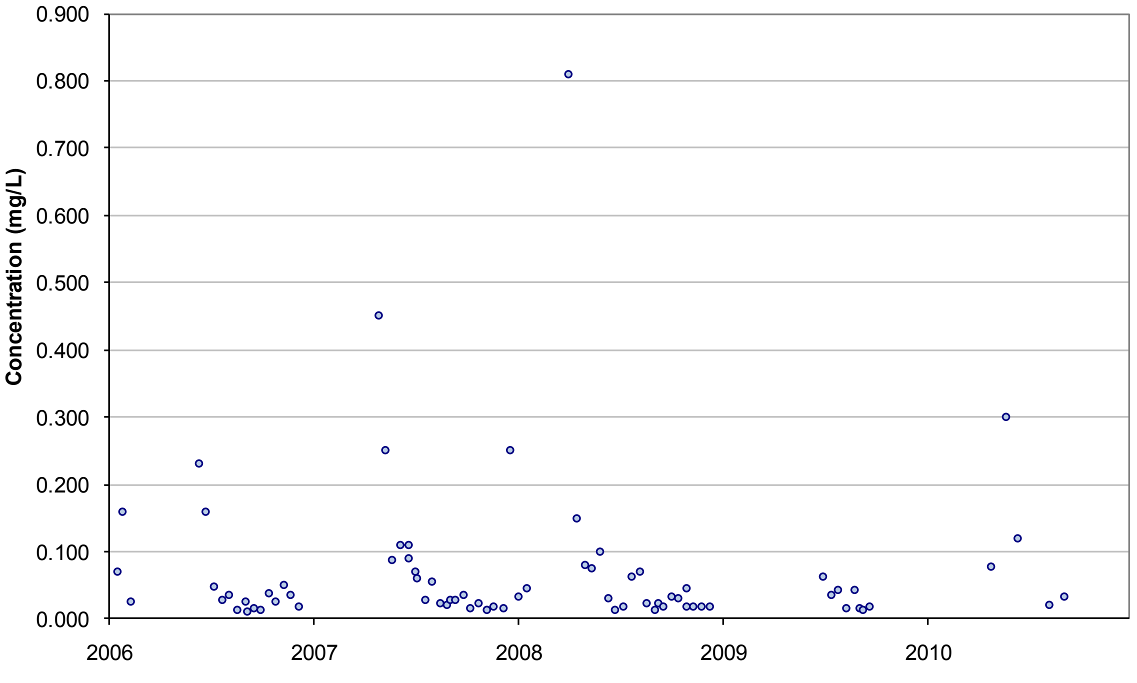
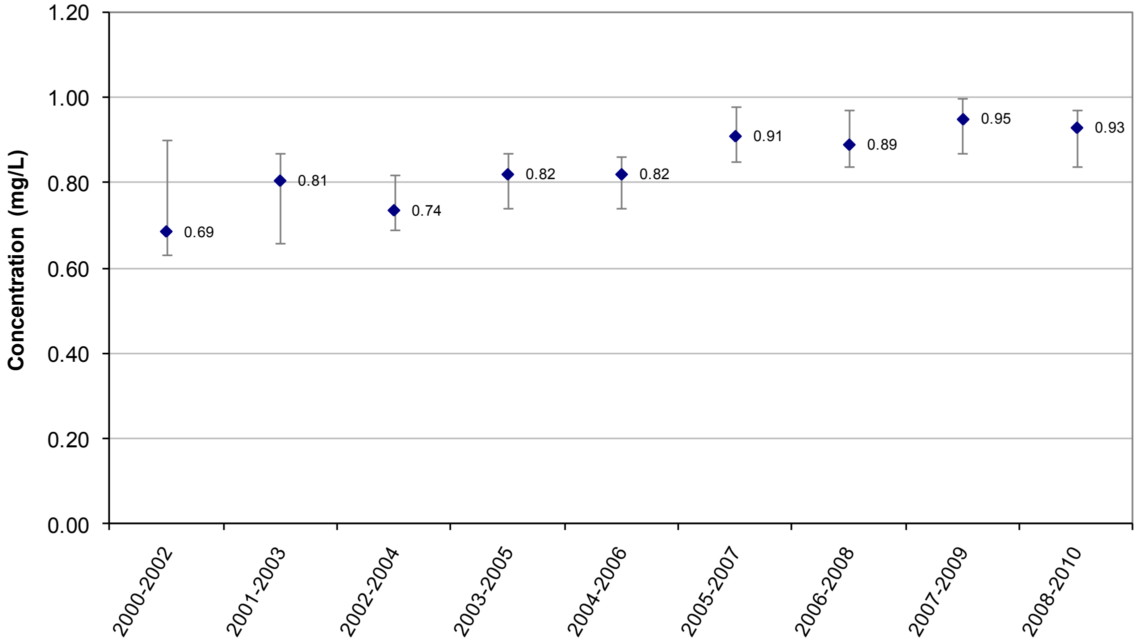


Figure A-16: *Total phosphorus at sampling location Avon River, Stirling Terrace Toodyay (615026) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



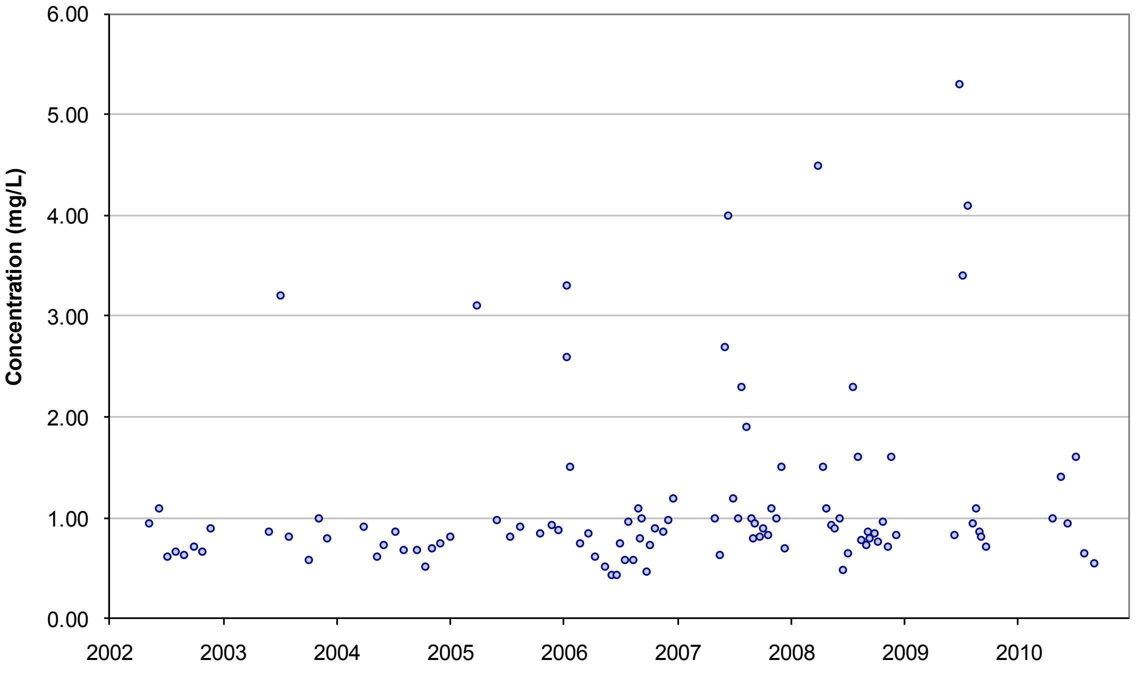
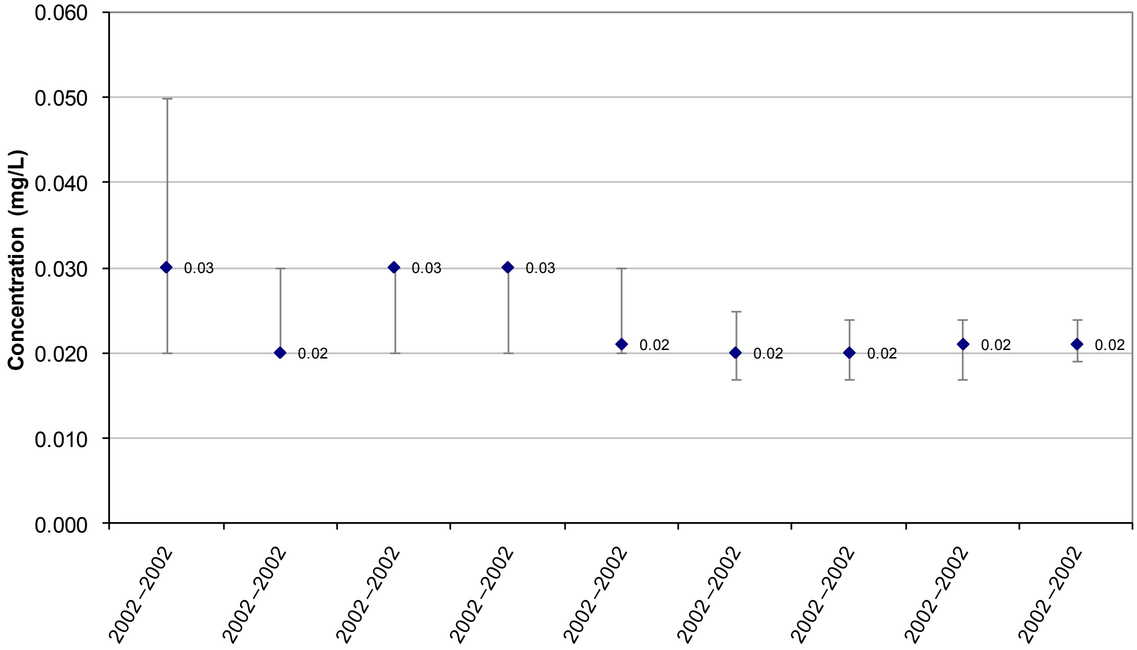


Figure A-17: *Total nitrogen at sampling location Dale River, Waterhatch Bridge (615027) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



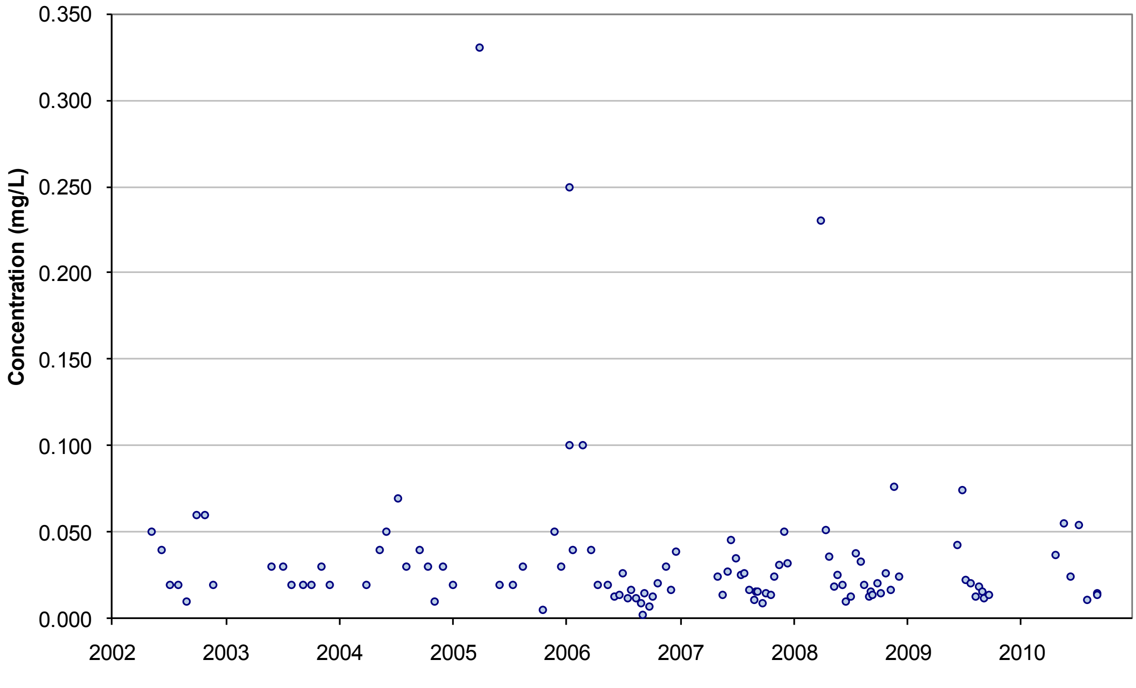
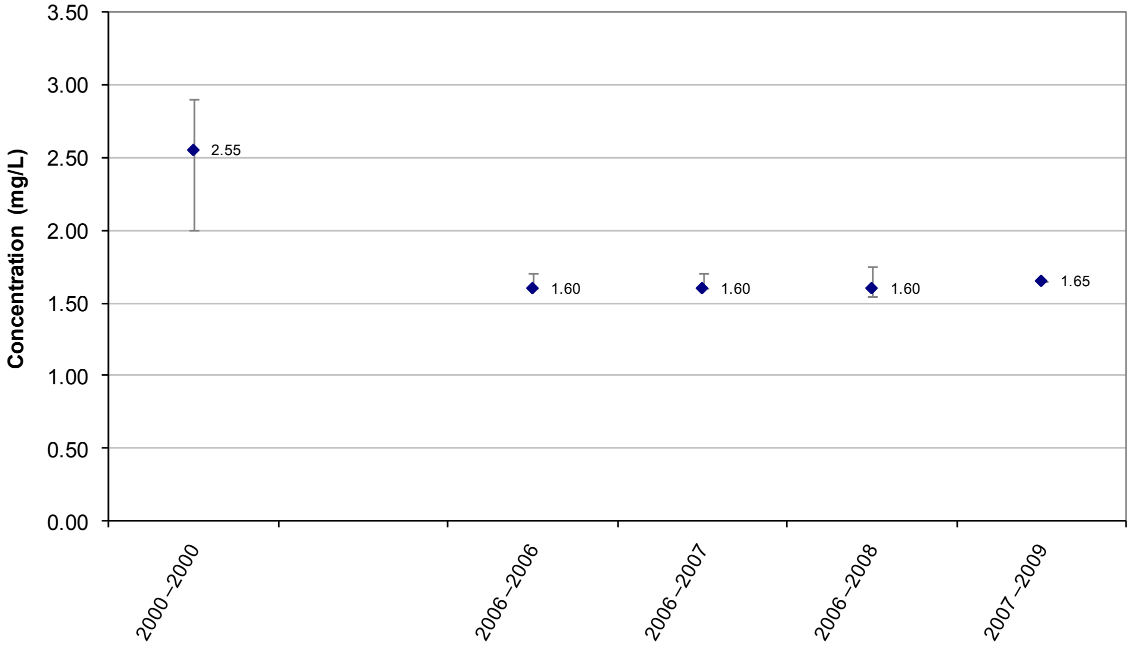


Figure A-18: *Total phosphorus at sampling location Dale River, Waterhatch Bridge (615027) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



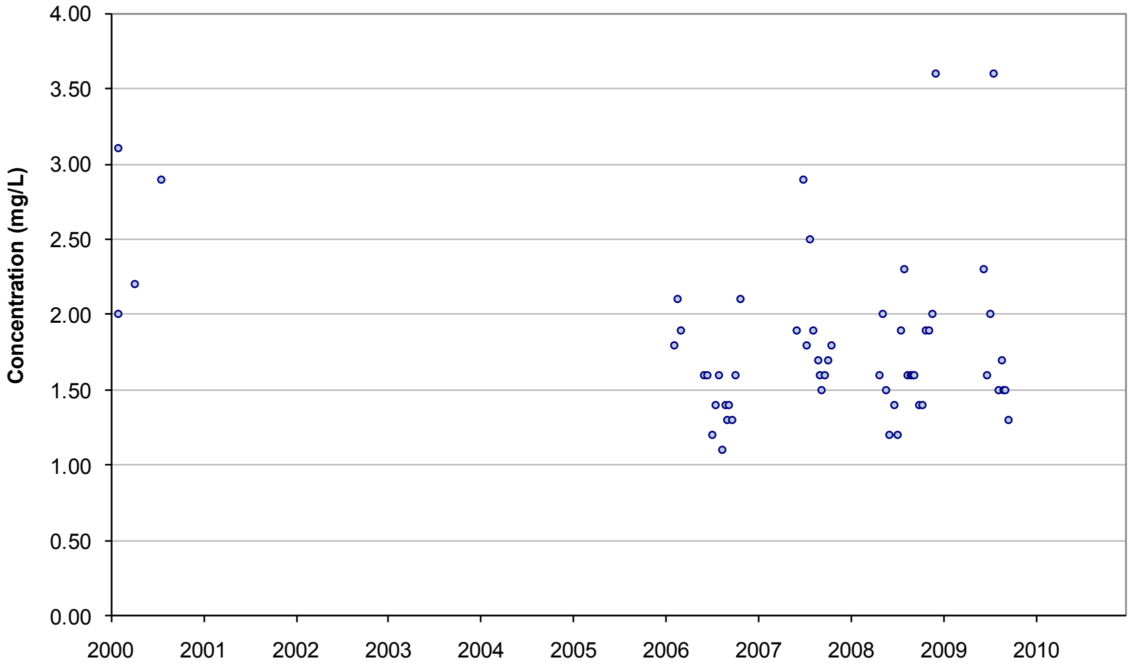
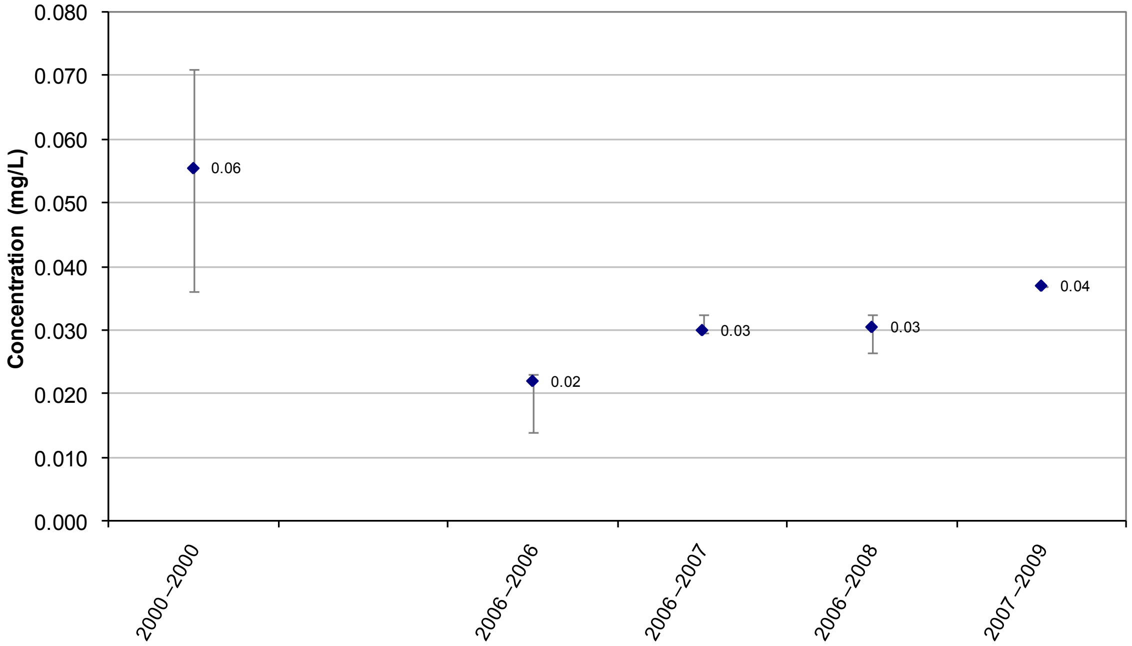


Figure A-19*: Total nitrogen at sampling location Avon River, Yenyening Confluence (615029) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



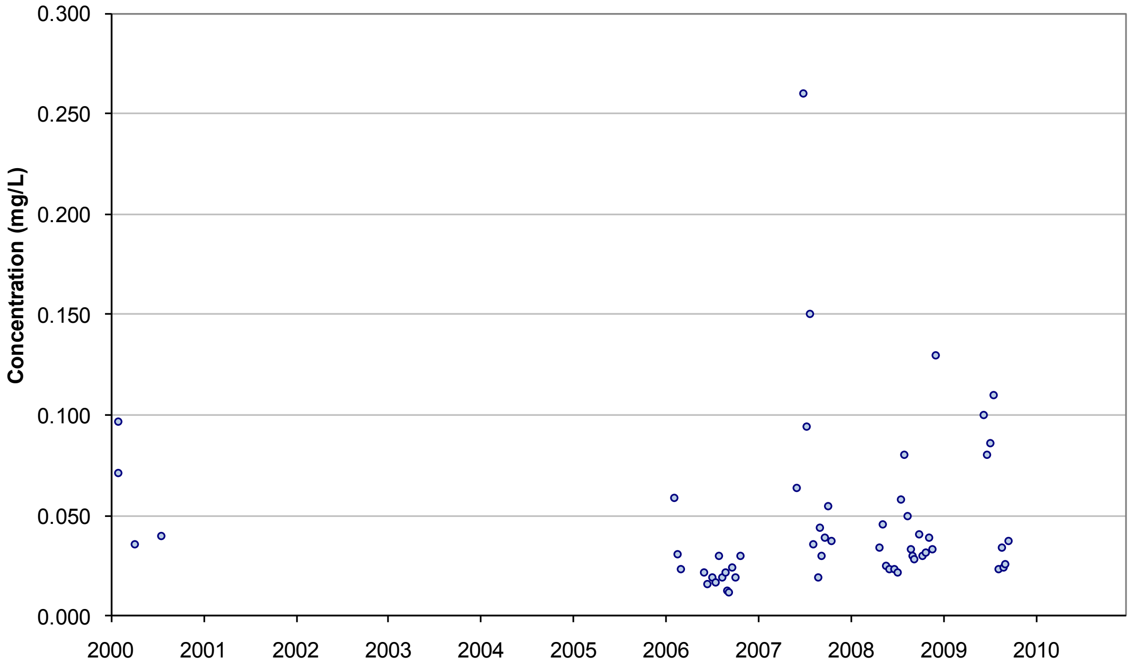
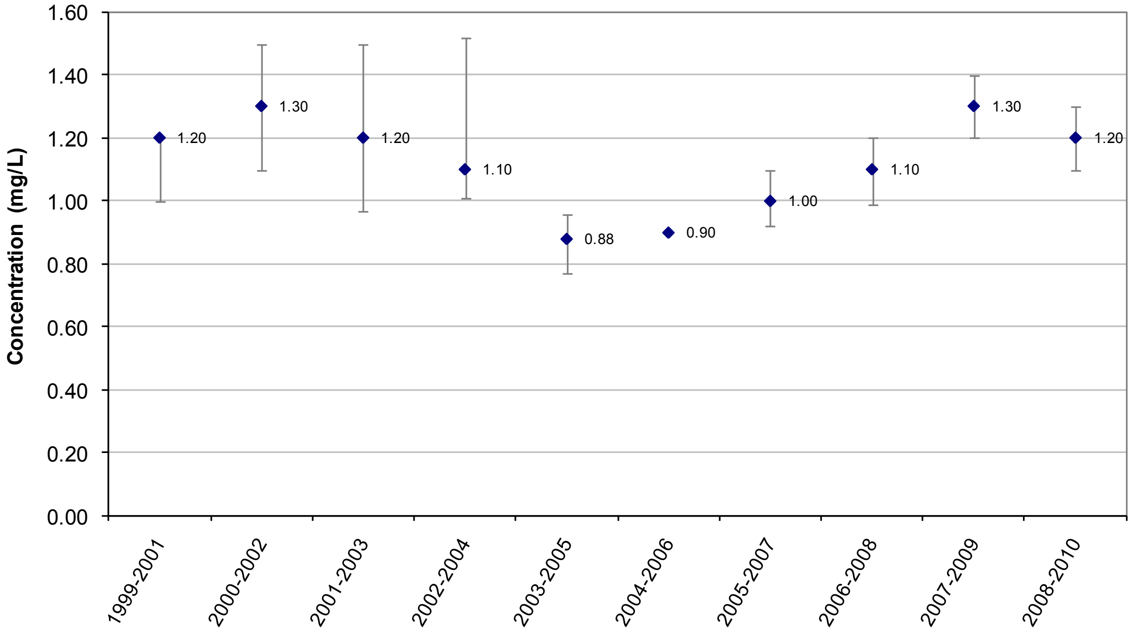


Figure A-20: *Total phosphorus at sampling location Avon River, Yenyening Confluence (615029) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



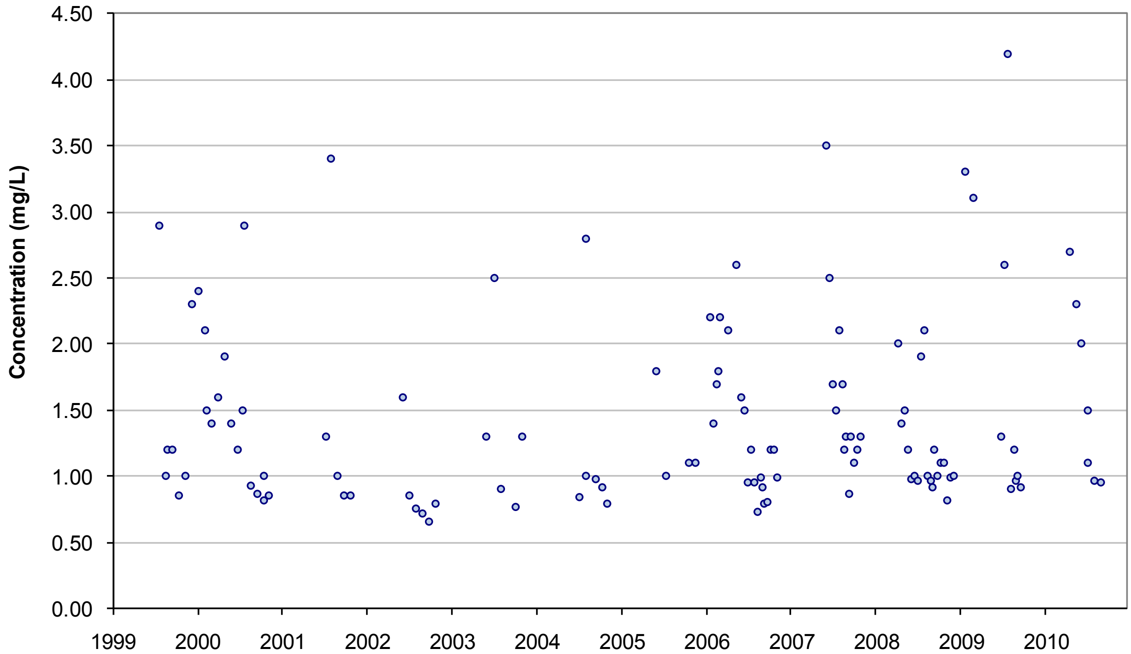


Figure A-21: *Total nitrogen at sampling location Avon River, Northam Weir (615062) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*

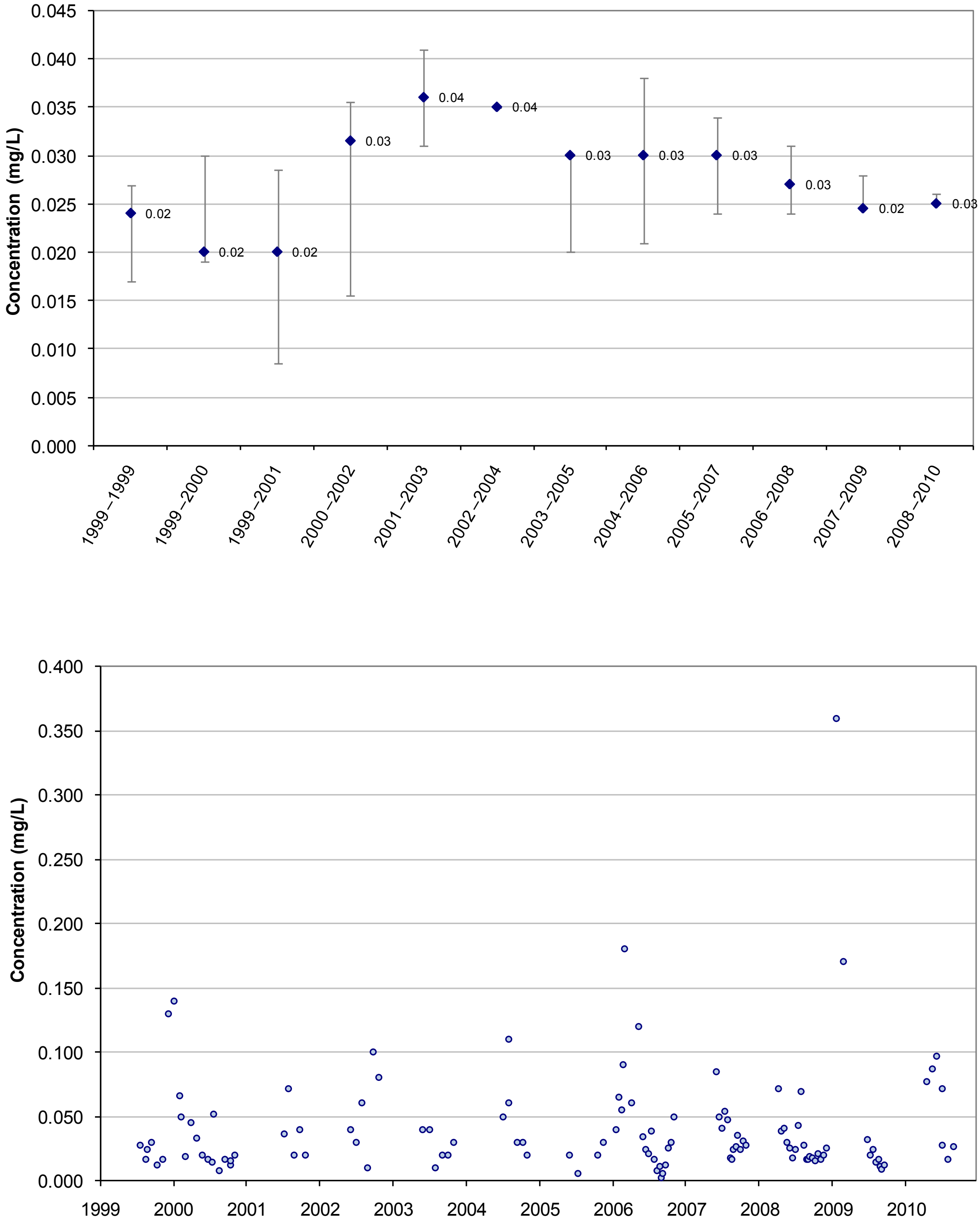
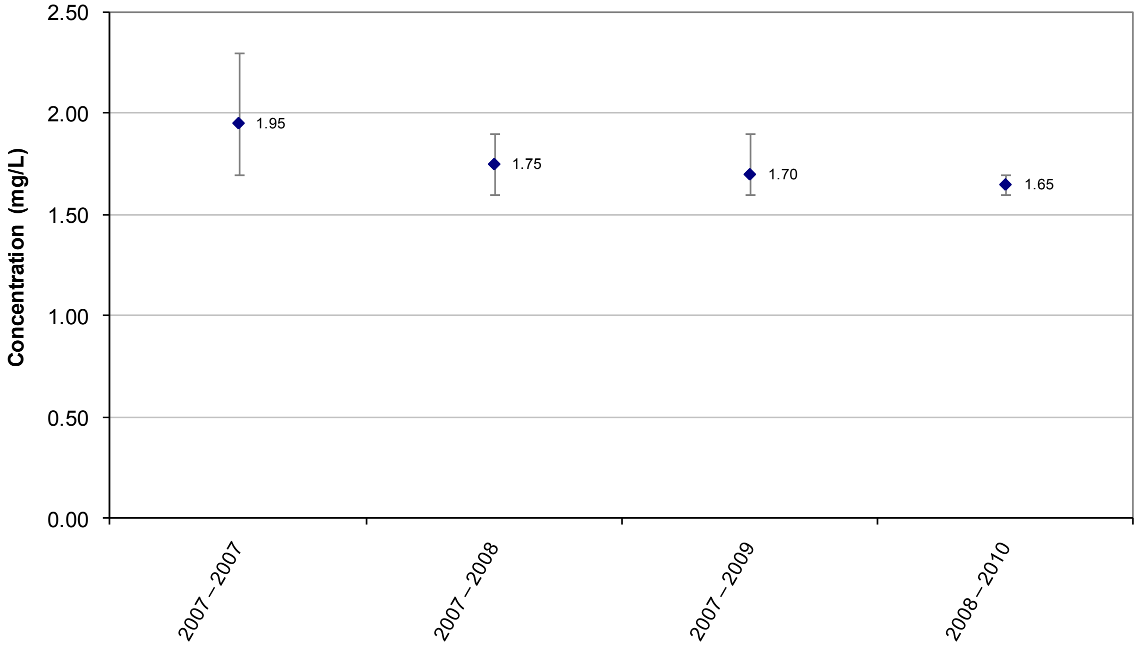


***Figure A-22**: Total phosphorus at sampling location Avon River, Northam Weir (615062) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



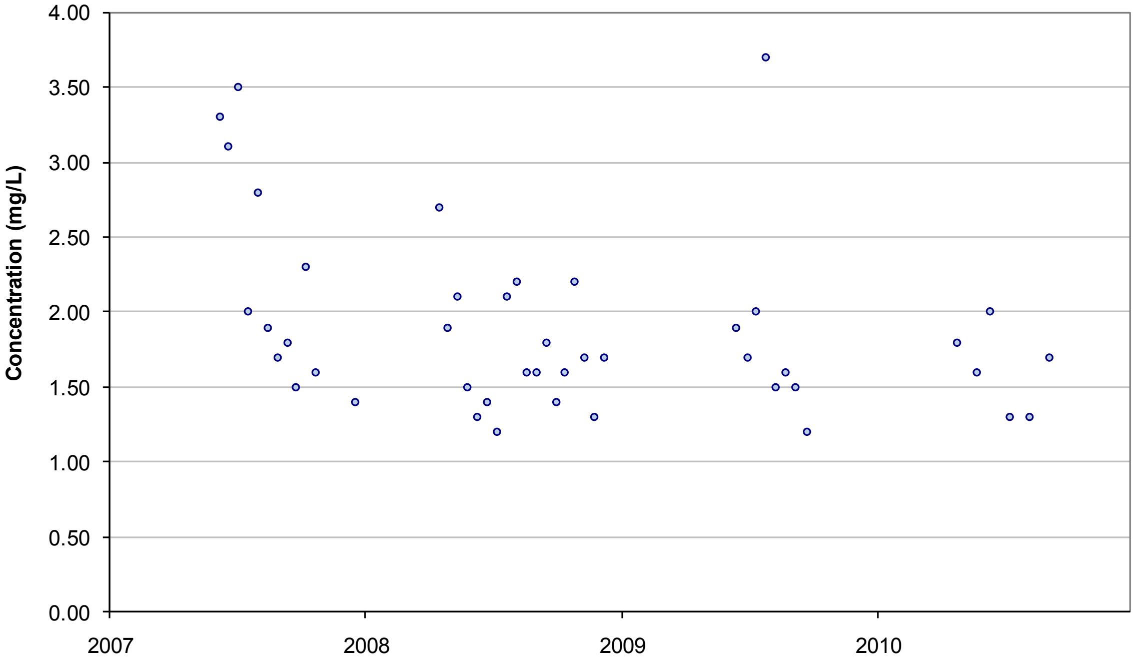
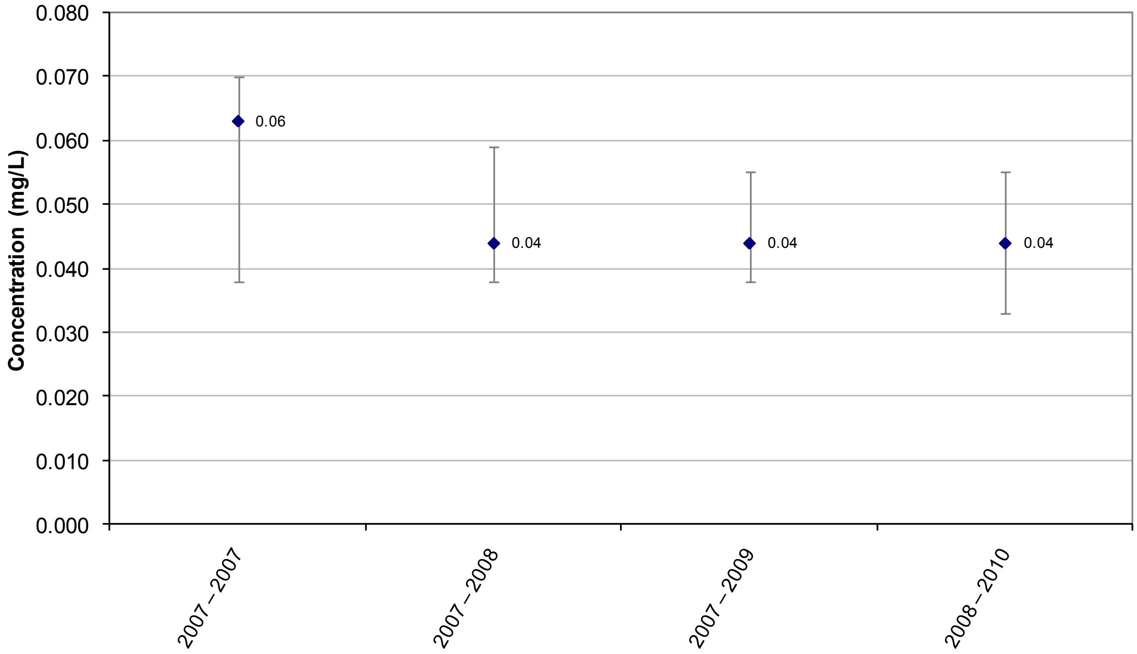


Figure A-23: *Total nitrogen at sampling location Avon River, Boyagarra Road (615063) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



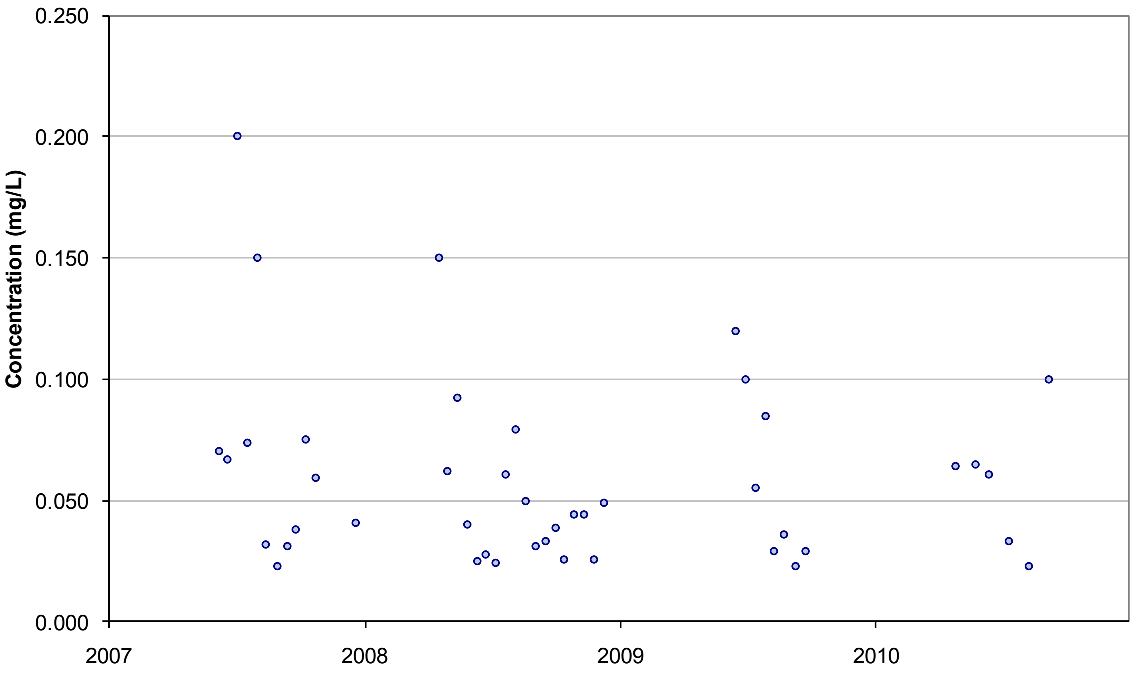
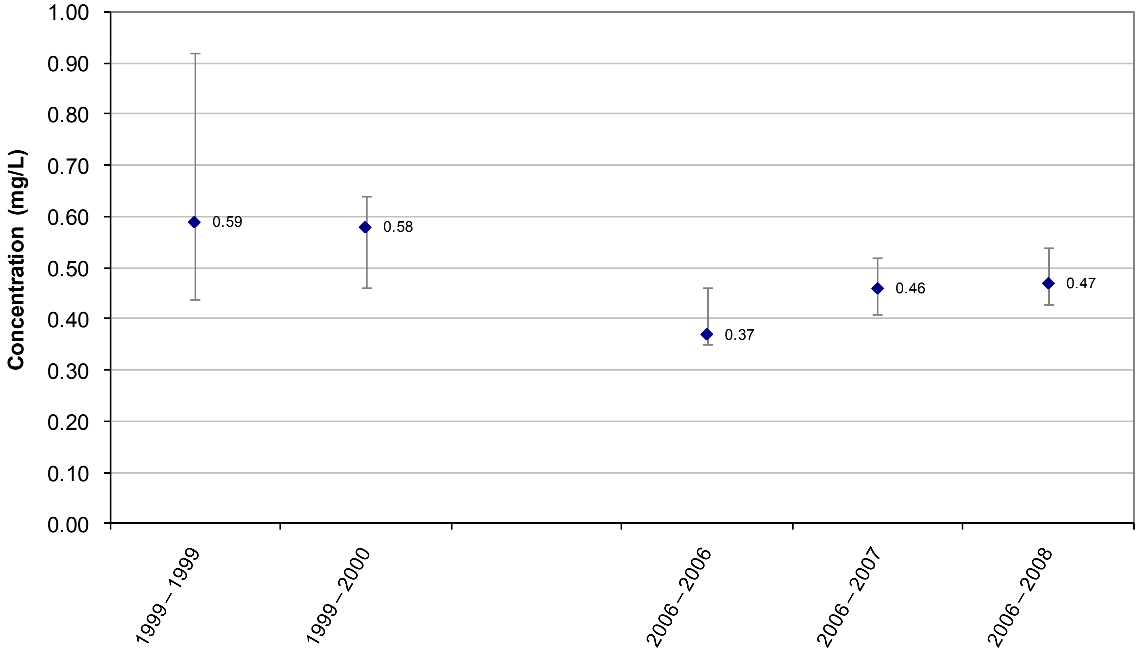


Figure A-24: *Total phosphorus at sampling location Avon River, Boyagarra Road (615063) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



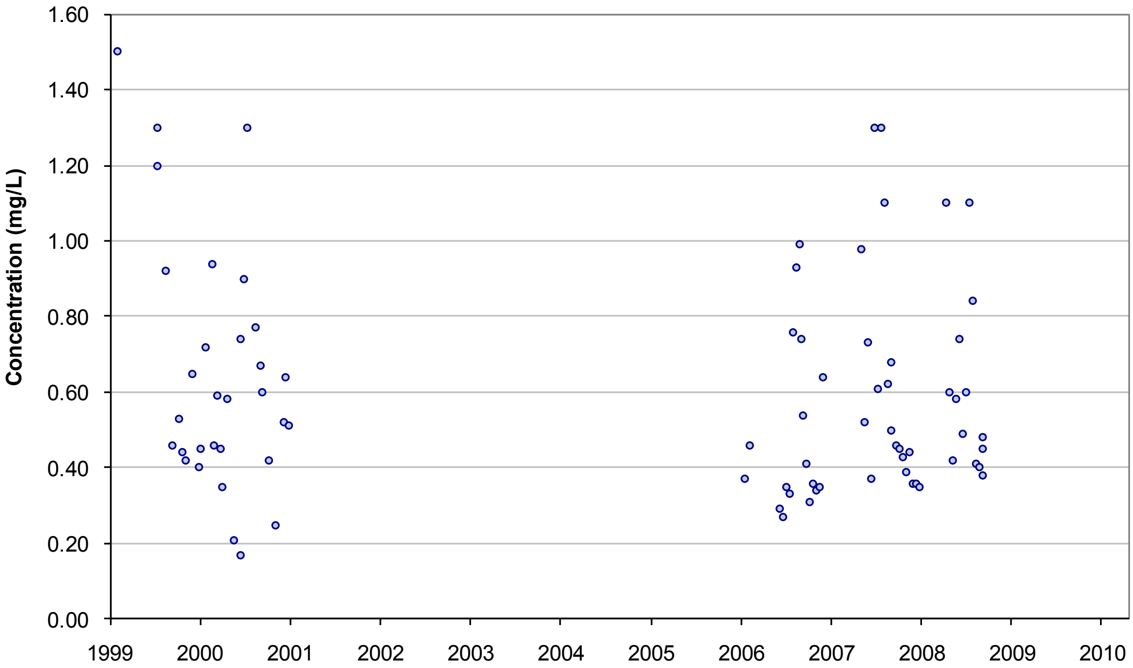
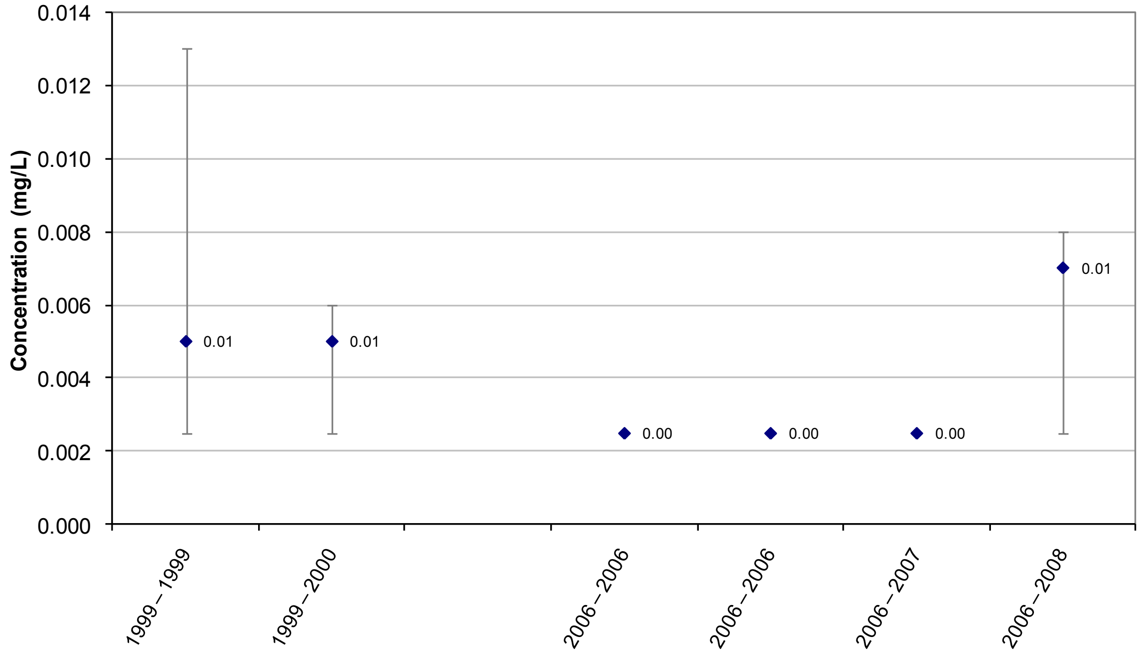


Figure A-25: *Total nitrogen at sampling location Wooroloo Brook, Karls Ranch (616001) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



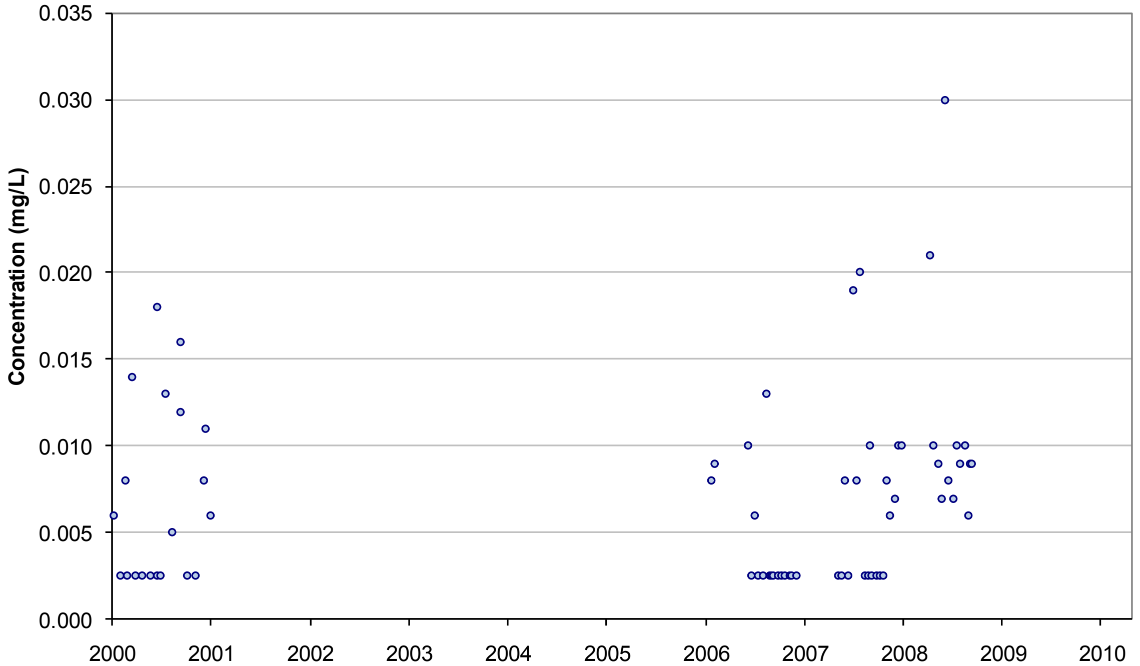
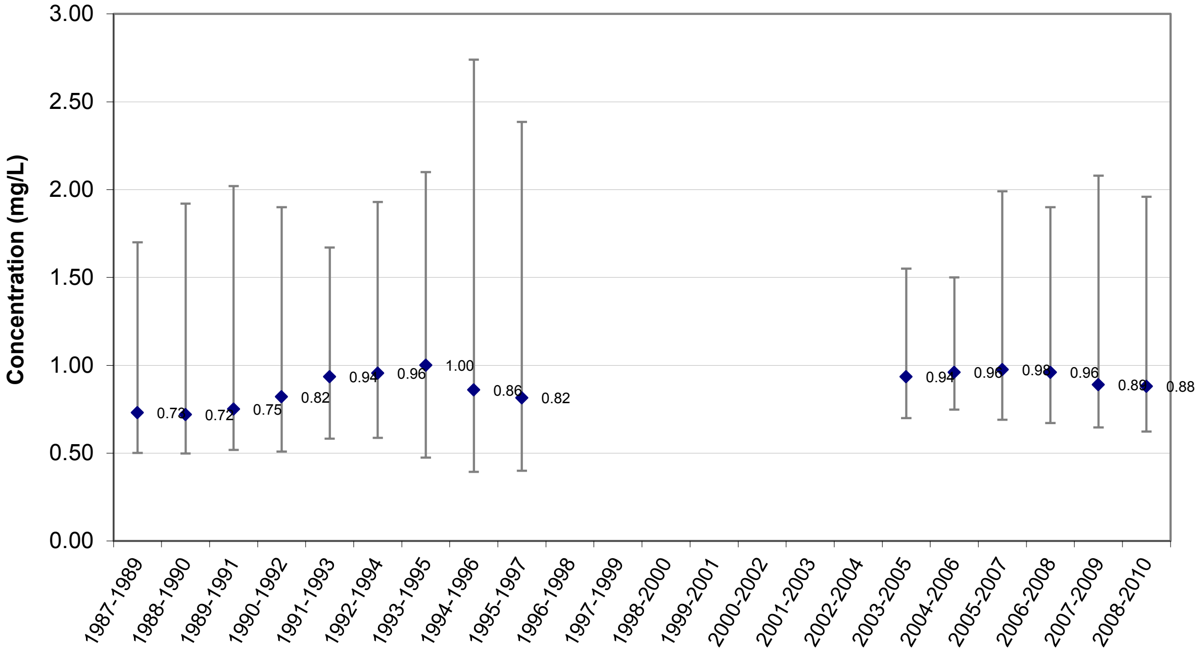


***Figure A-26:** Total phosphorus at sampling location Wooroloo Brook, Karls Ranch (616001) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



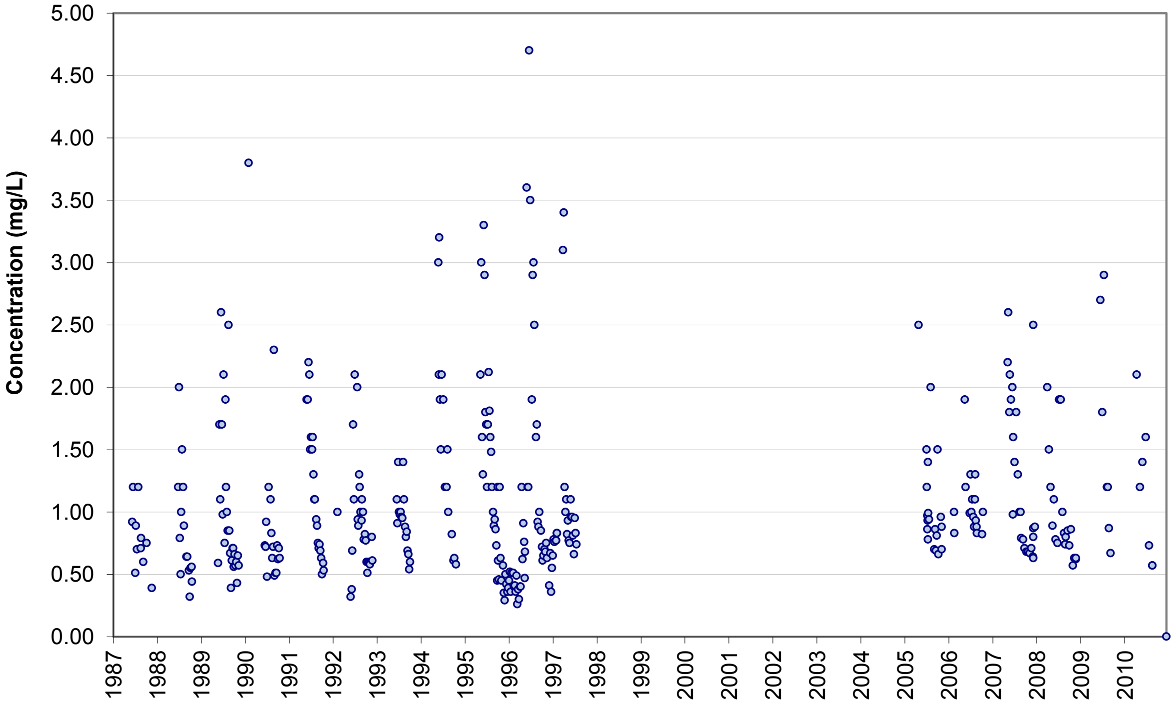
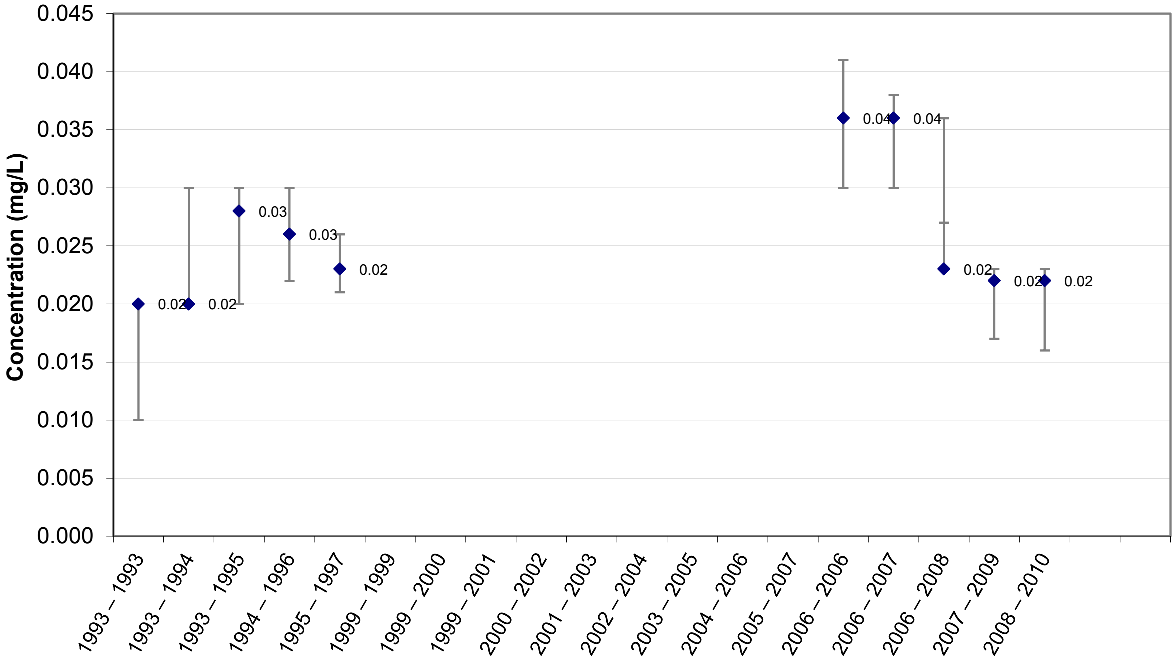


Figure A-27: *Total nitrogen at sampling location Avon River, Walyunga (616011) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



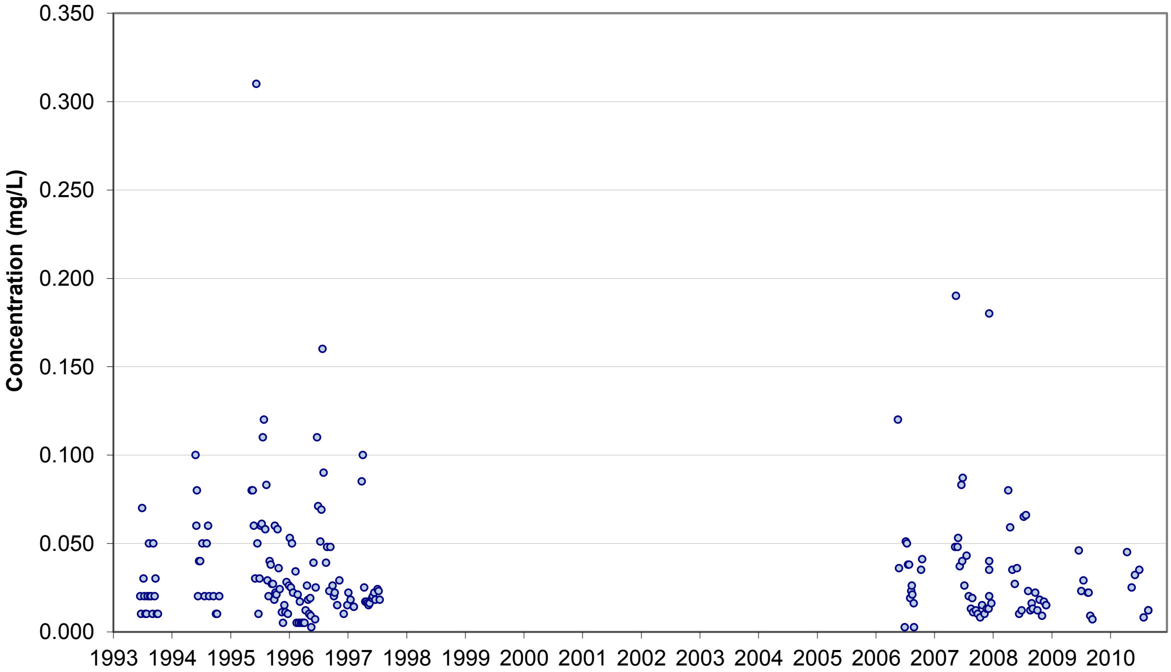
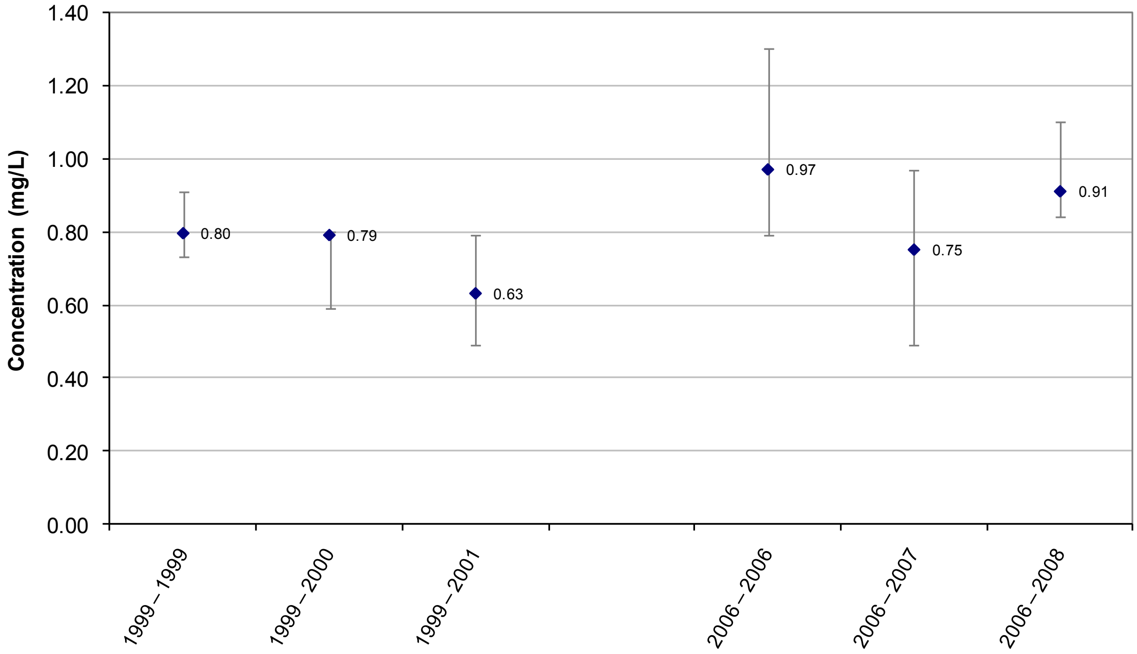


***Figure A-28**: Total phosphorus at sampling location Avon River, Walyunga (616011) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



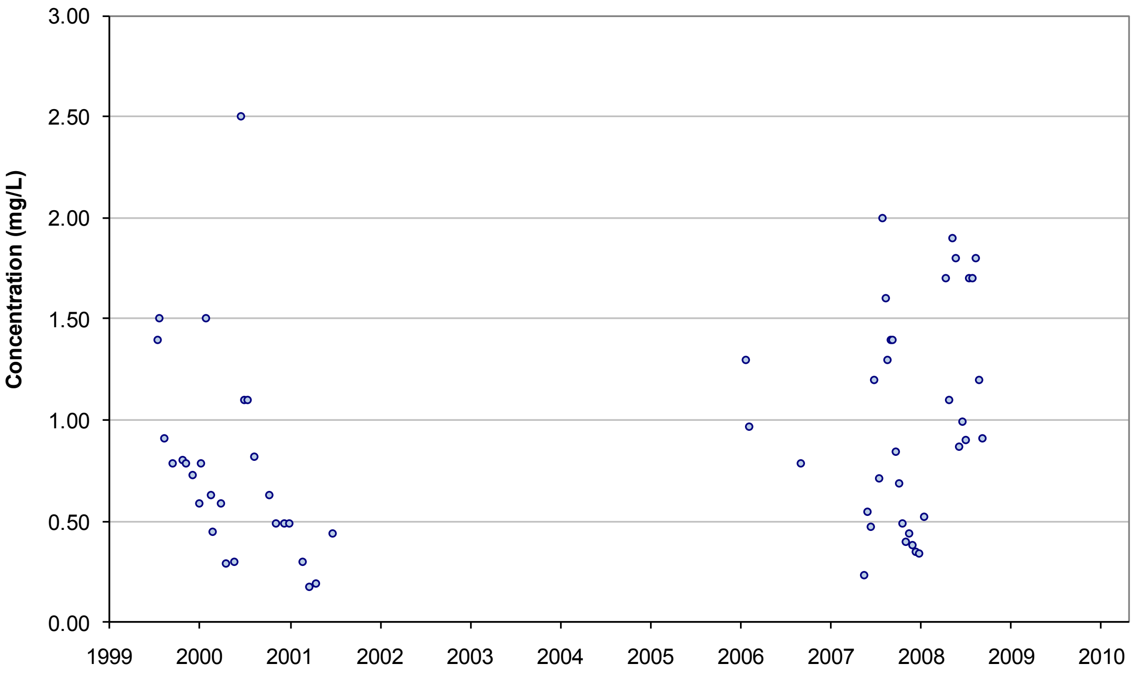
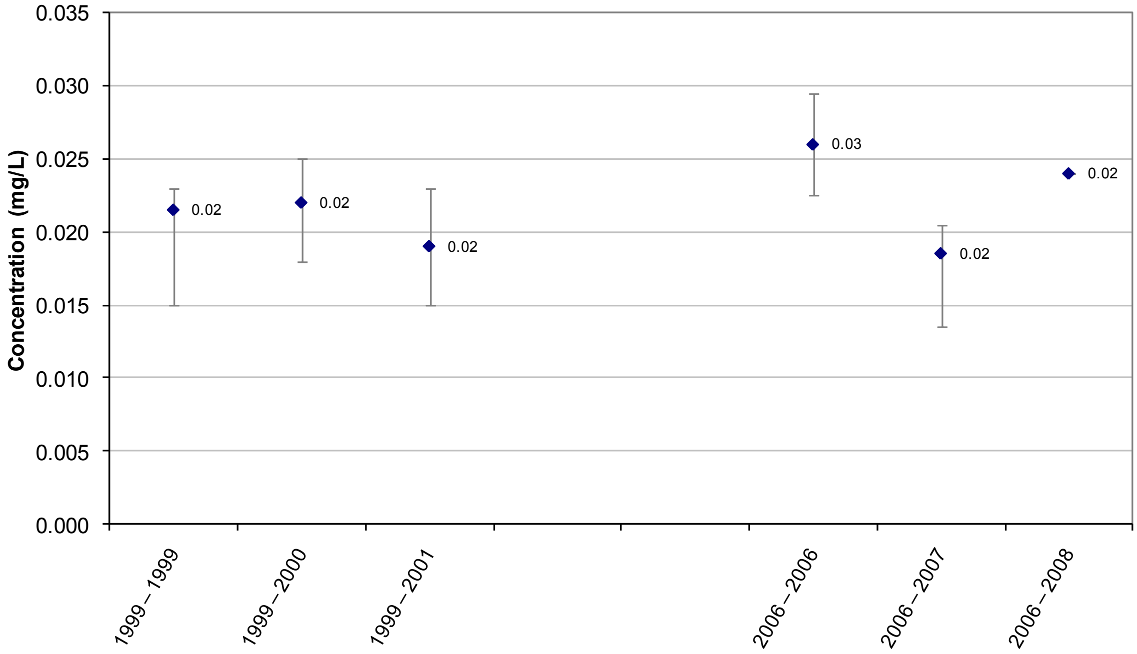


Figure A-29: *Total nitrogen at sampling location Brockman River, Yalliawirra (616019) (Yalliawarra) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



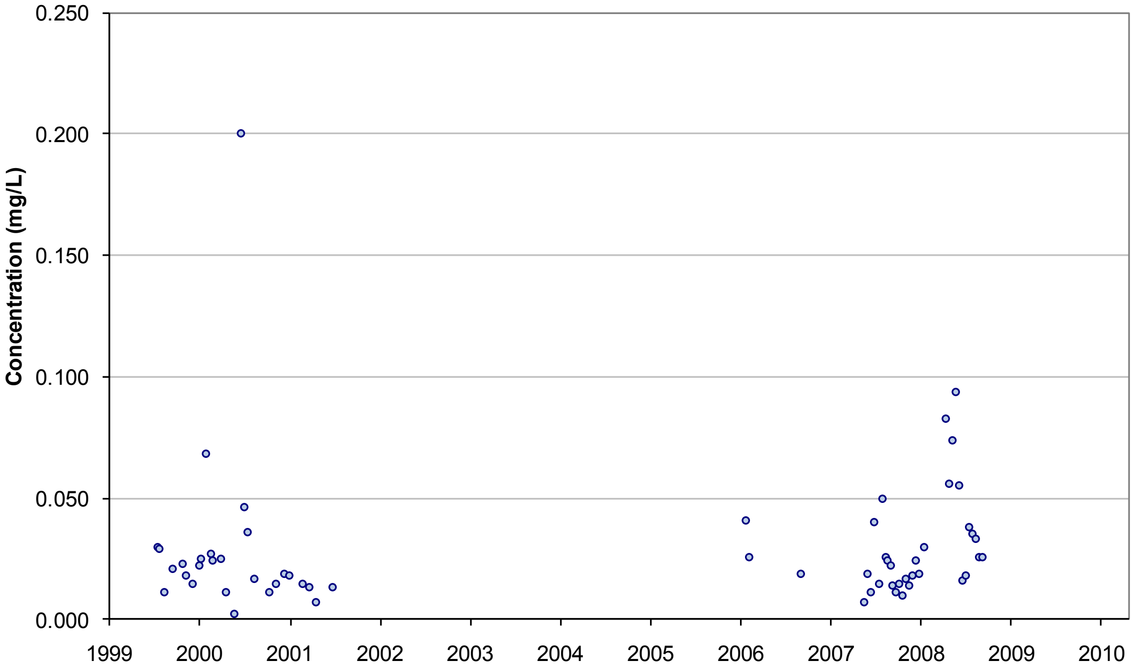
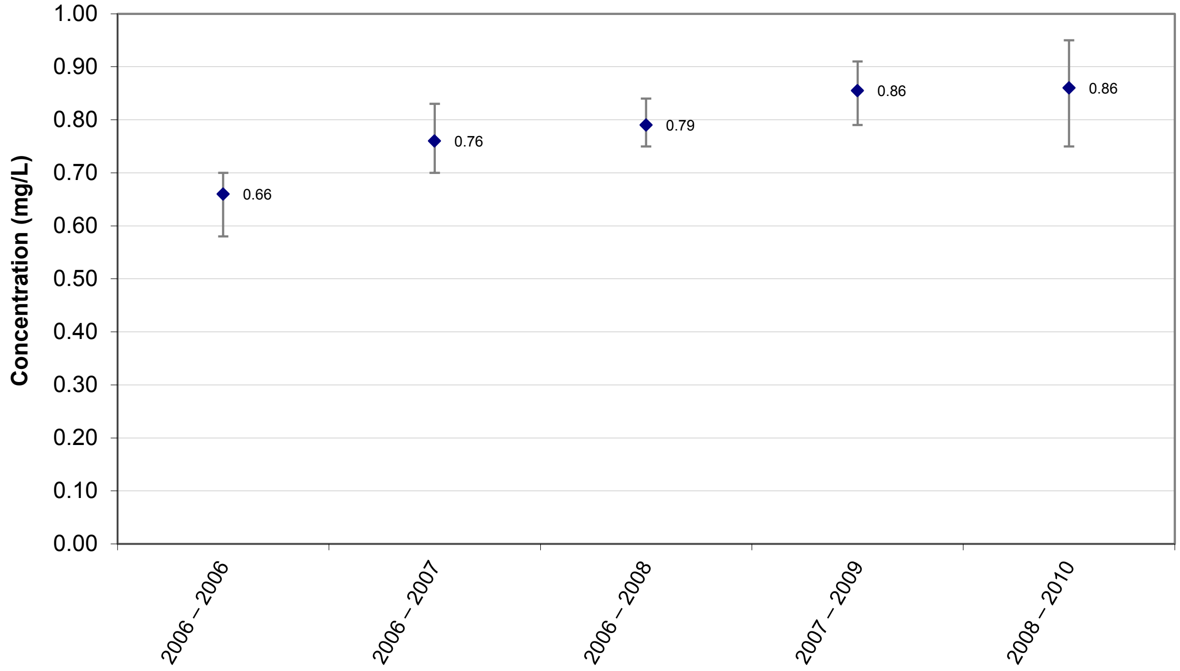


Figure A-30: *Total phosphorus at sampling location Brockman River, Yalliawirra (616019) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



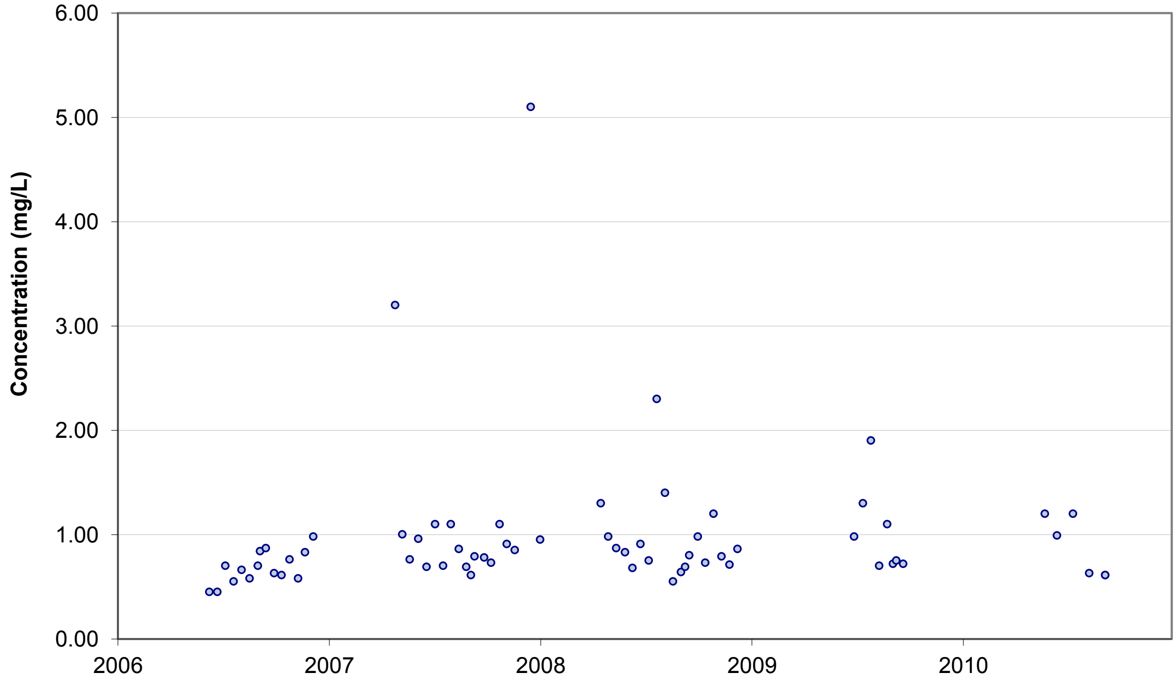
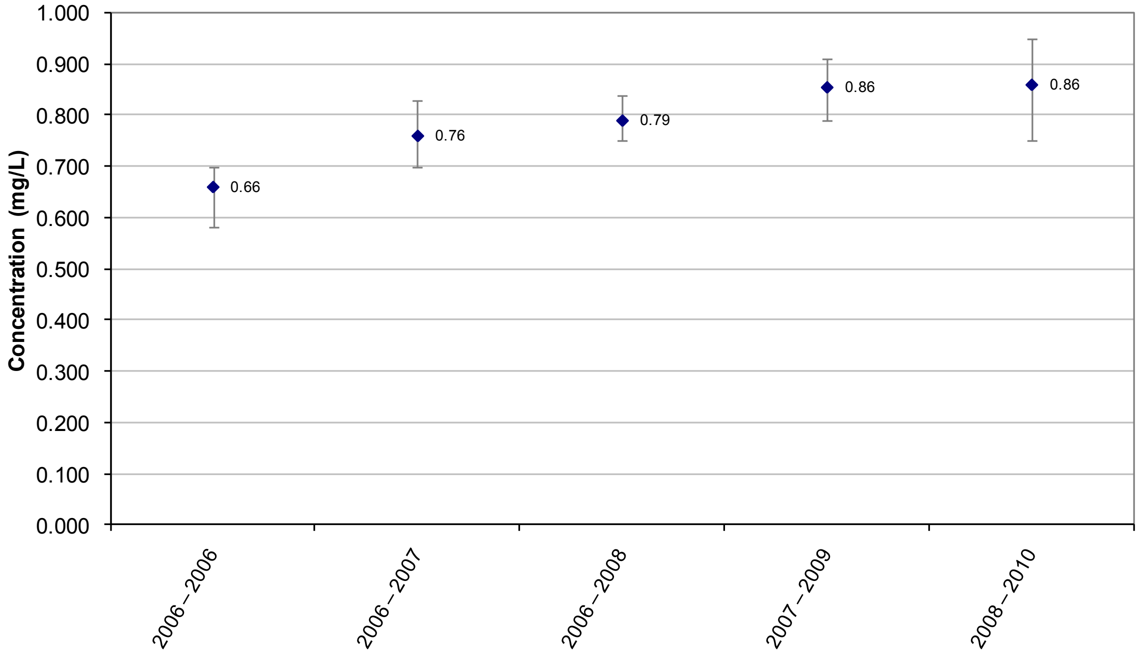


Figure A-31: *Total nitrogen at sampling location Toodyay Brook, Toodyay West Road (6151001) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



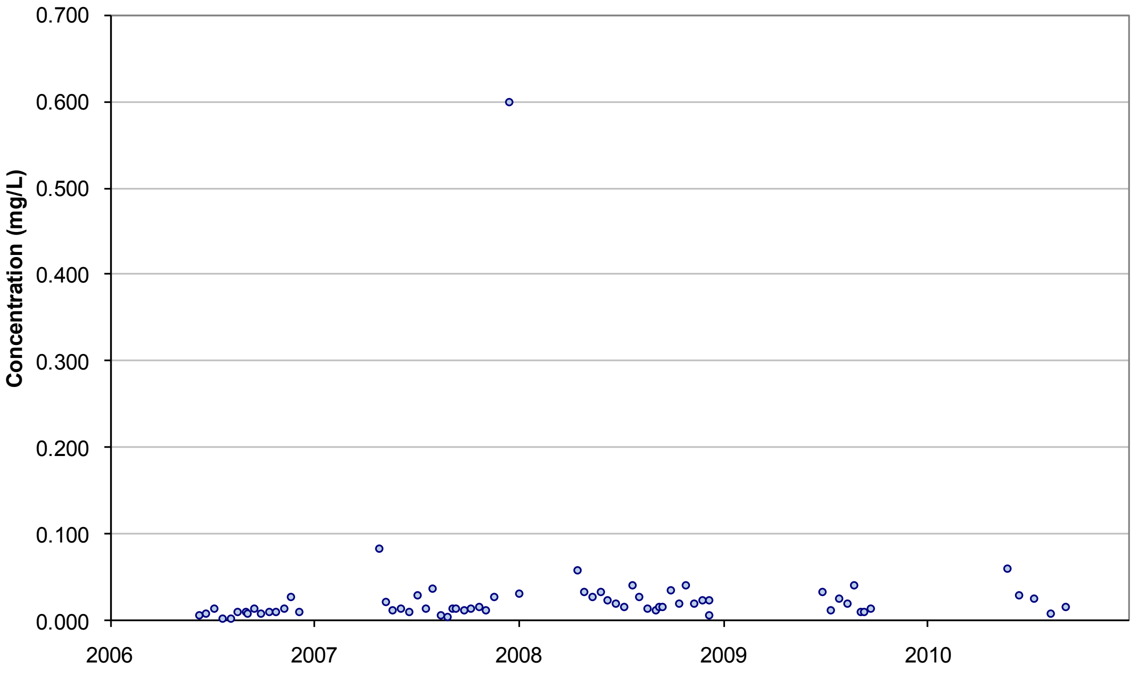
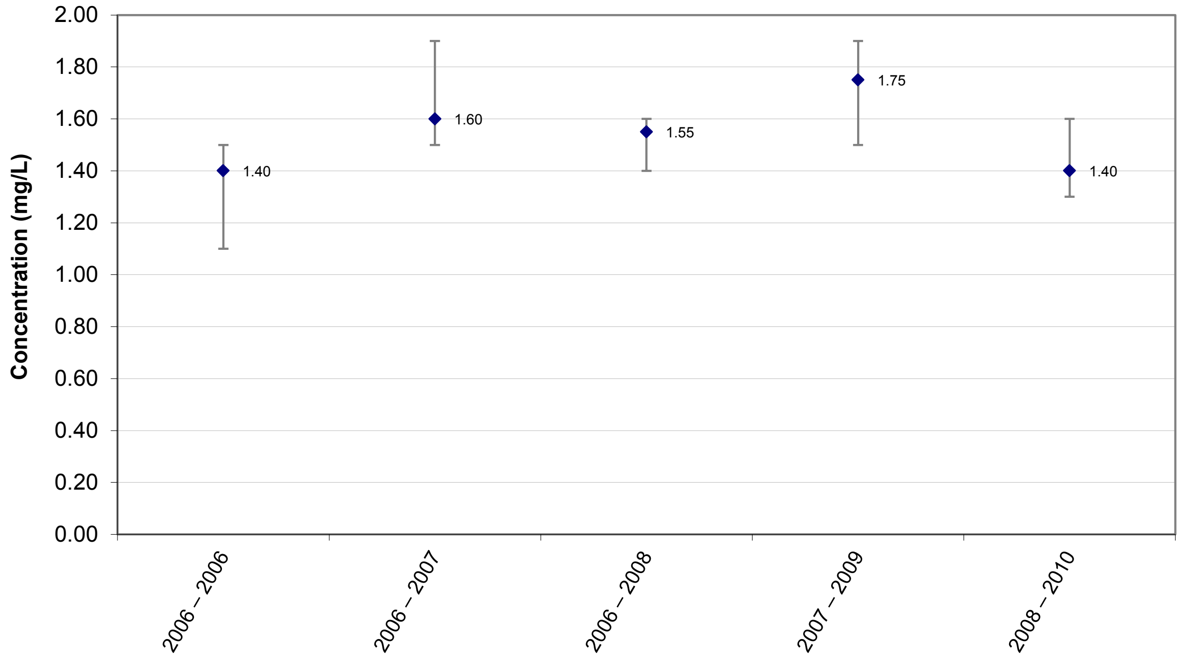


***Figure A-32**: Total phosphorus at sampling location Toodyay Brook, Toodyay West Road (6151001) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



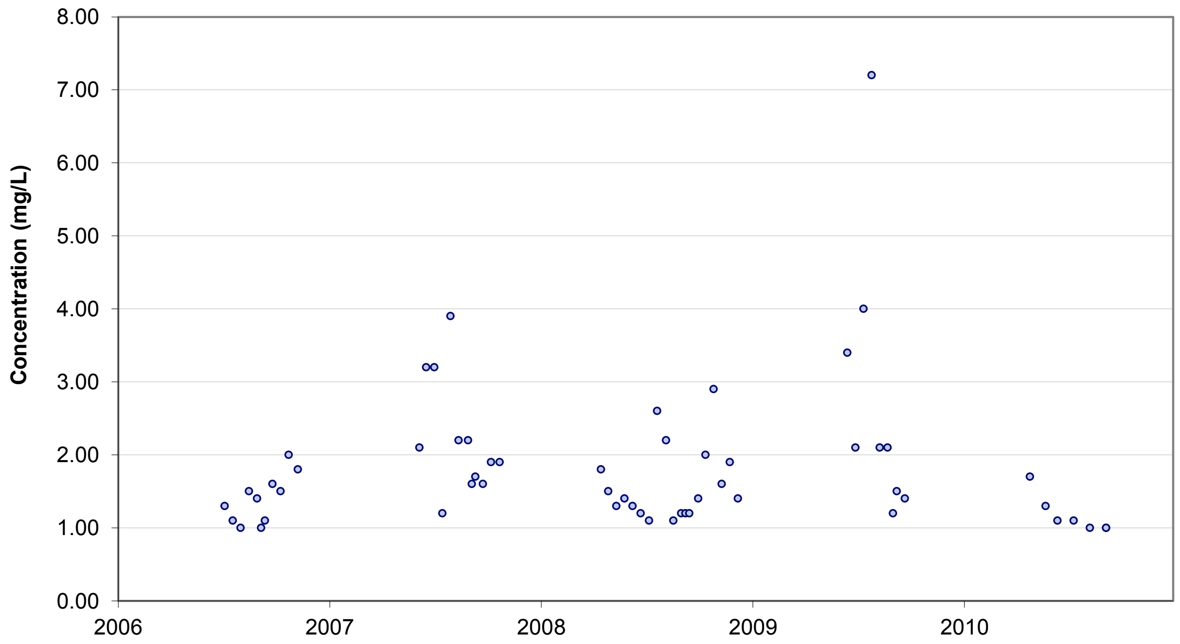


Figure A-33: *Total nitrogen at sampling location Avon River South, Downstream Brookton WWTP (6151007) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*

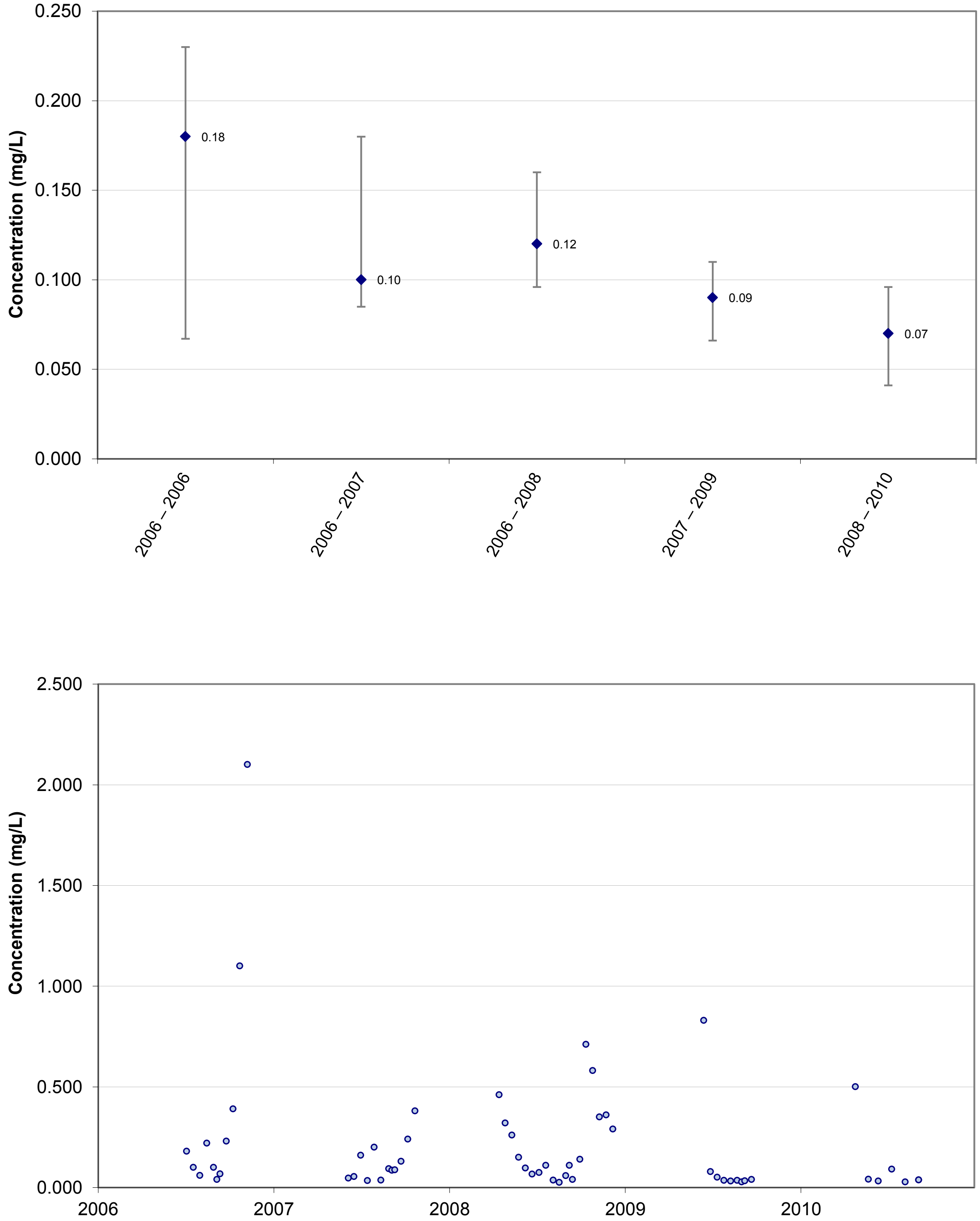
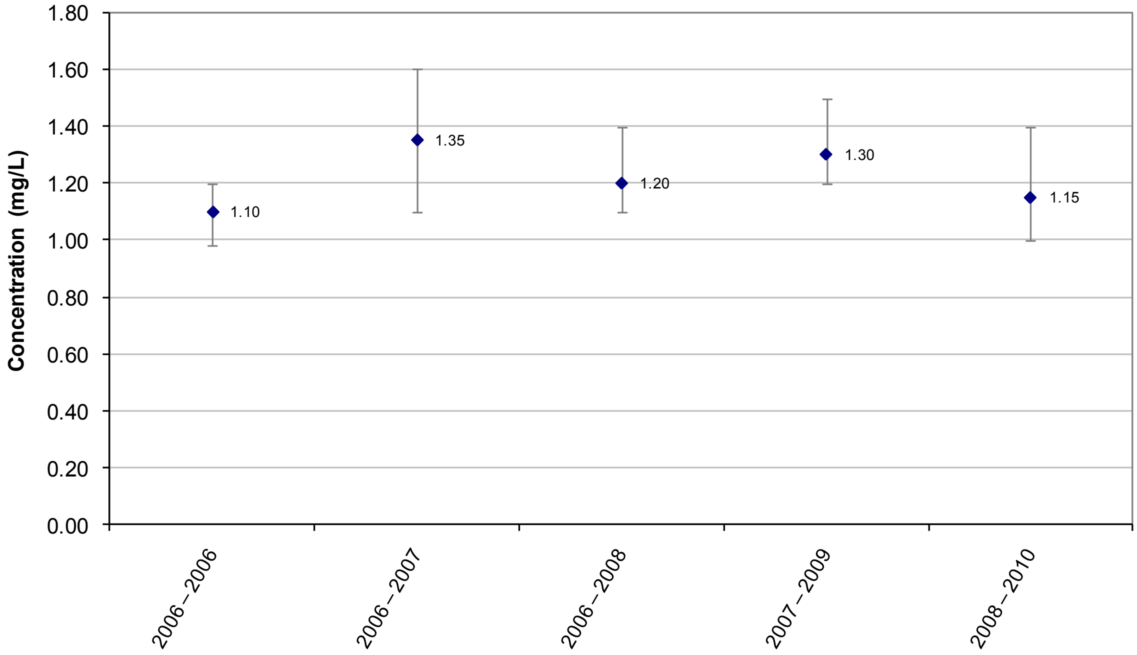


***Figure A-34**: Total phosphorus at sampling location Avon River South, Downstream Brookton WWTP (6151007) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



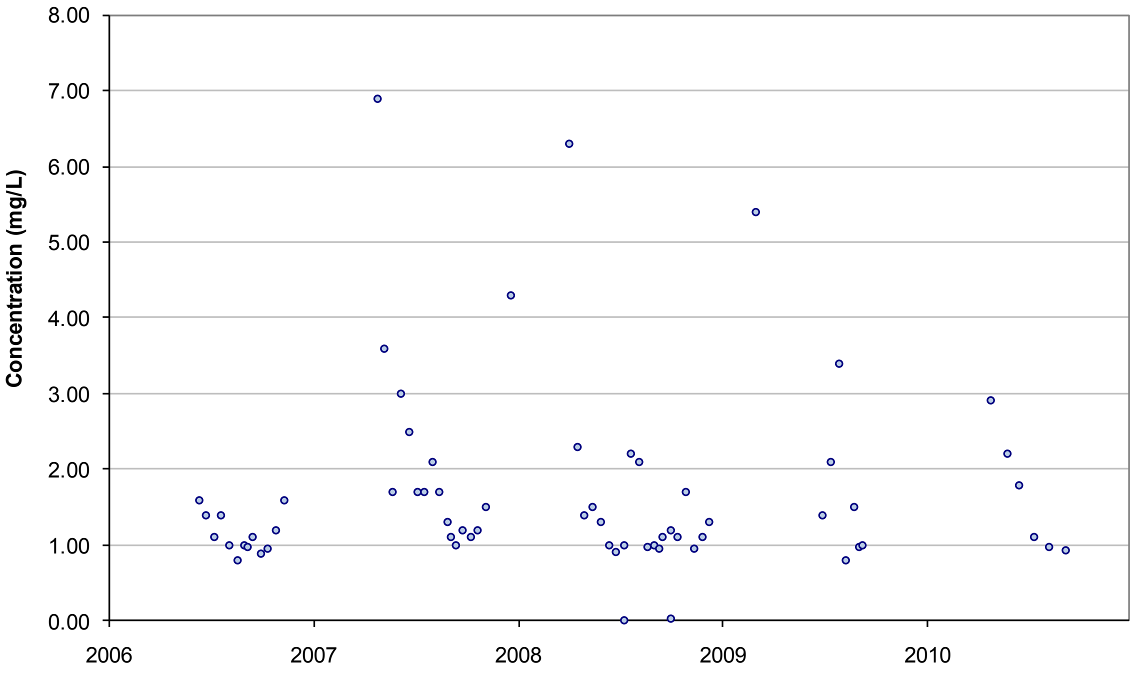
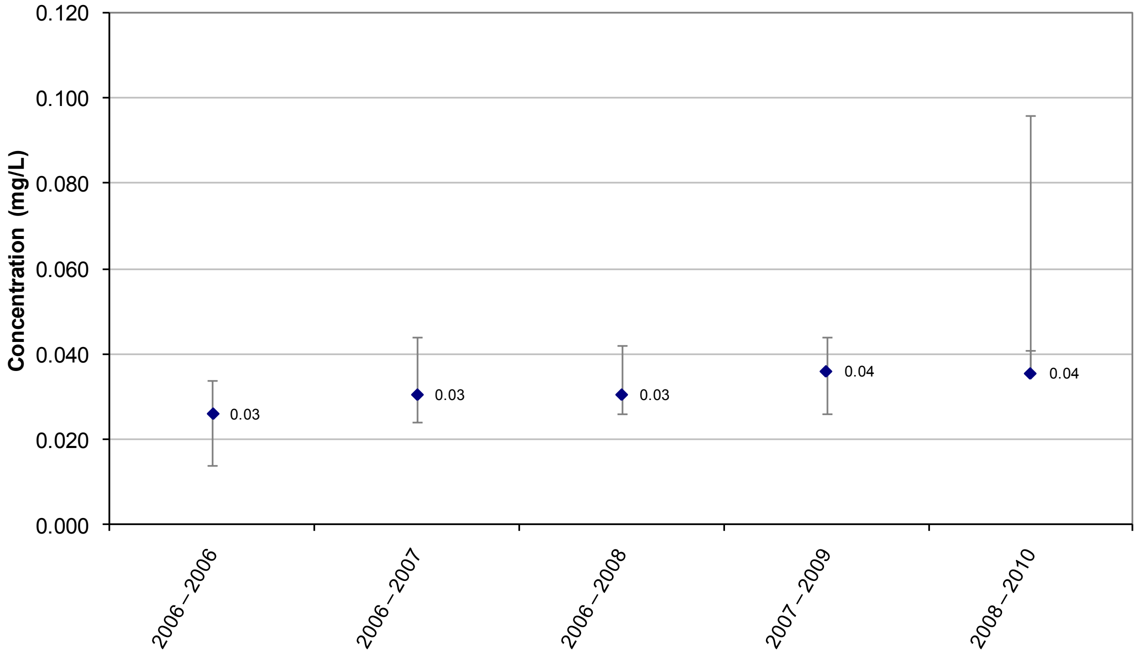


Figure A-35: *Total nitrogen at sampling location Avon River, Clark Street (6151008) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



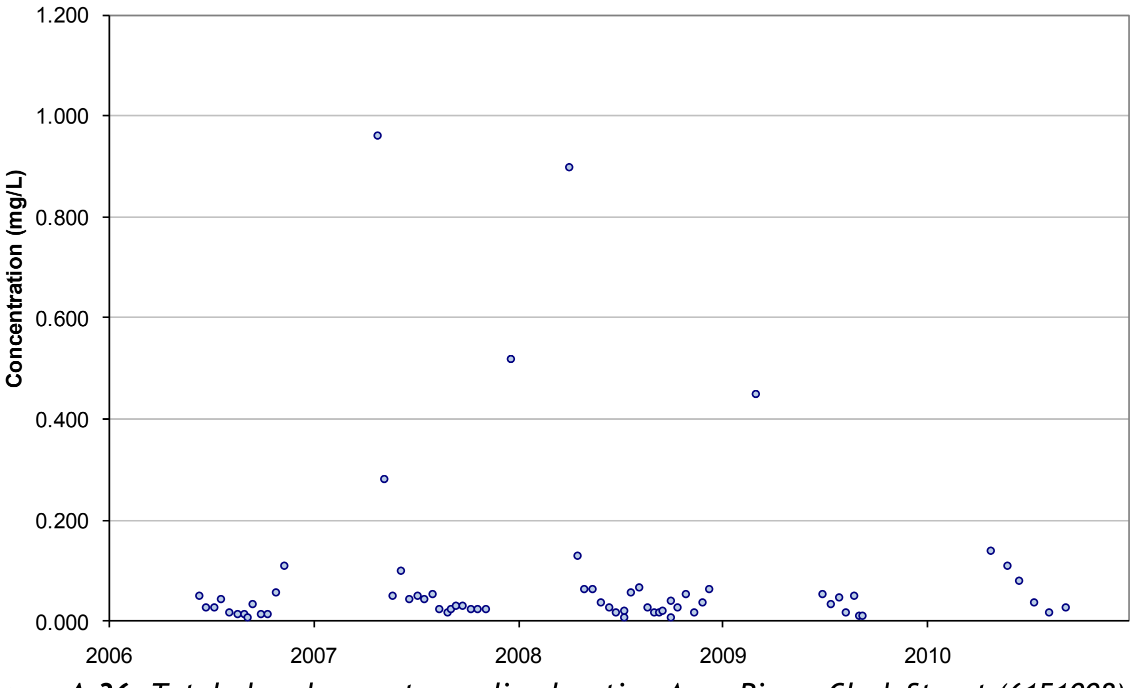
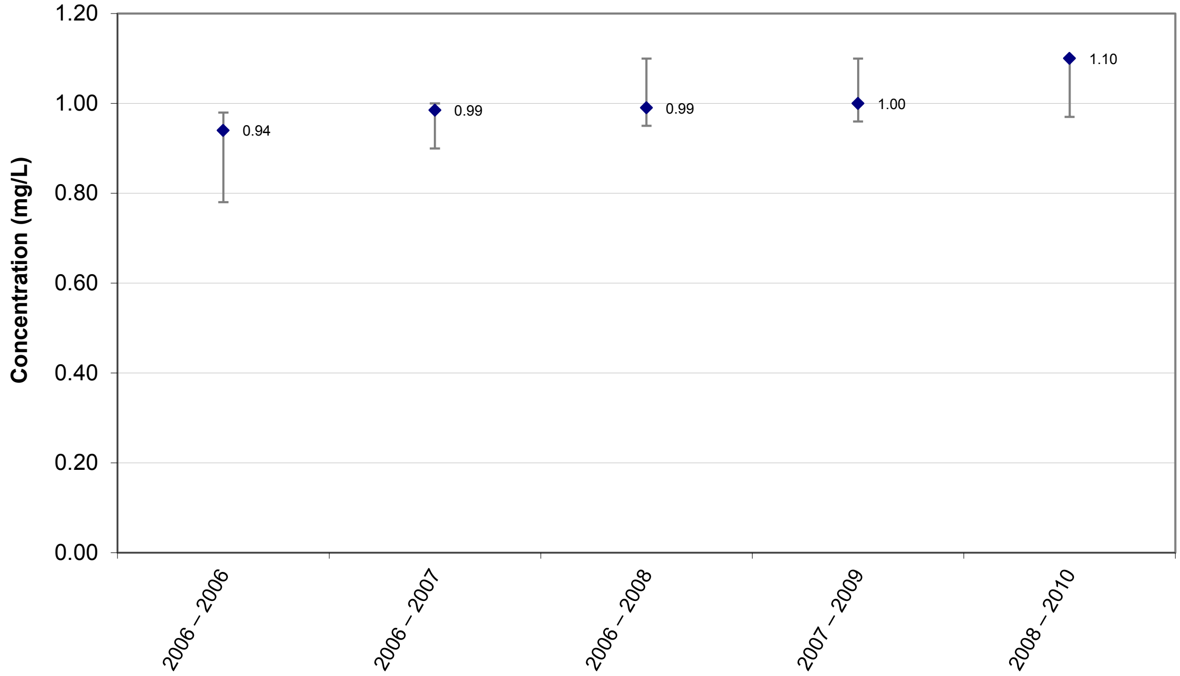


Figure A-36: *Total phosphorus at sampling location Avon River, Clark Street (6151008) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



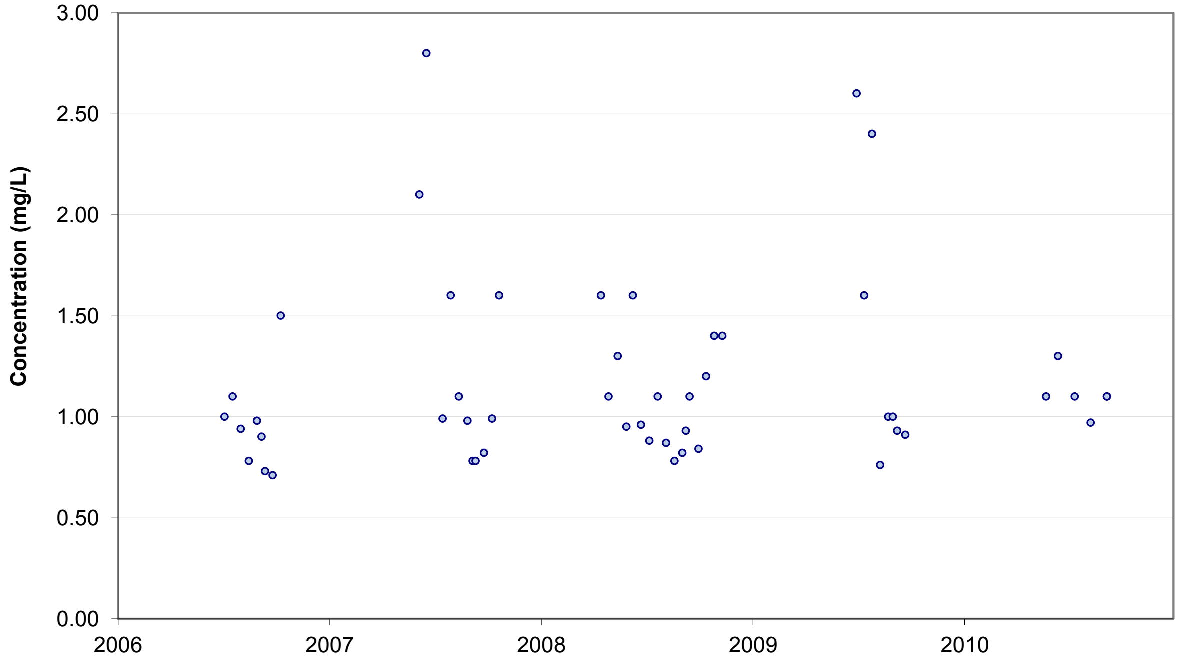
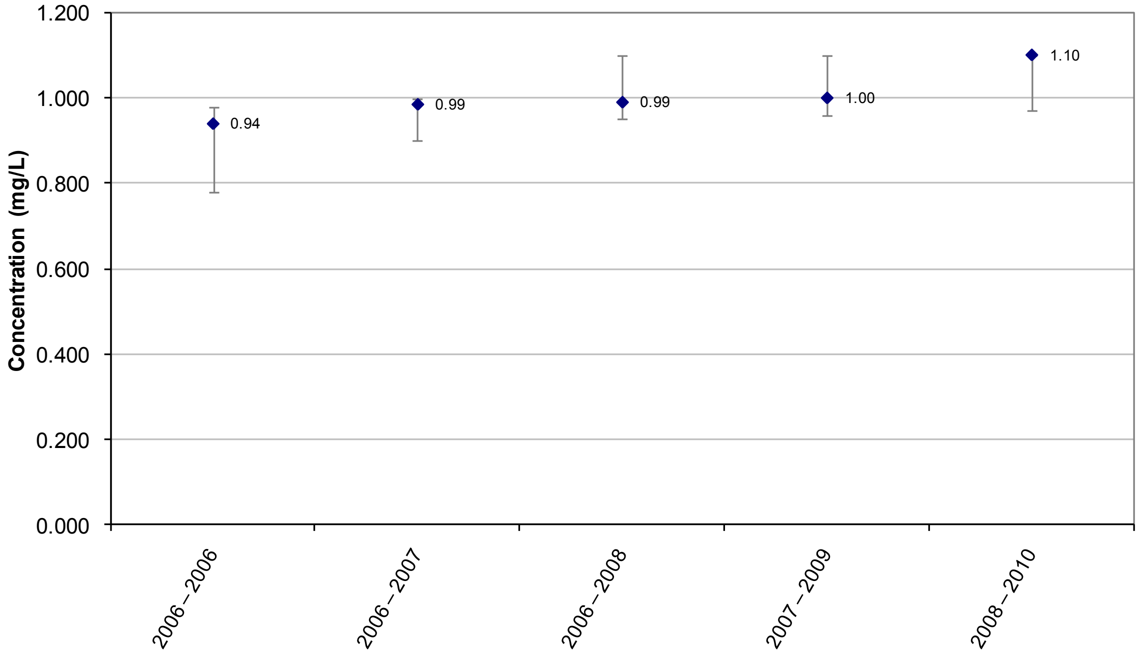


Figure A-37: *Total nitrogen at sampling location Mackie River, Top of Beverley-York Road (6151026) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



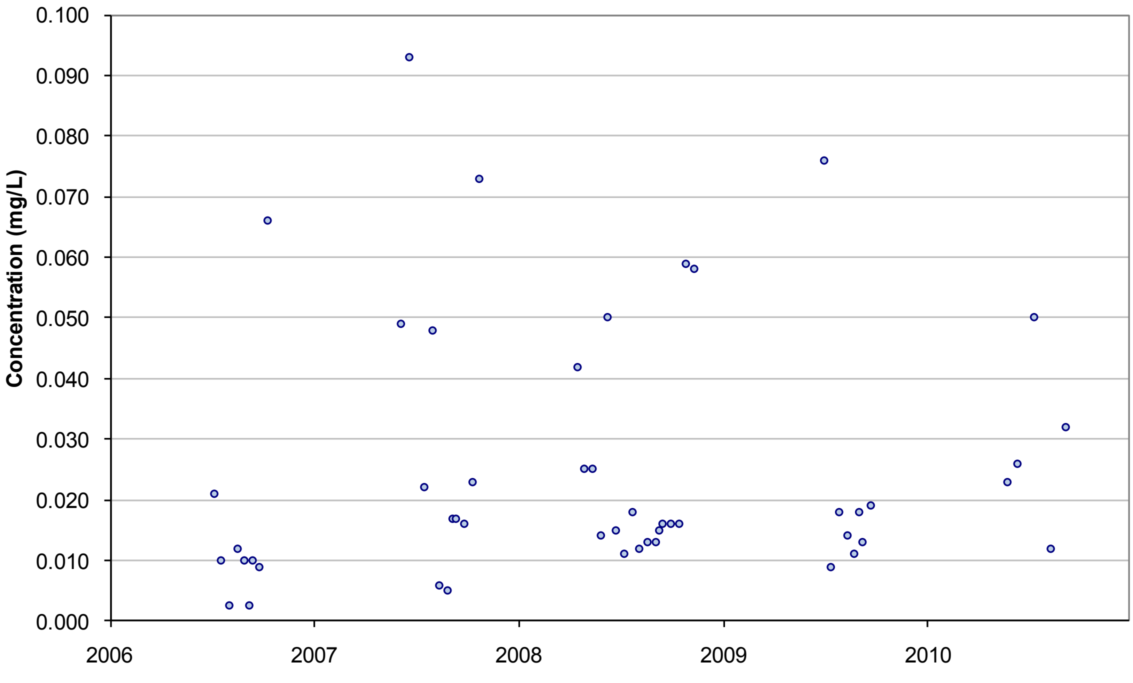
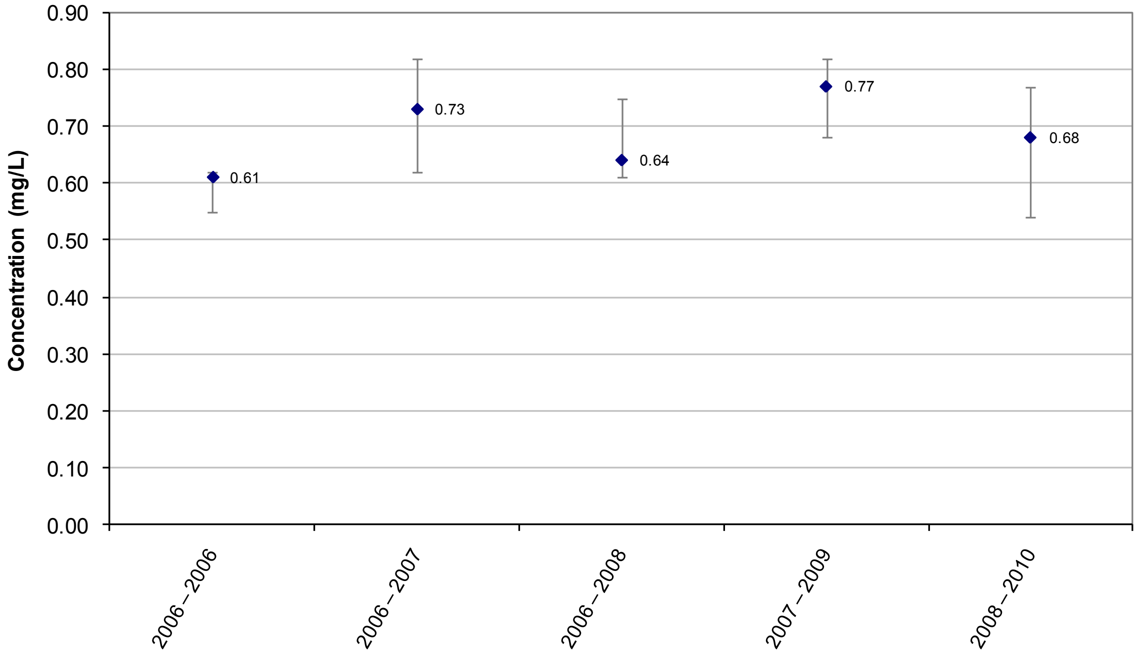


Figure A-38: *Total phosphorus at sampling location Mackie River, Top of Beverley-York Road (6151026) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



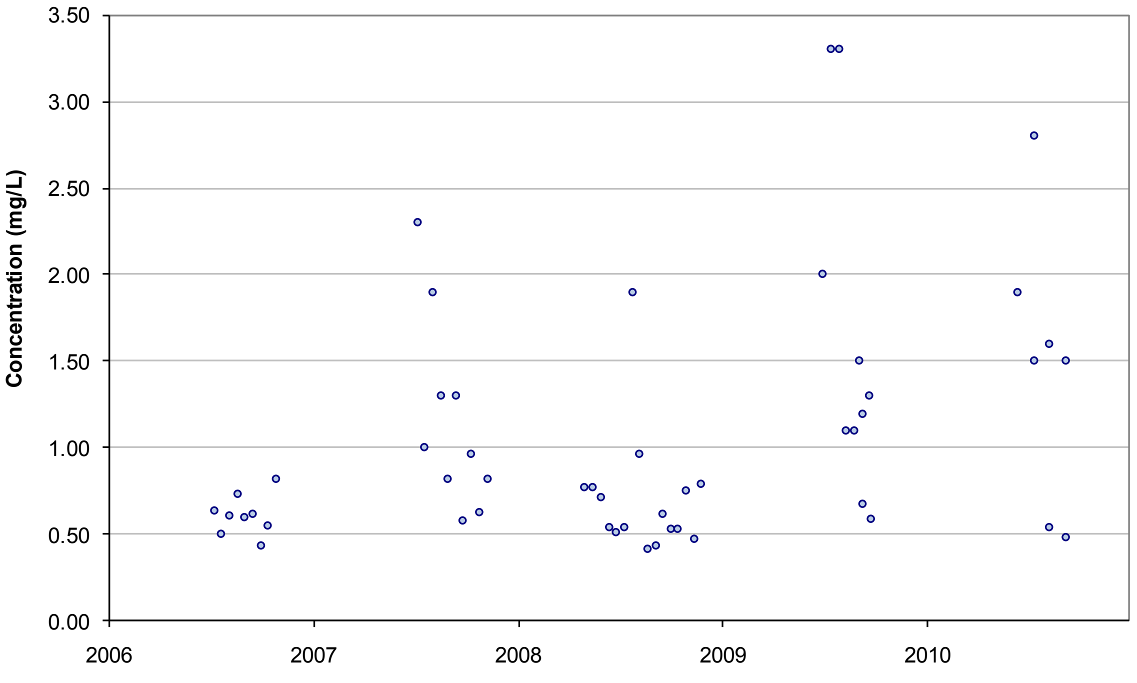
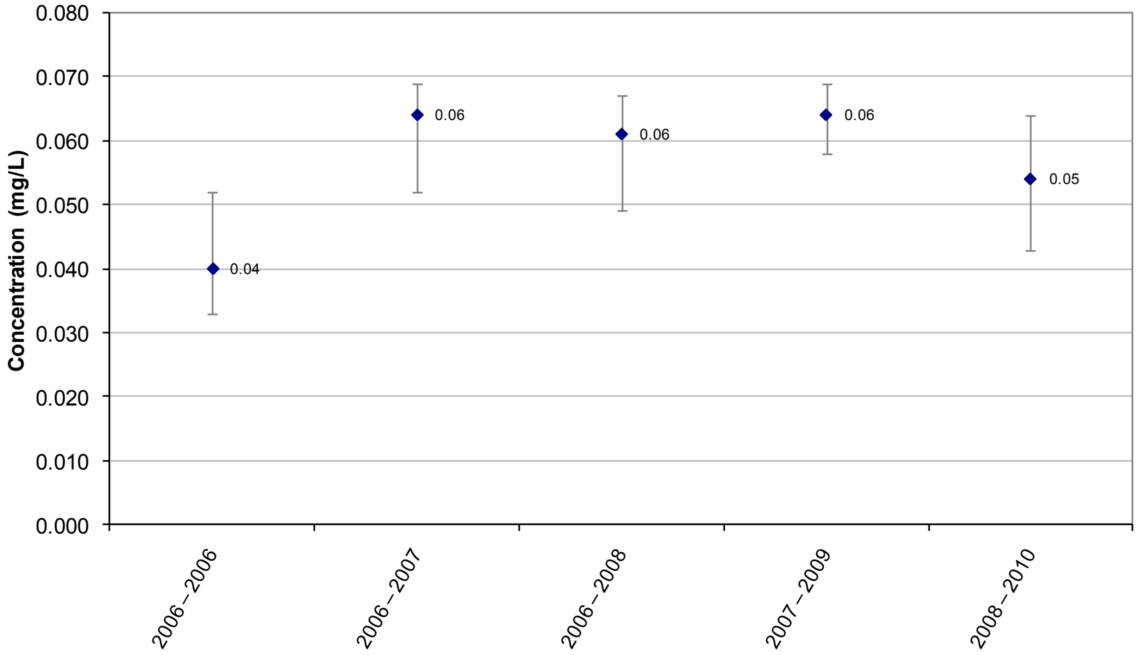


Figure A-39: *Total nitrogen at sampling location Mortlock River East Branch, Quellington Road (6151028) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



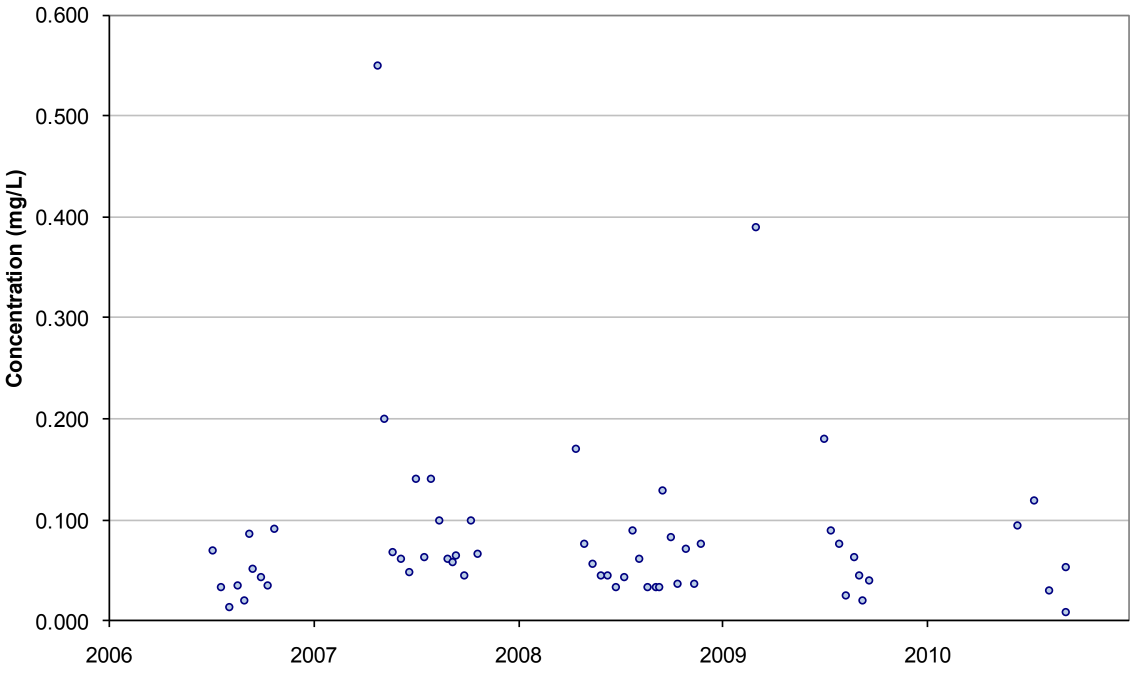
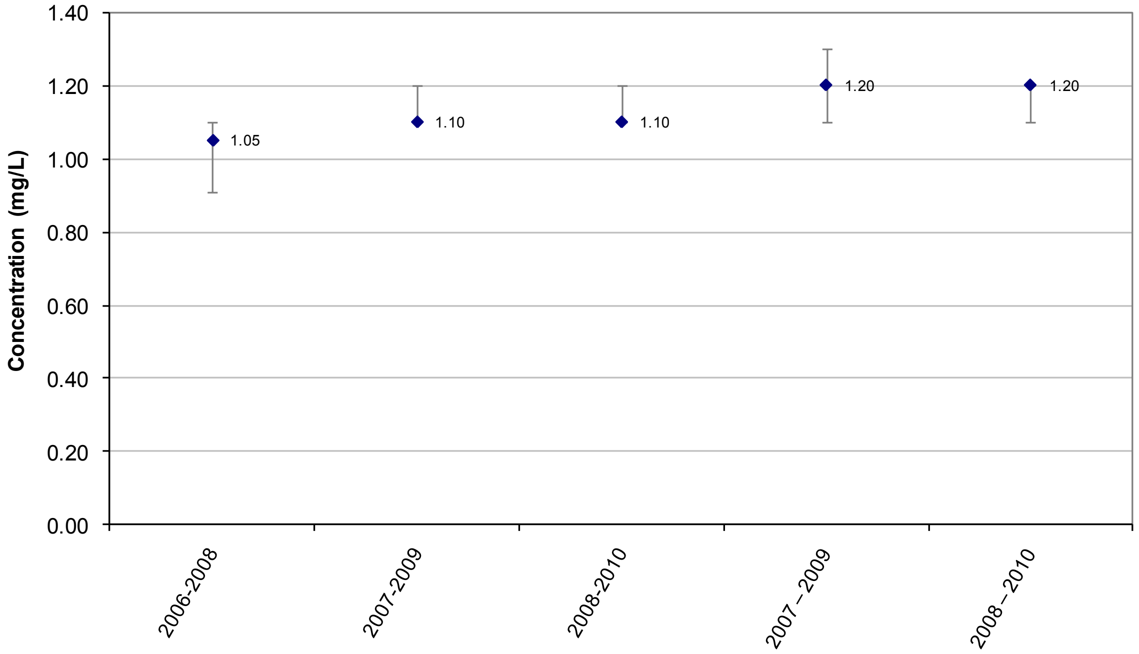


Figure A-40: *Total phosphorus at sampling location Mortlock River East Branch, Quellington Road (6151028) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



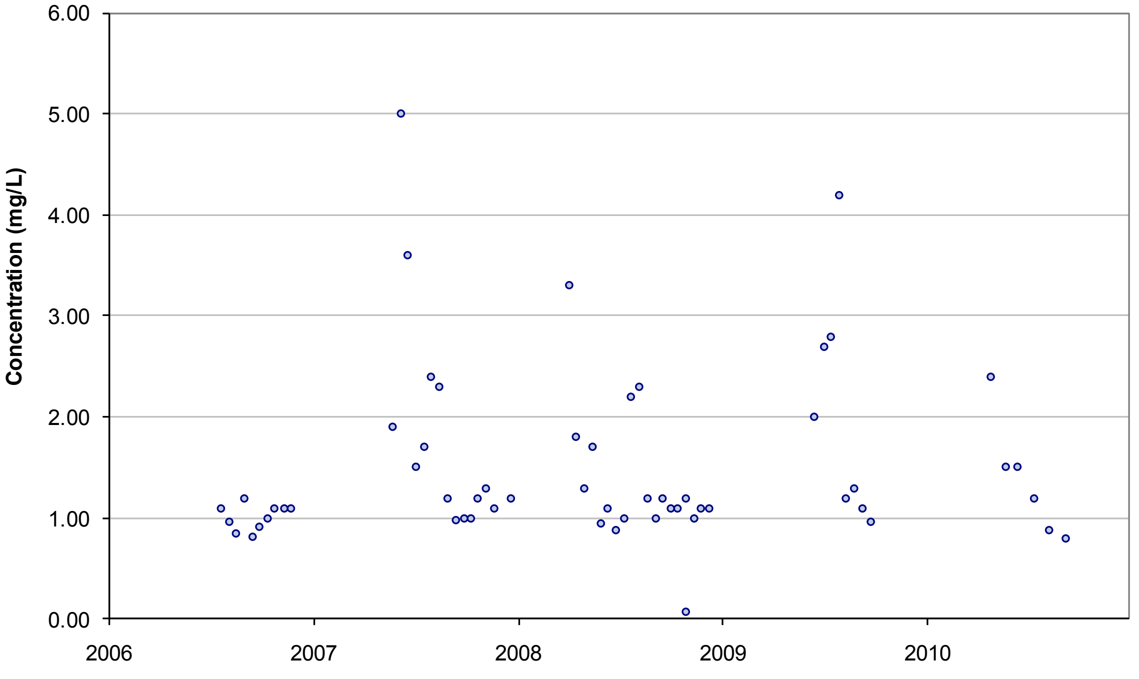
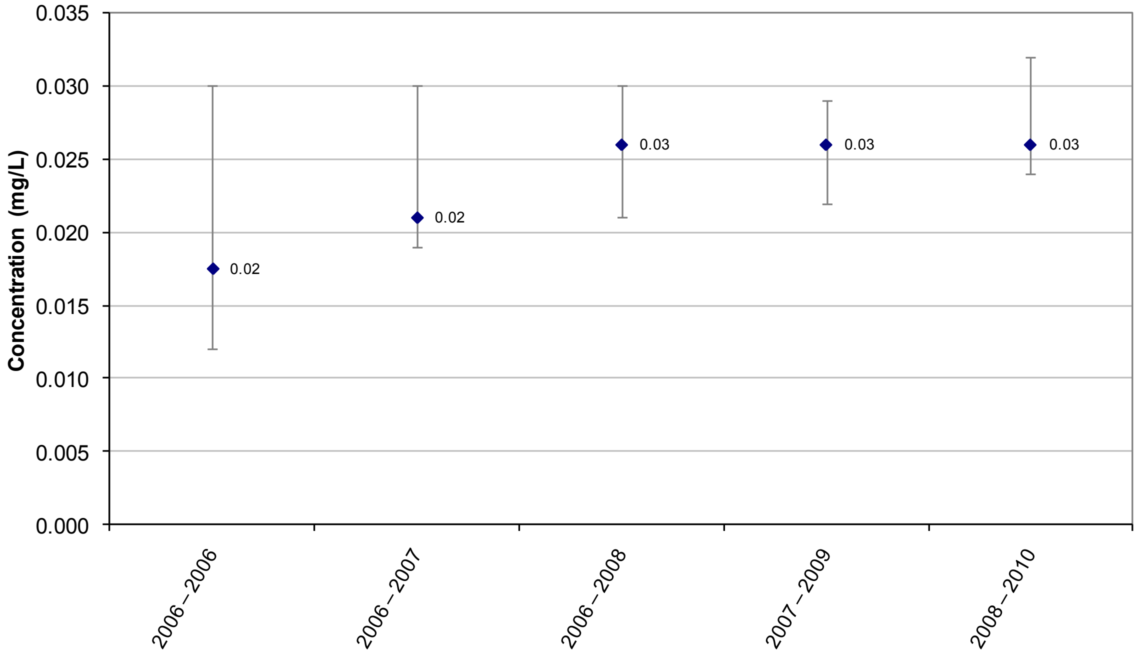


Figure A-41: *Total nitrogen at sampling location Avon River, York Town Pool (6151033) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



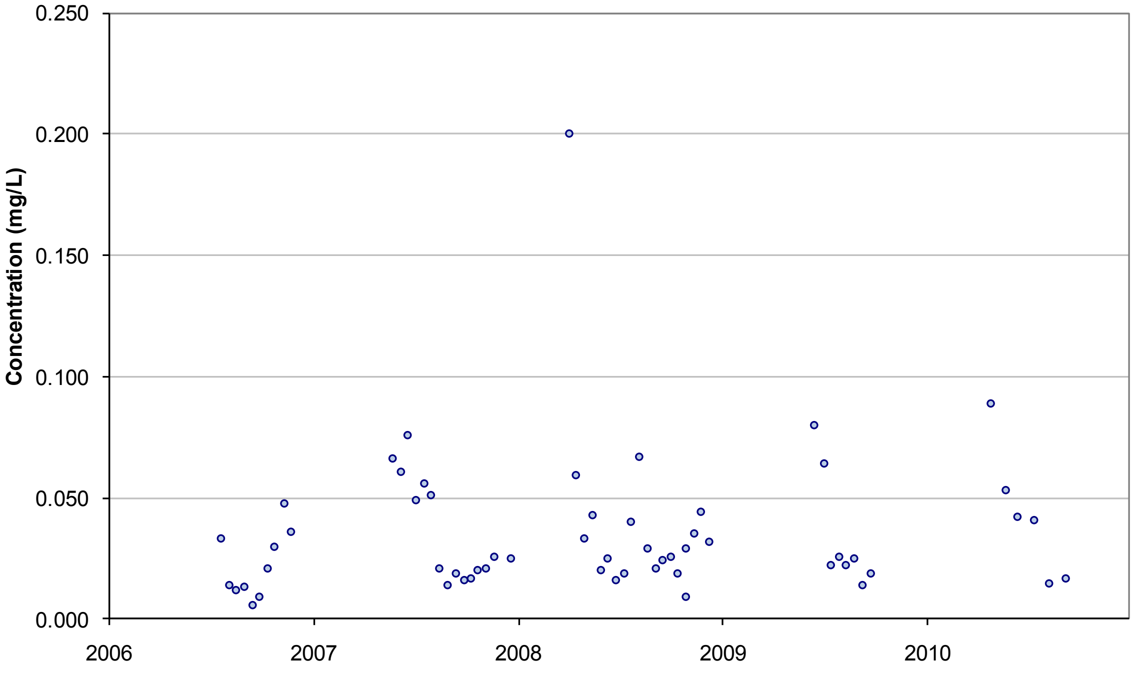
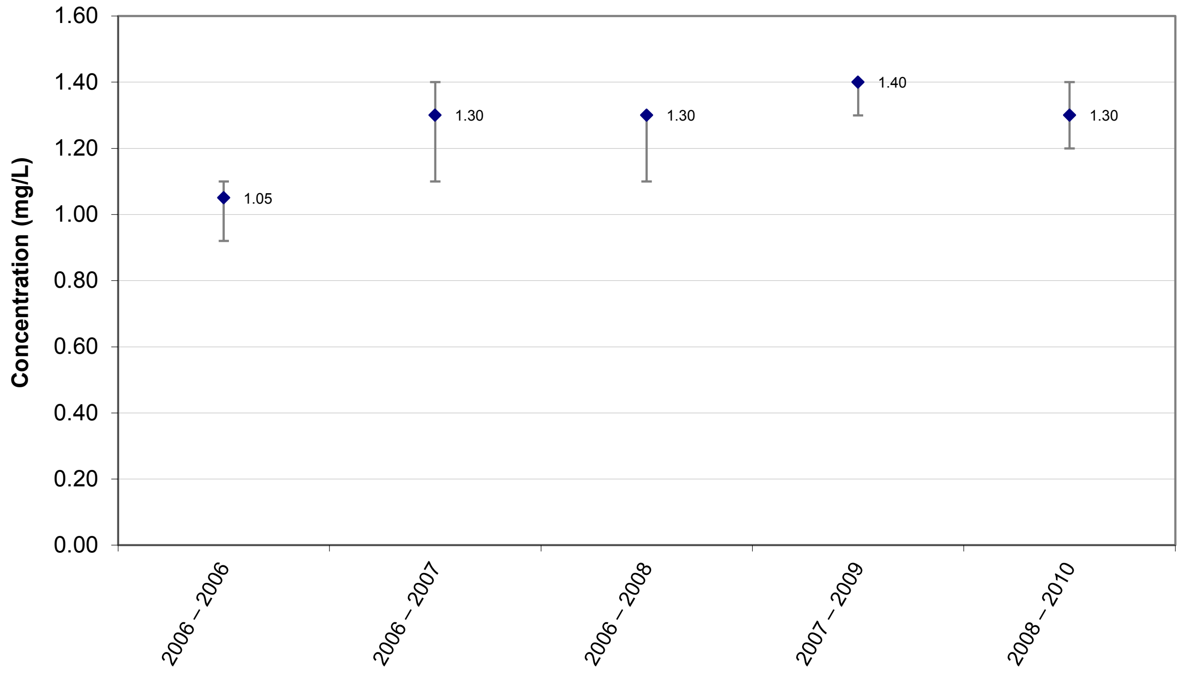


Figure A-42: *Total phosphorus at sampling location Avon River, York Town Pool (6151033) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



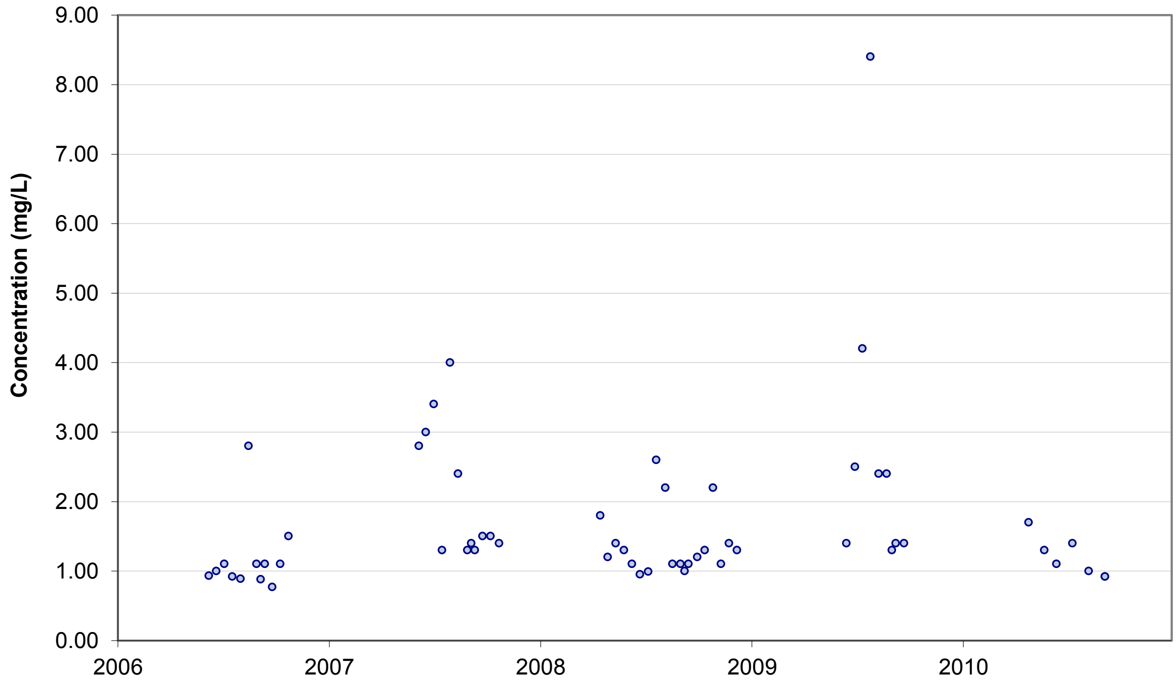
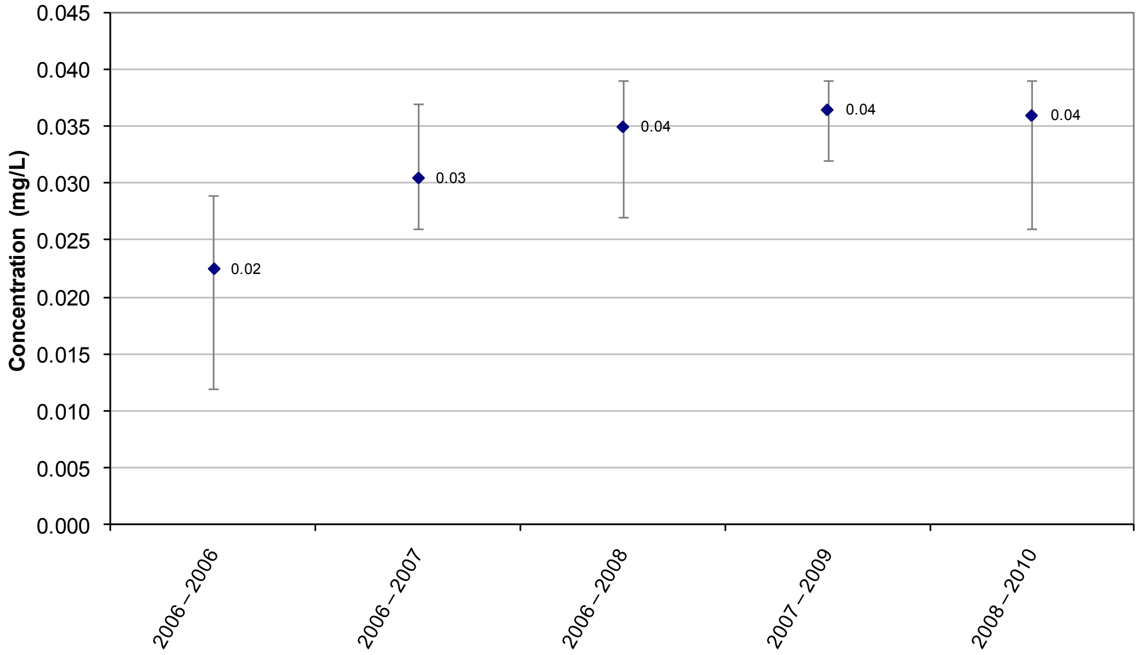


Figure A-43: *Total nitrogen at sampling location Avon River South, Brookton Highway (6151052) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



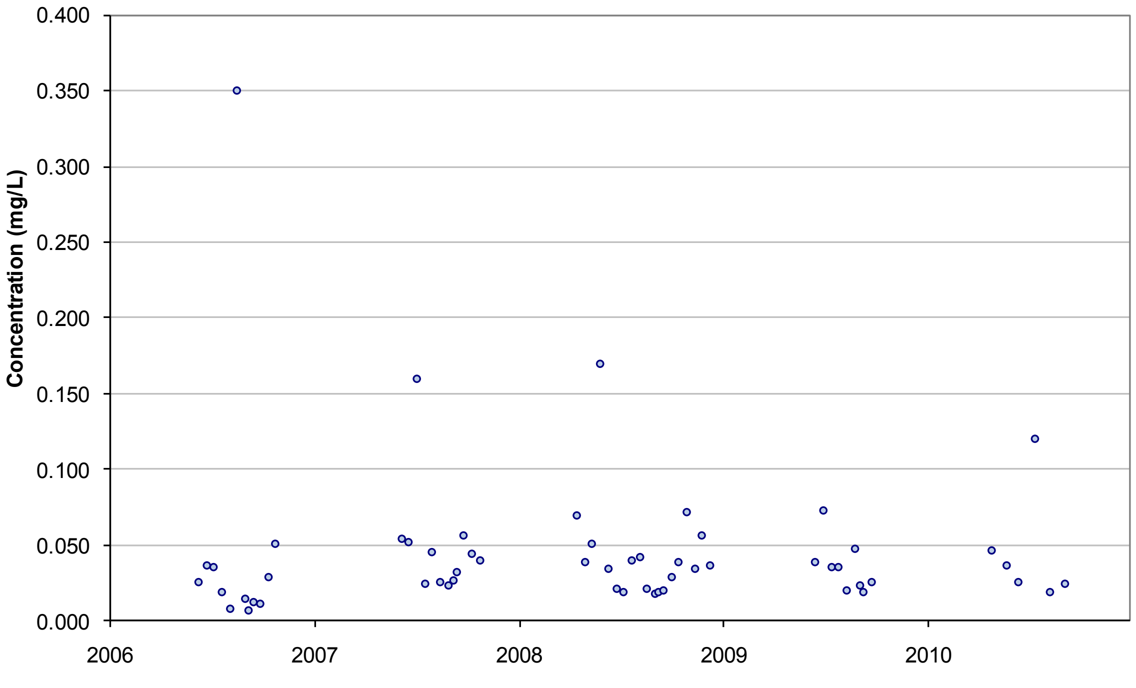
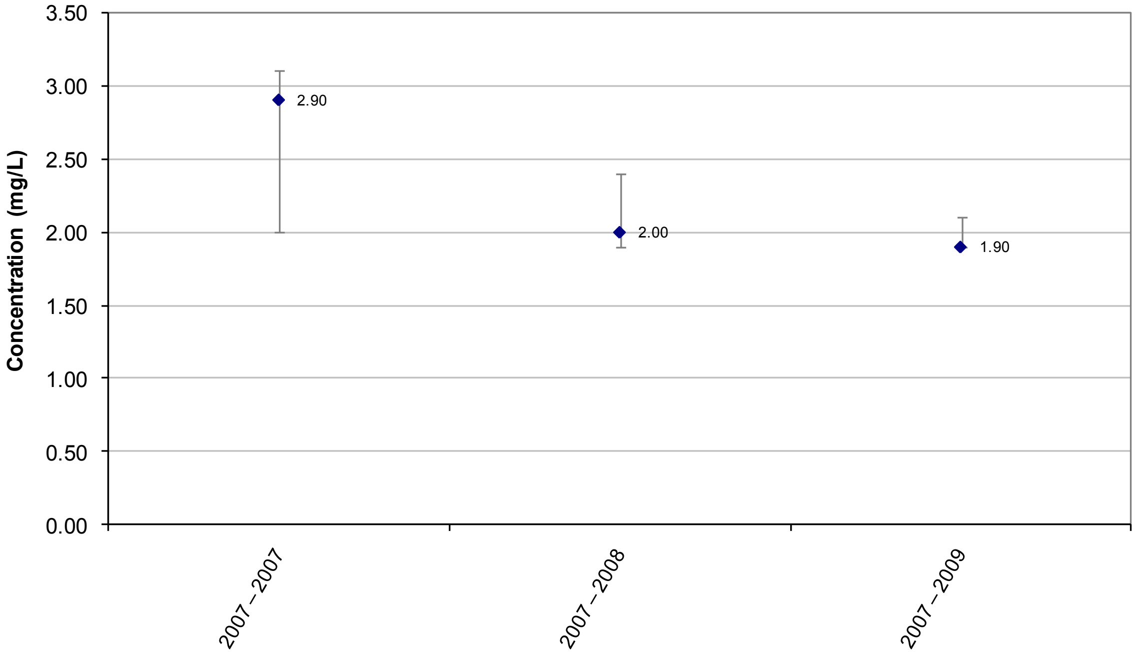


Figure A-44: *Total phosphorus at sampling location Avon River South, Brookton Highway (6151052)displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



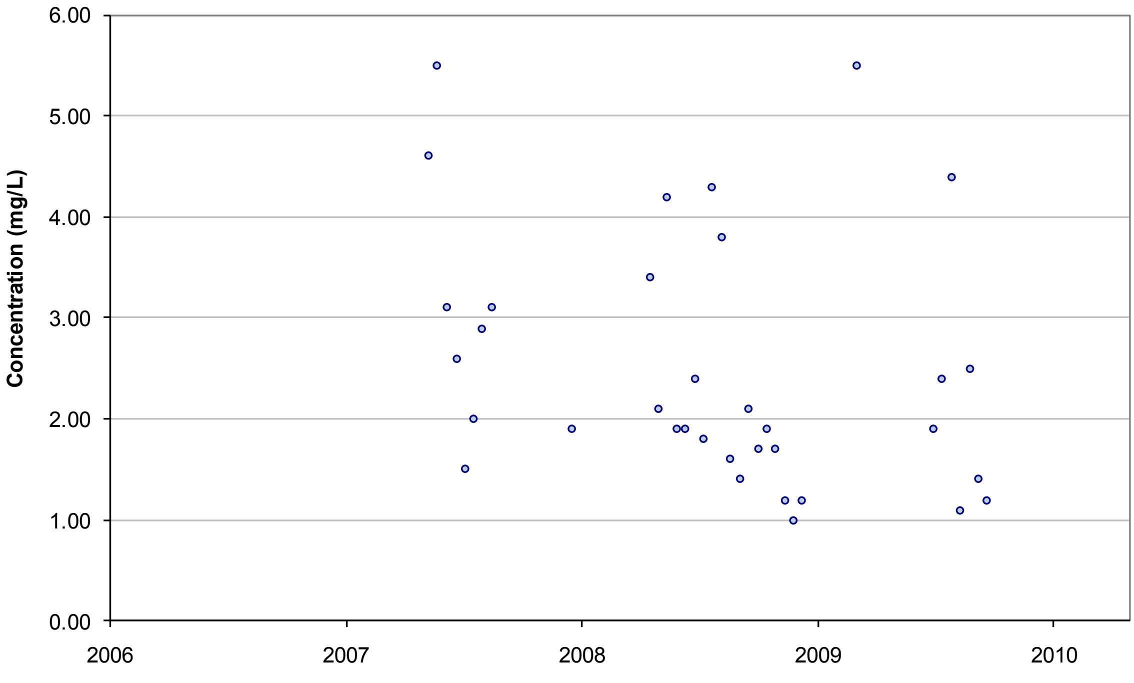
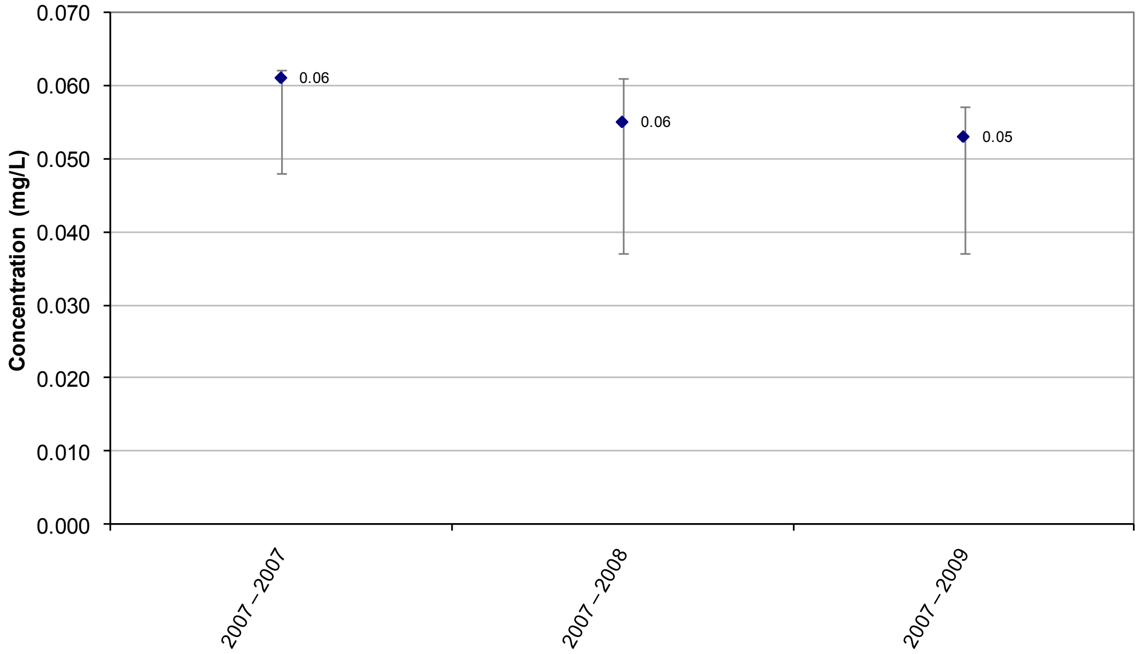


Figure A-45*: Total nitrogen at sampling location Avon River, Downstream of Inflow (6151125) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



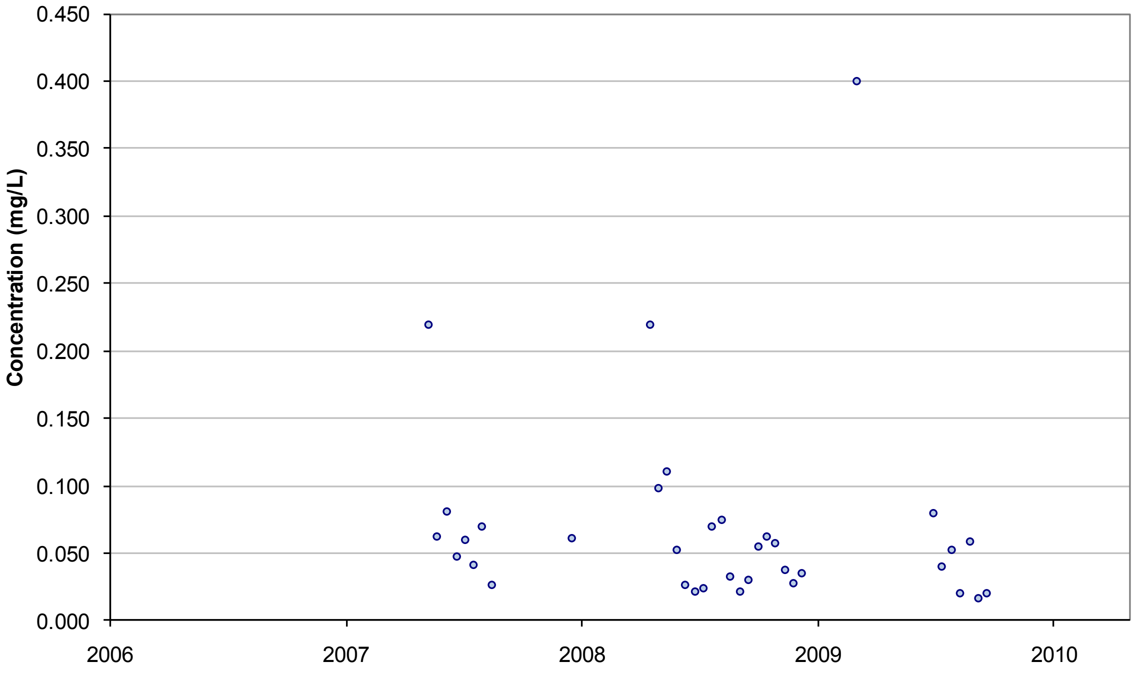
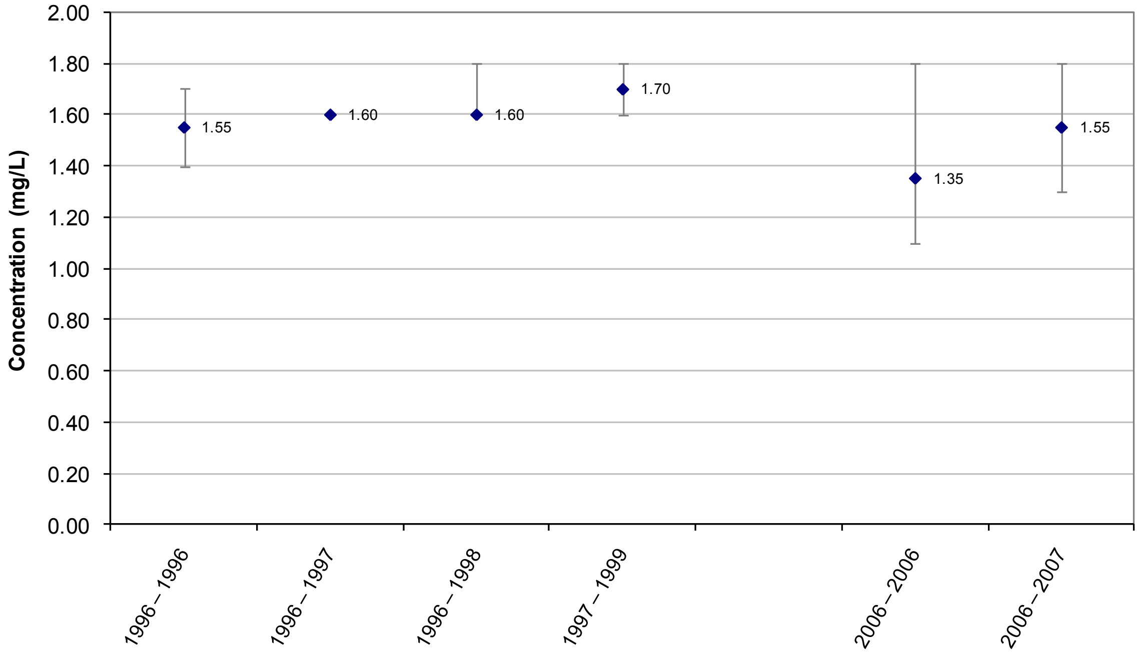


Figure A-46*: Total phosphorus at sampling location Avon River, Downstream of Inflow (6151125) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



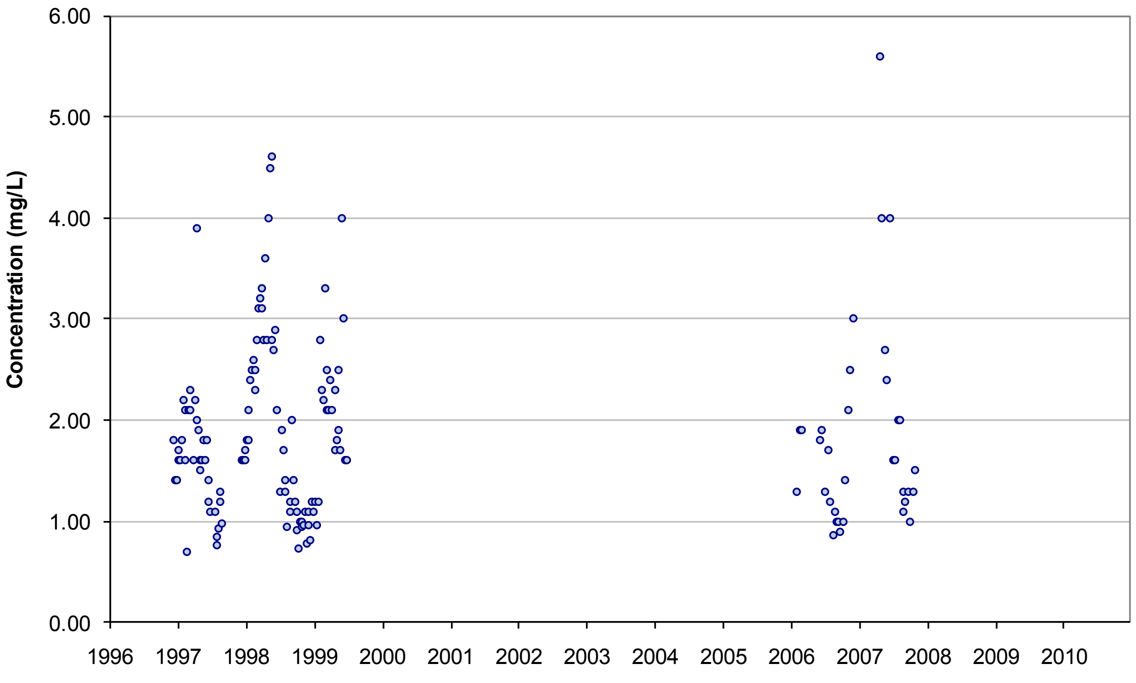
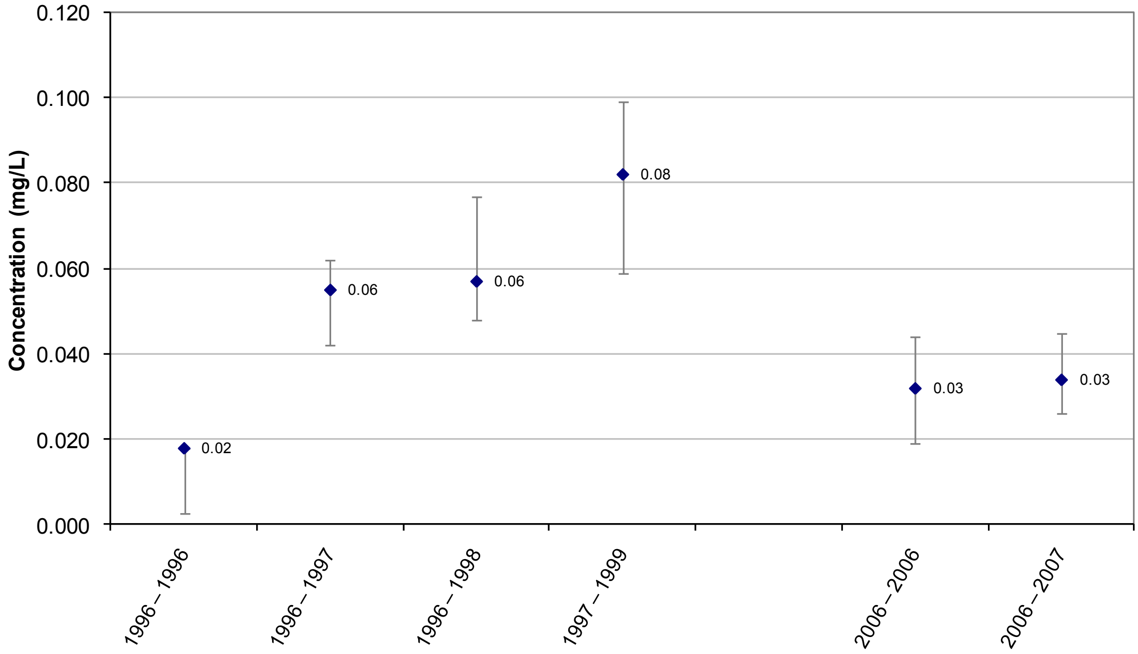


Figure A-47: *Total nitrogen at sampling locationAvon River, Katrine Bridge (6151155) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



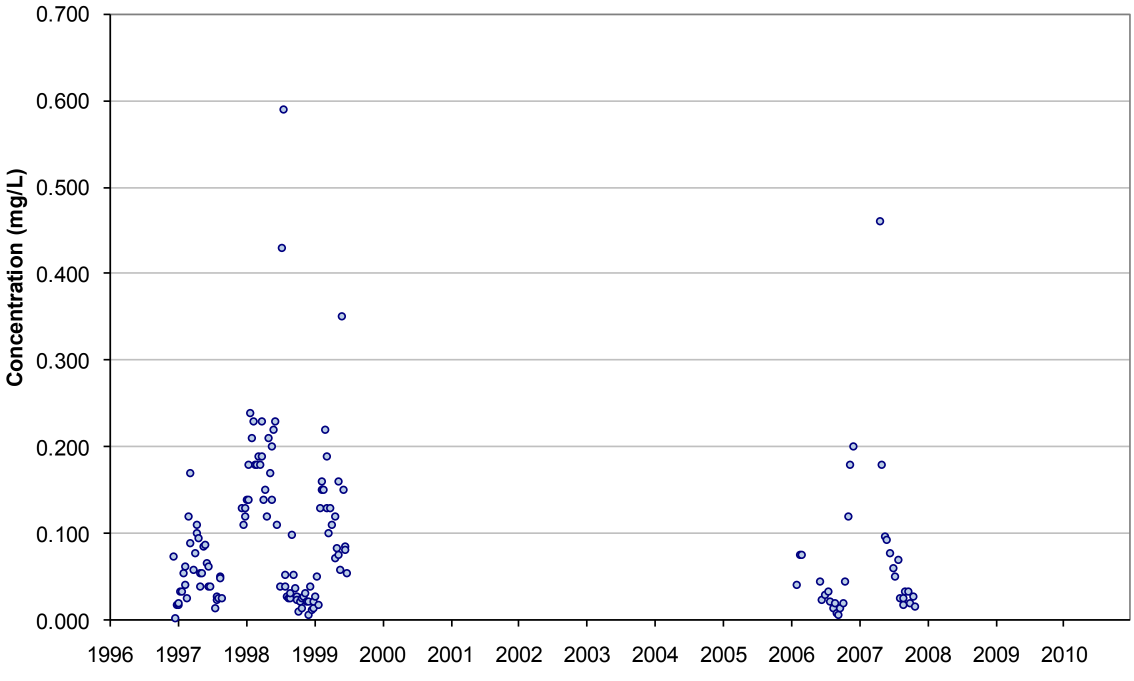
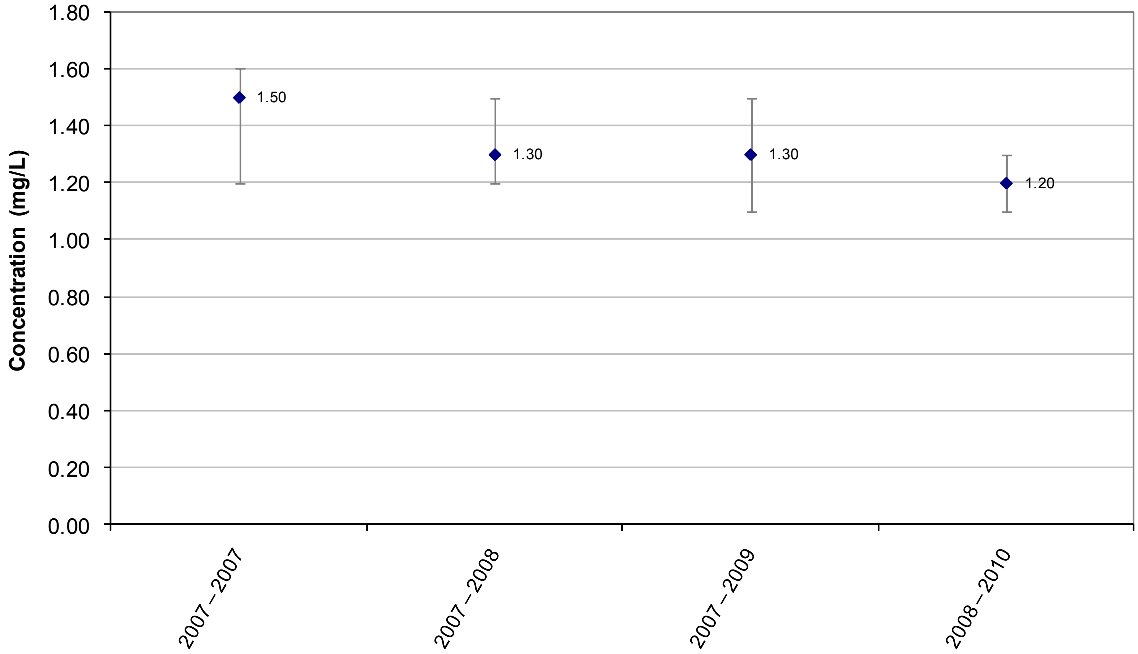


Figure A-48*: Total phosphorus at sampling location Avon River, Katrine Bridge (6151155) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



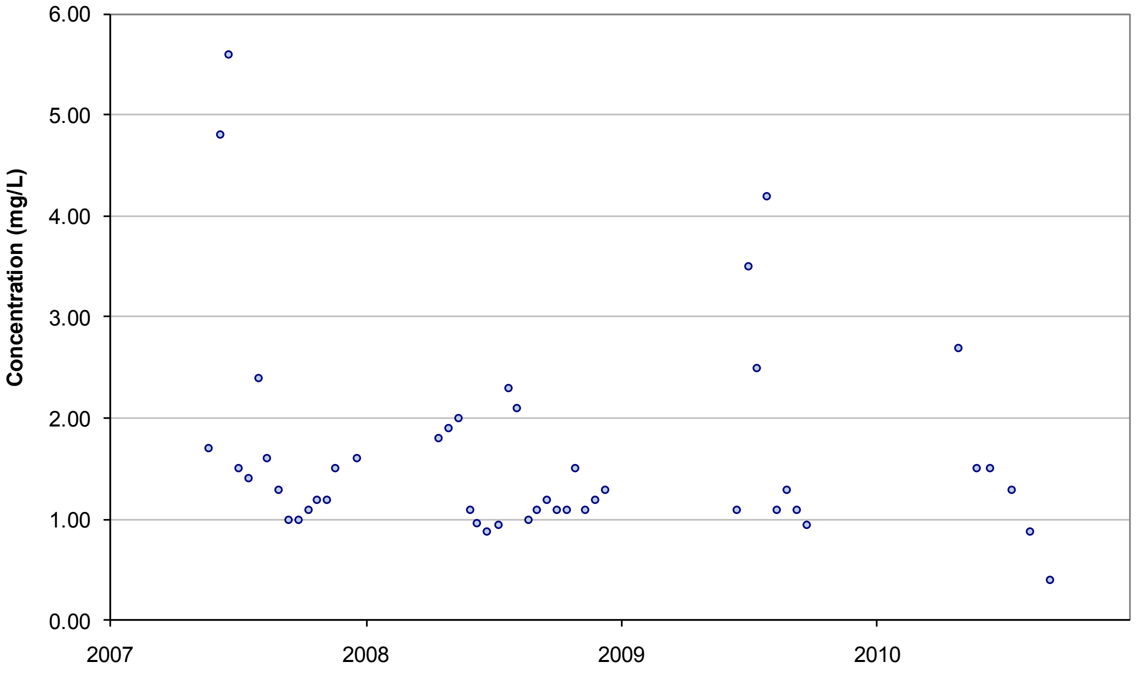
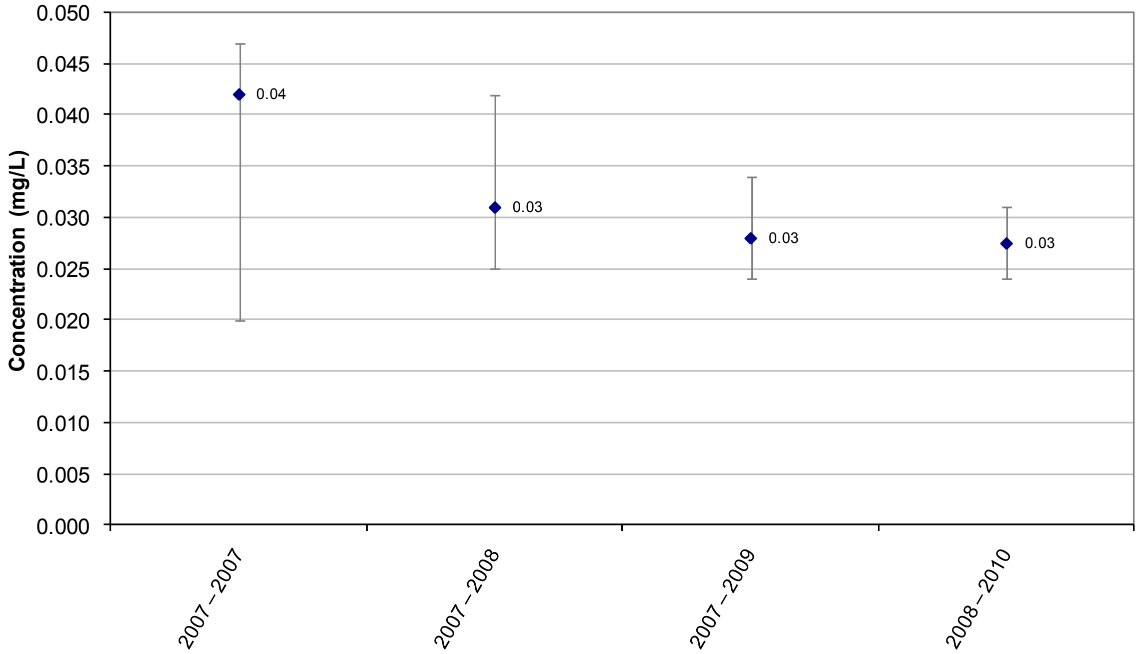


Figure A-49: *Total nitrogen at sampling locationAvon River, Gwambygine (6151157) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



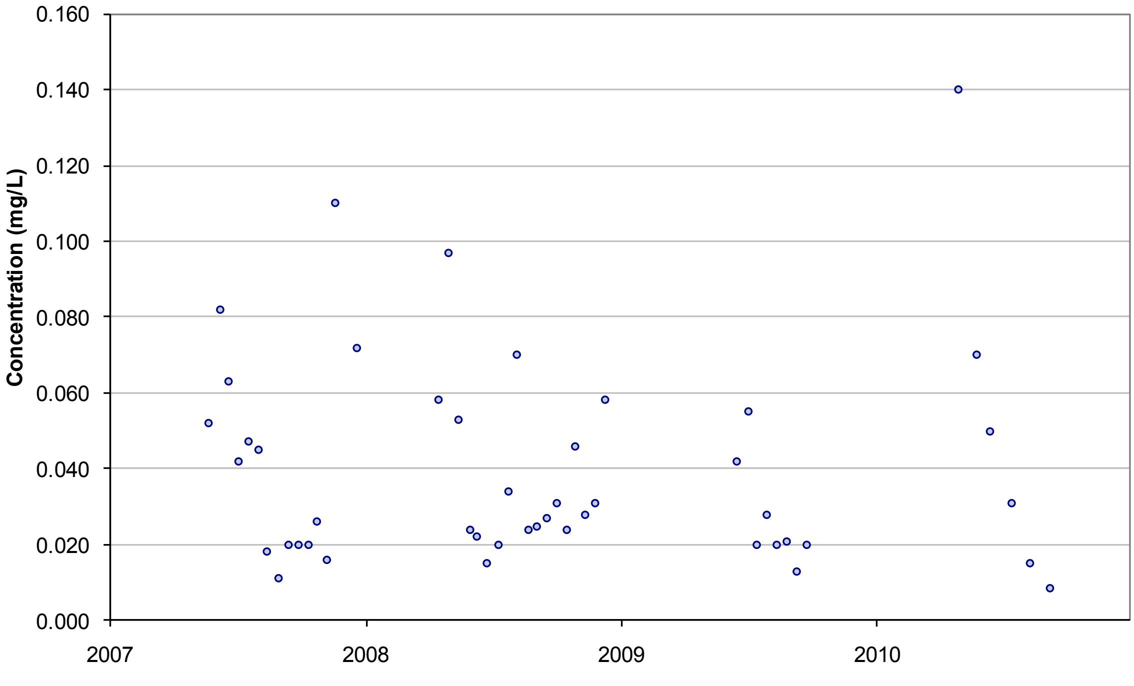
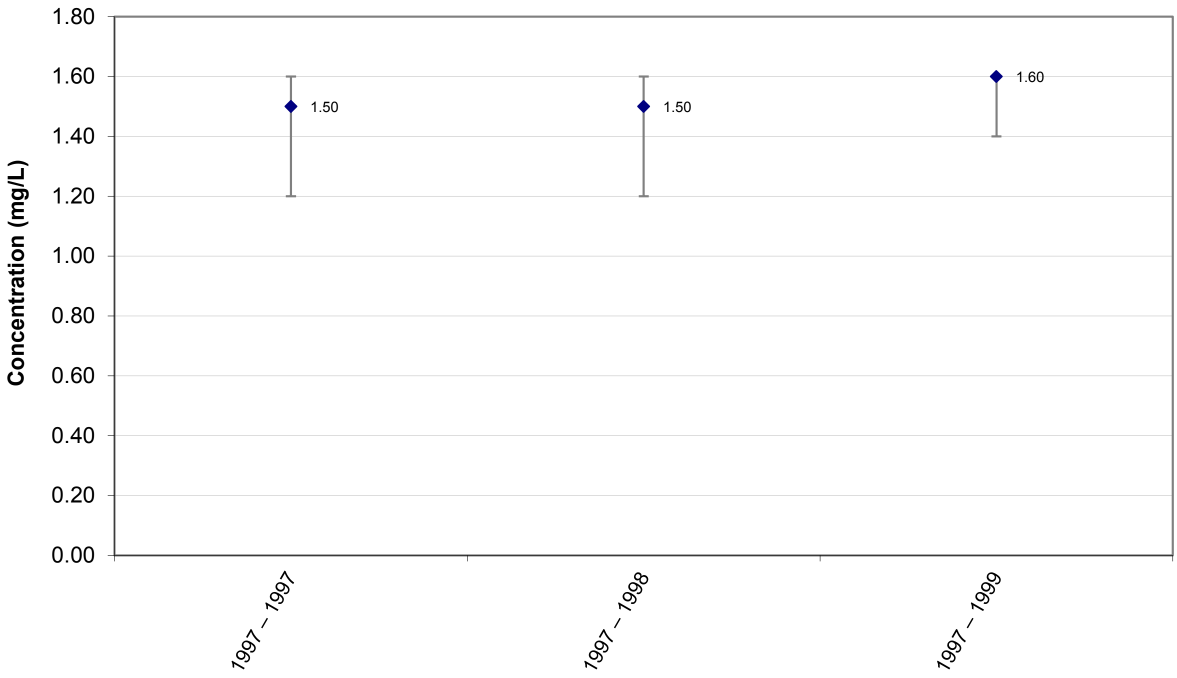


Figure A-50: *Total phosphorus at sampling location Avon River, Gwambygine (6151157) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



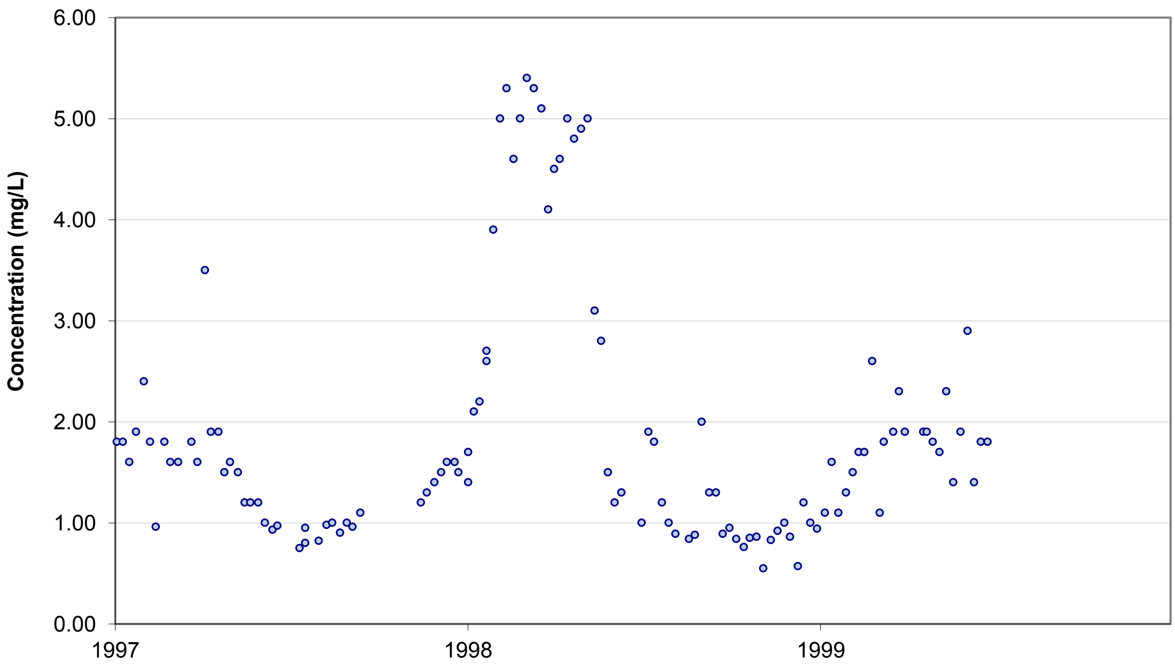
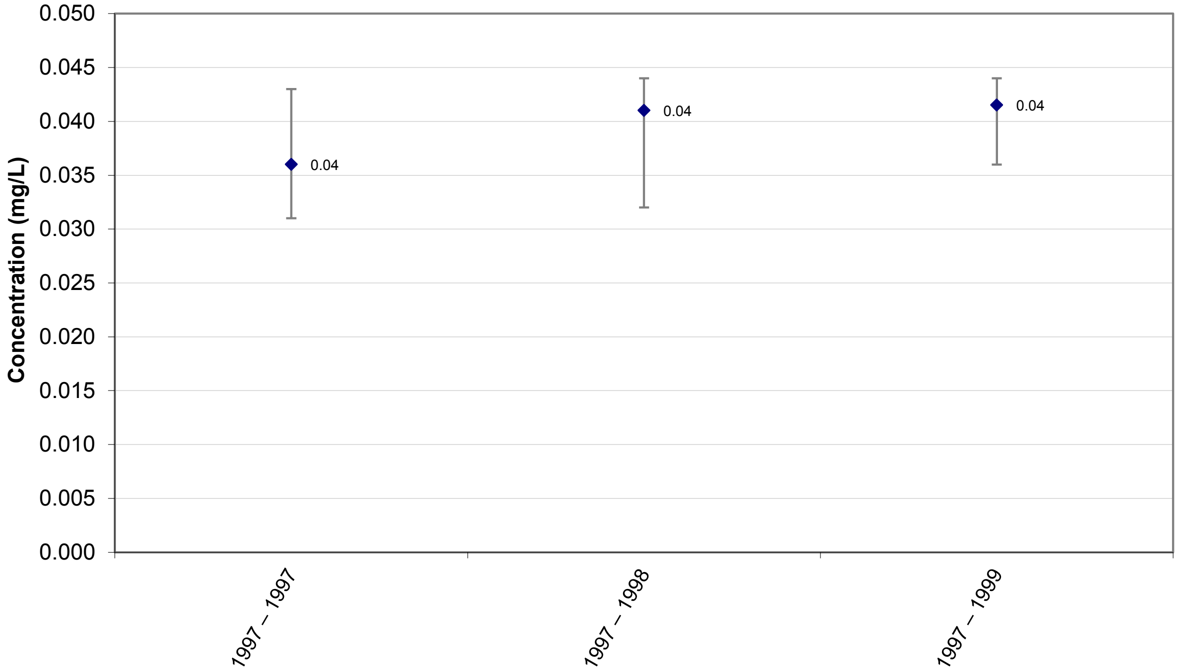


Figure A-51: *Total nitrogen at sampling locationAvon River, Mackies Crossing (6151159) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



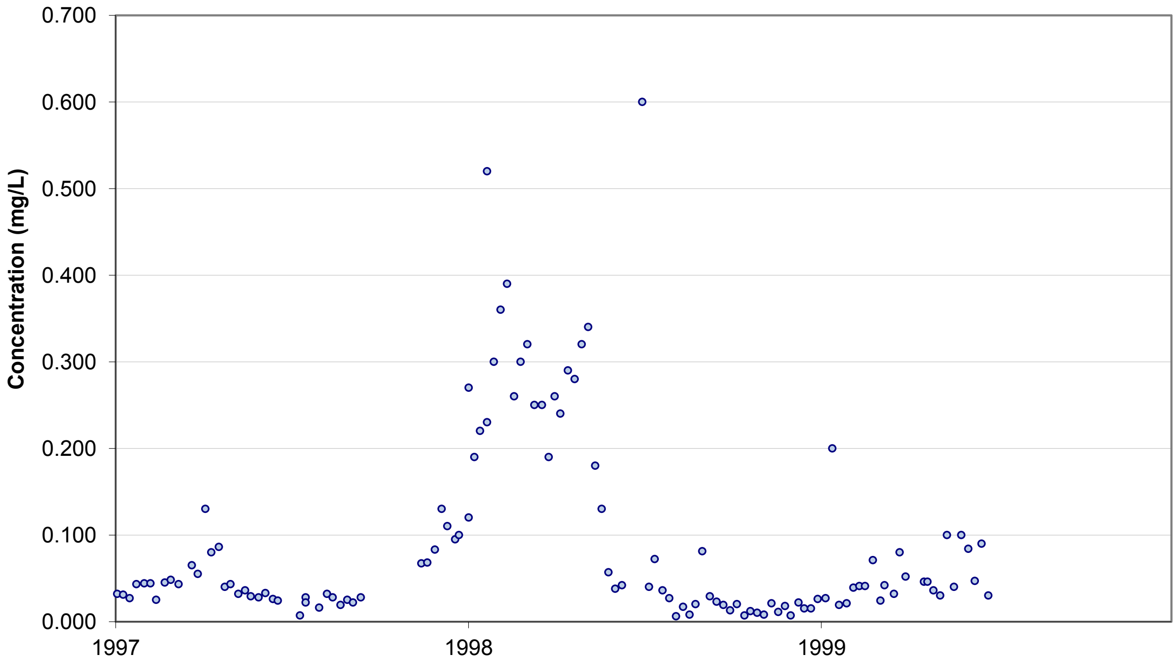
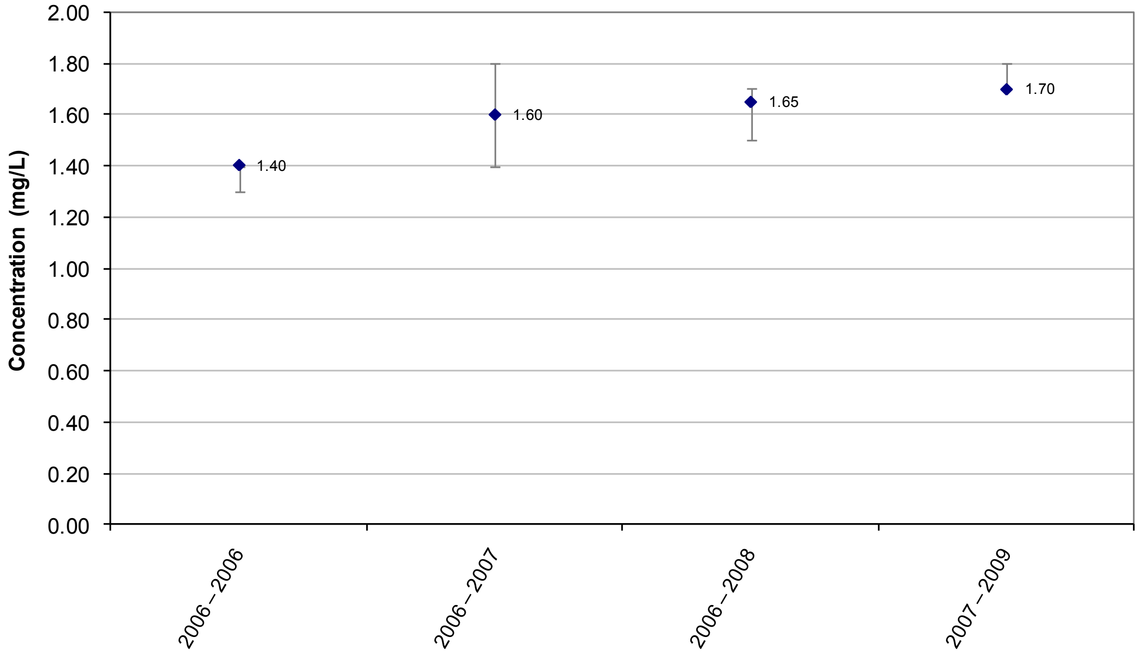


Figure A-52: *Total phosphorus at sampling location Avon River, Mackies Crossing (6151159) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



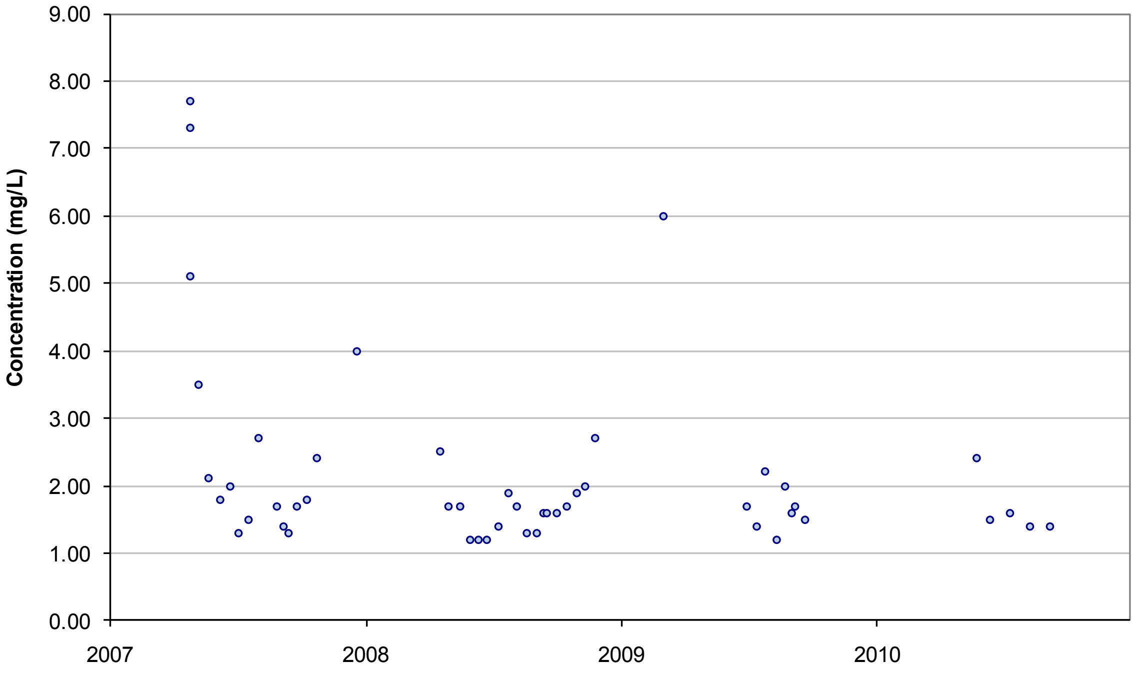
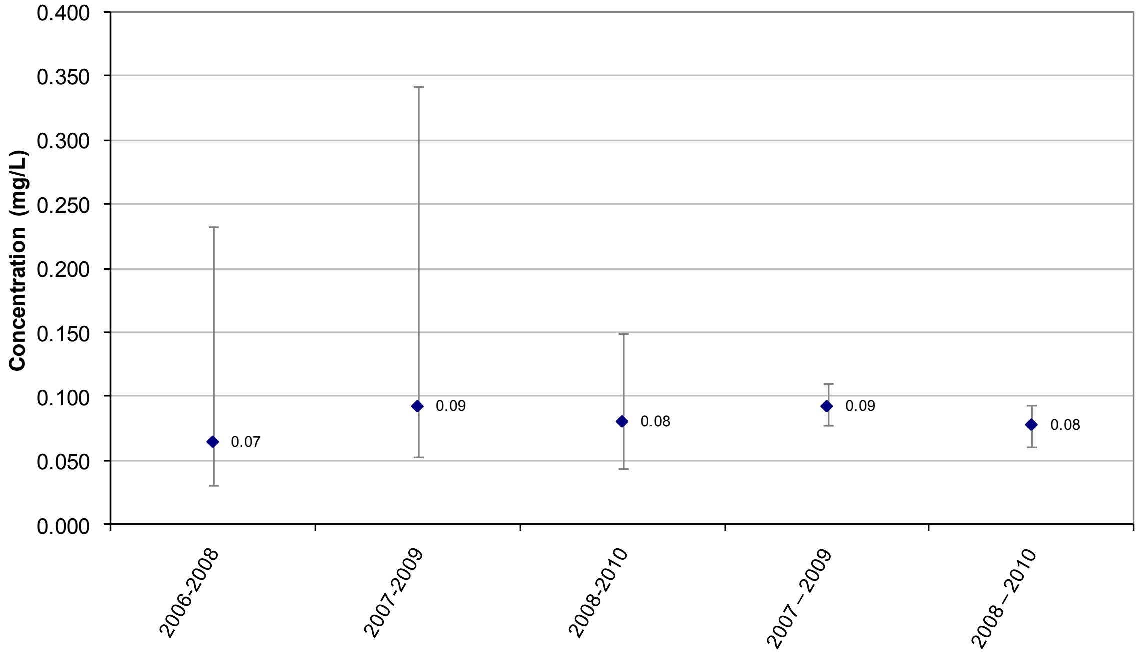


Figure A-53: *Total nitrogen at sampling location Mortlock River East Branch, Taylor Street Weir (6151278) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



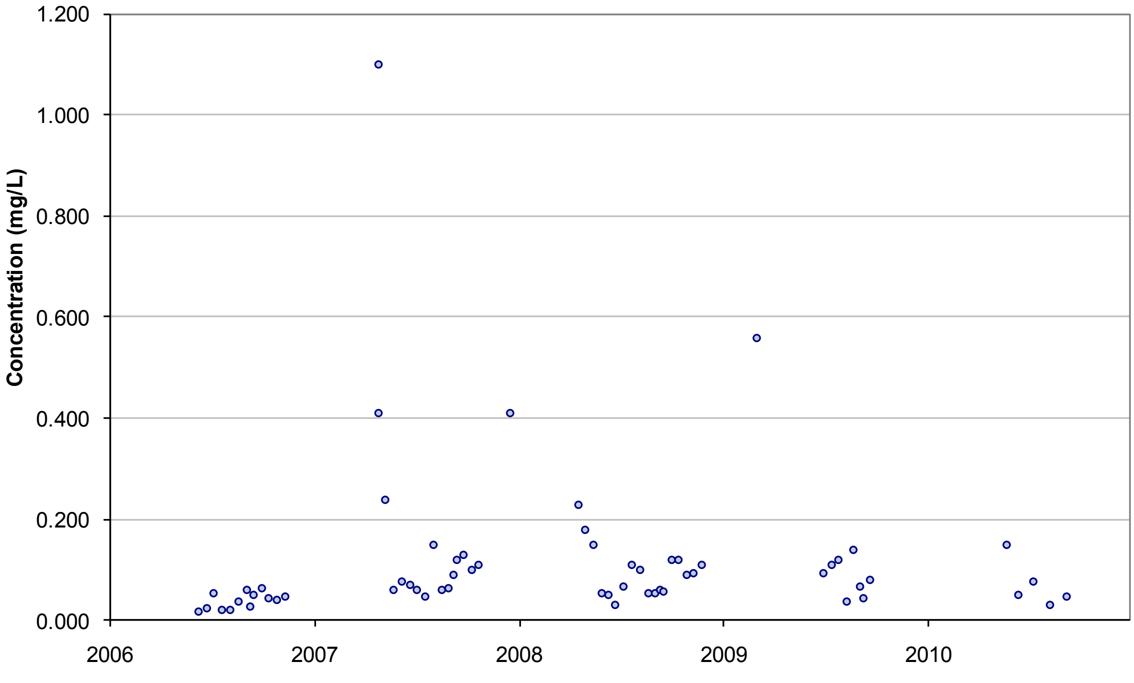
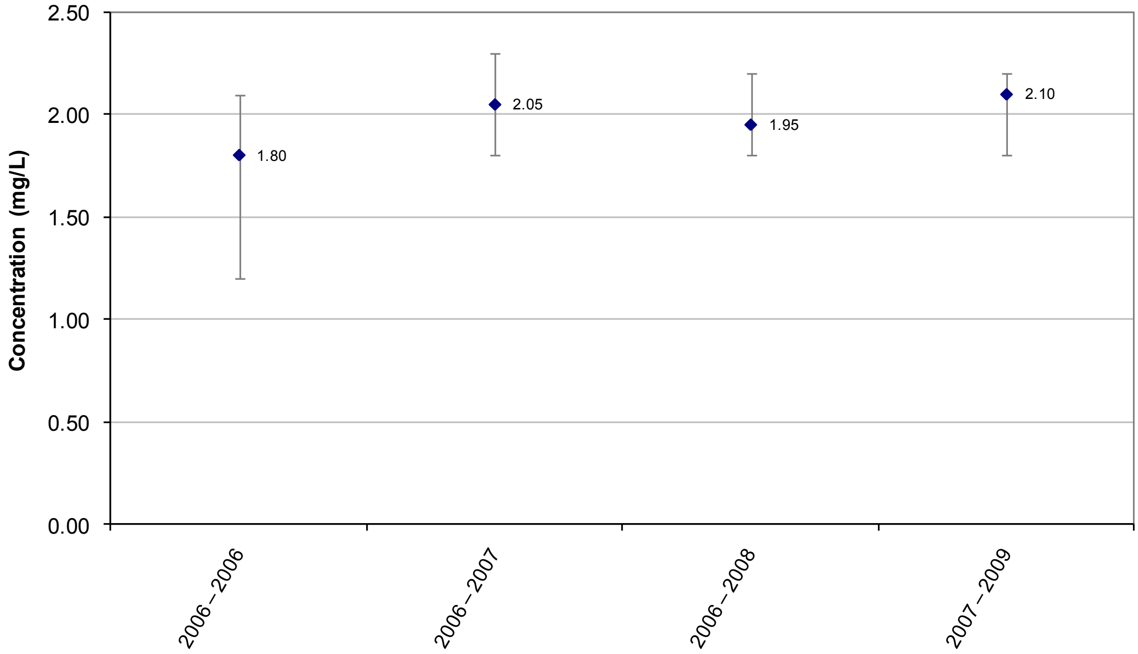


Figure A-54: *Total phosphorus at sampling location Mortlock River East Branch, Taylor Street Weir (6151278) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



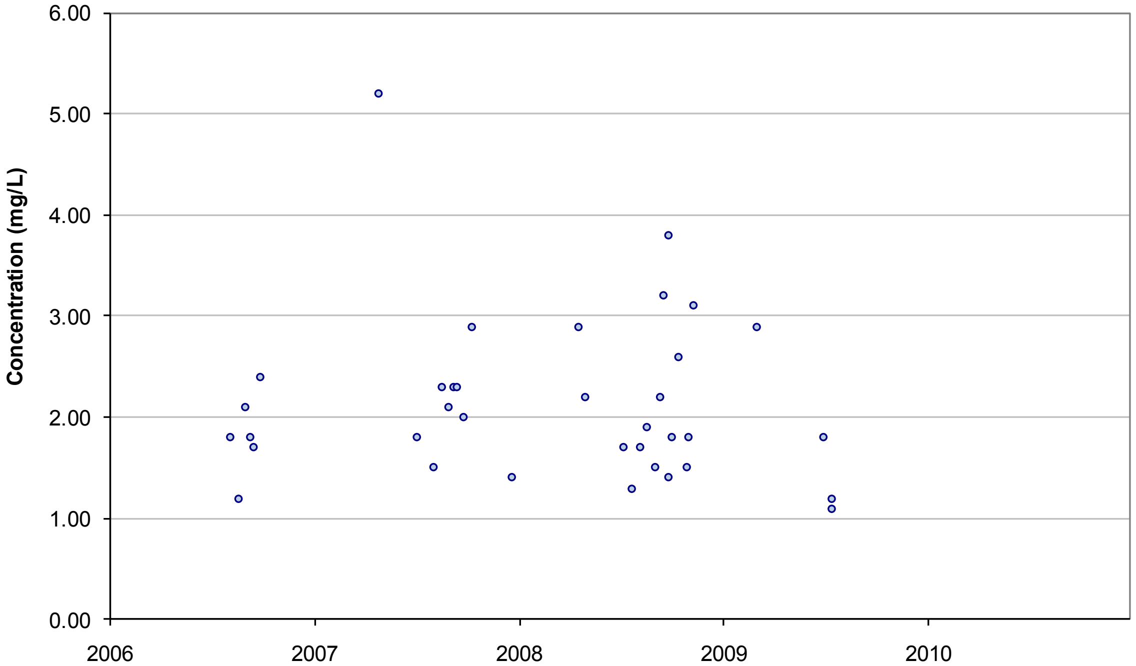
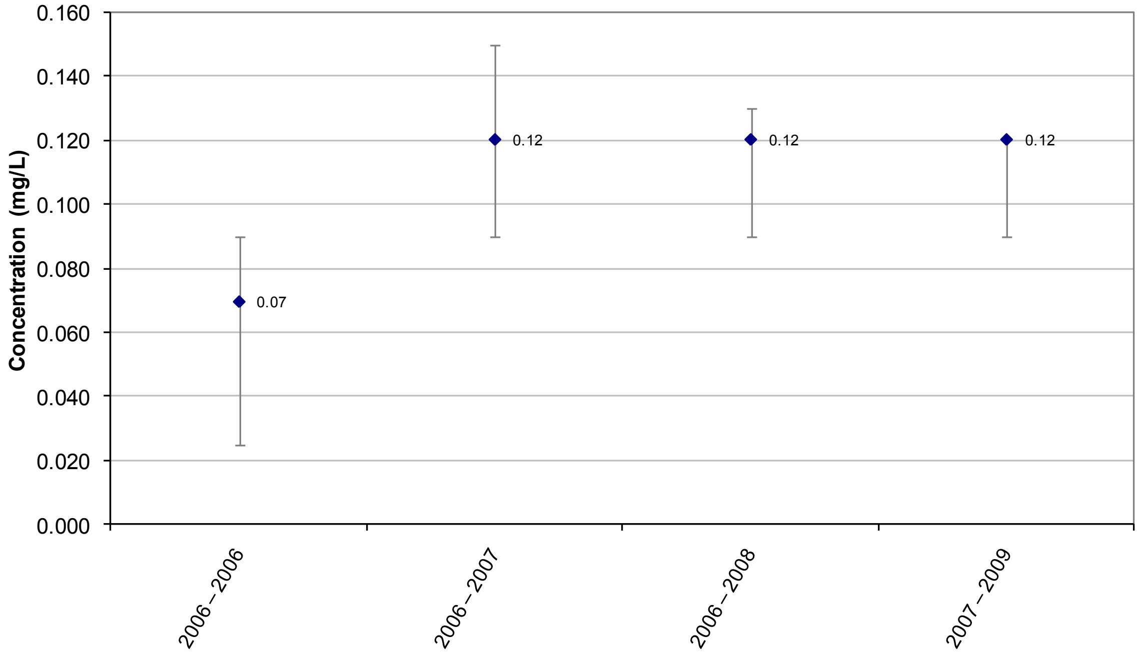


Figure A-55: *Total nitrogen at sampling location Mortlock River East Branch, Great Eastern Highway-Downstream Meckering (6151288) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



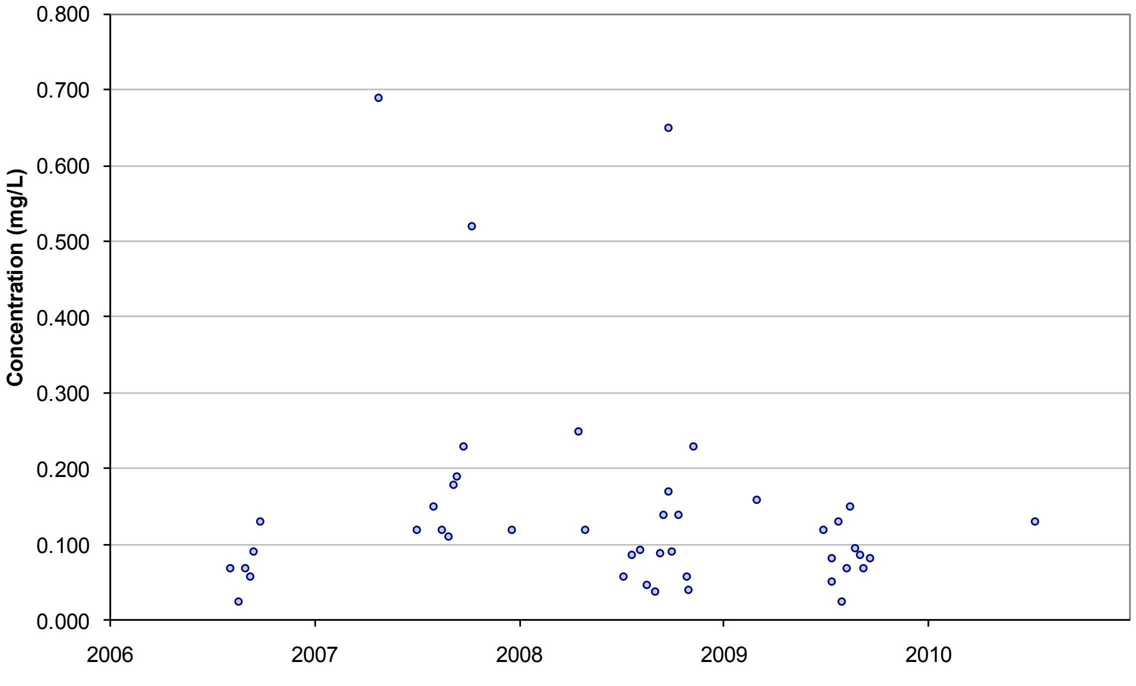
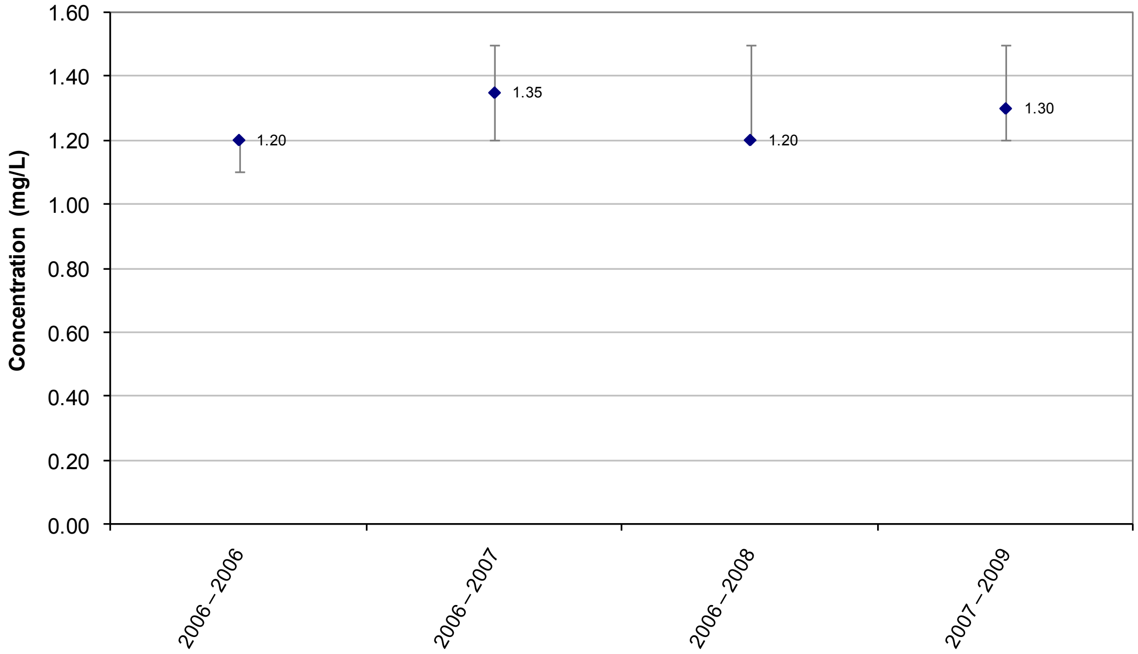


Figure A-56: *Total phosphorus at sampling location Mortlock River East Branch, Great Eastern Highway-Downstream Meckering (6151288) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



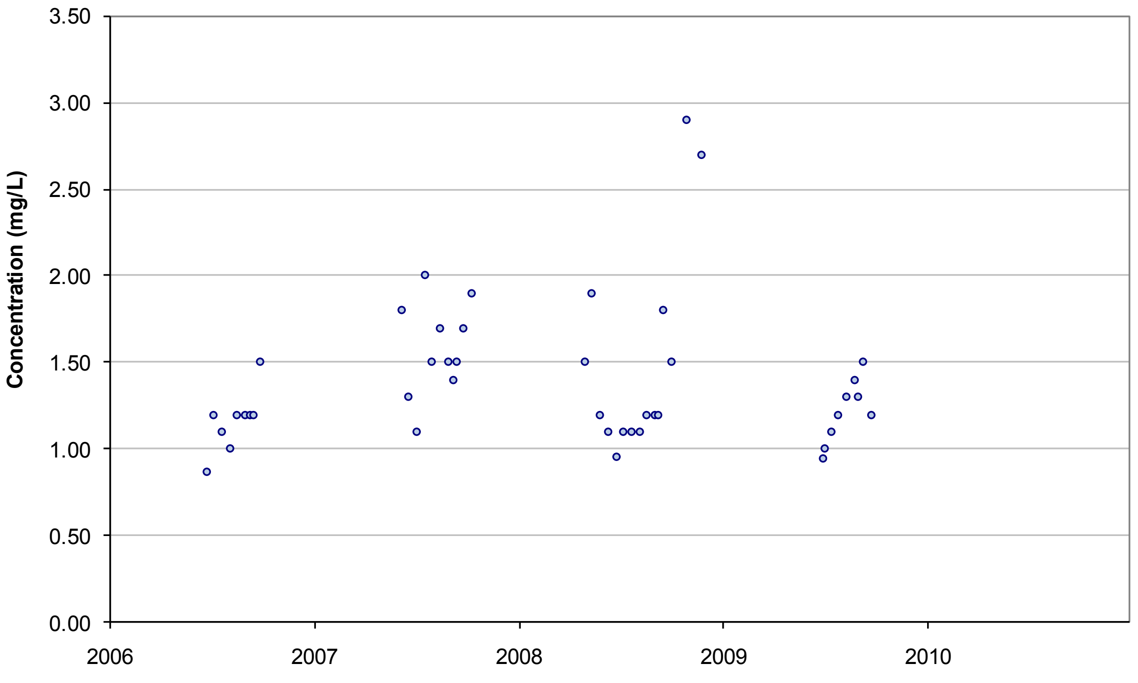
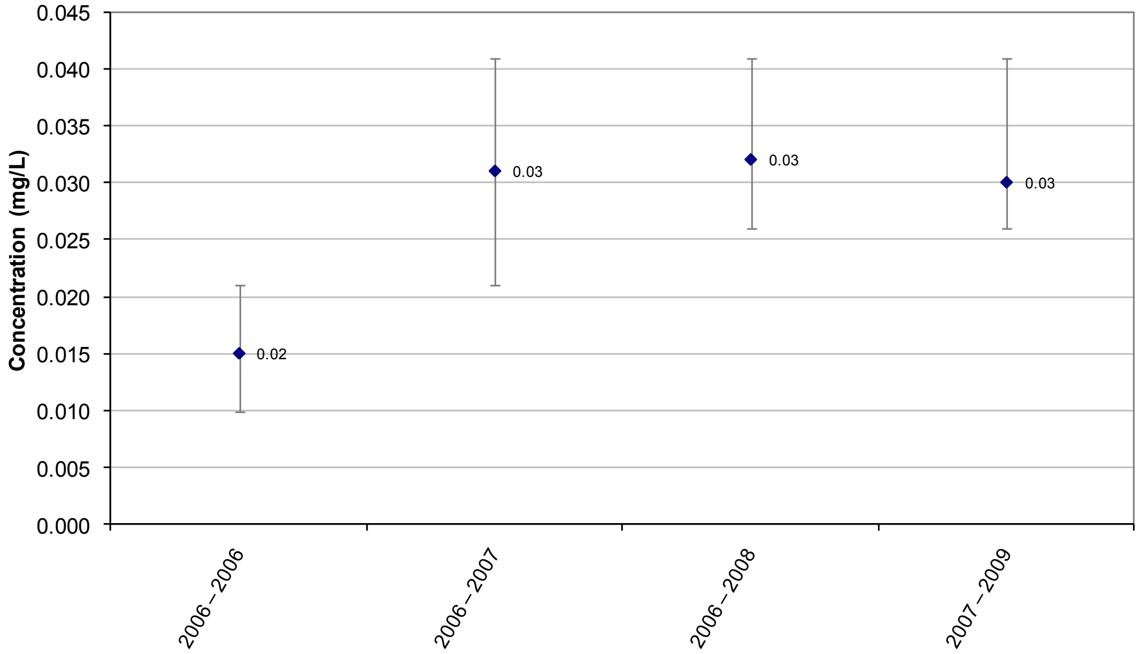


Figure A-57: *Total nitrogen at sampling location Kunjin Creek, Kunjin Creek Dangin Mears Road (6151350) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



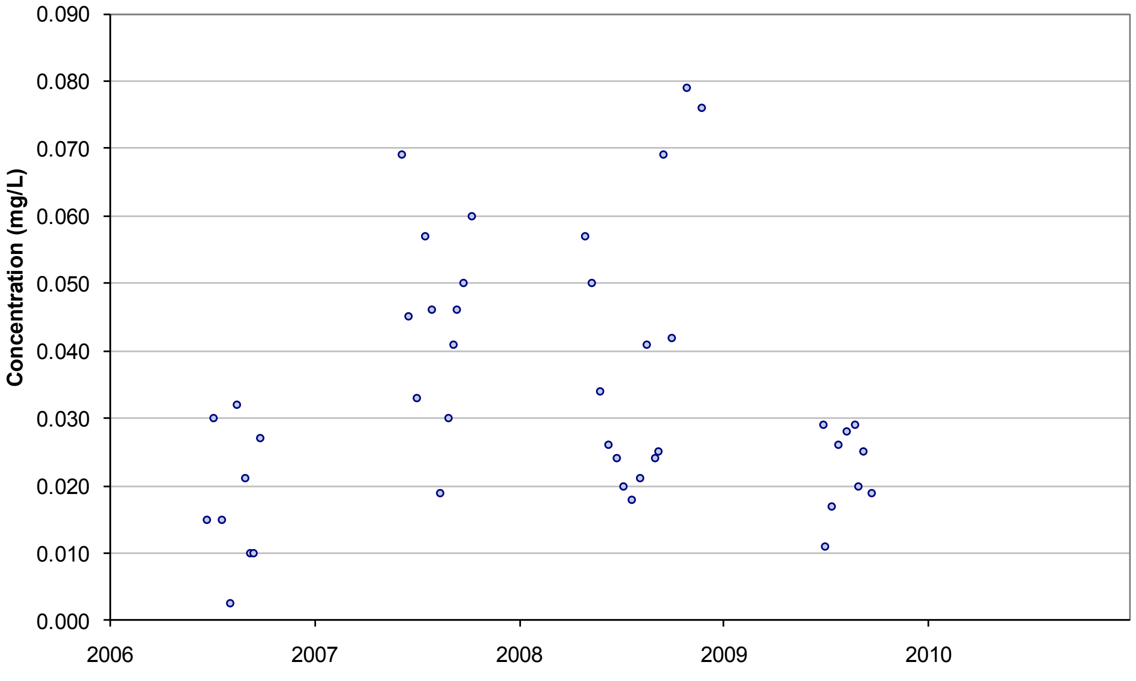
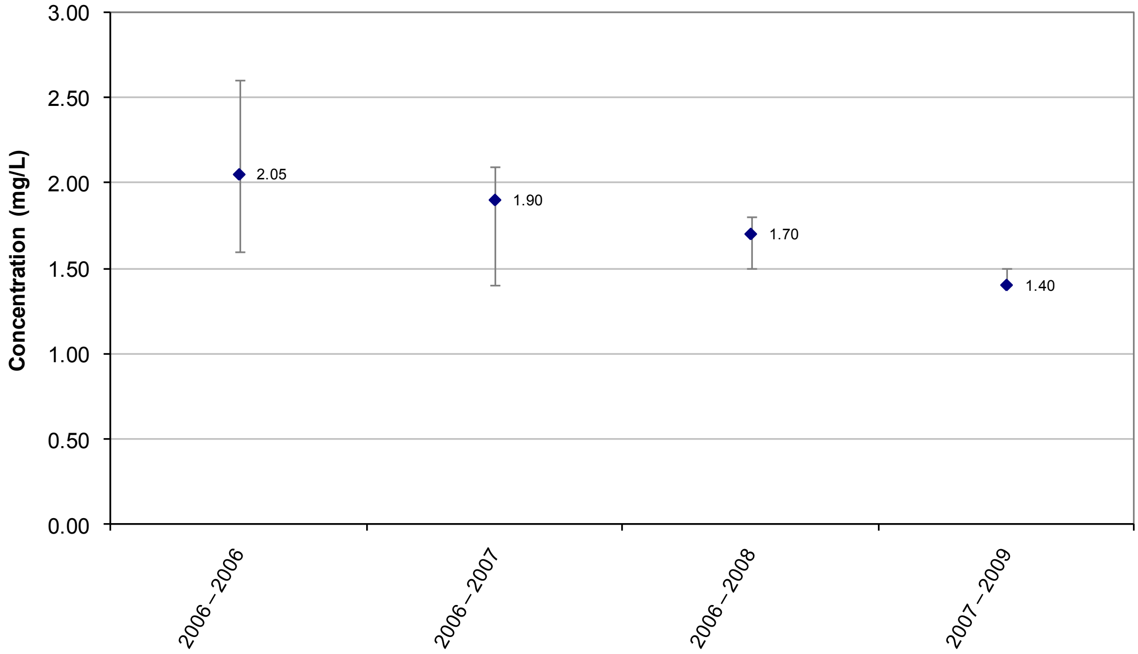


Figure A-58: *Total phosphorus at sampling location Kunjin Creek, Kunjin Creek Dangin Mears Road (6151350) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



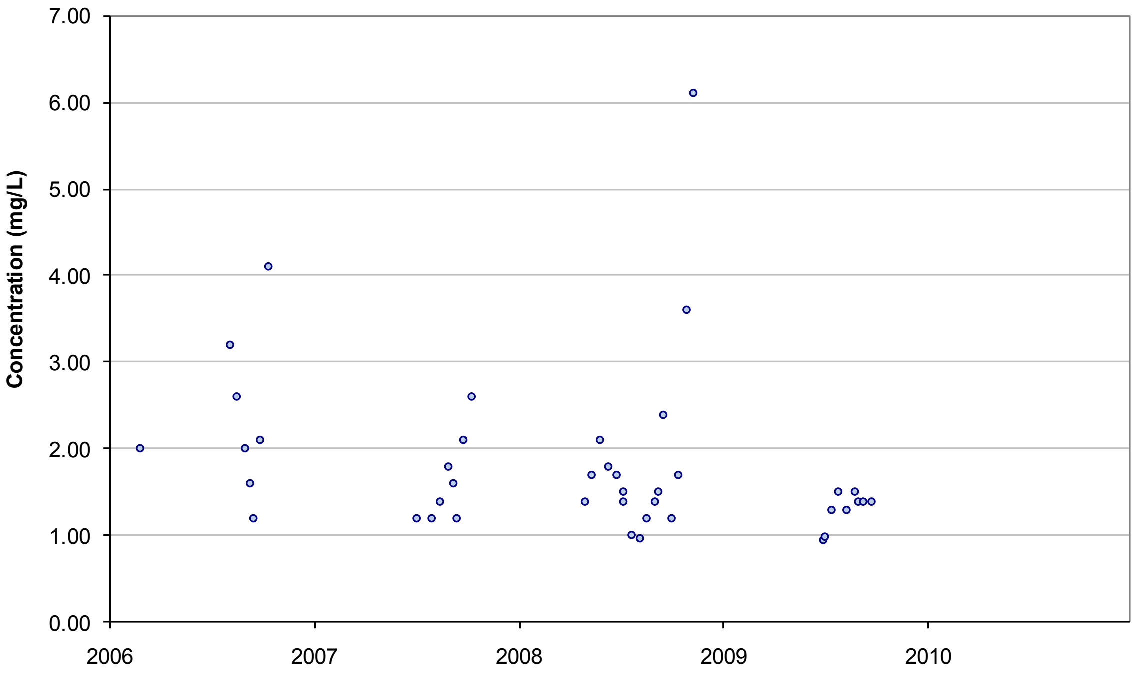
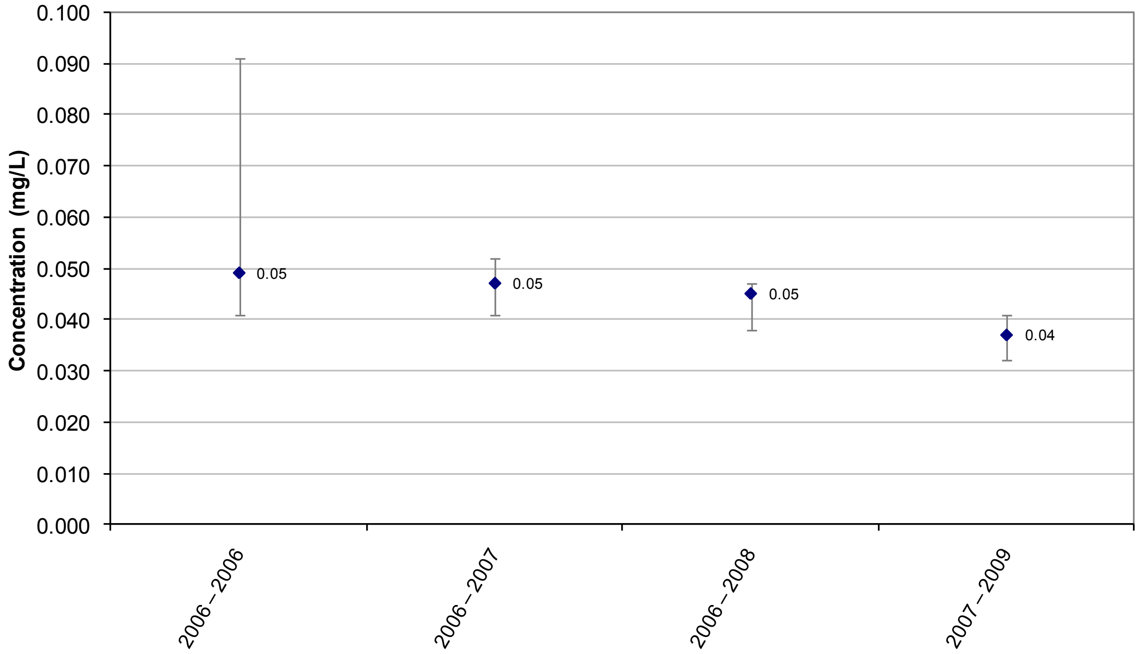


Figure A-59: *Total nitrogen at sampling location Salt River, Dangin Mears (6151353) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



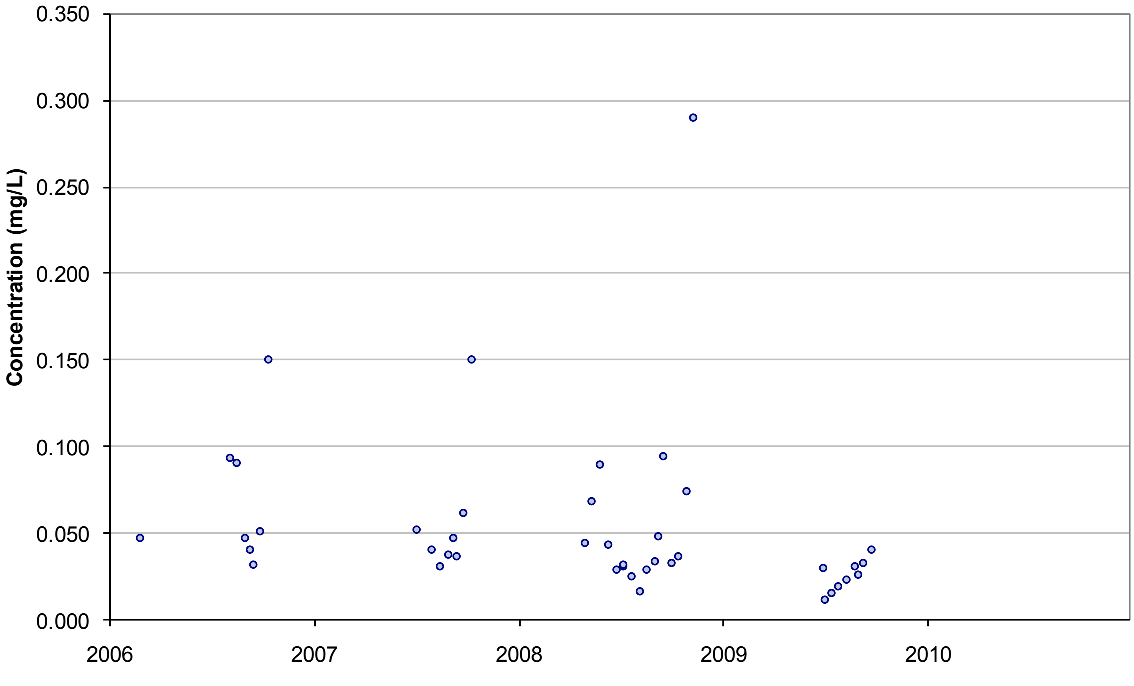
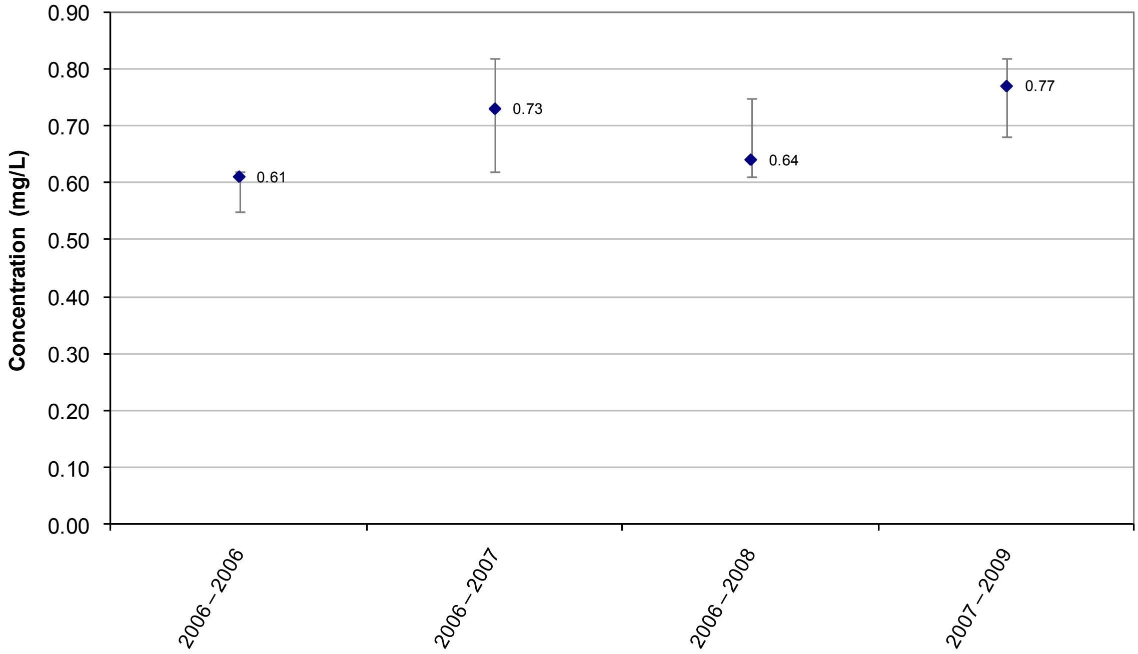


Figure A-60: *Total phosphorus at sampling location Salt River, Dangin Mears (6151353) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



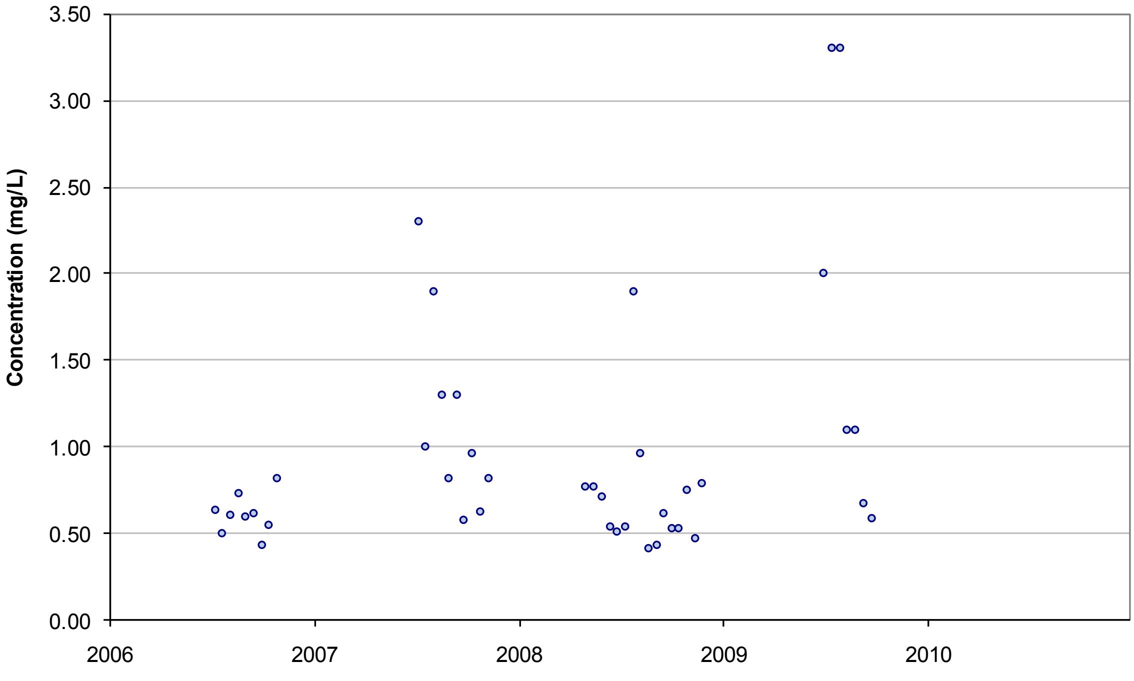
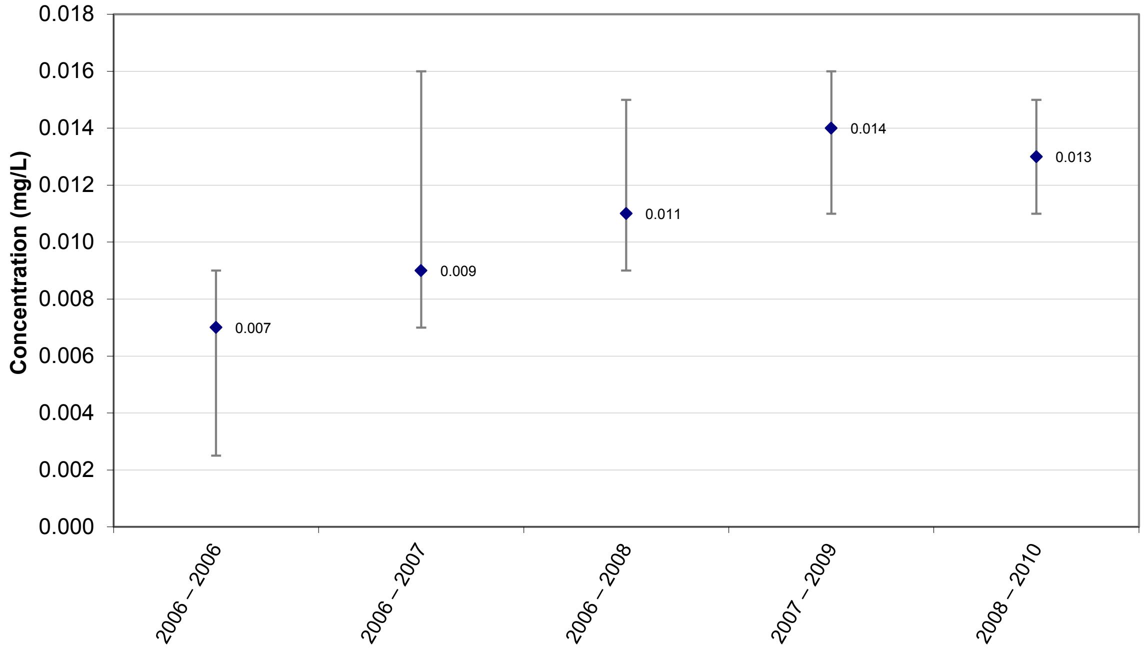


Figure A-61: *Total nitrogen at sampling location Spencers Brook, Spencers Brook (6151518) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*



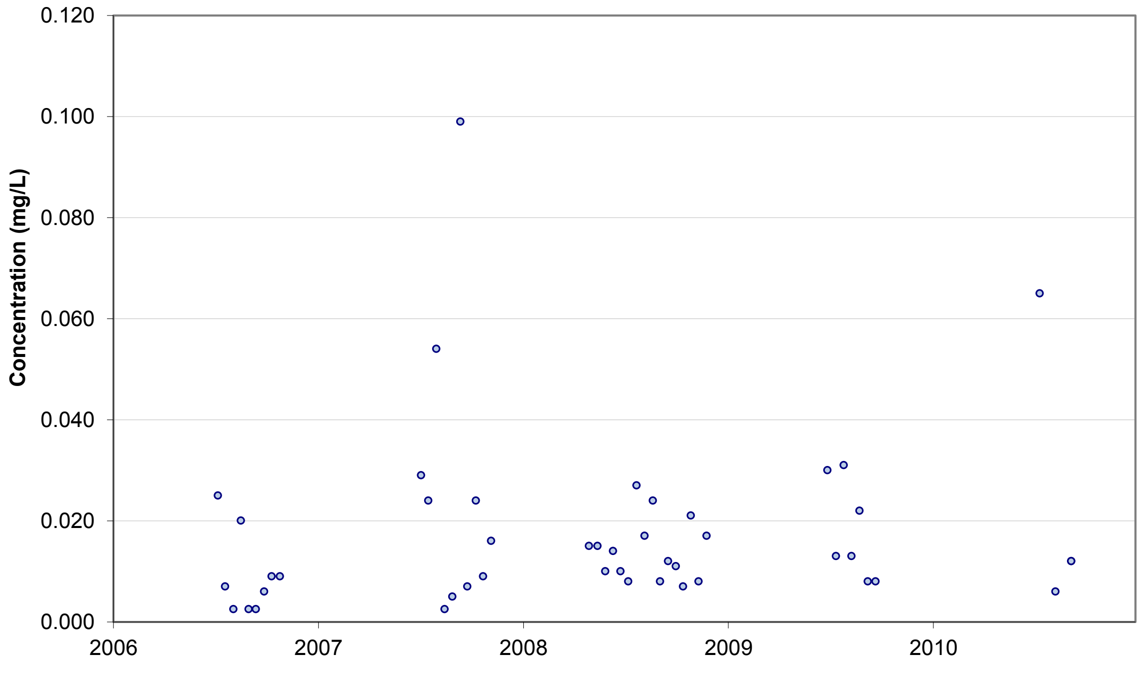


Figure A-62: *Total phosphorus at sampling location Spencers Brook, Spencers Brook (6151518) displaying changing median, 90th and 10th percentiles (top) and all data points used for the analysis (bottom).*

B. Status, trends and load calculation methods and results

Status

Nutrient status is calculated by taking the median of three consecutive years of water quality data. At the start of the record, the median of the first year of data is taken, in the second year, the median of the two previous years is taken and then a three-year median is calculated thereafter. This was done to provide an initial classification at the start of the record. Any subsequent changes in nutrient status are only deemed significant if both the three-year median and the 90% confidence interval move to a new classification category. This was done to reduce the effect that natural variability has on nutrient concentration data. Thus, a change in status indicates a significant change in water quality.

As an example of this methodology, the TN concentrations from the Mayfield Drain (613031) in Peel-Harvey catchment are shown in Figure B-1. Here, a change in nutrient status can be seen over a period of 10 years from high (1.2–2 mg/L) to low (< 0.75 mg/L). At the start of the record the status was determined to be high, however a gradual decrease in nutrient concentrations lead to a reclassification in 1996 to moderate (0.75–1.2 mg/L), and a further reclassification in 2000 to low. Note that the site was not reclassified in 1994 or 1995 as only the median concentration moved into a new classification band, and not the entire 90% confidence interval.

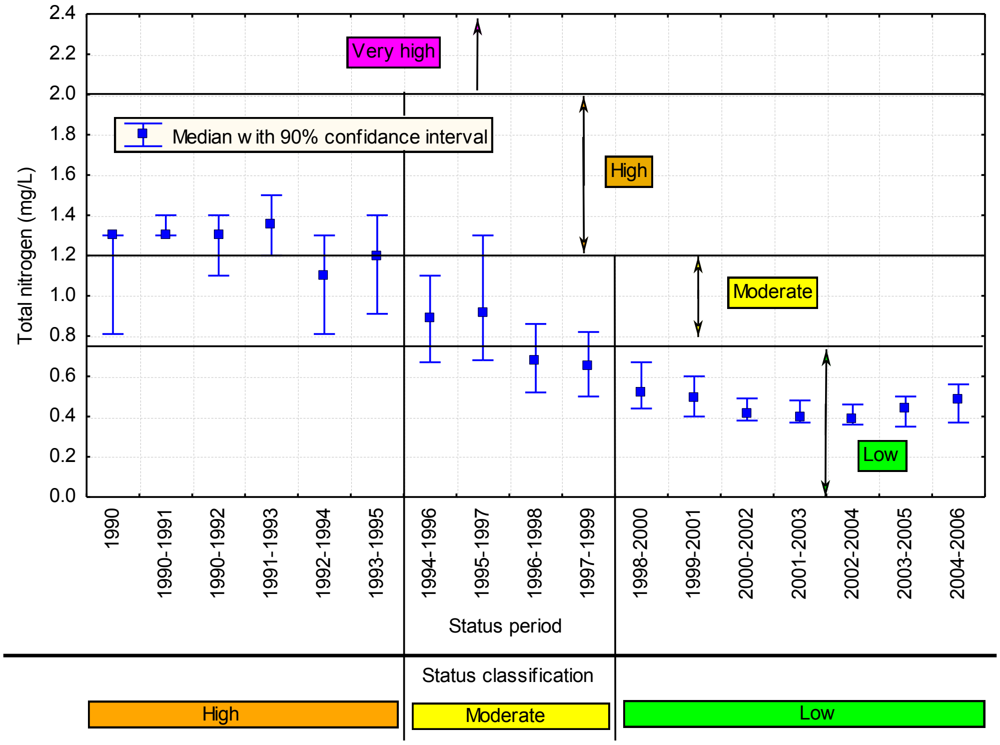


Figure B-1: Total nitrogen status classification for Mayfield Main Drain (AWRC ref 613031)

Trend 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-2). 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.

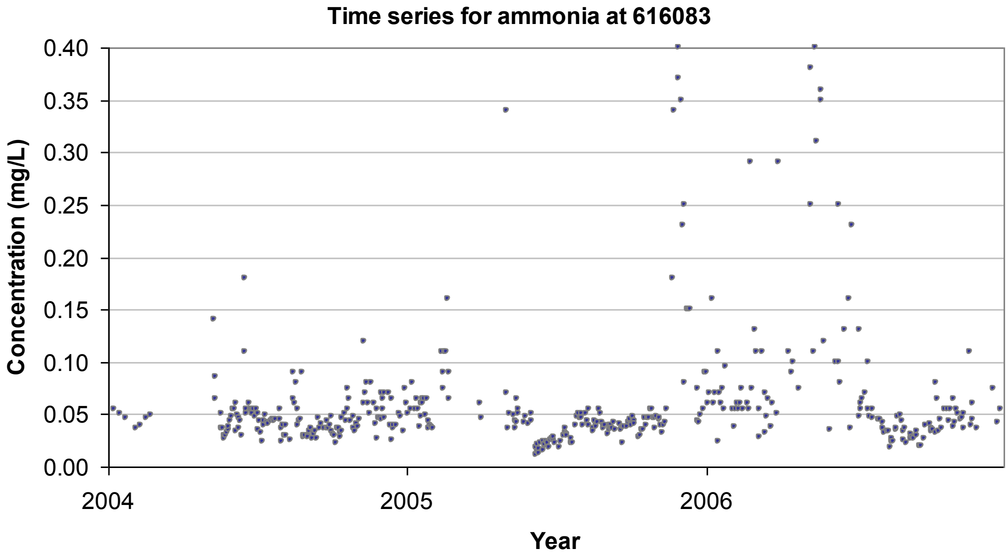


Figure B-2: Example of a time-series with little evidence of a seasonal pattern in ammonia concentration, hence the Mann-Kendall test for trend is used

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-3) 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.

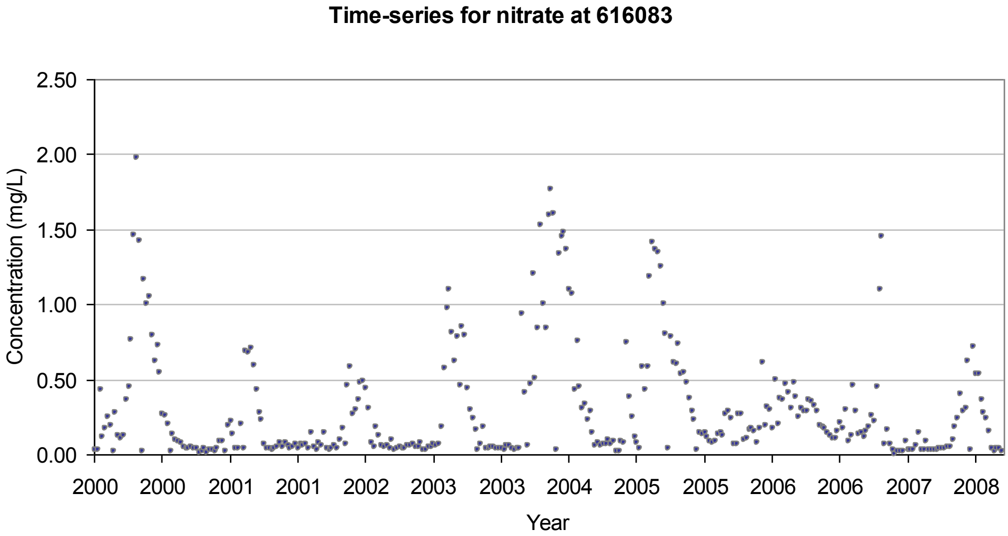


Figure B-3: An example of a pronounced seasonal pattern in nitrate concentration

Nutrient concentrations in waterways can also be affected by changes in flow. The relationship between nutrient concentration and flow is modelled using a locally weighted scatterplot smoothing (LOESS) fit between the concentration and flow (Helsel & Hirsch 1992). The difference of ‘residuals’ between the observed and LOESS modelled concentration are termed flow-adjusted concentrations (FAC), as shown in Figure B-4 (Hipel & McLeod 1994). Trend analyses may then be performed on the flow-adjusted concentrations. The flow-adjustment process often helps to remove seasonal variation although some evidence of seasonal variation often remains in the flow-adjusted data series.

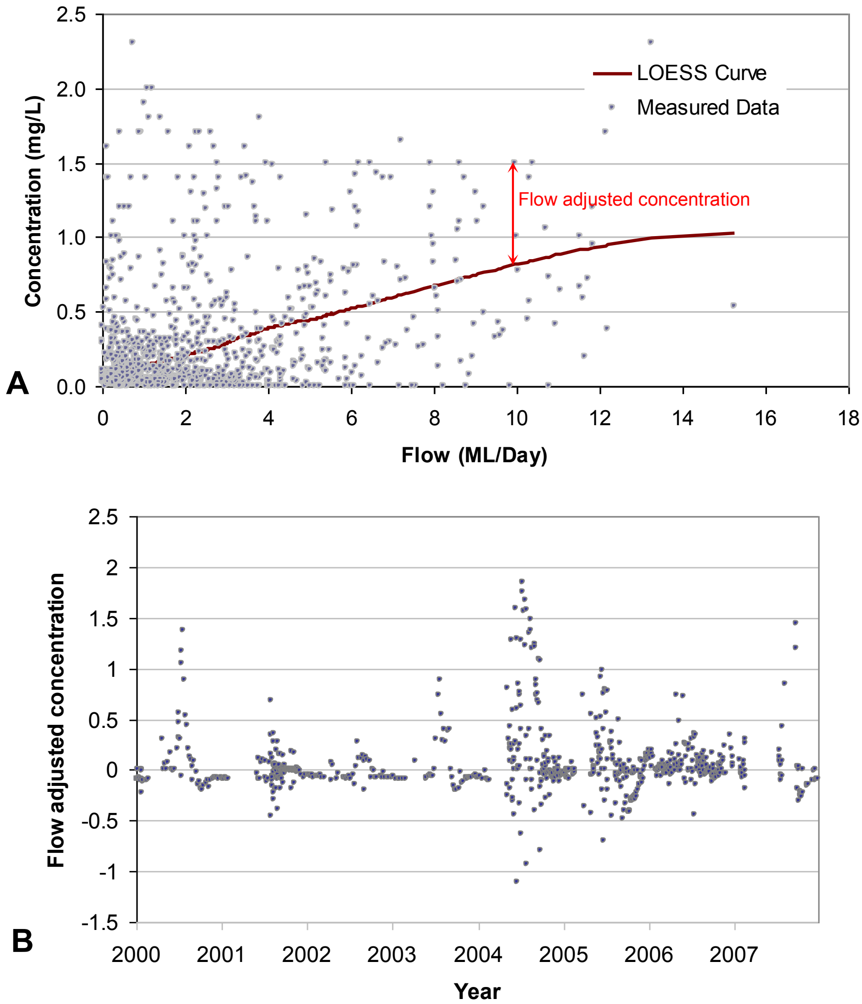


Figure B-4: The flow response plot shows whether a relationship exists between discharge and nutrient concentration (top). The flow-adjusted concentrations (or residuals) are the difference between observed and modelled (LOESS) concentrations (bottom).

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).

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

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 performed using the functions (Lettenmaier 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).

The TN and TP trend results for sites within the Avon Basin are given in Table B-1 and Table B-2. It can be seen that the value of n^* is smaller than $n^{\#}$ in all emerging trends. Thus no trends are statistically significant.

Table B-1: Total nitrogen trend results

Site	Site Name	Test	Period	Trend (mg/L/yr)	p	n	n*	n#	Trend
615013	Frenches	S	2003–10	0.017	0.282	87	80	2226	No trend
615020	Odriscolls Farm	MK	1999–2010	0.000	0.393	121	45		No trend
615024	Balladong Street York	MK	2003–10	0.023	0.378	55	29	3433	No trend
615025	Beverley Bridge	S	2000–10	0.025	0.166	96	45	797	No trend
615026	Stirling Terrace Toodyay	S	2006–10	-0.050	0.063	75	38	1194	No trend
615027	Waterhatch Bridge	MK	2002–10	0.026	0.036	106	58	1443	Emerging increasing trend
615062	Northam Weir	S	2003–10	0.010	0.227	84	46	4774	No trend
616011	Walyunga	S	2006–10	0.010	0.829	128	61	2970	No trend
6151001	Toodyay West Road	S	2006–10	0.020	0.312	66	62	3976	No trend
6151007	Downstream Brookton WWTP	S	2006–10	0.000	0.732	57	35		No trend
6151008	Clark Street	S	2006–10	0.000	0.62	66	35		No trend
6151026	Top of Beverley - York Road	S	2006–10	0.030	0.13	50	46	592	No trend
6151028	Quellington Road	MK	2006–10	0.000	0.901	57	27		No trend
6151033	York Town Pool	S	2006–10	0.000	0.917	59	35		No trend
6151052	Brookton Highway	S	2006–10	0.050	0.223	58	33	2008	No trend
6151278	Taylor Street Weir	MK	2006–10	0.000	0.438	62	22		No trend

S: Seasonal

Table B-2: Total phosphorus trend results

Site	Site Name	Test	Period	Trend (mg/L/yr)	p	n	n*	n#	Trend
615013	Frenches	MK	2003–10	0.000	0.874	88	41		No trend
615020	Odriscolls Farm	MK	1999–2010	0.000	0.799	122	62	1E+06	No trend
615024	Balladong Street York	S	2003–10	0.000	0.919	57	29		No trend
615025	Beverley Bridge	S	2000–10	-0.001	0.683	97	91	1501	No trend
615026	Stirling Terrace Toodyay	MK	2006–10	-0.004	0.155	75	34	4161	No trend
615027	Waterhatch Bridge	MK	2002–10	-0.001	0.087	107	61	2604	No trend
615062	Northam Weir	MK	2003–10	0.000	0.272	85	21	3185	No trend
616011	Walyunga	S	2006–10	-0.002	0.071	128	61	228	No trend
6151001	Toodyay West Road	MK	2006–10	0.004	0.001	67	62	1472	Emerging increasing trend
6151007	Downstream Brookton WWTP	S	2006–10	-0.015	0.006	57	53	907	Emerging decreasing trend
6151008	Clark Street	S	2006–10	0.001	0.464	66	29	113020	No trend
6151026	Top of Beverley - York Road	S	2006–10	0.002	0.046	50	46	165	Emerging increasing trend
6151028	Quellington Road	MK	2006–10	-0.002	0.596	57	31	9184	No trend
6151033	York Town Pool	S	2006–10	0.001	0.476	59	33	3053	No trend
6151052	Brookton Highway	MK	2006–10	0.001	0.648	58	54	388	No trend
6151278	Taylor Street Weir	MK	2006–10	0.010	0.06	63	27	409	No trend

S: Seasonal

MK: Mann-Kendal

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 Season-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-5 shows an example of a slope estimated for a seasonal nutrient data series.

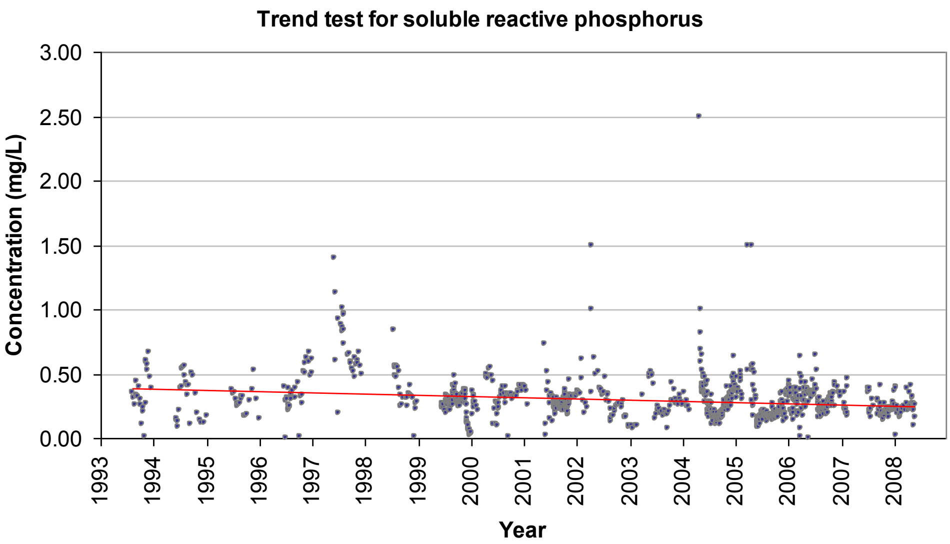


Figure B-5: An example of how the Seasonal Sen slope estimator represents the slope of the trend line in a seasonal nutrient data series.

Load calculations and results

Loads were estimated prior to modelling at selected flow gauging stations using a locally weighted scatter plot smoothing (LOESS) algorithm. Twelve out of the 35 flow gauging stations in the catchment had adequate nutrient data (more than 4 samples per year) to calculate loads. Table B-3 and Table B-4 show the calculated loads for the Avon Basin. LOESS loads were compared against modelled nutrient loads. However, LOESS is typically sensitive at high flows with strongly increasing or decreasing flow-concentration relationships. In the Avon Basin, sites generally had a strong flow-concentration relationship, and as such, LOESS loads in high flow years (i.e. 1999 and 2000) were large.

Table B-3:Annual LOESS nitrogen loads

Site name	Walyunga	Karls Ranch	Yalliawirra	Stirling Tce Toodyay	Frenches	Odiscrolls Farm
Context	Avon River	Wooroloo Brook	Brockman River	Avon River	Mortlock North	Mortlock East
AWRC ref	616011	616001	616019	615026	615013	615020
Year	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes
1997	218	25	31	149	9.1	17
1998	230	30	50	43	18	20
1999	1294	48	120	737	122	92
2000	2240	49	56	728	36	115
2001	107	12	20	71	5.5	7.5
2002	72	18	22	36	2.6	0.9
2003	380	40	67	197	35	24
2004	120	18	30	46	10	4.6
2005	409	32	71	261	17	13
2006	142	14	15	105	22	23
2007	174	32	21	90	5.0	7.3
2008	296	5.2	27	192	12	27
2009	374	40	51	200	15	22
2010	24	2.0	5.3	-	2.1	1.5
Average	**210**	**21**	**33**	**133**	**13**	**13**
Site name	**Northam Weir**	**Waterhatch Bridge**	**Boyagarra Road**	**Kwolyn Hill**	**Gairdners Crossing**	**Mooranoppin Rock**
Context	**Avon River**	**Dale River**	**Avon River**	**Lockhart River**	**Yilgarn River**	**Mooranoppin Creek**
AWRC ref	**615062**	**615027**	**615063**	**615012**	**615015**	**615011**
Year	**tonnes**	**tonnes**	**tonnes**	**tonnes**	**tonnes**	**tonnes**
1997	91	28	-	-	-	-
1998	-	127	-	2.7	4.9	2.4
1999	379	148	-	22	90	7.1
2000	589	157	-	358	12	-
2001	47	32	-	1.1	0.04	0.1
2002	19	12	-	0.1	0.01	0.02
2003	122	56	-	21	4.2	0.7
2004	35	17	-	0.2	0.1	0.2
2005	219	111	-	0.2	0.4	0.7
2006	57	20	-	1.3	0.6	0.2
2007	80	50	-	0.1	0.1	0.1
2008	141	104	40	5.1	0.1	0.1
2009	161	108	16	0.5	0.4	0.6
2010	15	6.9	5.7	0.04	0.03	0.03
Average	**89**	**52**	**21**	**3.0**	**0.6**	**0.3**

Table B-4:Annual LOESS phosphorus loads

Site name	Walyunga	Karls Ranch	Yalliawirra	Stirling Tce Toodyay	Frenches	Odiscrolls Farm
Context	Avon River	Wooroloo Brook	Brockman River	Avon River	Mortlock North	Mortlock East
AWRC ref	616011	616001	616019	615026	615013	615020
Year	tonnes	tonnes	tonnes	tonnes	tonnes	tonnes
1997	7.3	0.3	0.7	3.7	0.4	0.9
1998	7.7	0.4	1.1	1.1	0.9	1.1
1999	40	0.6	2.6	21	5.9	5.5
2000	92	0.7	1.2	31	1.5	6.9
2001	3.7	0.1	0.5	2.0	0.3	0.4
2002	2.3	0.2	0.5	1.0	0.1	0.0
2003	14	0.5	1.5	5.0	1.7	1.3
2004	3.7	0.2	0.7	1.1	0.5	0.2
2005	16	0.4	1.6	6.8	0.8	0.7
2006	5.1	0.2	0.4	2.8	1.0	1.4
2007	5.6	0.4	0.5	2.3	0.2	0.4
2008	12	-	0.6	6.8	0.6	1.5
2009	14	0.5	1.1	5.3	0.8	1.2
2010	0.7	0.02	0.1	-	0.1	0.1
Average	**7.7**	**0.3**	**0.7**	**3.7**	**0.6**	**0.7**
Site name	**Northam Weir**	**Waterhatch Bridge**	**Boyagarra Road**	**Kwolyn Hill**	**Gairdners Crossing**	**Mooranoppin Rock**
Context	**Avon River**	**Dale River**	**Avon River**	**Lockhart River**	**Yilgarn River**	**Mooranoppin Creek**
AWRC ref	**615062**	**615027**	**615063**	**615012**	**615015**	**615011**
Year	**tonnes**	**tonnes**	**tonnes**	**tonnes**	**tonnes**	**tonnes**
1997	1.7	0.5	-	0.00	0.00	0.01
1998	3.6	3.4	-	0.05	0.1	0.2
1999	7.1	3.0	-	0.6	1.6	1.0
2000	17	3.6	-	8.8	0.2	-
2001	0.9	0.7	-	0.02	0.00	0.00
2002	0.4	0.3	-	0.00	0.00	0.00
2003	2.2	1.0	-	0.6	0.09	0.03
2004	0.7	0.3	-	0.00	0.00	0.01
2005	4.0	2.2	-	0.00	0.01	0.05
2006	1.1	0.5	-	0.03	0.01	0.01
2007	1.5	0.9	-	0.00	0.00	0.01
2008	3.2	2.6	2.3	0.1	0.00	0.01
2009	3.4	2.4	0.6	0.01	0.01	0.03
2010	0.3	0.2	0.2	0.00	0.00	0.00
Average	**1.8**	**1.1**	**1.0**	**0.08**	**0.01**	**0.02**

C. Department of Water farm-gate surveys

Farm operation information

Date of survey	Name of recorder & interviewer
Name of respondent & role in farm operations	
Type of enterprise – circle major enterprise from the list, tick a secondary enterprise e.g. Cattle for Beef is a major enterprise (Circle), Viticulture a secondary enterprise(Tick)	Wheat-sheep Cattle for Beef – primary income Cattle for Beef – secondary income (i.e. part time beef farmer) Cattle for Dairy Feedlot Horses Mixed Grazing Other (specify)
Address: Location/Lot Number	
Address: Road name and nearest crossroad	
Address: Locality	
Address: registered name of owner if different from respondent (e.g. company name)	
Size (ha) of i) main farm and ii) all other properties under management	Main farm Other properties under management
When was your farm cleared? Approximately?	
What is the cleared area % or ha of your farm?	
Phone no.	
e-mail address	

Note to staff: Need to very clear about “what we are talking about” when it comes to areas and amounts of material coming into or off the farm if the nutrient budget is done. If someone has an outblock that is not spatially adjacent but is used like a paddock of the main farm (i.e. they move stock to and from, move hay to and from, and is part of their fertiliser program), then we need to know. So we need to fully understand the context of their operation if the budget is to make sense. Their budget questions must then be answered in this same context.

1. Farm nutrient budget

Note: Section B and C OF THE NUTRIENT BUDGET is optional, BUT PLEASE COMPLETE SECTION 2 ON FERTILISER MANAGEMENT

A: Fertiliser inputs

*1. Please **list** the fertilisers, manures and soil ameliorants (i.e. lime, gypsum) you used last calendar year (2012) – or the last year you fertilized) , and the average **amount** applied to farm operations (over the last 5–10 years (Question A2). Include manures, composts and mulches if they are brought in from outside the farm operation. In addition, so that we can identify the nutrient content of each input type, please indicate the **supplier** of each fertiliser. Book values of nutrient content are used to calculate nutrient balances.*

This farm 2011/12 OR the LAST YEAR you applied fertilizers (specify year if no fertilisers used in 2012

	Fertiliser type	Supplier	Area applied (ha)	Total (tonnes)
A	(example only) Super	CSBP	200	200 ha x 100 kg/ha x 2 applications /1000 = 40 tonnes
B				
C				
D				
E				
F				

Do you spread waste product on your property?

2. Farm 'average' last 5–10 years (if significantly different from the last year or 2012)

	Fertiliser type	Supplier	Area applied (ha)	Total (tonnes)
A	(example only) Super	CSBP	200	2
B				
C				
D				
E				
F				

B: Non-Fertiliser inputs

Feed – inputs

*1. Please list the feed types used each year, and the average amount <u>used on your property</u> (in kg or tonnes). **Include only feed brought in from outside the farm**. Include any supplements fed to animals.*

*2. In addition, so that we can identify the nutrient content of each input type, please indicate the **supplier** of each feed type.*

Feed type	Supplier	Area applied (ha)	Application rate (kg/ha)	No. of applications	Calculated tonnes	TOTAL brought in for this farm operation (tonnes)
(example only) Lamb Finisher Nuggets	WesFeeds					75

Pasture growth (N Fixation)

1. Please list the area (ha) and amount (tonnes per ha) of pasture grown on your property on average each year.

2. Of that, specifically note what is legume-based: clover, medics, etc. and note the proportion of legume in the pasture. Also indicate the end use of each pasture type (e.g. animal feed, silage, cut for hay, sell off-farm)

3. What is your annual average rainfall in mm? ....

Pasture Type (description)	Annual weight of dry matter (tonnes/ha)	Legume content (%)	Area (ha)	End User
(example only) Clover	5	40	100	Sell off farm
(example only) Kikuyu	10	0	50	Grazing

....

....

....

Animals – nutrient stores (optional)

Please list the ***total number*** *of different types of animals, the species type, average weight (in kg) and the average number of each animal that you have on your property.*

Animal Type	Species	Number	Average weight (kg)
(example only) Steers	Holsteins	200	400

Animals - inputs

*1. Please list the animals **you bring onto the farm** each year, and the average number and size (in kg) of each type. If you buy in different ages of animal – such as cattle – please list the number and size of each for each animal type.*

2. In addition, so that we can identify the nutrient content of each input type, please provide relevant Animal type details. Book values of nutrient content are used to calculate nutrient balances.

Animal type	Number of animals	Average weight (kg)
(example only) steers	1000	300

C: Outputs – Products removed off-farm

Animals

1. Please list the animals you move or sell off-farm each year, the number and average size of each (in kg). If you sell-off different ages of animal – such as cattle – please list their number and weight separately.

Animal Type	Number of Animals	Average Weight (kg)
(example only) Steers	100	500

Other products

1. Please list any other products you sell or move off farm each year, for example, wool, hay, milk, meat and the average weight of each (in kg).

Product	*Number*	*Amount*	*Units (litres, kg, tonnes)*
(example only) Wool	*1*	*8000*	*kg*
(example only) Hay	*135*	*400*	*kg*

e.g. milk, vegetables, waste product

2. Fertiliser Management

Fertiliser management practices

Have you heard of the Fertiliser Action Plan (FAP)? If so, what is your understanding of it (probe for need and current basis/approach)? DON'T ASK THIS QUESTION NOT RELEVANT TO WHEATBELT

1. Do you soil test? .... Yes ❑ No ❑

If no – Have you soil tested in the past ? If yes, list the last year you soil tested & why you stopped.

2. What is your frequency of soil testing (based on a whole farm average)? (every X years)

3a. During a sampling program/campaign, how much of the farm do you soil test for P and pH – i.e. each paddock on farm, or same few paddocks, or rotate your sampling program around your farm?

P _ All ❑ .... Same paddocks ❑ Rotate ❑

pH _ All ❑ .... Same paddocks ❑ Rotate ❑

Other chemicals (list below) All ❑ Same paddocks ❑ Rotate ❑

3b. If you soil test the whole farm – how often?

If your sampling program is focused on the same paddocks, how many (and what % of farm) and why those paddocks (e.g. soil type)?

If you rotate your sampling program around the farm, what proportion of the farm would you sample in a campaign/program?

If you rotate your sampling program around the farm, how many years would that approach take for you to have covered the whole farm?

3c) How do you record soil sampling points or transect ?

4. Do you tissue test? Yes ❑ No ❑

5. What is your frequency of tissue testing (based on a whole farm average)?

Once every X years	Once only (year)	Never
		❑

Other ….

6. *When do you apply fertilizers?*

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑	❑
% fert A												
% fert B												
% fert C												
% fert D												
% fert E												

7. Do you usually fertilise before or after the break of season?..............................

Before ❑ After ❑ Multiple applications ❑ or comment

(Make sure this refers to their 'normal' practice. If year *x* was different capture that)

8a). How do you make fertiliser decisions?

Note to staff: Probe for decisions about lime and P specifically, also probe around application to whole farm or parts, how often and rates. Probe if they get advice from fertiliser companies or agronomists etc. Do they follow it exactly? Probe if there are tools to assist in decision making i.e. farm nutrient map, farm map, some software or decision-support tool. *You may like to use the following headings to structure your comments.*

Processes used in decision making

Tools used to assist decision making

Decision advisers/influencers

8b…. If you get advice from a private agronomist (i.e. not a fertiliser company representative) are they FertCare accredited? …………………………………………Yes ❑ No ❑ Don't know ❑

9a. Do you keep records of:

Fertiliser application rates	Soil test results
Yes ❑ No ❑	Yes ❑ No ❑

9b If yes how do you keep the records? (paper or electronic copy etc.)

10a. Have you previously prepared a whole farm nutrient budget

Yes ❑ No ❑ Don't know ❑

10b *If yes – what (how) do you use it (for) ?* ....

Fertiliser spreader calibration

11. Do you calibrate your (or your contractor's) fertiliser spreader, i.e. do you know the rate of output and the distance that it spreads, or the amount (L/ha being applied of liquid fertilizer)?:

Yes ❑ No ❑ Don't know ❑

Comments...

12. Is your contractor a member of the fertiliser spreading association (AFSA)?

Yes ❑ No ❑ Not Contractor ❑ Don't know ❑

Attitudes and knowledge

1. What do you see as the big limitations to plant productivity on your farm in terms of things that you can manage for? (See what the farmer says but probe for P status, soil type, acidity, pasture mix, grazing management. If they are having trouble, please see if they can rank.)

2. What is your view on acidity? (Probe around on the degree to which it's a problem, how they test if at all, what they do or plan to do about it, whether they know its impacts on the utilisation of nutrients they already have)

Other Comments...

....

....

....

Other issues:

3. *Salinity – do you have deep drains? Do you plant for salinity reduction?*

4. *Perennial pasture – do you have perennial pasture?*

5. *Riparian/drain management*

6. *Shelterbelts/alley farming (fodder crops and wind breaks)*

7. *Agroforestry*

8. *Organic farming*

D. Hydrological calibration report

The hydrological calibration statistics for the eight models were given in Section 4.6. Here the model parameters, flow gauging quality statistics and the modelled and observed hydrographs are given.

Table D-1: LASCAM model parameters

Parameter	Avon River	Wooroloo	Brockman	Mortlock	Dale	Lockhart	Yilgarn	Helena
alphaa	5.83	4.35	4.05	2.42	3.89	3.32	6.07	0.56
alphab	1.42	1.73	1.34	0.47	0.03	0.83	1.28	4.91
alphac	0.49	5.30	0.23	5.69	0.22	0.08	6.29	0.24
alphaf	0.57	9.79	5.47	5.29	0.99	6.87	4.45	6.03
alphag	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
alphass	9.88	0.91	4.40	10.72	0.87	2.74	6.48	3.59
amn	0.62	11.81	4.04	61.27	12.91	1.93	48.62	71.97
amx	196.86	296.36	674.21	784.82	154.60	681.88	658.72	493.71
anrain	400.00	800.00	700.00	400.00	500.00	300.00	300.00	800.00
betaa	530.80	5328.88	3372.14	6950.12	4.36	4013.75	4946.90	0.19
betab	0.76	5.57	0.02	4.64	0.02	1.19	1.10	6.74
betac	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
betaf	4.39	1.80	0.05	2.18	1.69	0.42	4.20	0.00
betag	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
betass	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
bmx	2117.88	2345.17	1113.07	1535.98	2496.65	2488.39	1324.12	2440.26
delatab	0.17	4.63	2.63	1.74	3.34	0.64	1.50	1.61
deltaf	0.90	0.97	0.38	0.53	1.00	0.64	0.85	1.00
dfs	3.94	50.05	177.19	87.14	198.99	97.19	130.15	195.88
dmu1	0.52	0.86	0.89	0.86	0.00	1.15	1.55	0.54
dmu2	2133.02	1462.43	1760.30	342.25	1709.54	1043.57	579.36	1802.54
dmu3	1.00	0.38	1.24	0.66	1.54	1.58	1.83	0.28
fmx	200.01	220.31	266.54	318.24	204.07	212.97	364.06	896.61
fs0	82.04	27.65	172.73	54.42	90.36	87.68	80.63	8.55
gammaa	1.39	3.92	9.00	3.41	9.12	8.51	4.36	9.81
gammab	0.98	0.60	0.94	0.81	0.46	0.96	0.43	0.18
gammaf	0.69	0.52	0.59	0.34	0.10	0.25	0.34	0.69
td	227.67	514.11	558.40	38.33	239.05	114.17	185.19	665.53

Table D-2: Muskingum flow routing parameters

Modelling subcatchment link ID	Reporting catchment	*k*	*x*	Modelling subcatchment link ID	Reporting catchment	*k*	*x*
1	Lower Avon	43 200	0.00	32	Mortlock East	43 200	0.00
2	Lower Avon	43 200	0.00	33	Dale	43 200	0.00
3	Lower Avon	43 200	0.00	34	Dale	83 000	0.00
4	Lower Avon	43 200	0.00	35	Dale	76 000	0.00
5	Lower Avon	43 200	0.00	36	Salt	43 200	0.00
6	Lower Avon	43 200	0.00	37	Salt	86 400	0.30
7	Lower Avon	43 200	0.00	38	Salt	86 400	0.50
8	Lower Avon	43 200	0.00	39	Lockhart	43 200	0.00
9	Lower Avon	43 200	0.00	40	Lockhart	43 200	0.00
10	Middle Avon	43 200	0.00	41	Lockhart	82 286	0.07
11	Middle Avon	55 747	0.23	42	Lockhart	43 200	0.00
12	Middle Avon	43 200	0.00	43	Lockhart	43 200	0.00
13	Middle Avon	85 536	0.05	44	Lockhart	43 200	0.00
14	Middle Avon	43 200	0.00	45	Lockhart	85 657	0.32
15	Middle Avon	43 200	0.00	46	Lockhart	43 200	0.00
16	Middle Avon	43 200	0.00	47	Lockhart	86 400	0.03
17	Upper Avon	46 974	0.08	48	Yilgarn	43 200	0.00
18	Upper Avon	83 966	0.08	49	Yilgarn	43 200	0.00
19	Wooroloo	43 223	0.00	50	Yilgarn	43 200	0.00
20	Wooroloo	67 414	0.30	51	Yilgarn	59 774	0.18
21	Wooroloo	60 264	0.27	52	Yilgarn	44 636	0.03
22	Wooroloo	85 765	0.50	53	Yilgarn	43 200	0.00
23	Brockman	43 200	0.00	54	Yilgarn	83 966	0.08
24	Brockman	43 200	0.00	55	Helena	43 200	0.00
25	Mortlock North	43 200	0.00	56	Helena	43 200	0.00
26	Mortlock North	86 031	0.50	57	Helena	43 200	0.00
27	Mortlock North	79 687	0.46	58	Helena	43 200	0.00
28	Mortlock North	79 687	0.46	59	Helena	65 905	0.34
29	Mortlock East	43 200	0.00	60	Helena	86 021	0.49
30	Mortlock East	43 200	0.00	61	Upper Avon	43 902	0.02
31	Mortlock East	85 684	0.18				

The Department of Water's hydrography staff create a quality control record for all flow data. This record enabled good quality data (data deemed as accurate) to be used in the modelling and poor quality data (e.g. data calculated outside of known bounds, data derived from faulty equipment, spurious data) to be excluded. Table D-3 was used as a guide to remove poor quality data. The calibration weighting of each flow gauging station is also reported here. Calibration weighting values of 1 represent the highest weighting, with values below 1 representing a lower weighting.

Table D-3: Flow quality description

Quality description	Comment
Very good record	Used
Very good record - corrections applied	Used
Good record - corrections or estimations applied	Used
Estimated record - good	Used
Estimated record - fair	Mostly not used
Estimated record - poor	Never used
Estimated record - not reviewed / quality not known	Never used
Theoretical rating	Used
Estimated rating	Mostly not used
Below inlet	Zero reading
Unrated	Never used
Not available	Zero reading

Avon

Table D-4: Flow statistics and data quality report for three of five flow gauging stations used to calibrate the Avon hydrological model

Site details						
Calibration weighting	1		0.5		0.5	
Site name	Walyunga		Stirling Terrace		Wongamine Brook	
Site context	Avon River		Avon River		Wongamine Brook	
AWRC reference	616011		615026		615030	
Flow statistics						
Start of record	15/05/1970		18/10/1996		6/06/1997	
End of record	31/12/2010		31/12/2010		16/10/2001	
Minimum recorded daily flow (ML/day)	0		0		0	
Maximum recorded daily flow (ML/day)	51221		25394		348	
Average daily flow (ML/day)	845		335		6	
Median daily flow(ML/day)	83		40		1	
Number of days in record	14941		5188		1594	
Number of missing flows	222	1.5%	17	0.3%	1594	100%
Number of excluded data points	266	1.8%	367	7.1%	0	0.0%
Flow quality						
Very good record	13129	87.9%	3175	61.2%	0	0.0%
Very good record - corrections applied	902	6.0%	571	11.0%	1566	98.2%
Good record - corrections or estimations applied	168	1.1%	31	0.6%	28	1.8%
Estimated record - good	41	0.3%	25	0.5%	0	0.0%
Estimated record - fair	264	1.8%	23	0.4%	0	0.0%
Estimated record - poor	238	1.6%	0	0.0%	0	0.0%
Estimated record - not reviewed / quality not known	151	1.0%	306	5.9%	0	0.0%
Estimated rating	0	0.0%	998	19.2%	0	0.0%
Not available	82	0.5%	42	0.8%	0	0.0%
No record	0	0.0%	17	0.3%	0	0.0%

Table D-5: Flow statistics and data quality report for two of five flow gauging stations used to calibrate the Avon hydrological model

Site details				
Calibration weighting	0.5		0.5	
Site name	Northam Weir		Boyagarra Rd	
Site context	Avon River		Avon River	
AWRC reference	615062		615063	
Flow statistics				
Start of record	30/03/1977		39,197.00	
End of record	21/11/2011		31/12/2010	
Minimum recorded daily flow (ML/day)	0		0	
Maximum recorded daily flow (ML/day)	6316		634	
Average daily flow (ML/day)	257		20	
Median daily flow(ML/day)	15		1	
Number of days in record	12655		1347	
Number of missing flows	0	0.0%	0	0.0%
Number of excluded data points	483	3.8%	5	0.4%
Flow quality				
Very good record	11675	92.3%	1105	82.0%
Very good record - corrections applied	497	3.9%	220	16.3%
Good record - corrections or estimations applied	150	1.2%	0	0.0%
Estimated record - good	9	0.1%	17	1.3%
Estimated record - fair	12	0.1%	0	0.0%
Estimated record - poor	0	0.0%	0	0.0%
Estimated record - not reviewed / quality not known	210	1.7%	0	0.0%
Estimated rating	101	0.8%	0	0.0%
Not available	1	0.0%	5	0.4%
No record	0	0.0%	0	0.0%

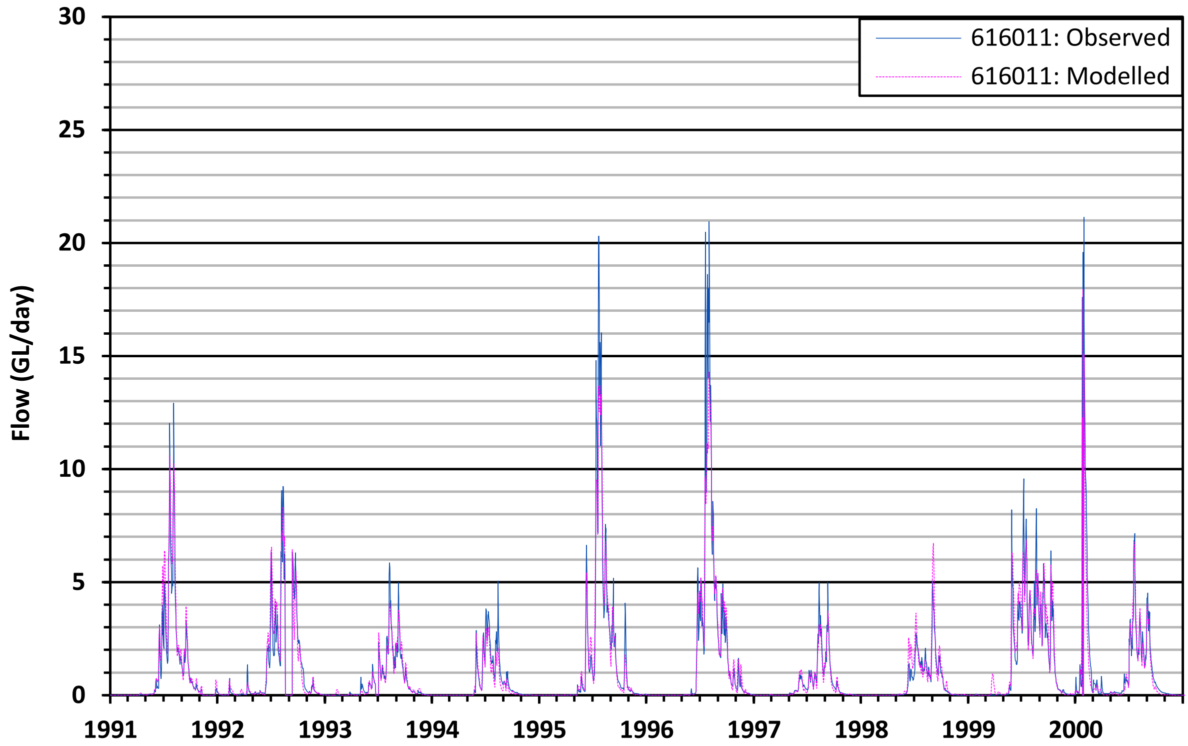


Figure D-1: Observed and modelled daily flows at Walyunga (616011)

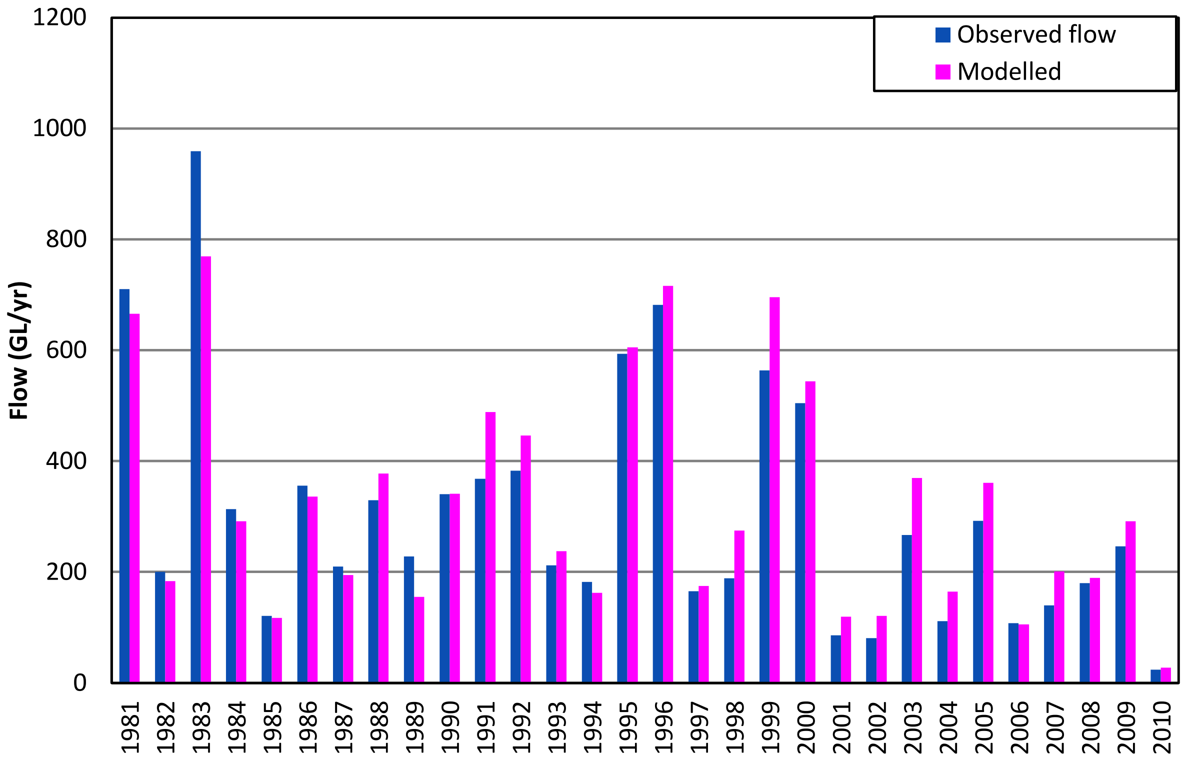


***Figure D-2:** Observed and modelled annual flows at Walyunga (616011)*

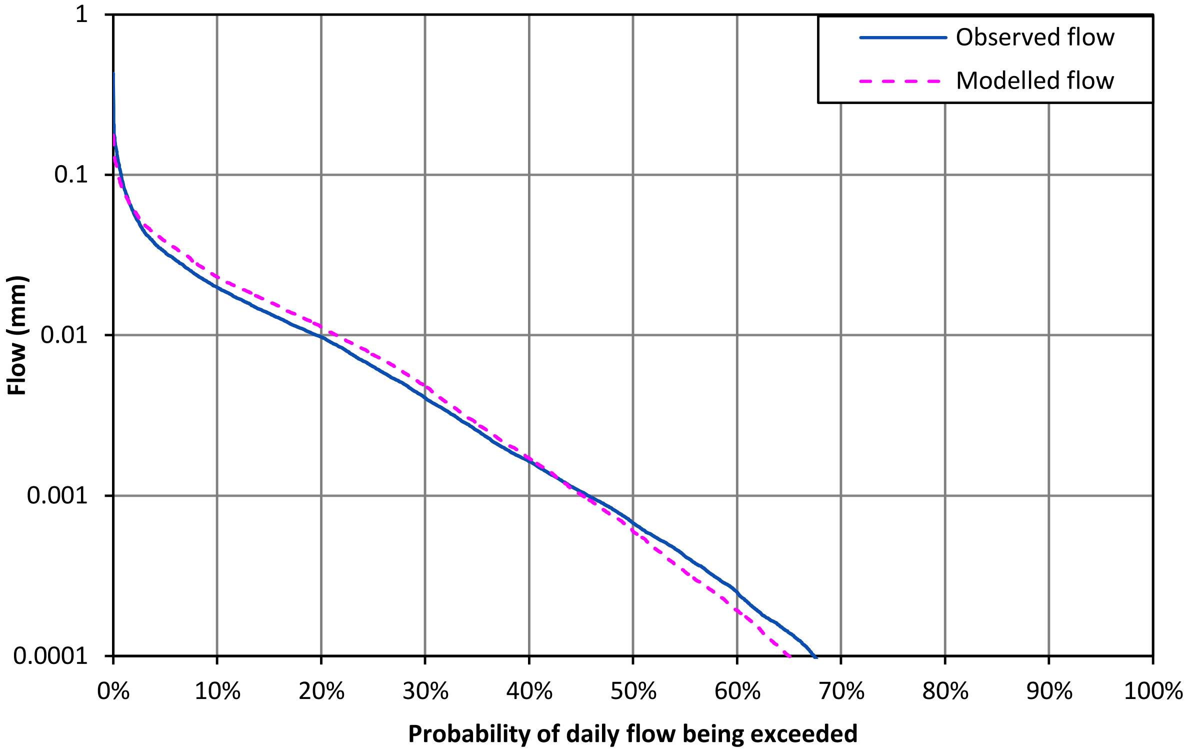


Figure D-3: Observed and modelled flow duration curves at Walyunga (616011)

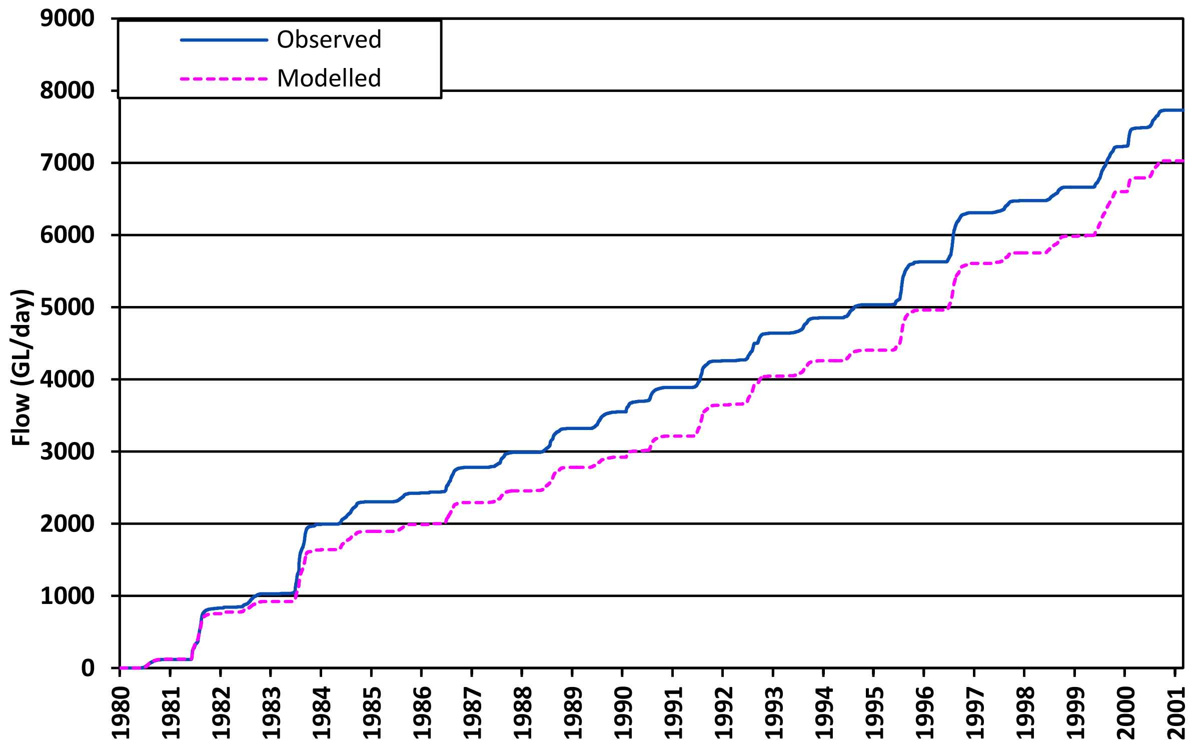


Figure D-4: Cumulative daily observed and modelled flow at Walyunga (616011)

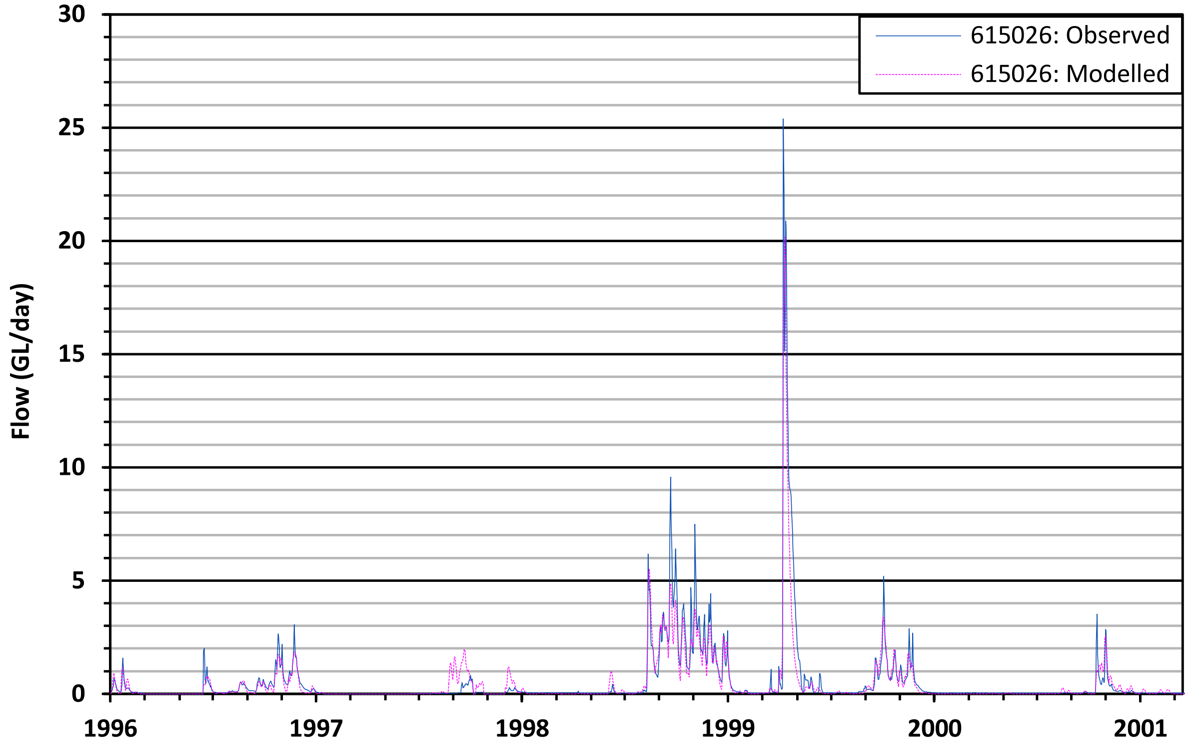


Figure D-5: Observed and modelled daily flows at Stirling Tce (615026)

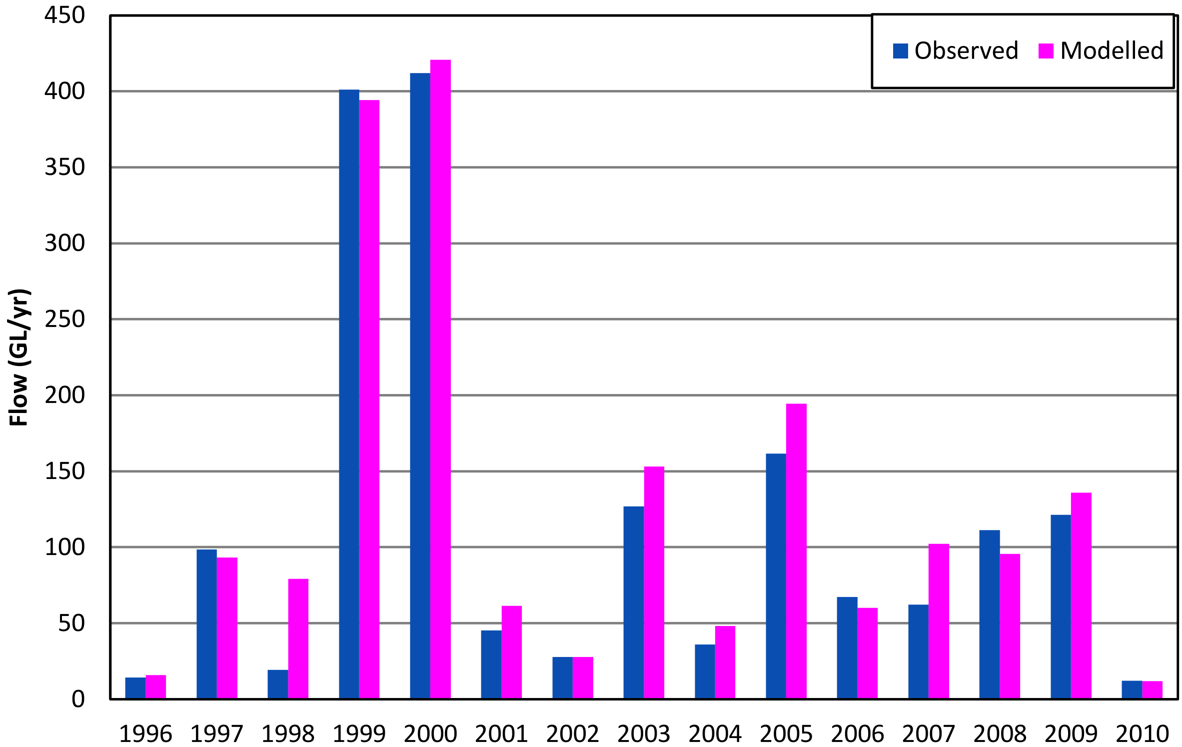


Figure D-6: Observed and modelled annual flows at Stirling Tce (615026)

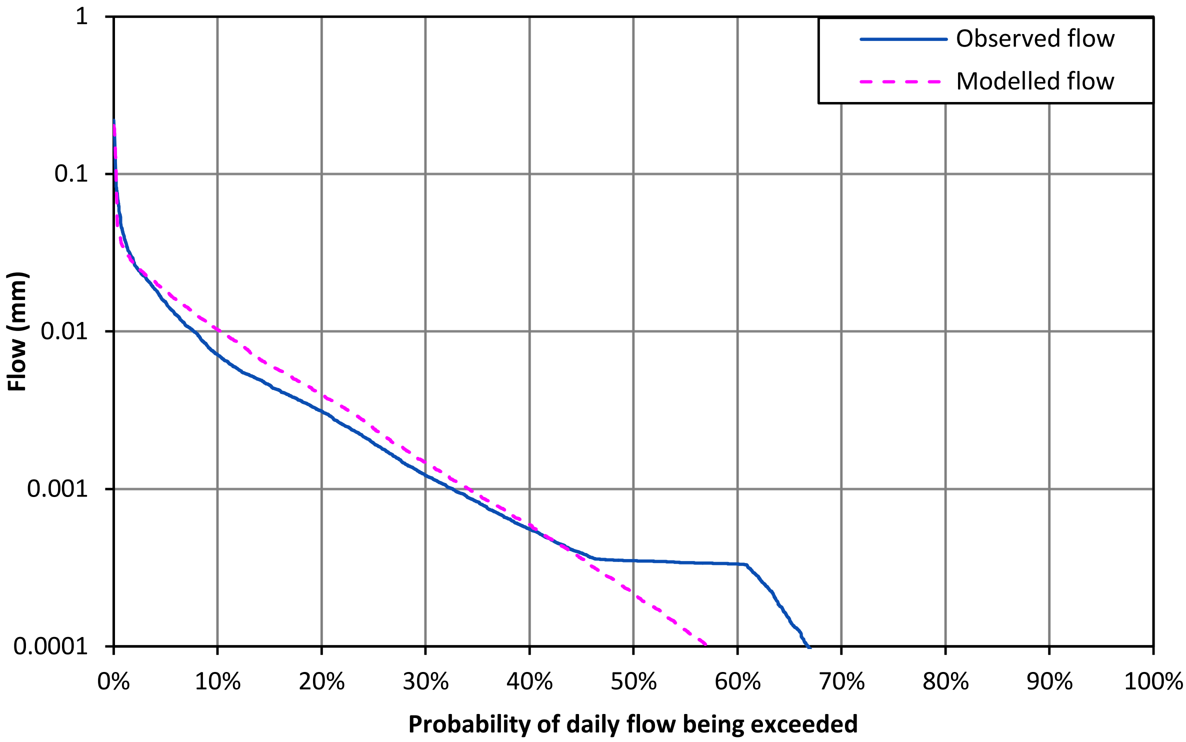


Figure D-7: Observed and modelled flow duration curves at Stirling Tce (615026)

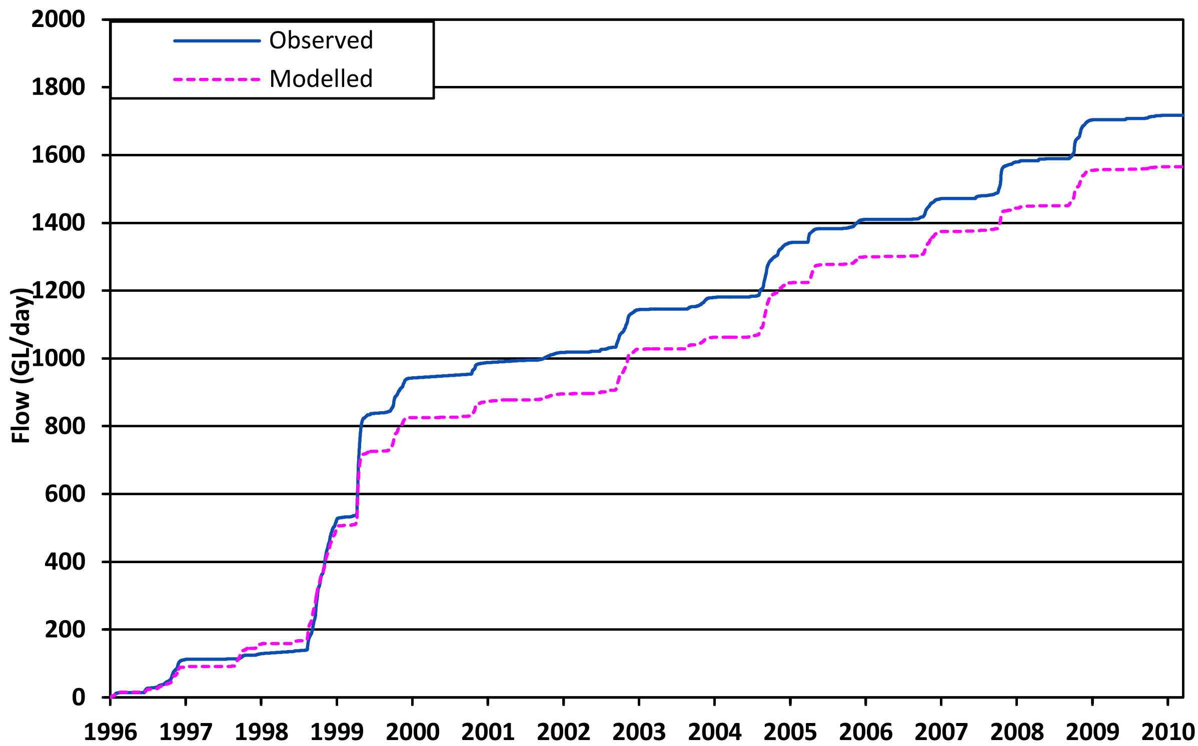


Figure D-8: Cumualtive daily observed and modelled flows at Stirling Tce (615026)

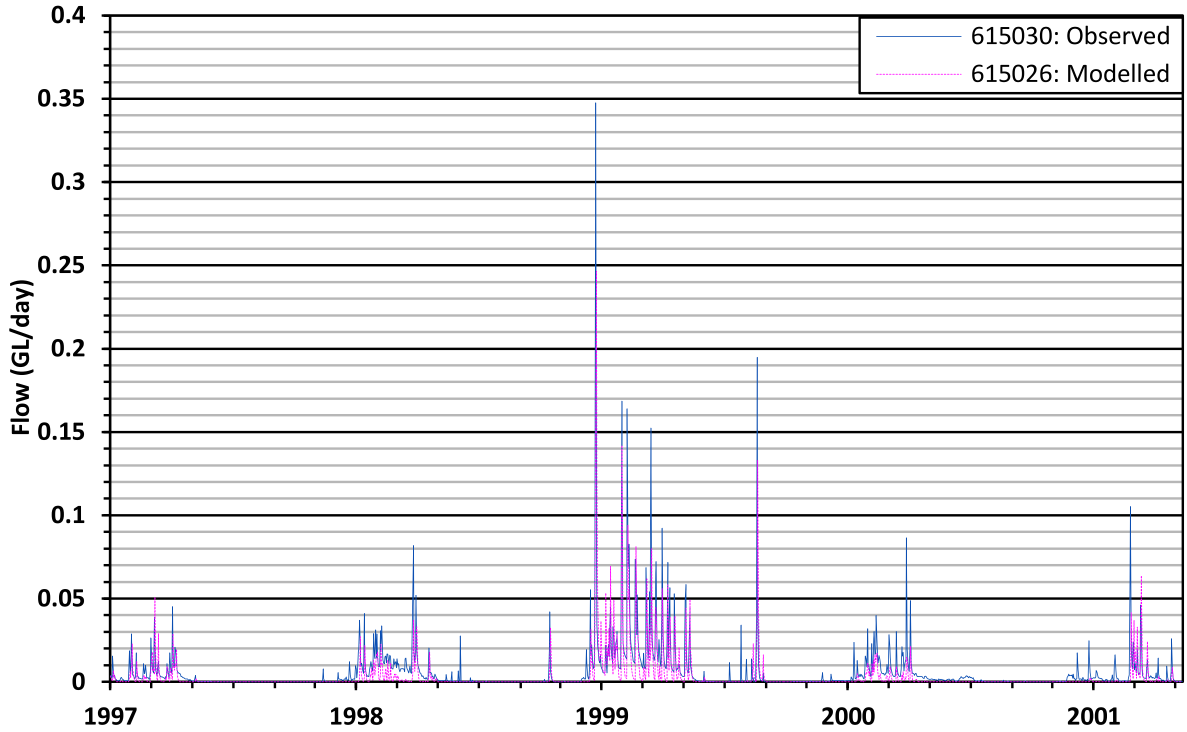


Figure D-9: Observed and modelled daily flows at Wongamine Brook (615030)

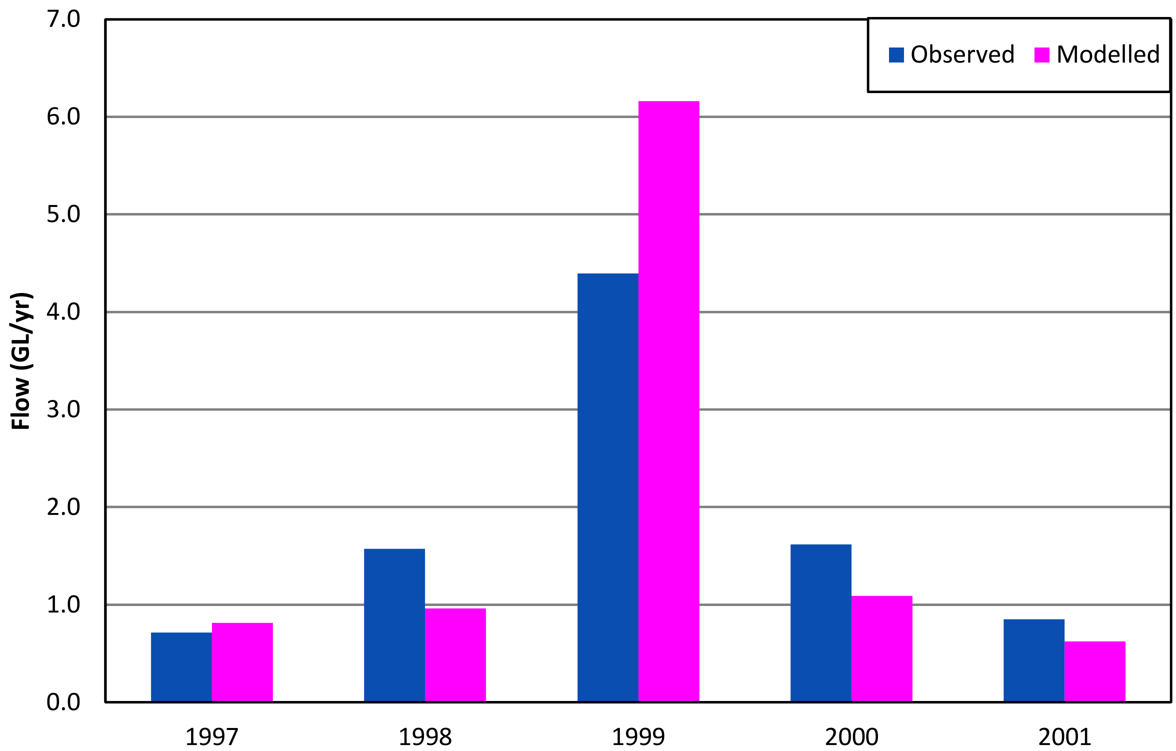


Figure D-10: Observed and modelled annual flows at Wongamine Brook (615030)

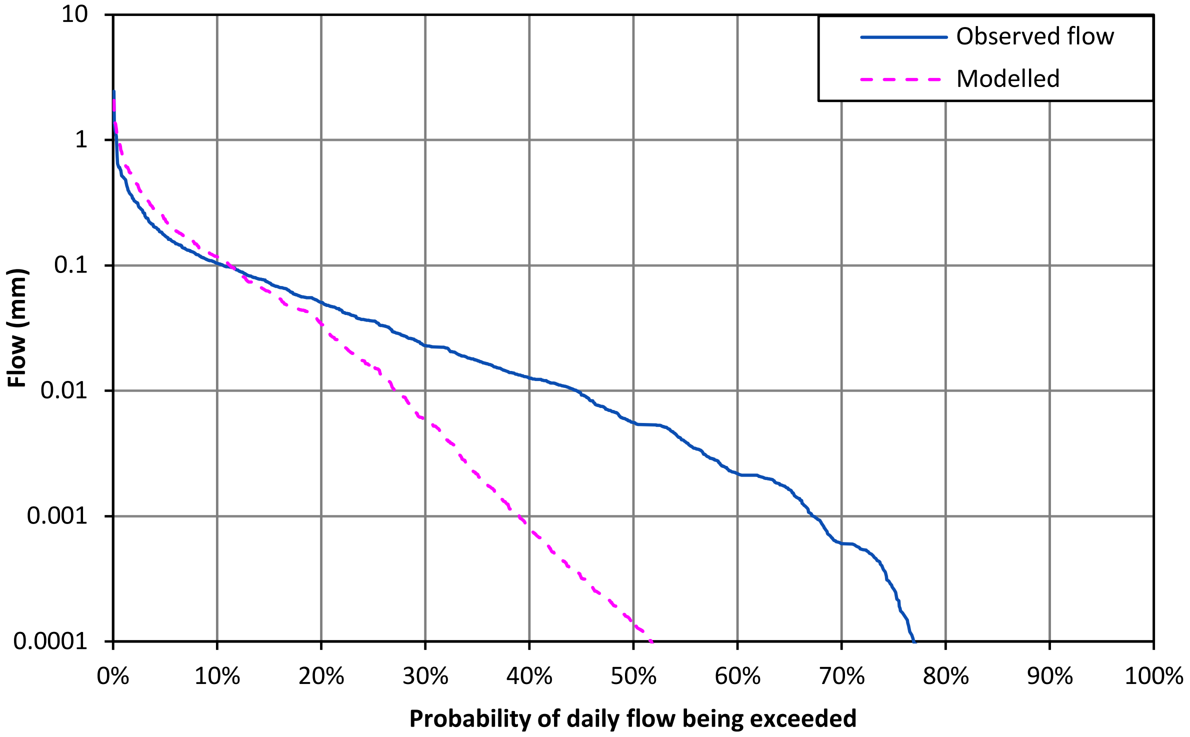


Figure D-11: Observed and modelled flow duration curves at Wongamine Brook (615030)

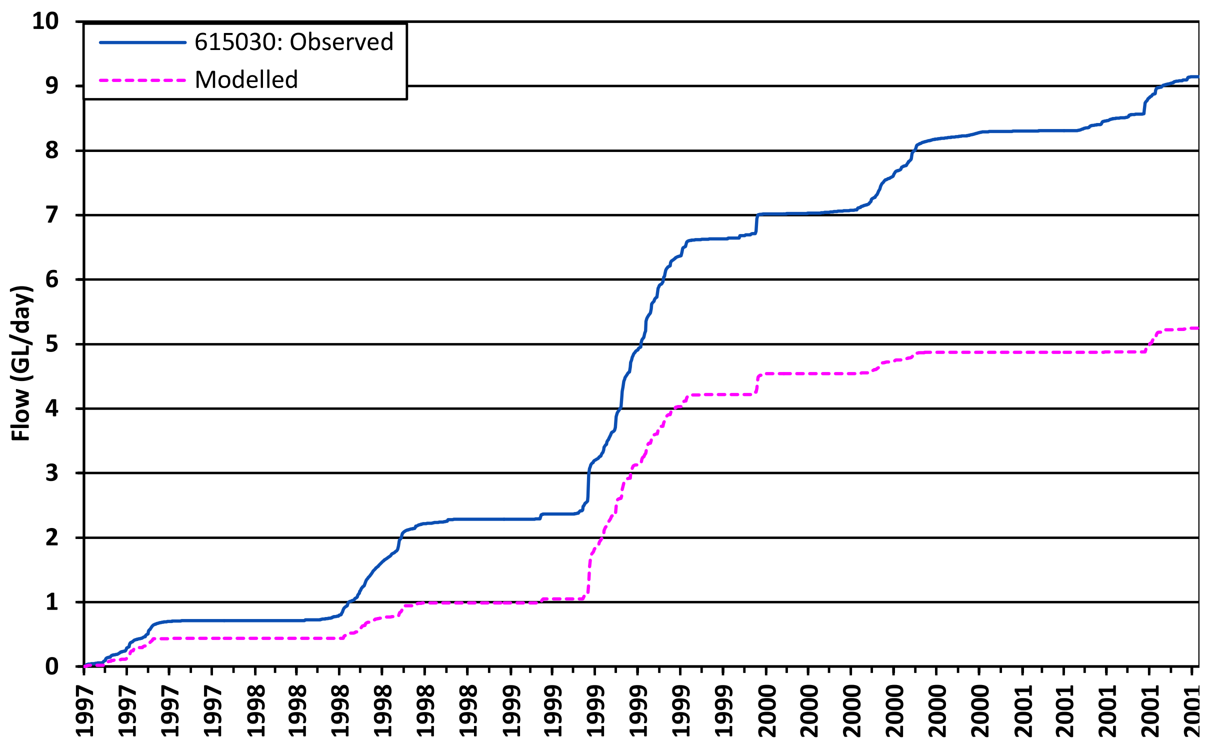


Figure D-12: Cumulative daily observed and modelled flow at Wongamine Brook (615030)

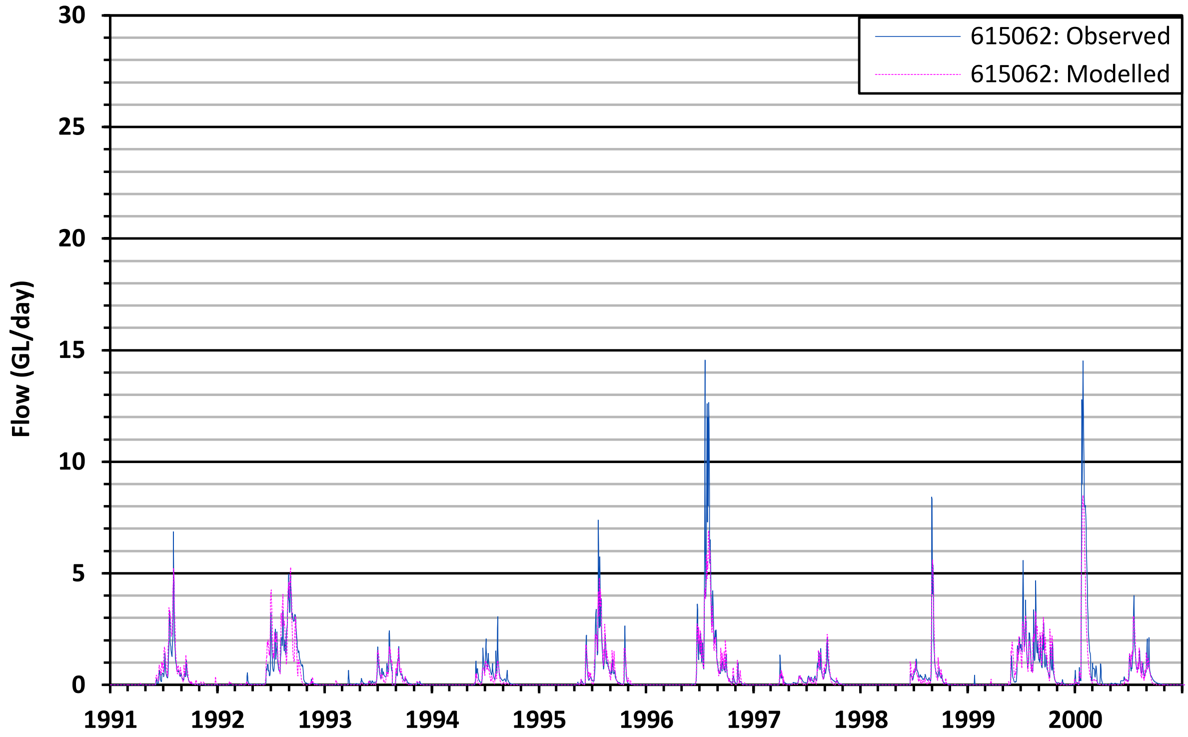


Figure D-13: Observed and modelled daily flows at Northam Weir (615062)

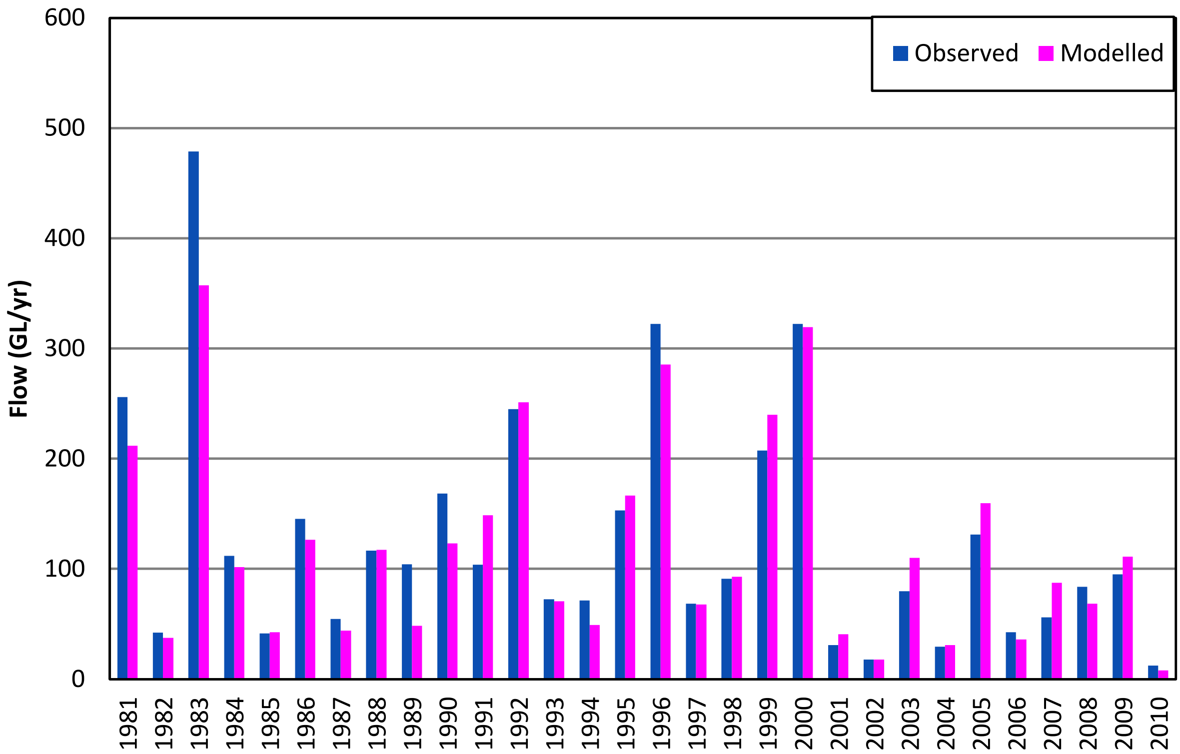


Figure D-14: Observed and modelled annual flows at Northam Weir (615062)

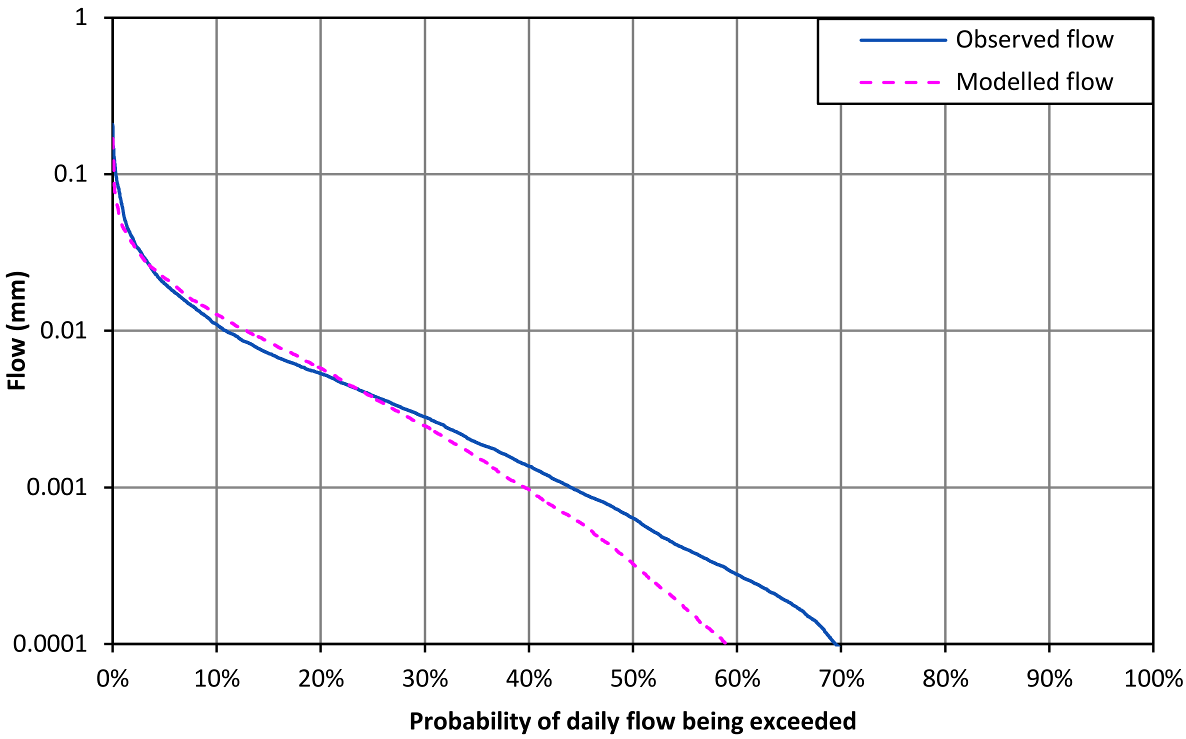


Figure D-15: Observed and modelled flow duration curves at Northam Weir (615062)

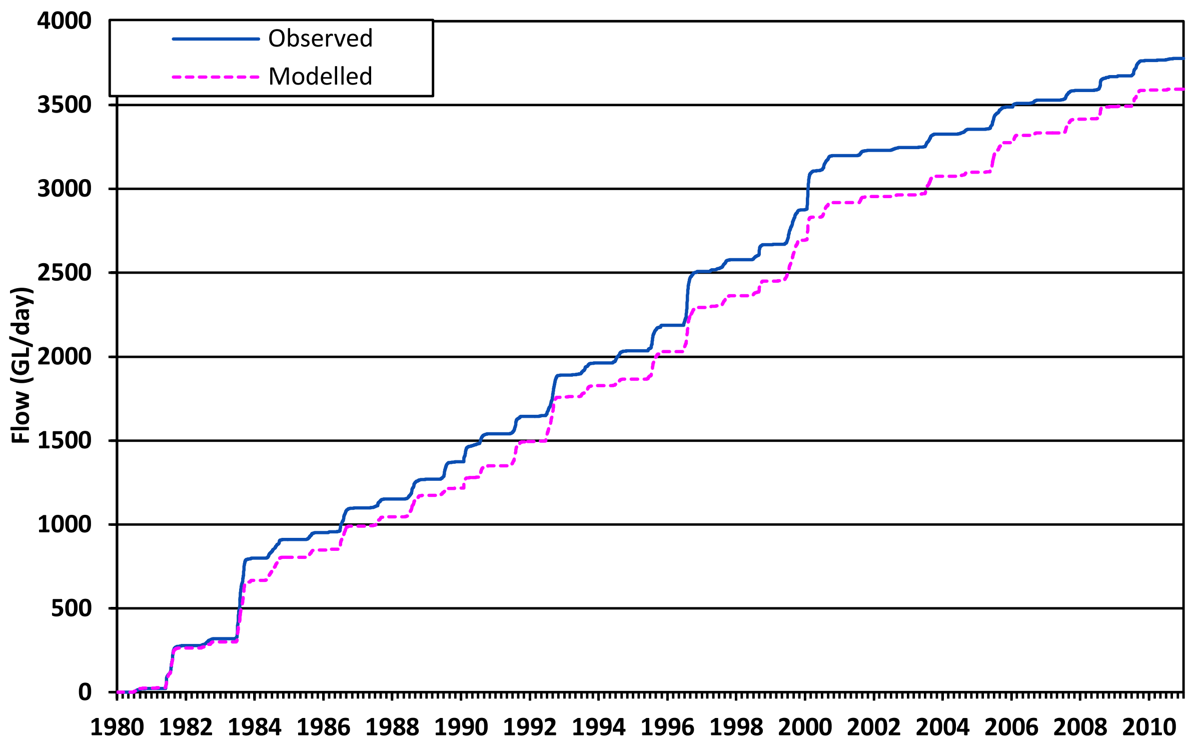


Figure D-16: Cumulative daily observed and modelled flow at Northam Weir (615062)

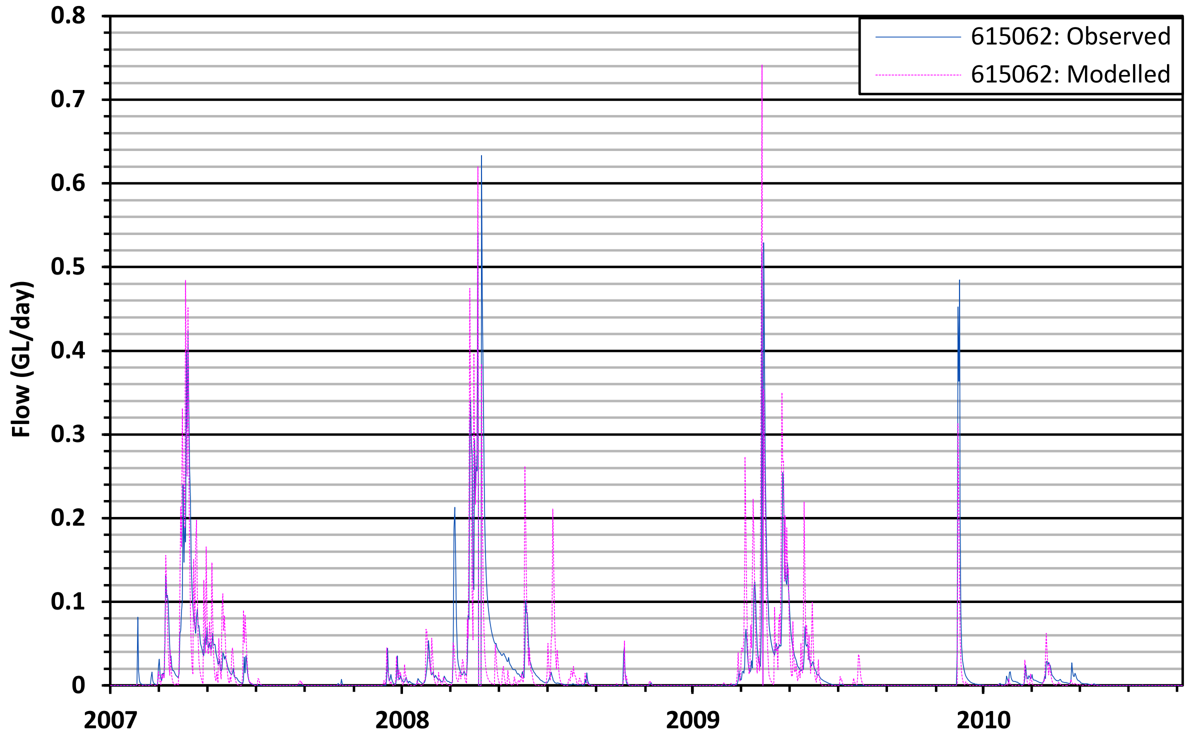


Figure D-17: Observed and modelled daily flows at Boyagarra (615063)

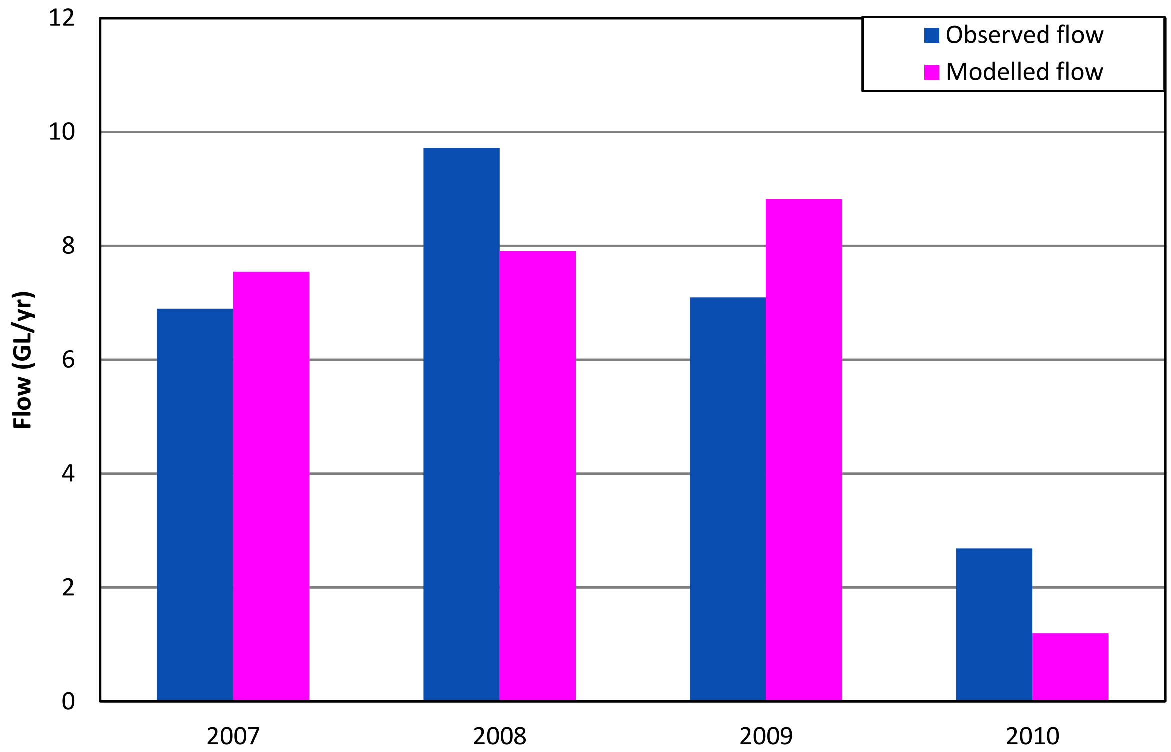


Figure D-18: Observed and modelled annual flows at Boyagarra (615063)

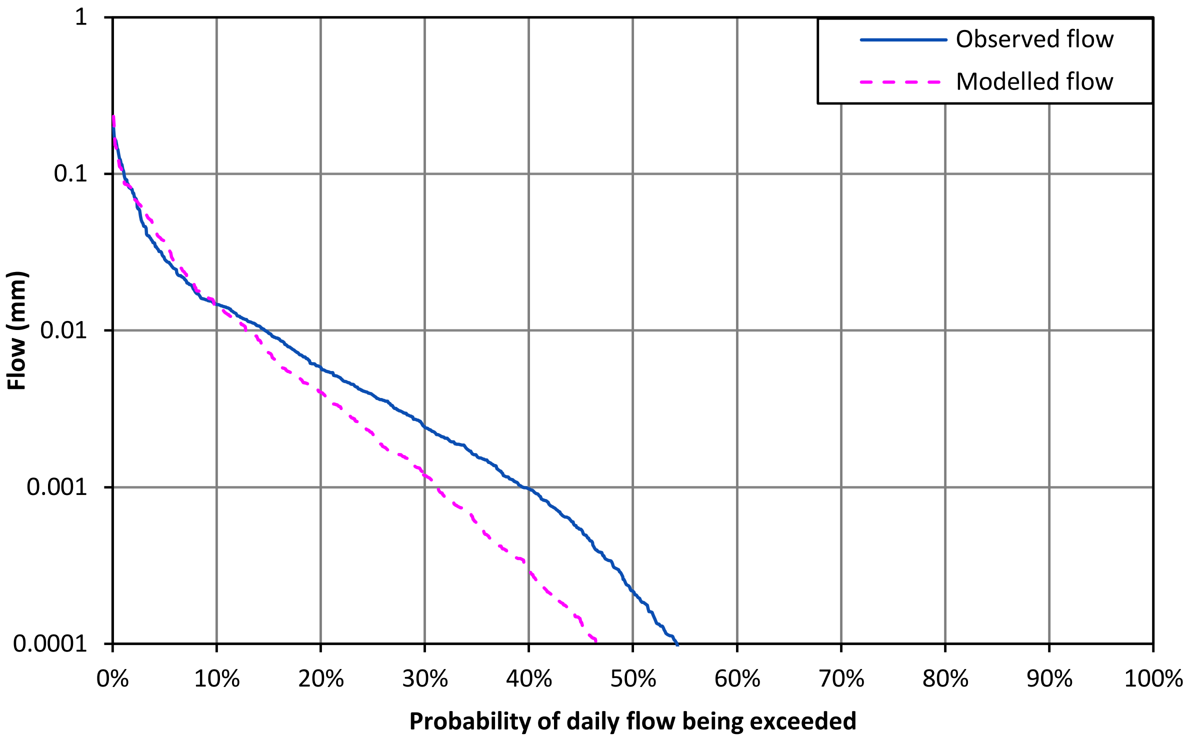


Figure D-19: Observed and modelled flow duration curves at Boyagarra (615063)

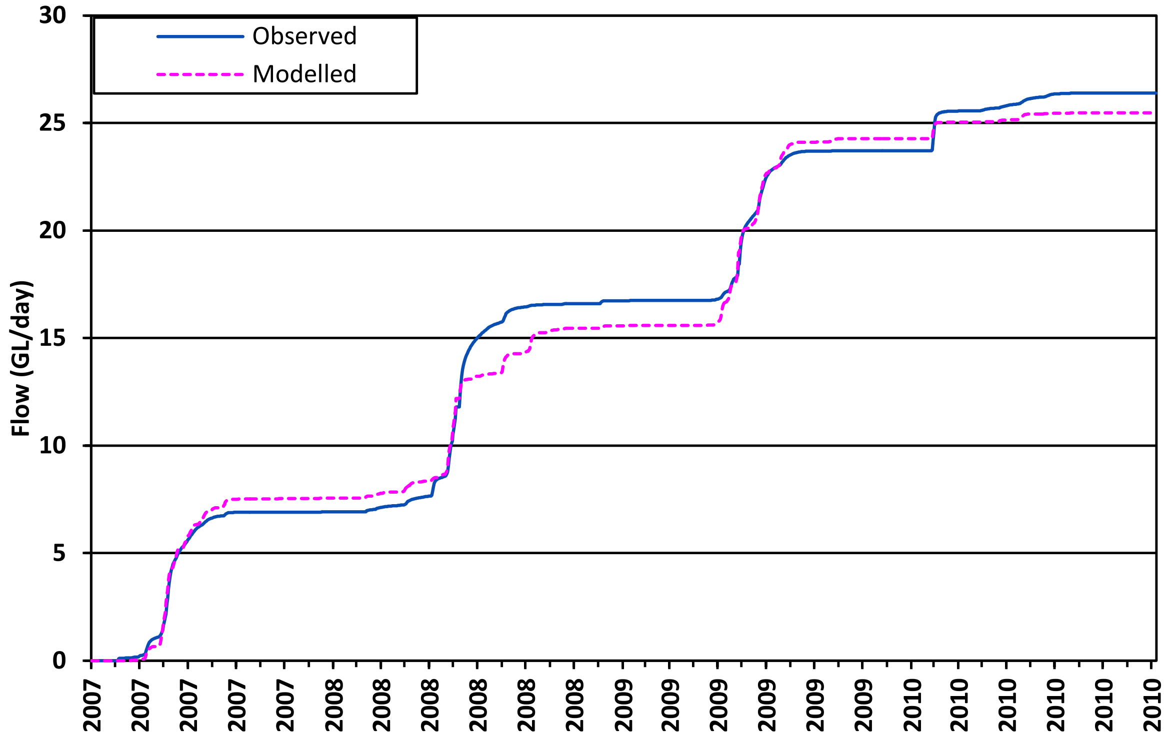


Figure D-20: Cumulative daily observed and modelled flow at Boyagarra (615063)

Wooroloo

Table D-6: Flow statistics and data quality report for all flow gauging stations used to calibrate the Wooroloo hydrological model

Site details				
Calibration weighting	1		0.5	
Site name	Karl's Ranch		Noble Falls	
Site context	Wooroloo Brook		Wooroloo Brook	
AWRC reference	616001		616005	
Flow statistics				
Start of record	1/01/1970		30/05/1980	
End of record	31/12/2010		11/06/1999	
Minimum recorded daily flow (ML/day)	0		0	
Maximum recorded daily flow (ML/day)	4521		1384	
Average daily flow (ML/day)	119		62	
Median daily flow(ML/day)	21		14	
Number of days in record	14975		6952	
Number of missing flows	82	0.5%	129	1.9%
Number of excluded data points	694	5.2%	279	5.9%
Flow quality				
Very good record	13129	87.7%	6303	90.7%
Very good record - corrections applied	902	6.0%	176	2.5%
Good record - corrections or estimations applied	168	1.1%	65	0.9%
Estimated record - good	41	0.3%	106	1.5%
Estimated record - fair	264	1.8%	0	0.0%
Estimated record - poor	238	1.6%	0	0.0%
Estimated record - not reviewed / quality not known	151	1.0%	173	2.5%
Not available	82	0.5%	57	0.8%
No record	0	0.0%	72	1.0%

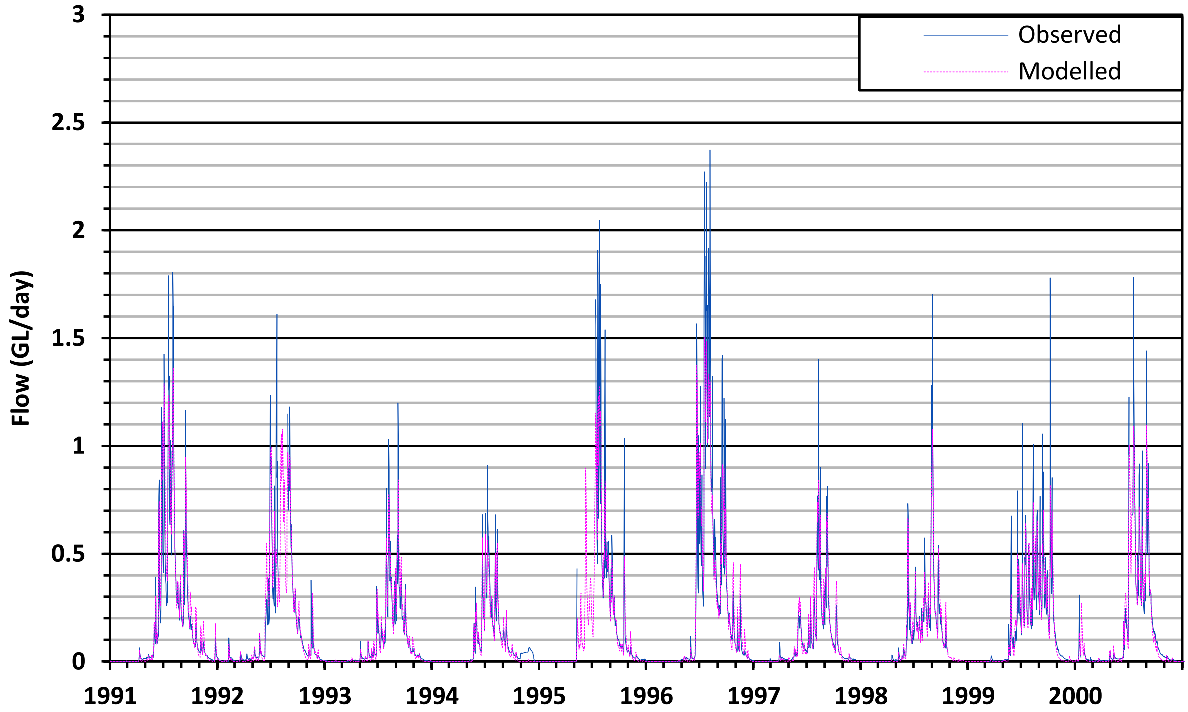


Figure D-21: Observed and modelled daily flows at Karl's Ranch (606001)

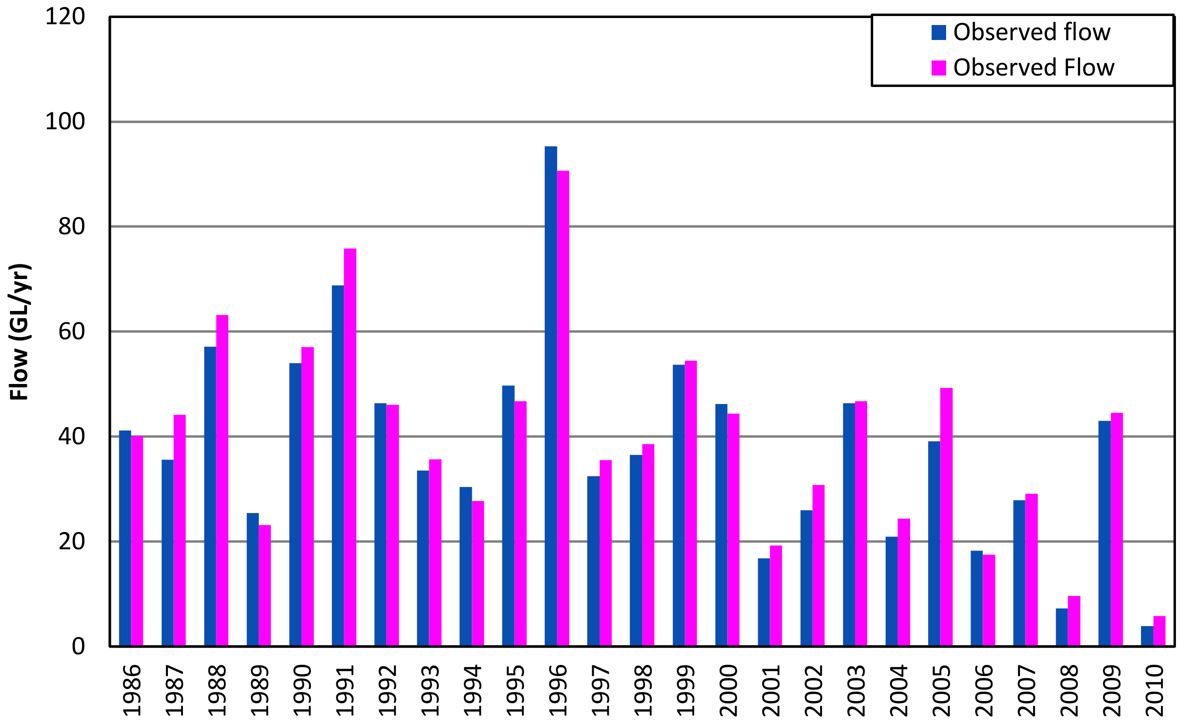


Figure D-22: Observed and modelled annual flows at Karl's Ranch (606001)

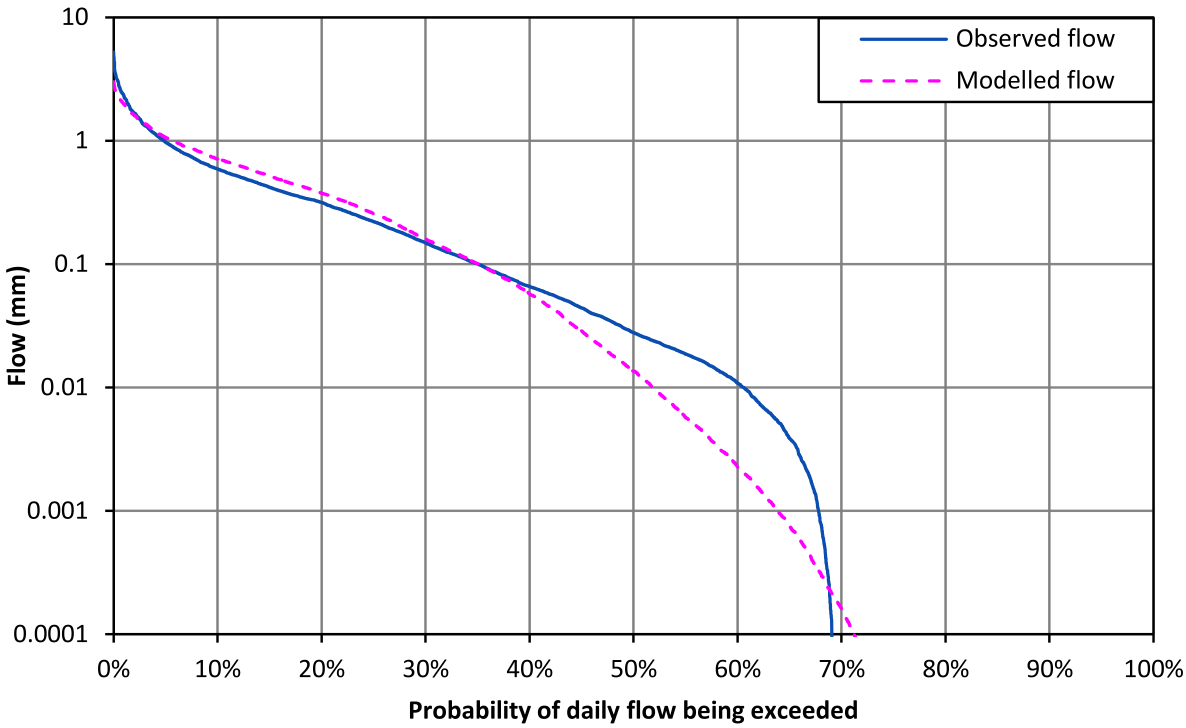


Figure D-23: Observed and modelled flow duration curves at Karl's Ranch (606001)

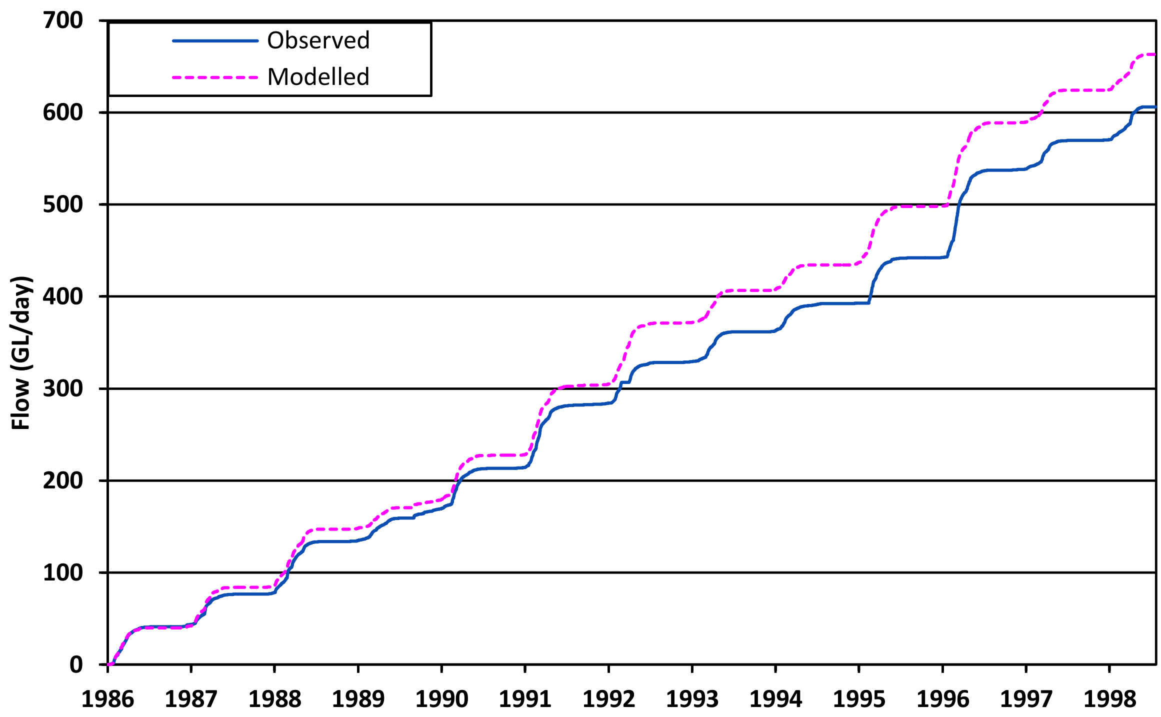


Figure D-24: Cumulative daily observed and modelled flow at Karl's Ranch (606001)

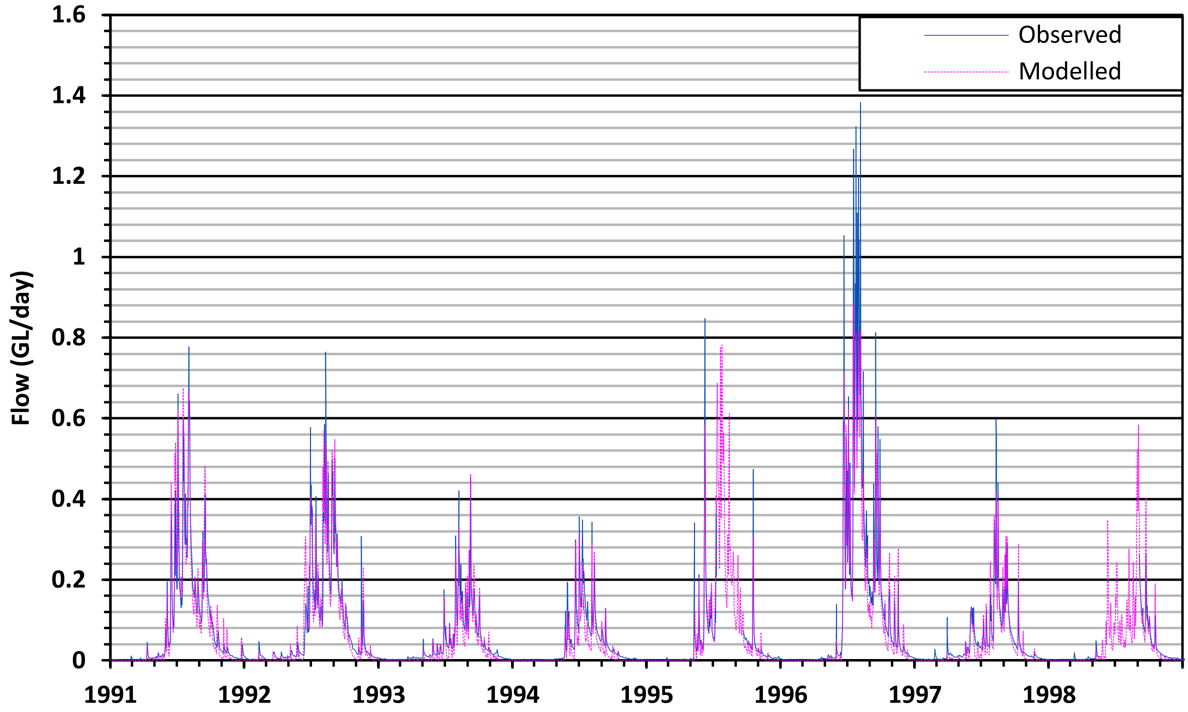


Figure D-25: Observed and modelled daily flows at Nobel Falls (606005)

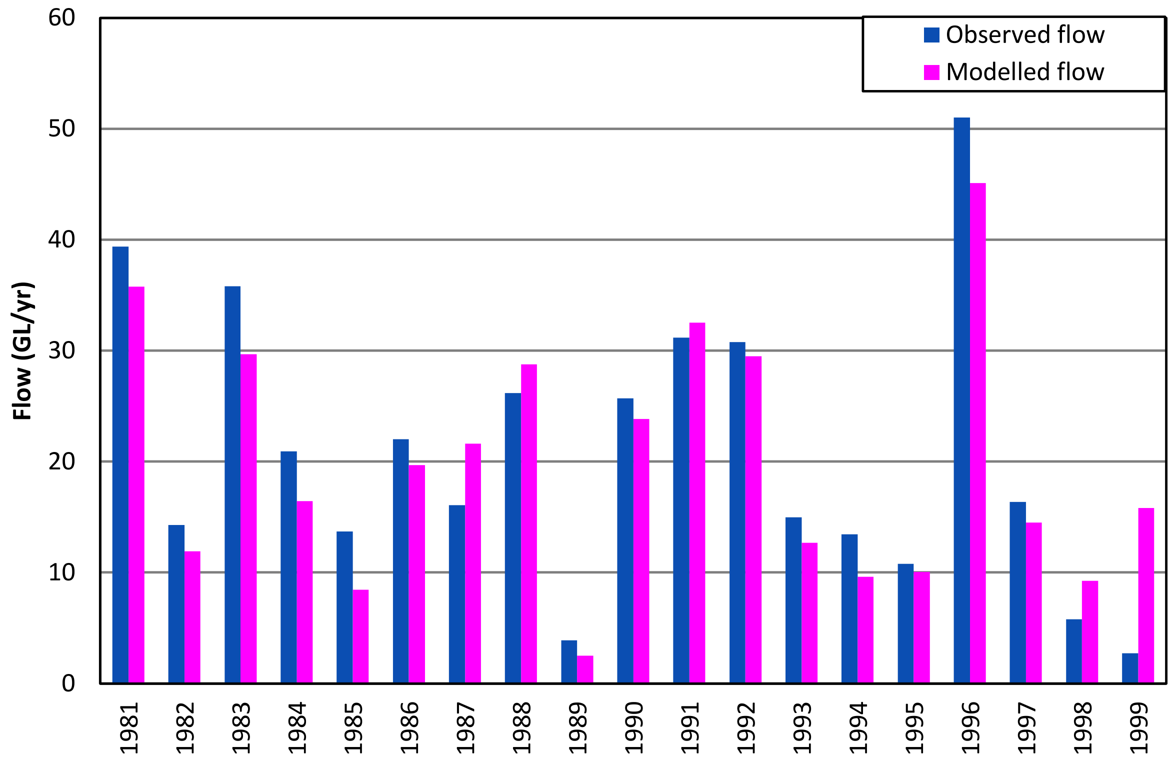


Figure D-26: Observed and modelled annual flows at Nobel Falls (606005)

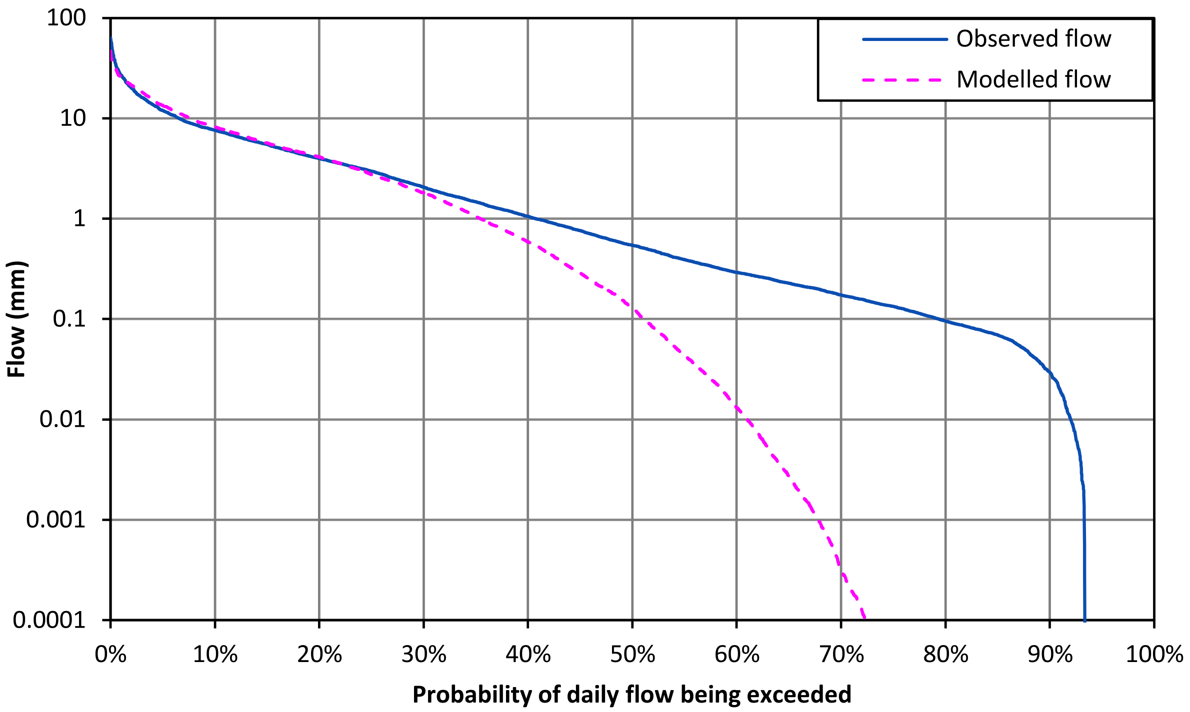


Figure D-27: Observed and modelled flow duration curves at Nobel Falls (606005)

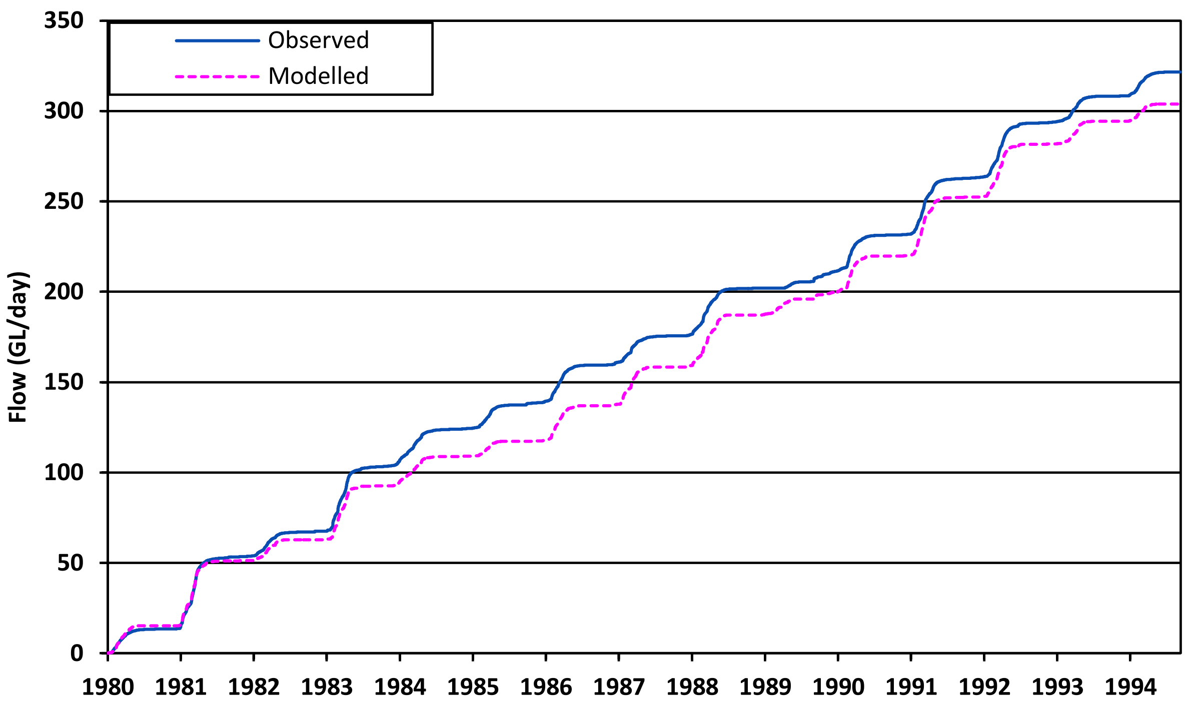


Figure D-28: Cumulative daily observed and modelled flow at Nobel Falls (606005)

Brockman

Table D-7: Flow statistics and data quality report for all flow gauging stations to calibrate the Brockman hydrological model

Site details				
Calibration weighting	1		0.5	
Site name	Yalliawirra		Tanamer	
Site context	Brockman River		Brockman River	
AWRC reference	616019		616006	
Flow statistics				
Start of record	10/04/1975		7/06/1980	
End of record	31/12/2010		31/12/2010	
Minimum recorded daily flow (ML/day)	0		0	
Maximum recorded daily flow (ML/day)	2562		2161	
Average daily flow (ML/day)	106		55	
Median daily flow(ML/day)	9		5	
Number of days in record	13050		11165	
Number of missing flows	45	0.4%	0	0.0%
Number of excluded data points	547	5.3%	213	1.9%
Flow quality				
Very good record	10676	95.6%	9995	89.5%
Very good record - corrections applied	594	5.3%	609	5.5%
Good record - corrections or estimations applied	1131	10.1%	334	3.0%
Estimated record - good	57	0.5%	14	0.1%
Estimated record - fair	119	1.1%	102	0.9%
Estimated record - poor	47	0.4%	0	0.0%
Estimated record - not reviewed / quality not known	374	3.3%	111	1.0%
Estimated rating	7	0.1%	0	0.0%
Not available	45	0.4%	0	0.0%

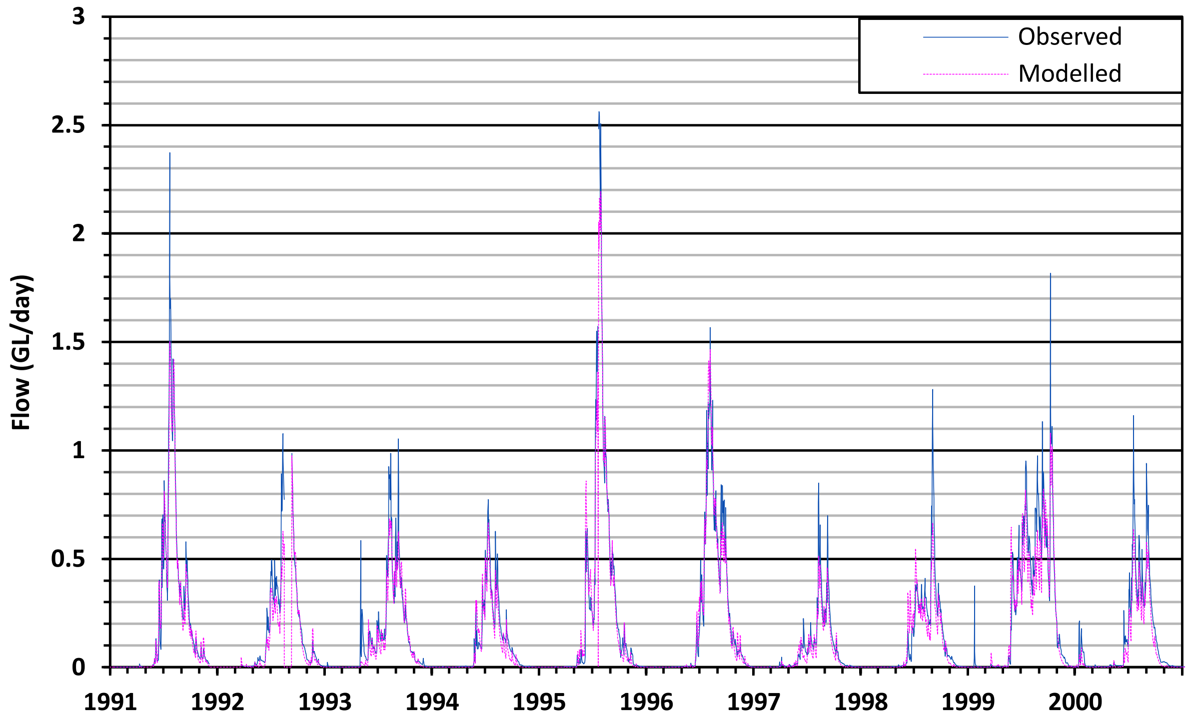


Figure D-29: Observed and modelled daily flows at Yalliawirra (606019)

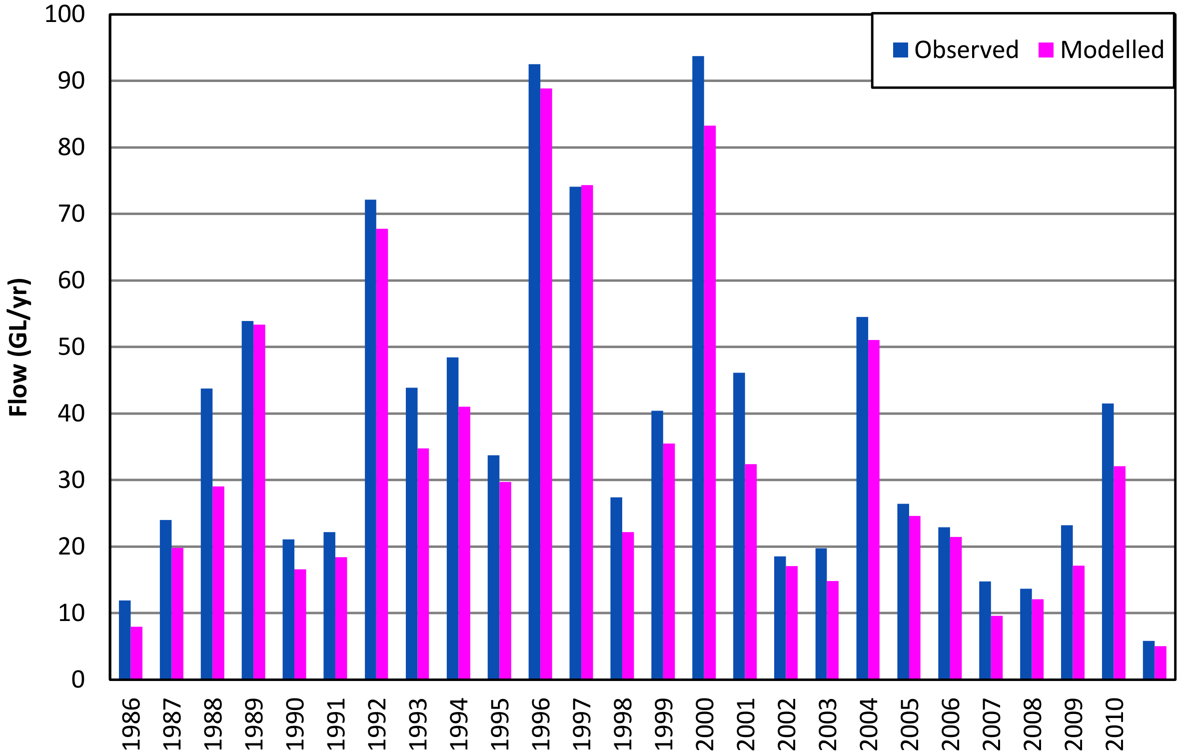


Figure D-30: Observed and modelled annual flows at Yalliawirra (606019)

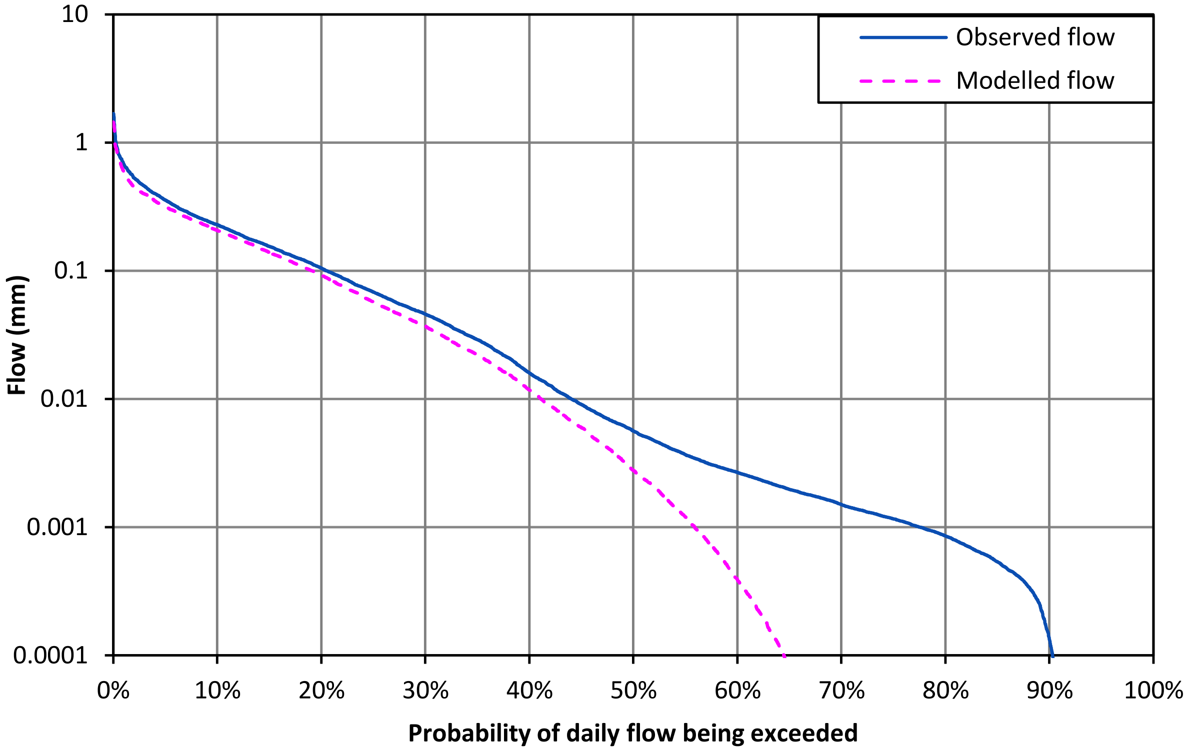


Figure D-31: Observed and modelled flow duration curves flows at Yalliawirra (606019)

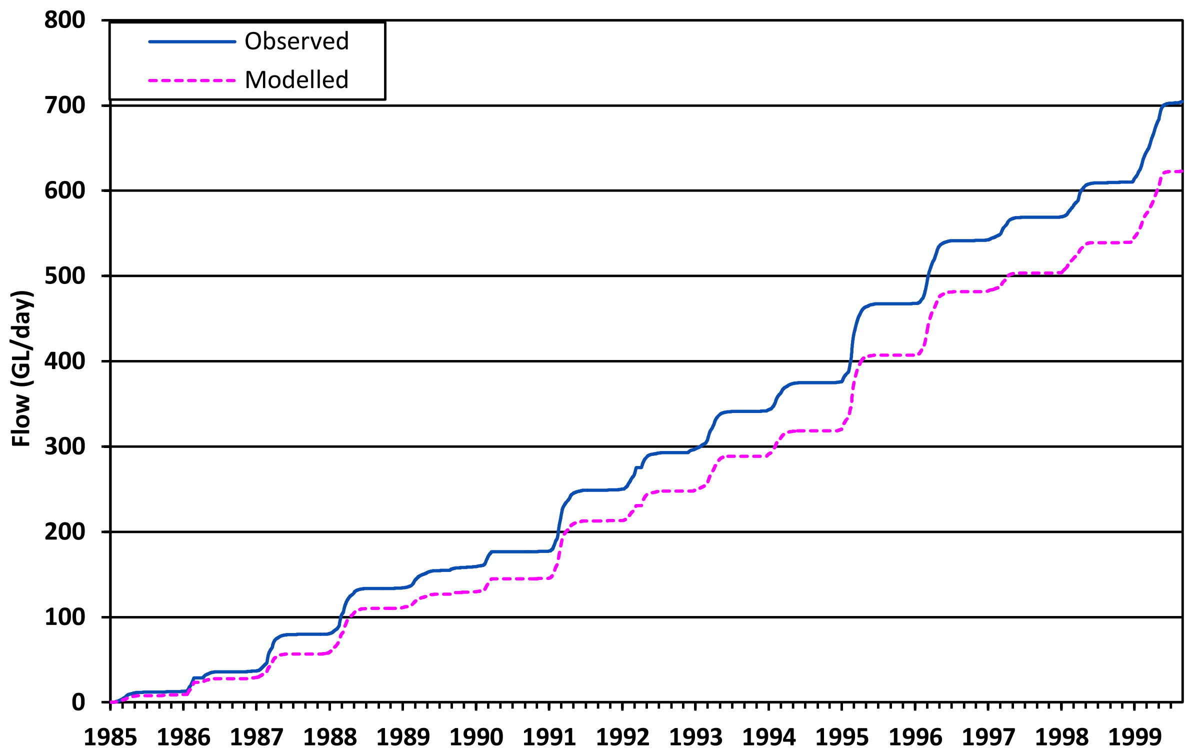


Figure D-32: Cumulative daily observed and modelled flow at Yalliawirra (606019)

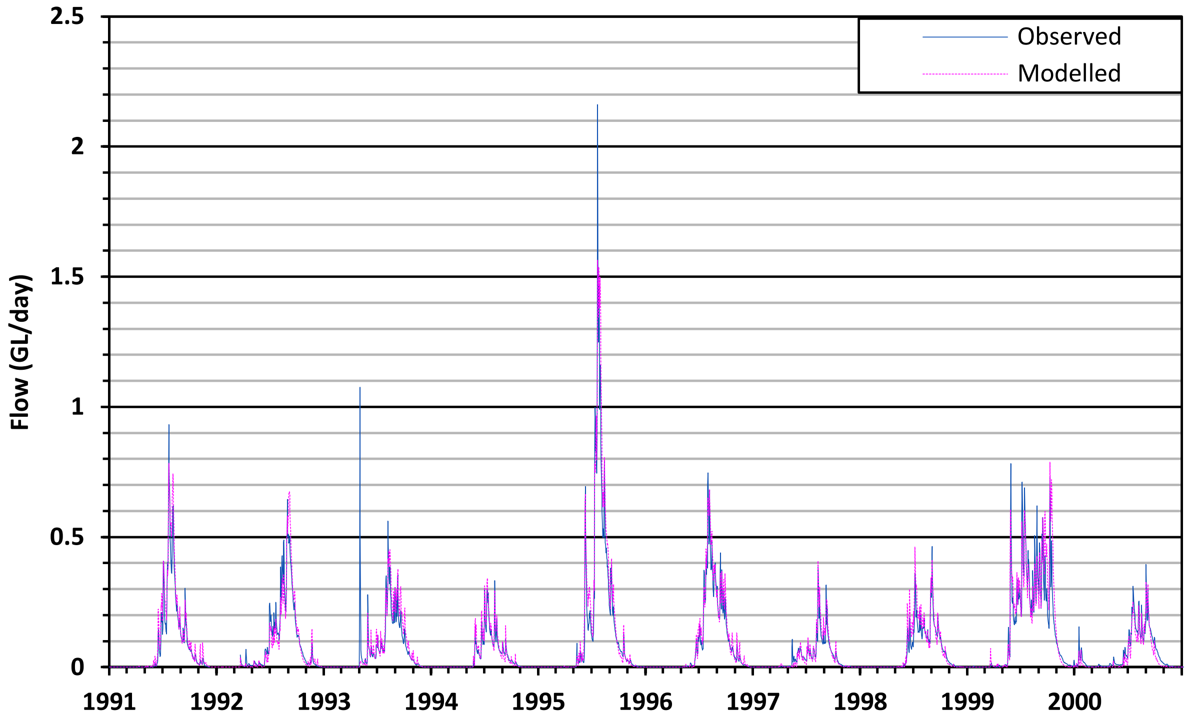


Figure D-33: Observed and modelled daily flows at Tanamerah (616006)

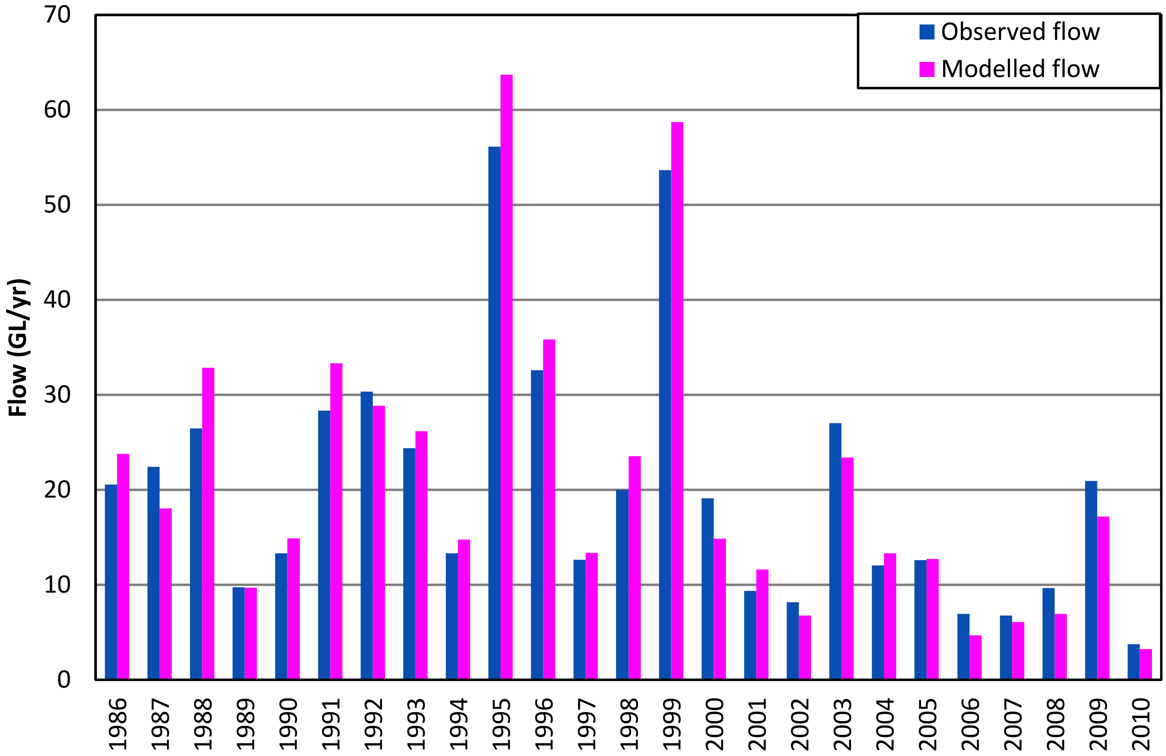


Figure D-34: Observed and modelled annual flows at Tanamerah (616006)

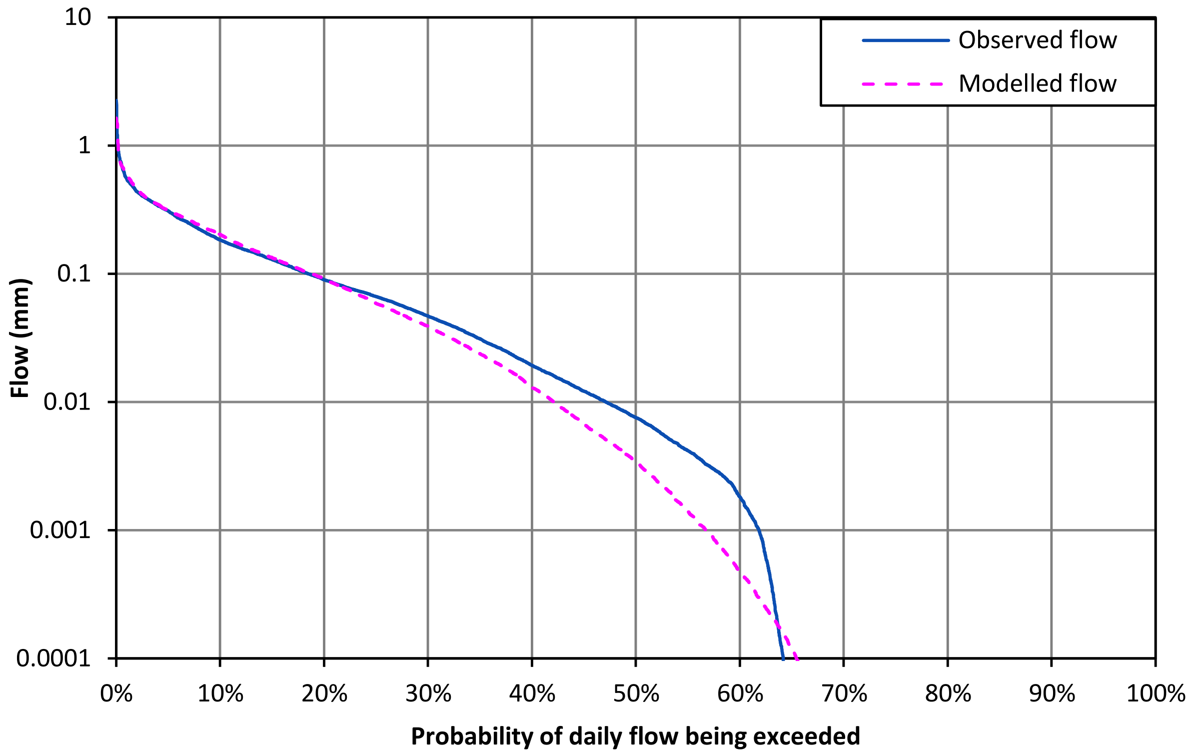


Figure D-35: Observed and modelled flow duration curves at Tanamerah (616006)

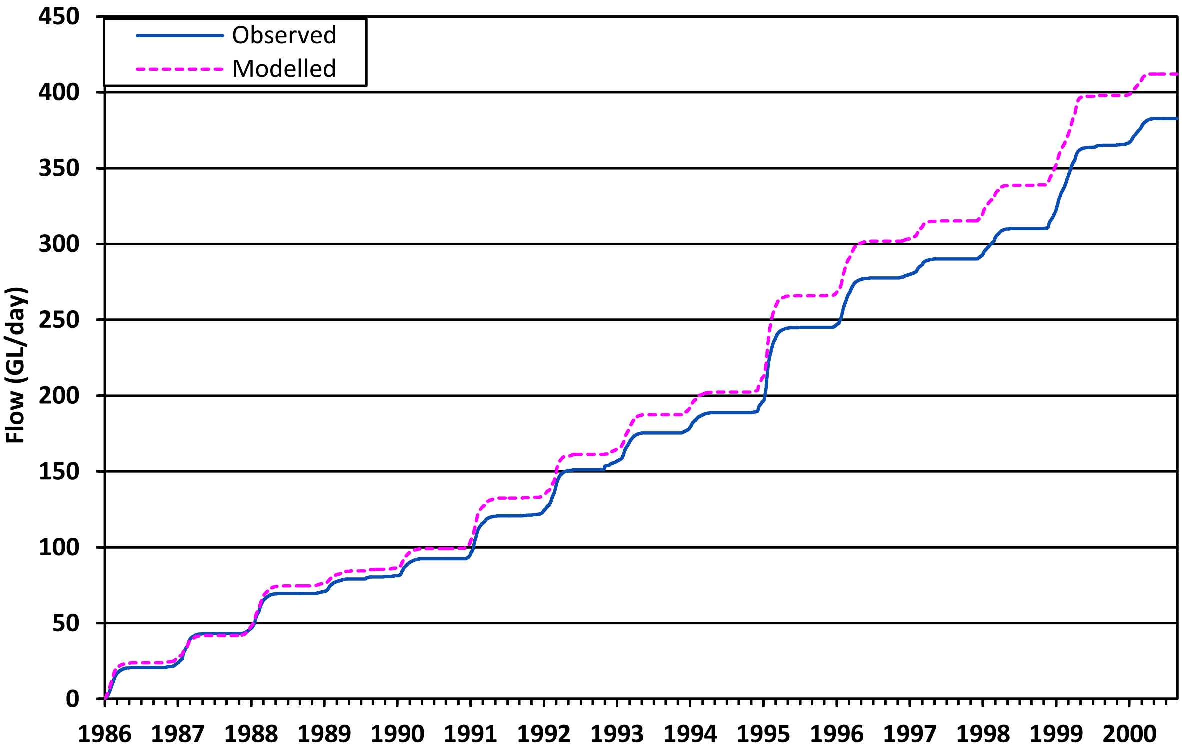


Figure D-36: Cumulative daily observed and modelled flow at Tanamerah (616006)

Mortlock North and Mortlock East

Table D-8: Flow statistics and data quality report for all flow gauging stations used to calibrate the Mortlock hydrological model

Site details				
Calibration weighting	1		Validation only	
Site name	O'Discrolls		Frenches	
Site context	Mortlock River East Branch		Mortlock River North Branch	
AWRC reference	615020		615013	
Flow statistics				
Start of record	25/04/1975		21/06/1975	
End of record	31/12/2010		31/12/2010	
Minimum recorded daily flow (ML/day)	0		0	
Maximum recorded daily flow (ML/day)	9393		5221	
Average daily flow (ML/day)	44		47	
Median daily flow(ML/day)	0		3	
Number of days in record	13035		12978	
Number of missing flows	29	0.2%	9	0.1%
Number of excluded data points	227	2.0%	470	3.7%
Flow quality				
Very good record	11021	84.5%	9418	72.6%
Very good record - corrections applied	1758	13.5%	695	5.4%
Good record - corrections or estimations applied	187	1.4%	273	2.1%
Estimated record - good	24	0.2%	21	0.2%
Estimated record - fair	0	0.0%	101	0.8%
Estimated record - poor	8	0.1%	13	0.1%
Estimated record - not reviewed / quality not known	8	0.1%	62	0.5%
Estimated rating	0	0.0%	2386	18.4%
Not available	29	0.2%	9	0.1%

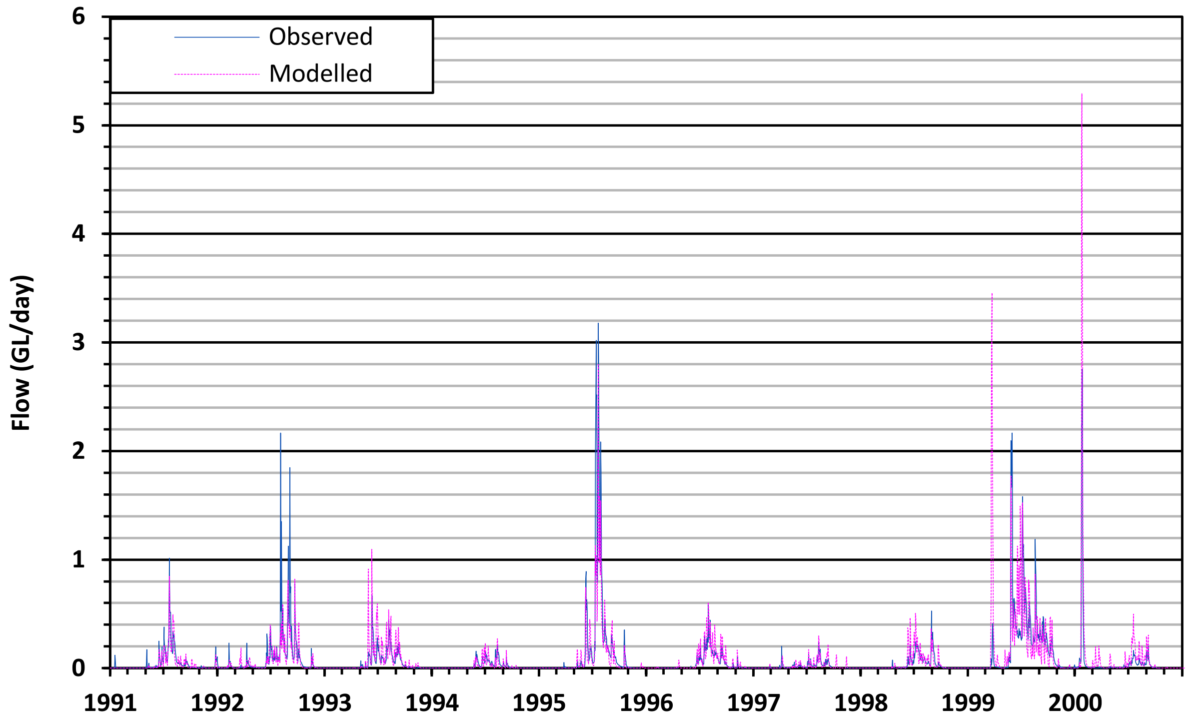


Figure D-37: Observed and modelled daily flows at Frenches (615013)

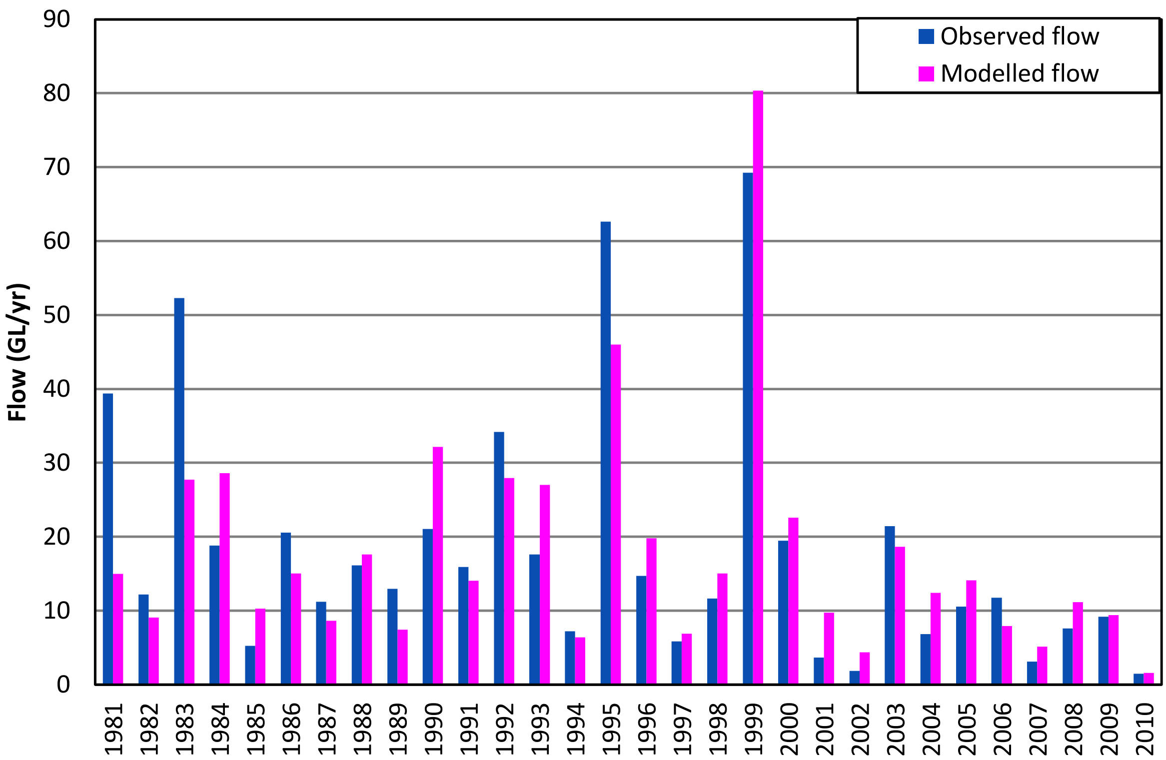


Figure D-38: Observed and modelled annual flows at Frenches (615013)

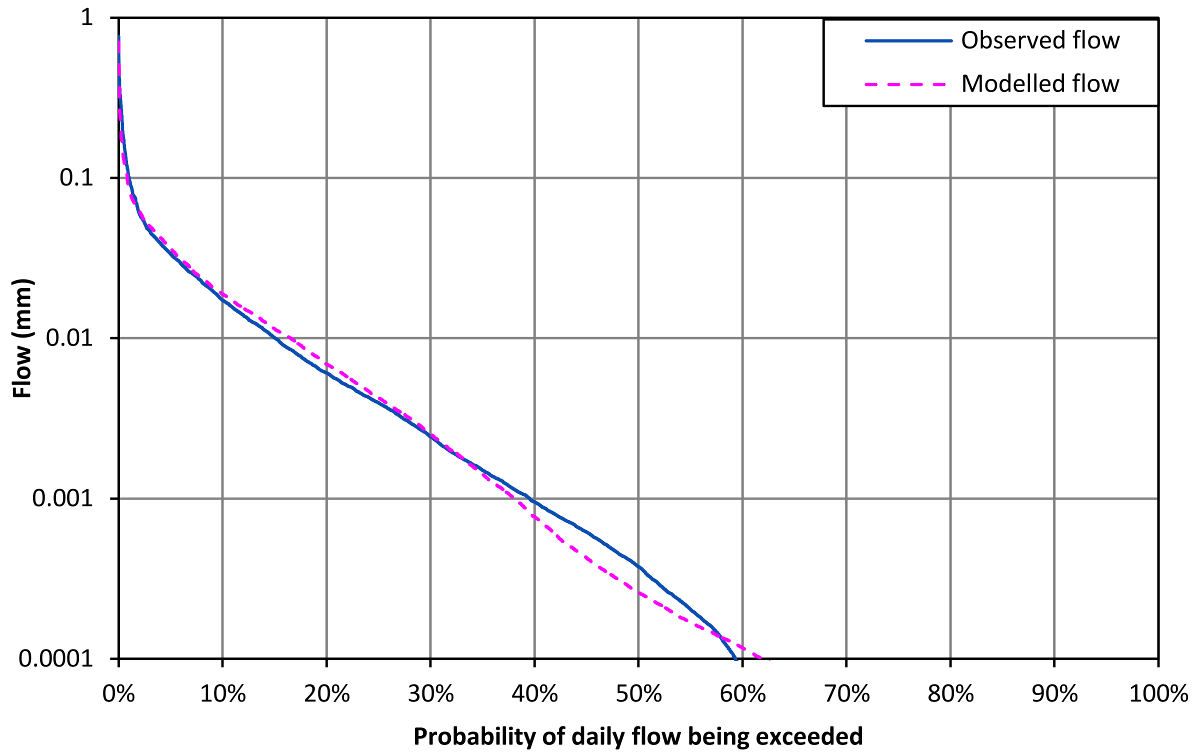


Figure D-39: Observed and modelled flow duration curves annual flows at Frenches (615013)

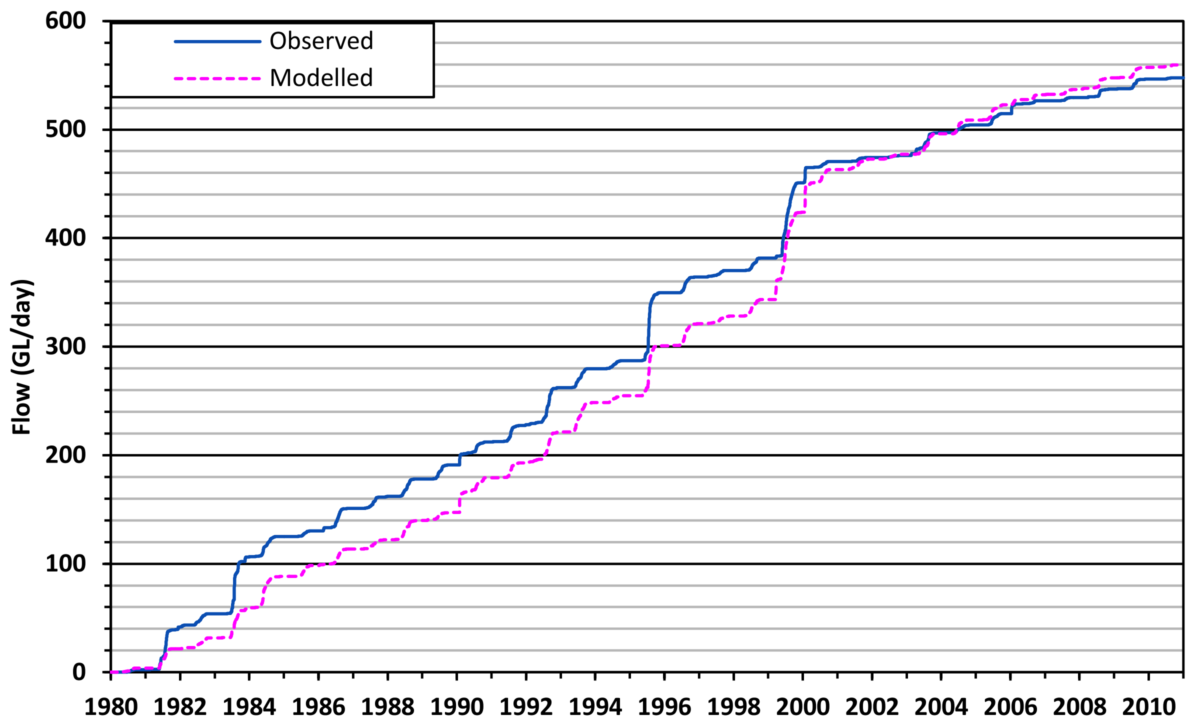


Figure D-40: Cumulative daily observed and modelled flow at Frenches (615013)

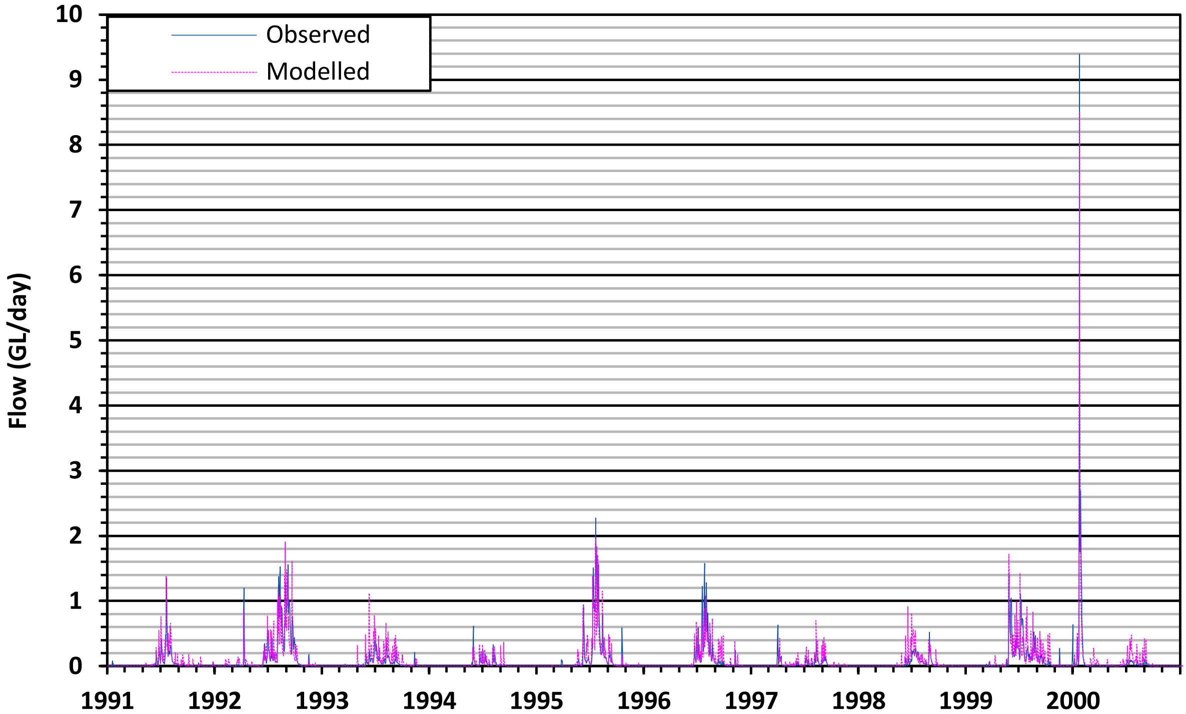


Figure D-41: Observed and modelled daily flows at O'Driscolls Farm (615020)

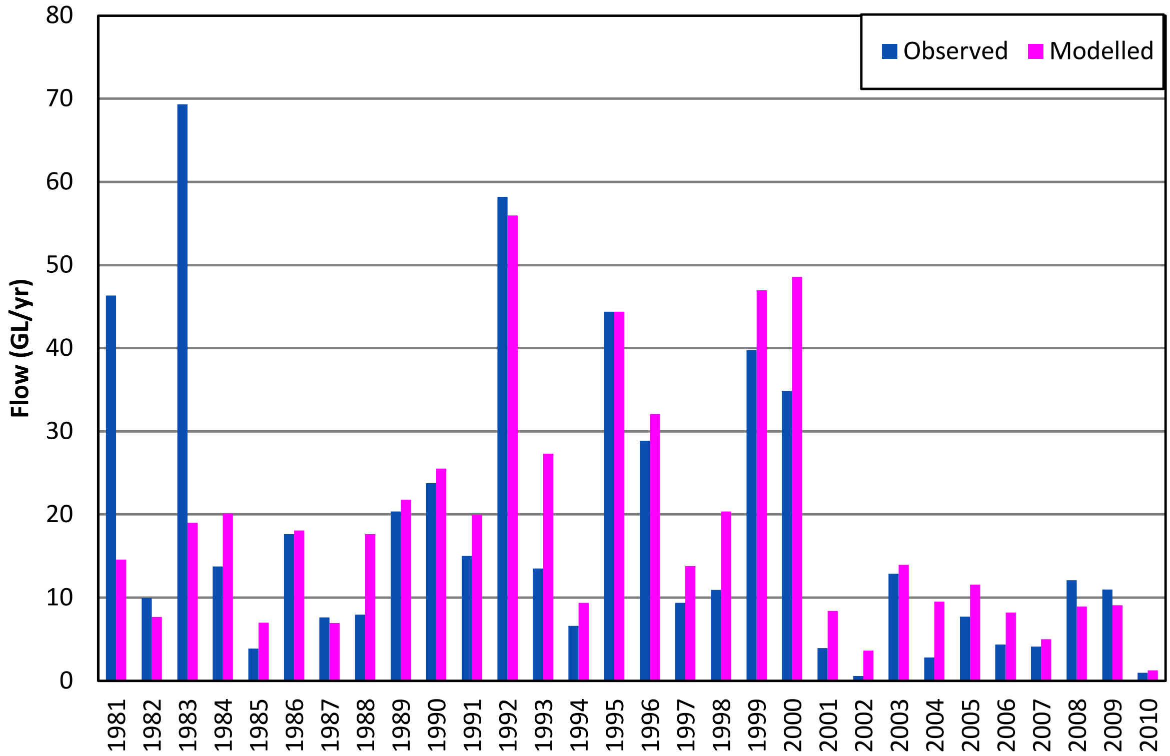


Figure D-42: Observed and modelled annual flows at O'Driscolls Farm (615020)

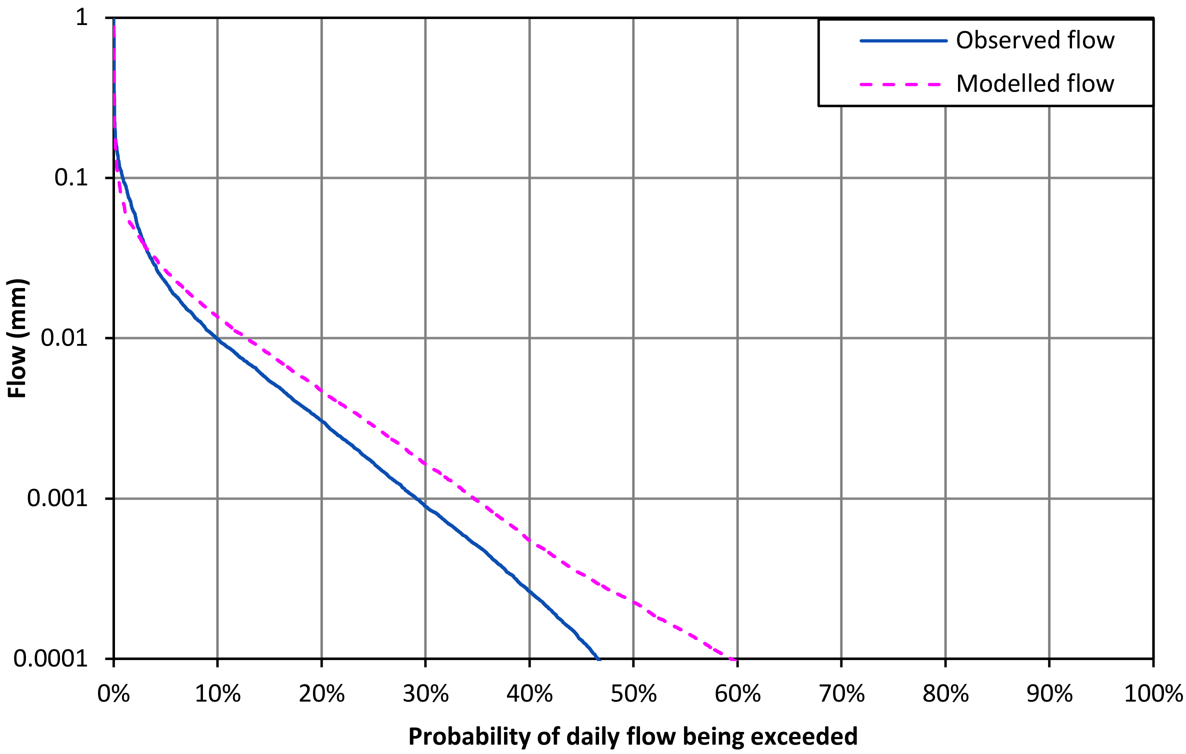


Figure D-43: Observed and modelled flow duration curves annual flows at O'Driscolls Farm (615020)

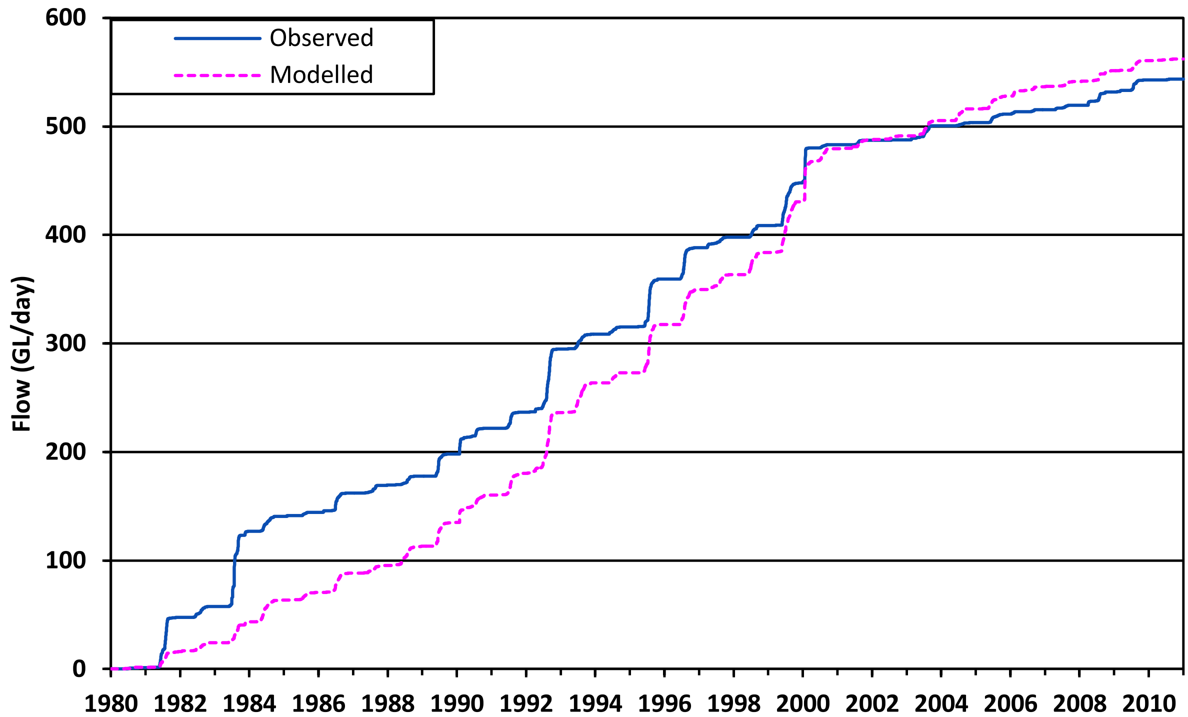


Figure D-44: Cumulative daily observed and modelled flow at O'Driscolls Farm (615020)

Dale

Table D-9: Flow statistics and data quality report for all flow gauging stations in the Dale catchment

Site details				
Calibration weighting	1		0.5	
Site name	Waterhatch Bridge		Brookton Highway	
Site context	Dale River		Dale River South	
AWRC reference	615027		615222	
Flow statistics				
Start of record	10/06/1995		1/01/1970	
End of record	31/12/2010		21/05/1999	
Minimum recorded daily flow (ML/day)	0		0	
Maximum recorded daily flow (ML/day)	9536		1803	
Average daily flow (ML/day)	111		17	
Median daily flow(ML/day)	14		2	
Number of days in record	5684		11718	
Number of missing flows	0	0.0%	1220	10.4%
Number of excluded data points	396	7.0%	68	5.6%
Flow quality				
Very good record	1628	28.6%	9842	84.0%
Very good record - corrections applied	2473	43.5%	423	3.6%
Good record - corrections or estimations applied	649	11.4%	165	1.4%
Estimated record - good	113	2.0%	0	0.0%
Estimated record - fair	138	2.4%	0	0.0%
Estimated record - poor	136	2.4%	0	0.0%
Estimated record - not reviewed / quality not known	499	8.8%	67	0.6%
Estimated rating	39	0.7%	0	0.0%
Not available	9	0.2%	1	0.0%
No record	0	0.0%	235	2.0%

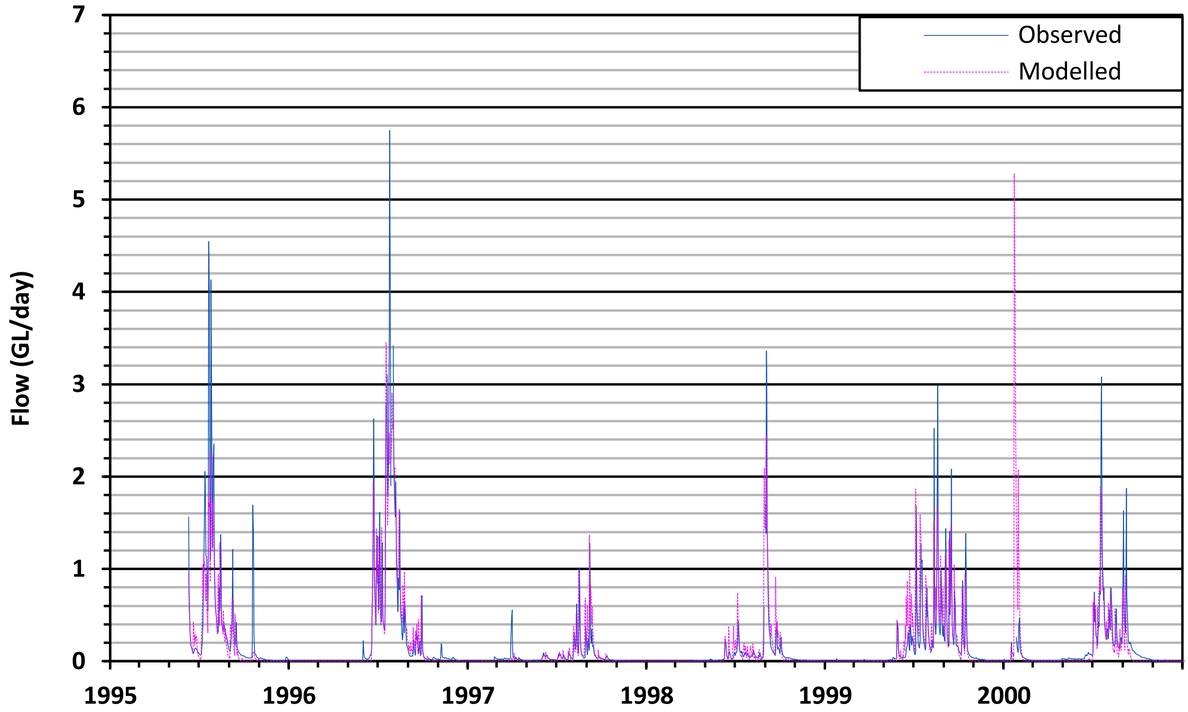


Figure D-45: Observed and modelled daily flows at Waterhatch Bridge (615027)

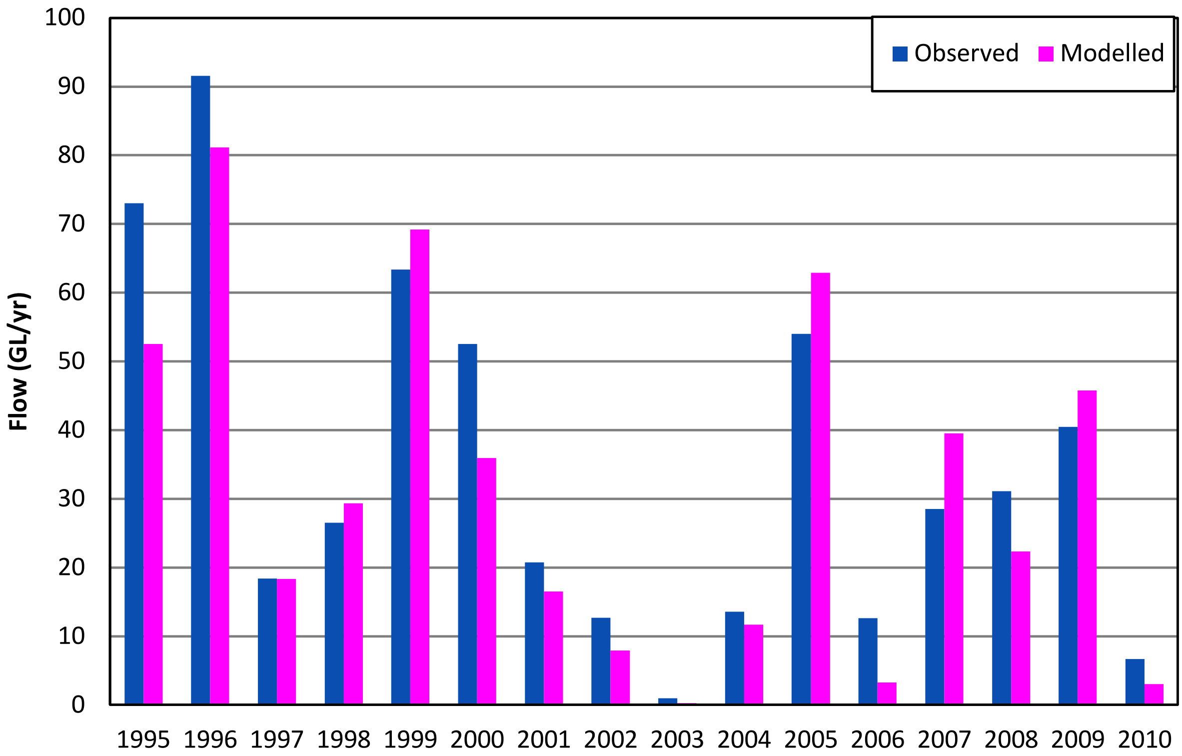


Figure D-46: Observed and modelled annualflows at Waterhatch Bridge (615027)

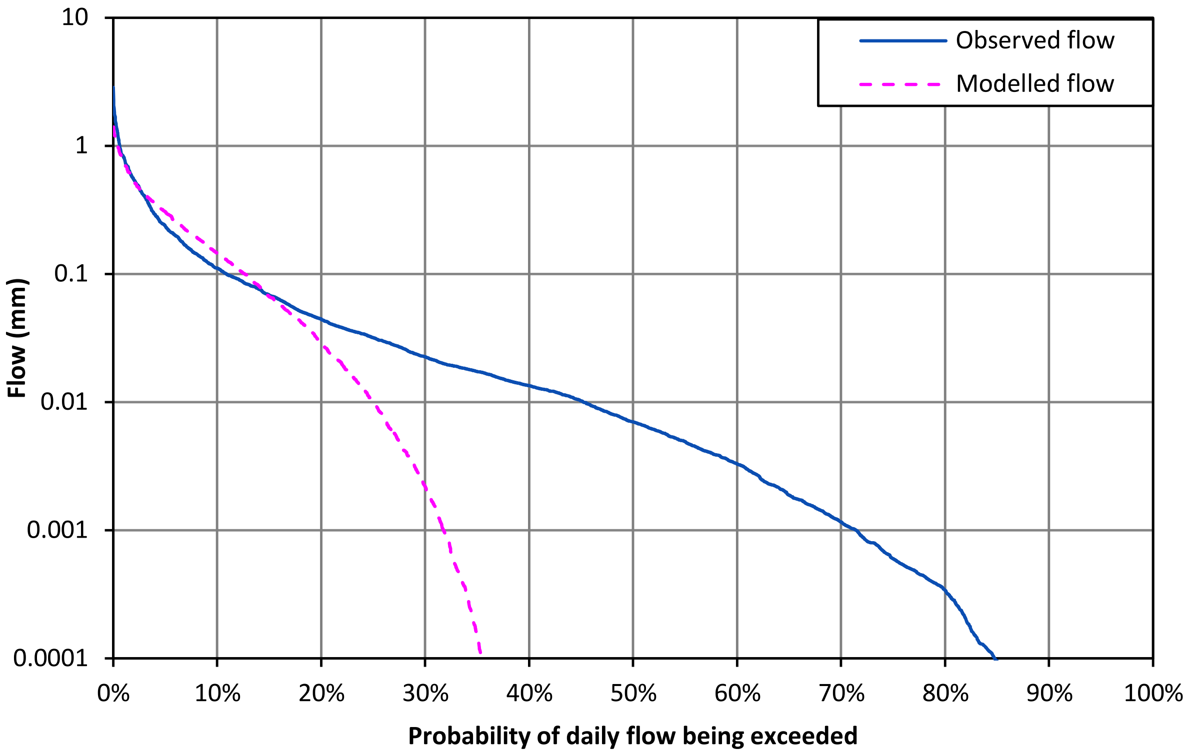


Figure D-47: Observed and modelled flow duration curves at Waterhatch Bridge (615027)

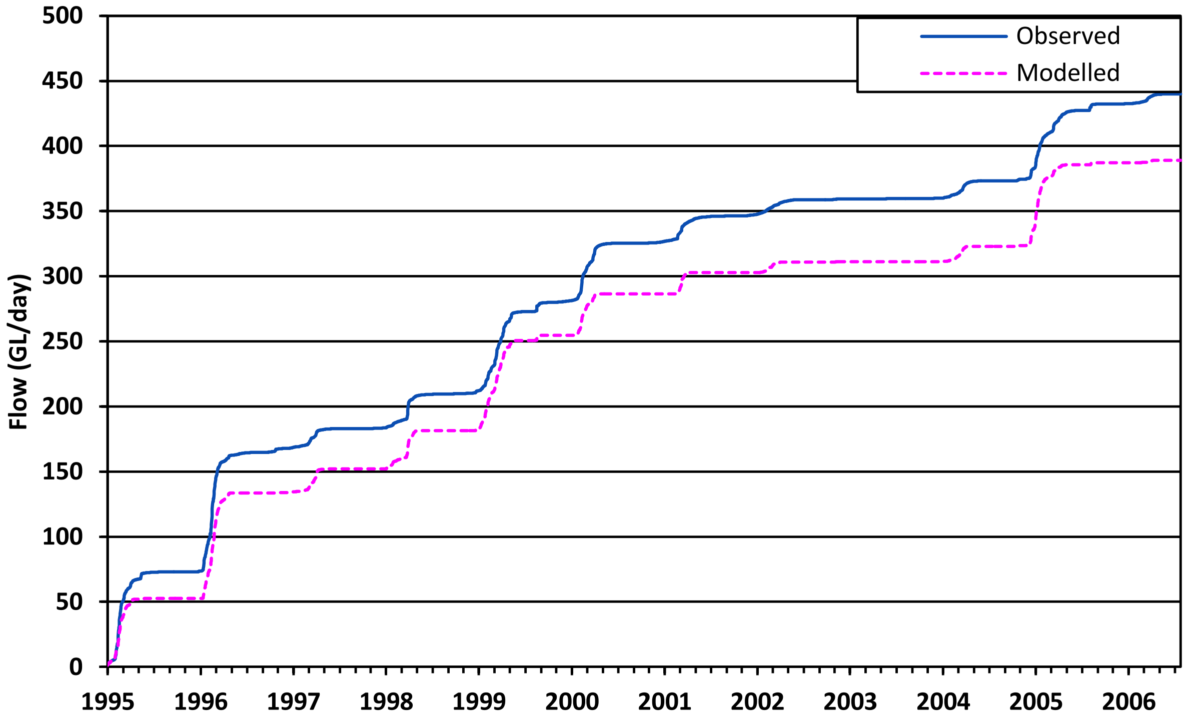


Figure D-48: Cumulative daily observed and modelled flow at Waterhatch Bridge (615027)

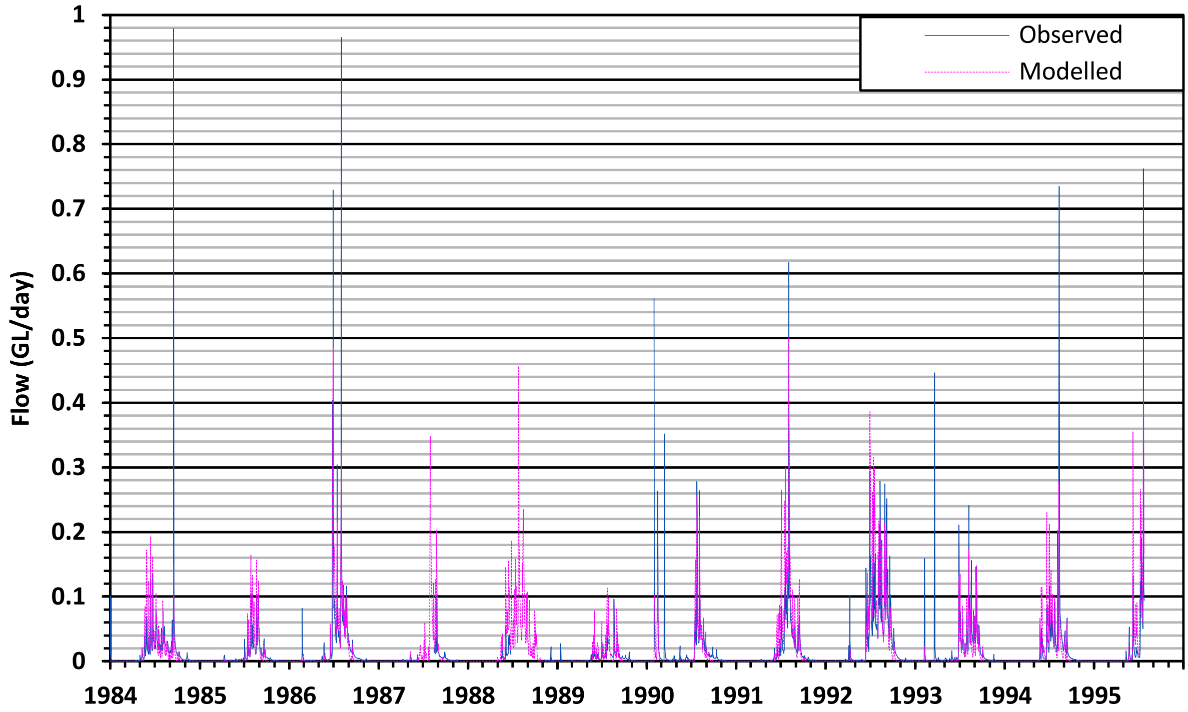


Figure D-49: Observed and modelled daily flows at Brookton Highway (615222)

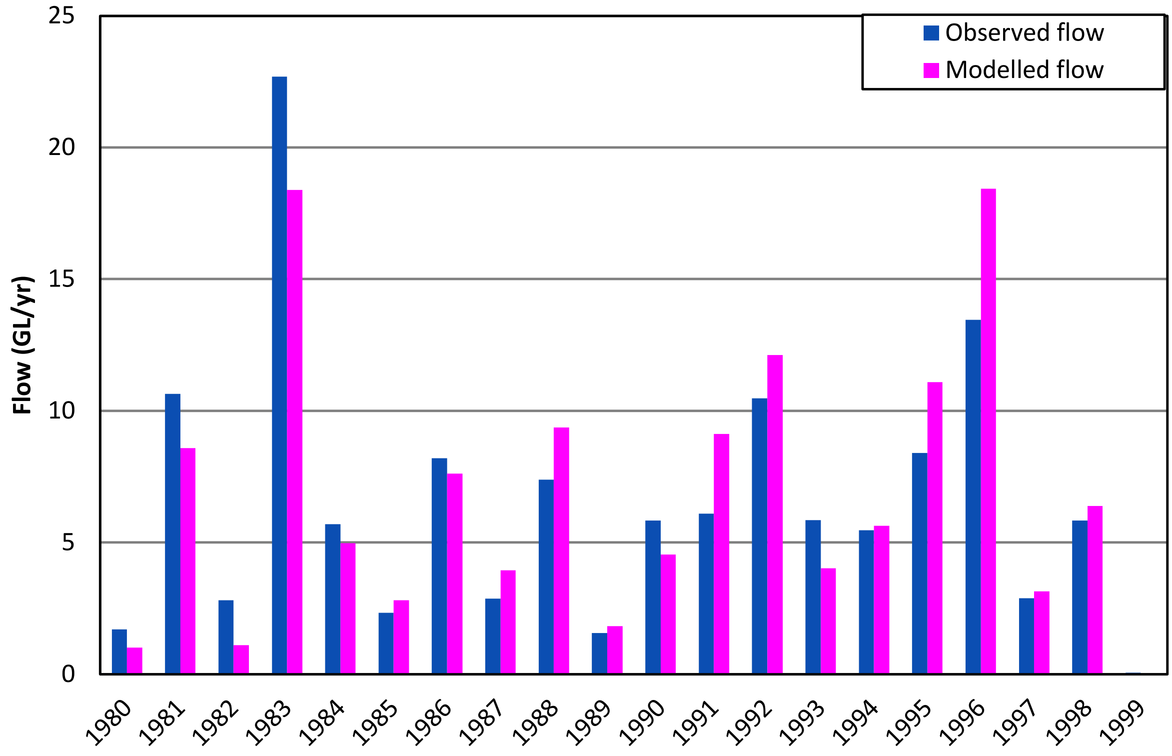


Figure D-50: Observed and modelled annual flows at Brookton Highway (615222)

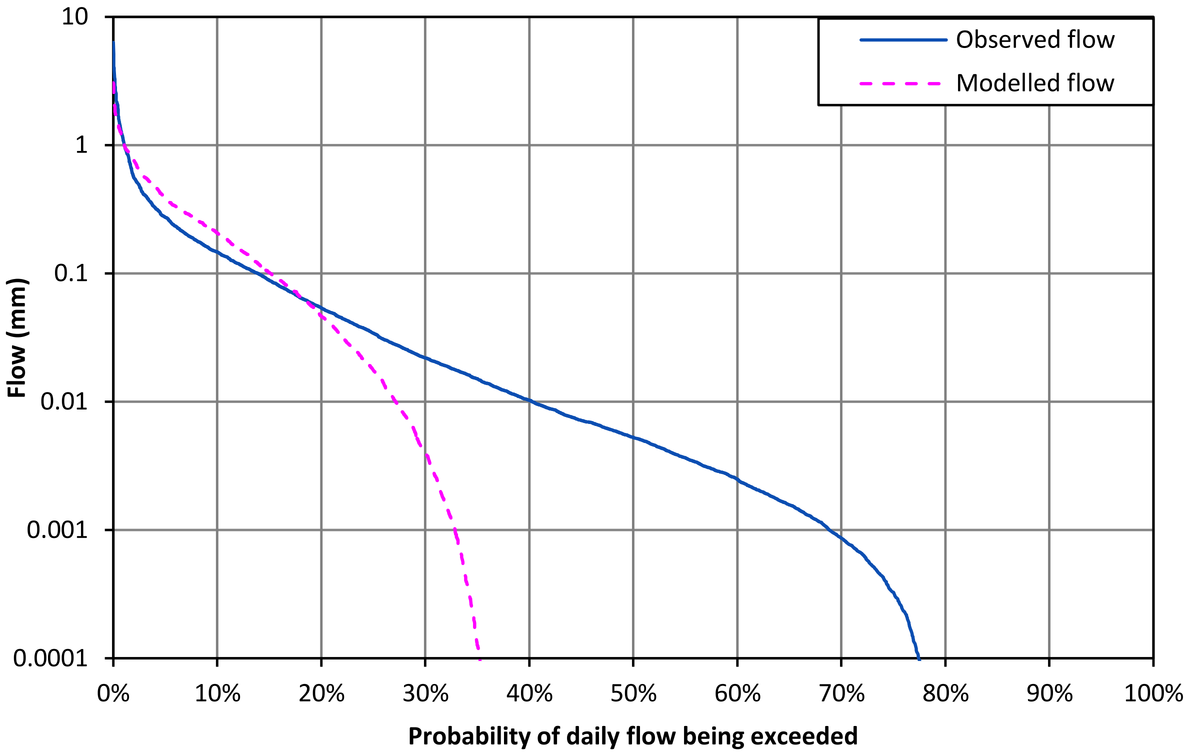


Figure D-51: Observed and modelled flow duration curves at Brookton Highway (615222)

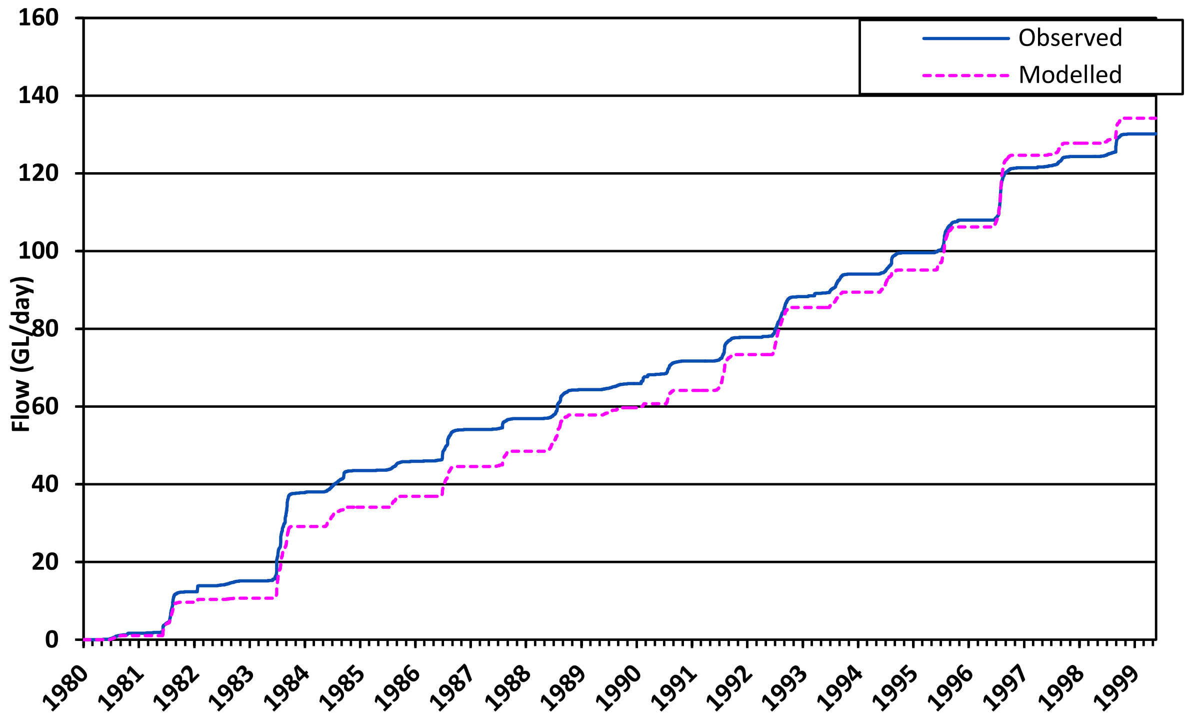


Figure D-52: Cumulative daily observed and modelled flow at Brookton Highway (615222)

Lockhart

Table D-10: Flow statistics and data quality report for all flow gauging stations in the Lockhart catchment

Site details		
Site name	Kwolyn Hill	
Site context	Lockhart River	
AWRC reference	615012	
Flow statistics		
Start of record	20/02/1976	
End of record	31/12/2010	
Minimum recorded daily flow (ML/day)	0	
Maximum recorded daily flow (ML/day)	7195	
Average daily flow (ML/day)	22	
Median daily flow(ML/day)	0	
Number of days in record	12734	
Number of missing flows	0	0.0%
Number of excluded data points	604	4.7%
Flow quality		
Very good record	11301	88.7%
Very good record - corrections applied	829	6.5%
Good record - corrections or estimations applied	214	1.7%
Estimated record - fair	173	1.4%
Estimated record - poor	12	0.1%
Estimated record - not reviewed / quality not known	188	1.5%
Theoretical rating	4	0.0%
Estimated rating	13	0.1%

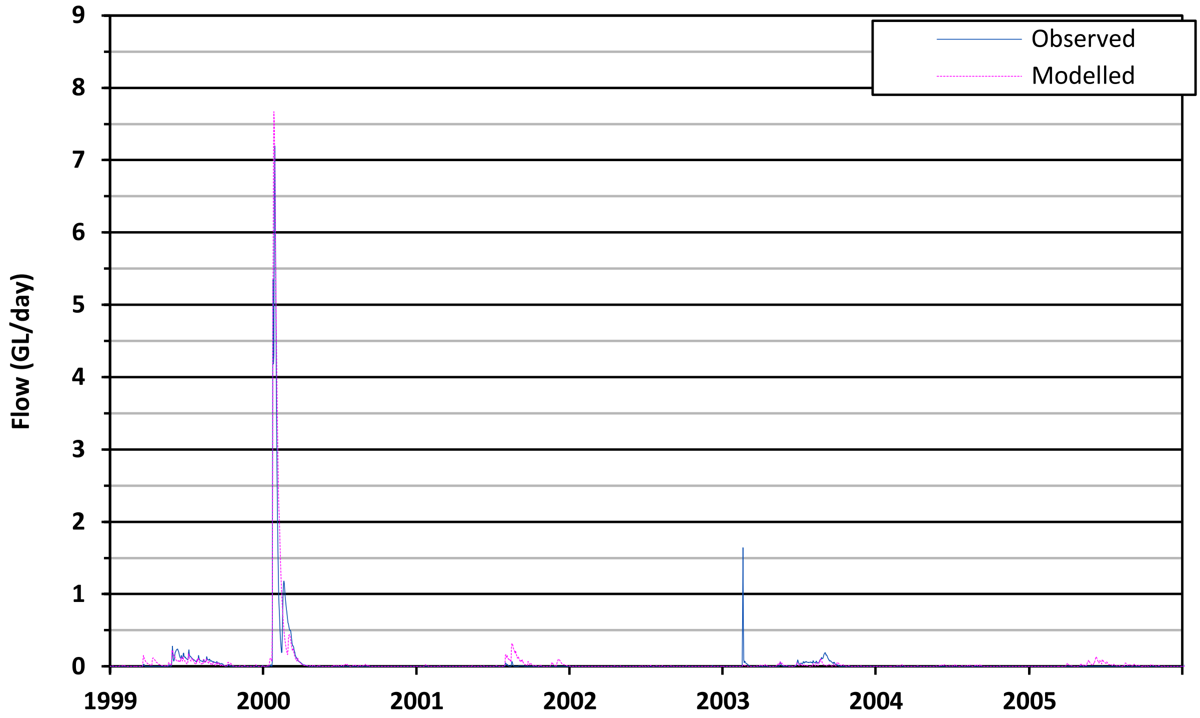


Figure D-53: Observed and modelled daily flow at Kwolyn Hill (615012)

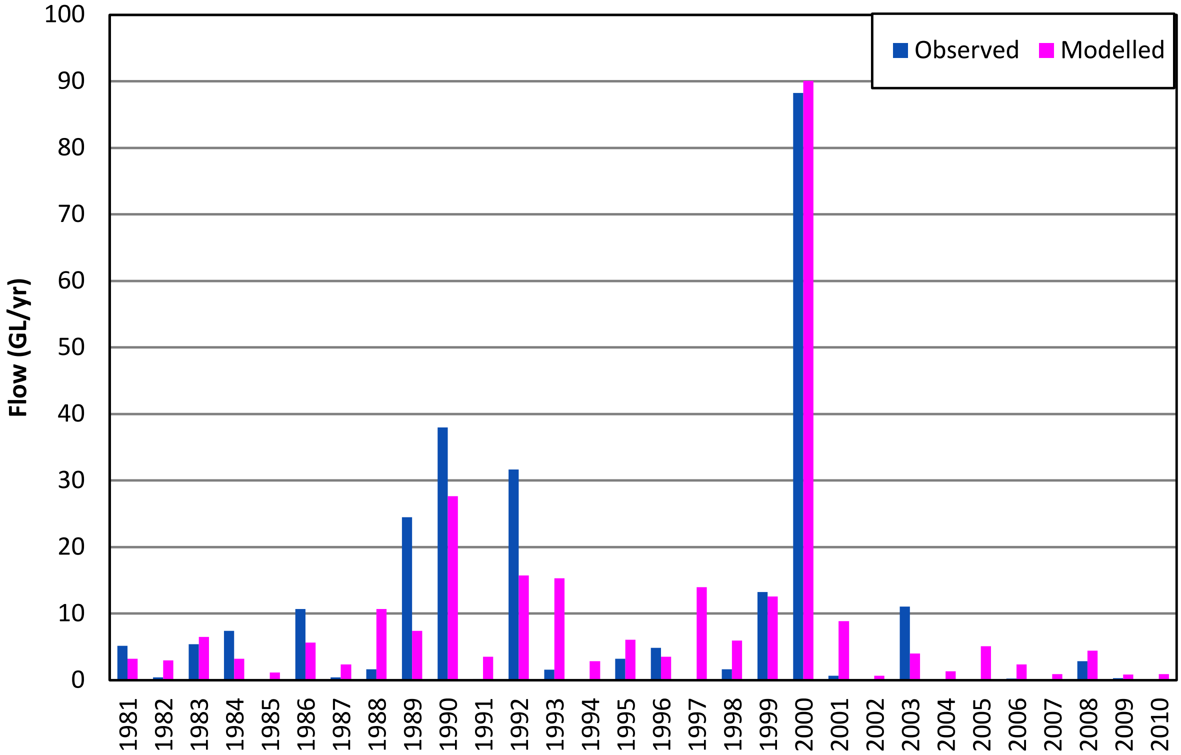


Figure D-54: Observed and modelled annual flow at Kwolyn Hill (615012)

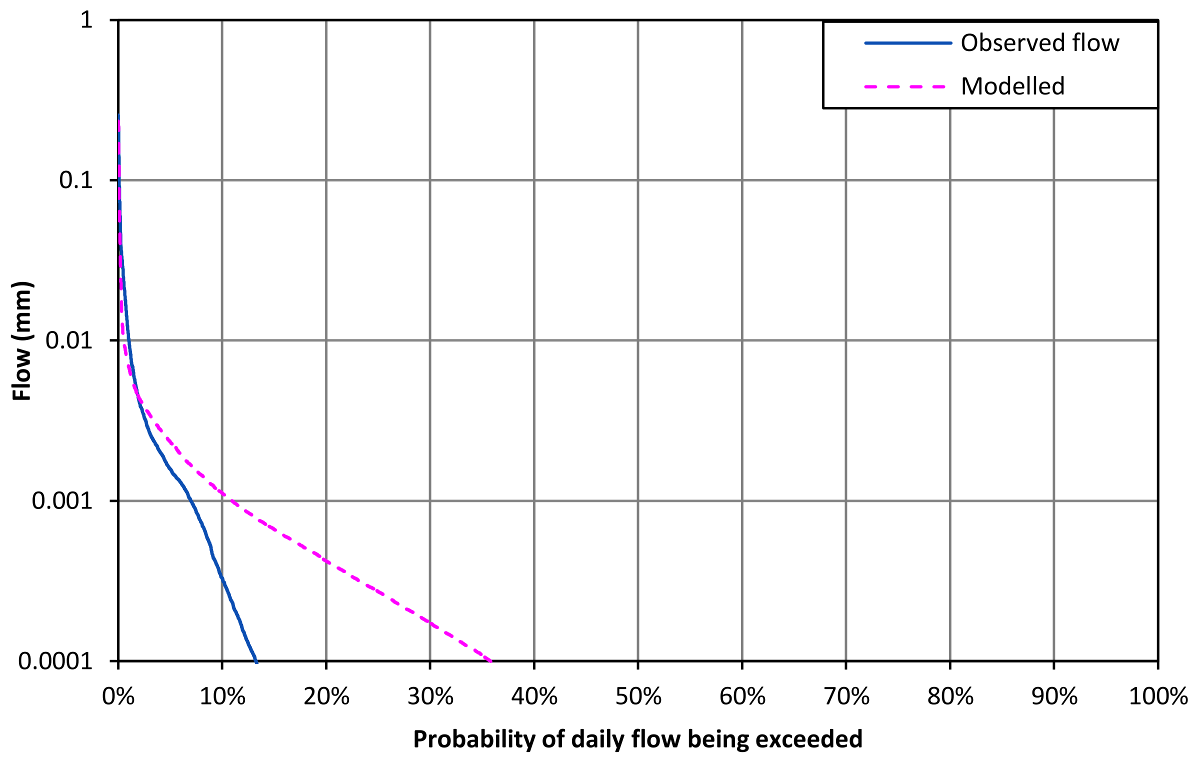


Figure D-55: Observed and modelled flow duration curves at Kwolyn Hill (615012)

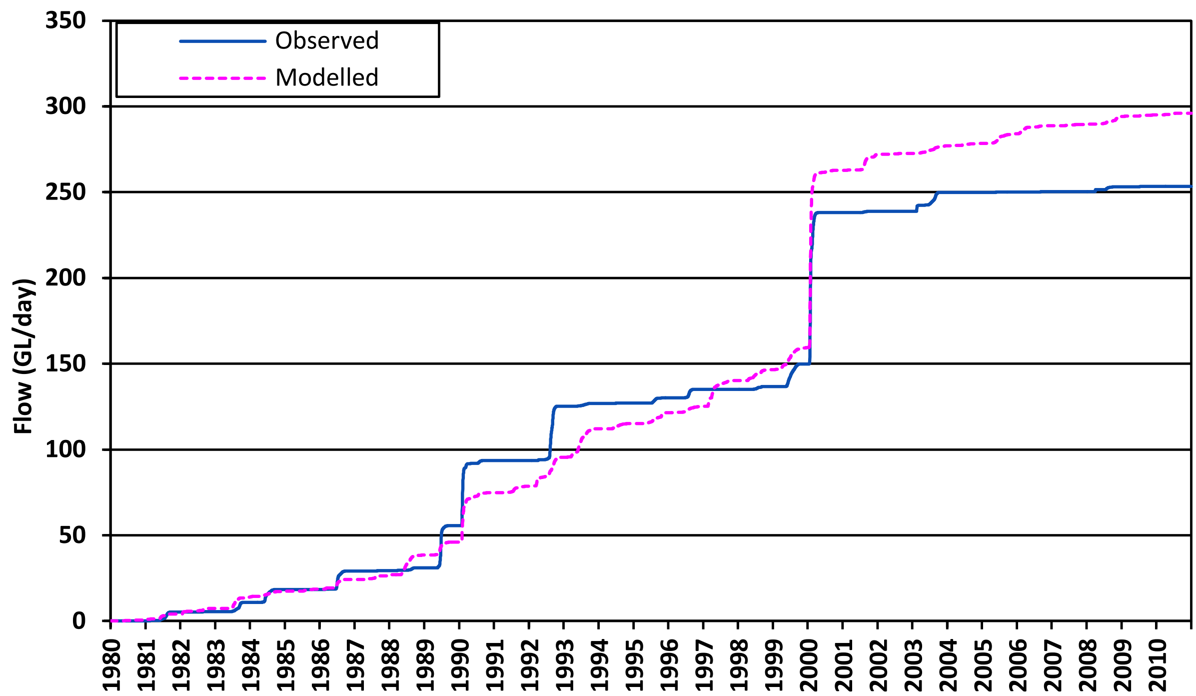


Figure D-56: Cumulative observed and modelled flow at Kwolyn Hill (615012)

Yilgarn

Table D-11: Flow statistics and data quality report for all flow gauging stations in the Yilgarn catchment

Site details		
Site name	Gairdners Crossing	
Site context	Yilgarn River	
AWRC reference	615015	
Flow statistics		
Start of record	21/02/1976	
End of record	16/05/2012	
Minimum recorded daily flow (ML/day)	0	
Maximum recorded daily flow (ML/day)	2064	
Average daily flow (ML/day)	11	
Median daily flow(ML/day)	0	
Number of days in record	12733	
Number of missing flows	159	1.3%
Deleted data	15	0.5%
Flow quality		
Very good record	12016	94.6%
Very good record - corrections applied	381	2.9%
Good record - corrections or estimations applied	113	0.9%
Estimated record - not reviewed / quality not known	49	0.4%
Theoretical rating	15	0.1%
Not available	157	1.2%
Unrated	2	0.0%

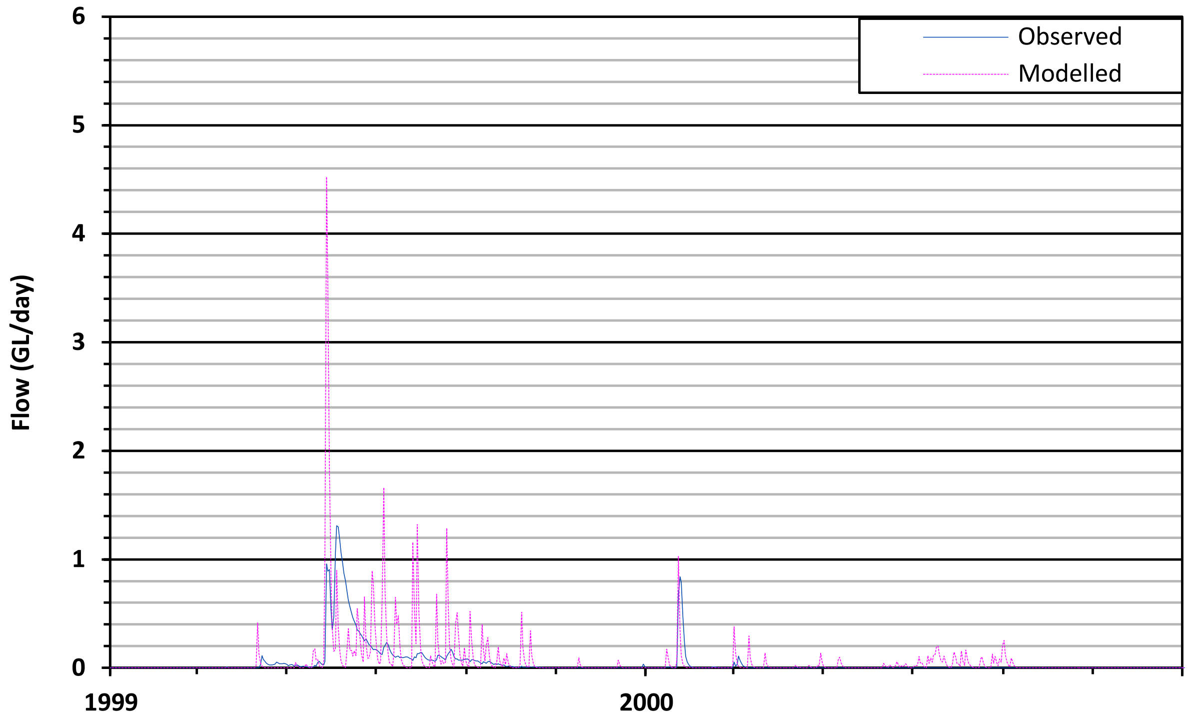


Figure D-57: Observed and modelled daily flow at Gairdners Crossing (615015)

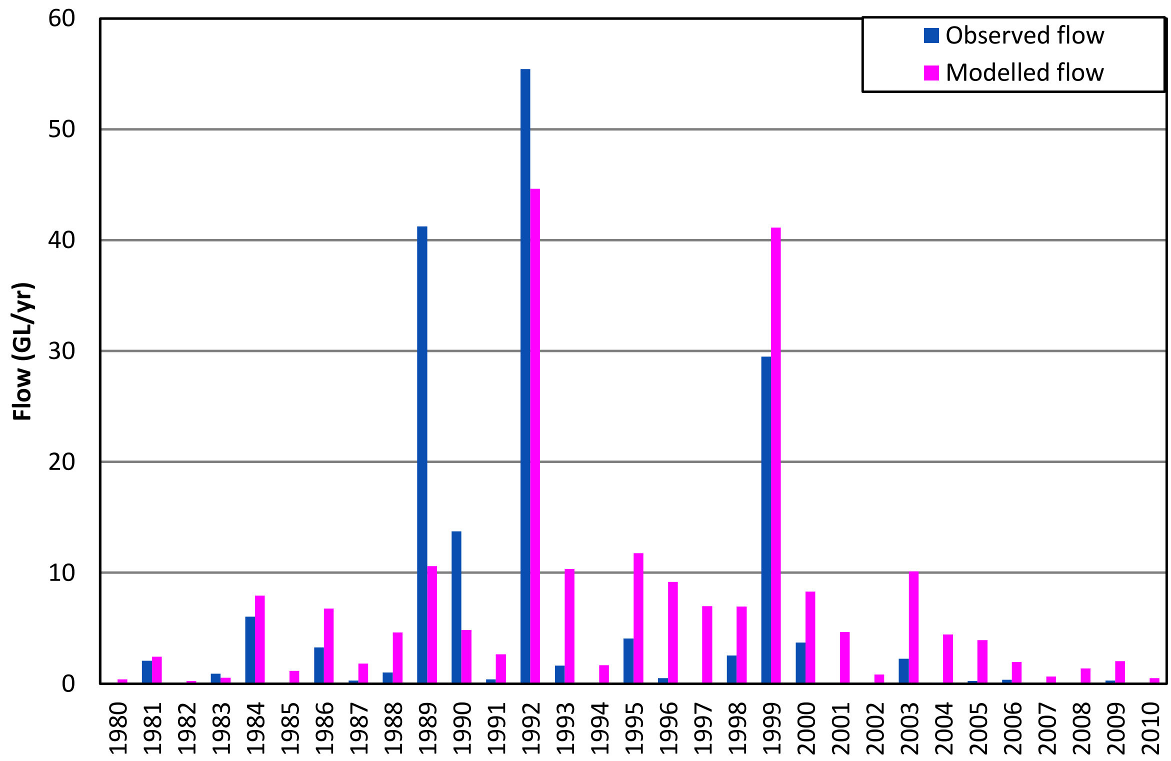


Figure D-58: Observed and modelled annual flow at Gairdners Crossing (615015)

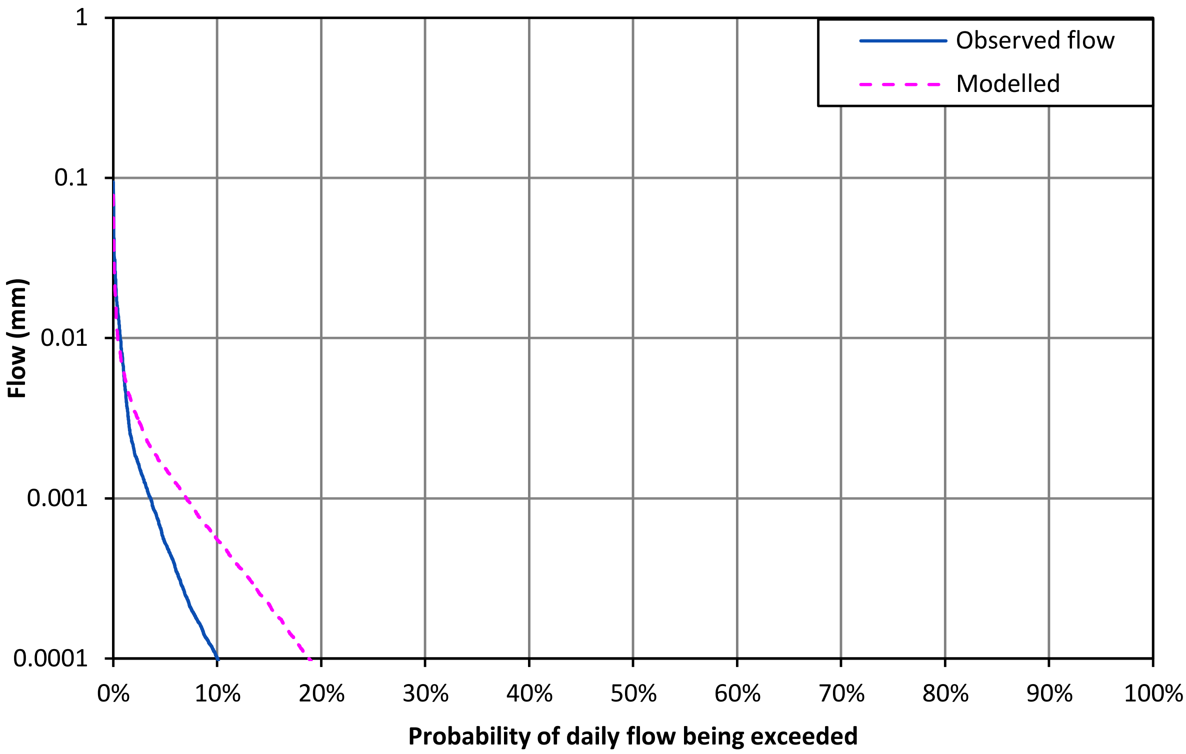


Figure D-59: Observed and modelled flow duration curves at Gairdners Crossing (615015)

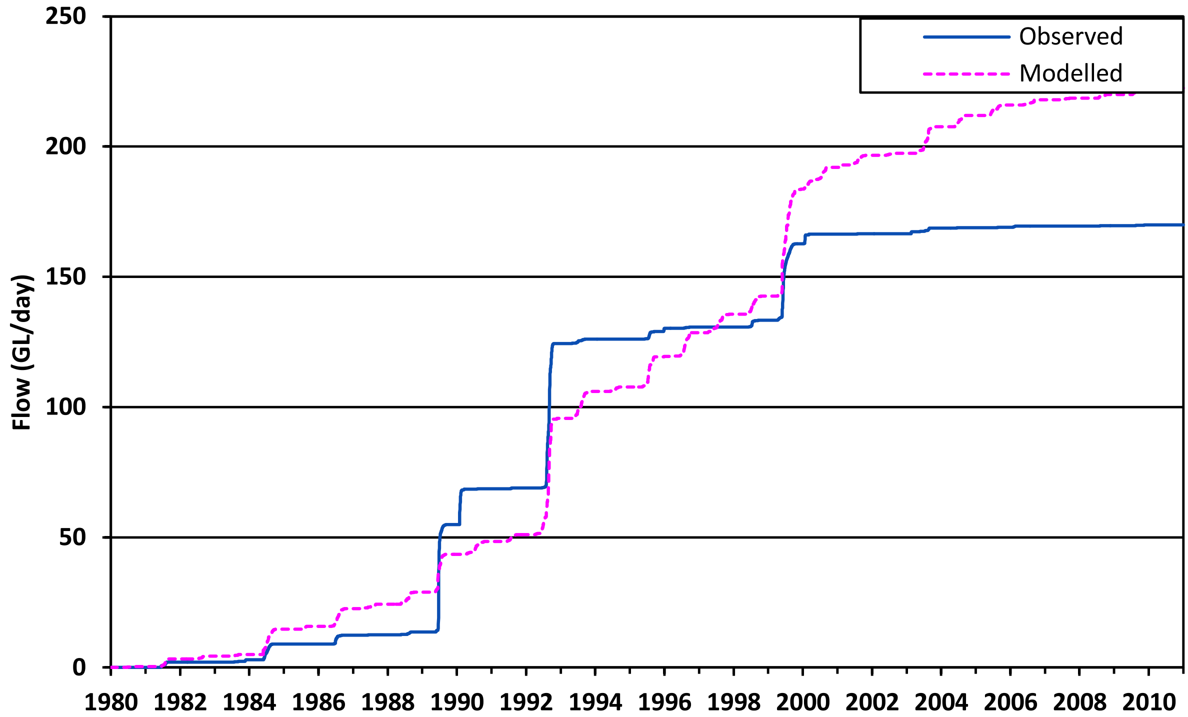


Figure D-60: Cumulative daily observed and modelled flow at Gairdners Crossing (615015)

Helena

Table D-12: Flow statistics and data quality report for all flow gauging stations in the Helena catchment

Site details				
Calibration weighting	1		1	
Site name	Poison Lease		Pine Plantation	
Site context	Helena River		Darkan River	
AWRC reference	616216		616002	
Flow statistics				
Start of record	24/03/1972		2/01/1970	
End of record	31/12/2010		31/12/2010	
Minimum recorded daily flow (ML/day)	0		0	
Maximum recorded daily flow (ML/day)	277		2580	
Average daily flow (ML/day)	2		11	
Median daily flow(ML/day)	0		0	
Number of days in record	14162		14974	
Number of missing flows	2	0.0%	53	0.4%
Number of excluded data points	293	2.1%	0	0.0%
Flow quality				
Very Good Record	12625	89.1%	14006	93.5%
Very Good Record - Corrections applied	1126	8.0%	761	5.1%
Good Record - Corrections or Estimations applied	114	0.8%	92	0.6%
Estimated Record - Good	0	0.0%	0	0.0%
Estimated Record - Fair	0	0.0%	0	0.0%
Estimated Record - Poor	0	0.0%	0	0.0%
Estimated Record - Not reviewed / Quality not known	107	0.8%	62	0.4%
Theoretical Rating	0	0.0%	0	0.0%
Estimated Rating	0	0.0%	0	0.0%
Not available	186	1.3%	54	0.4%

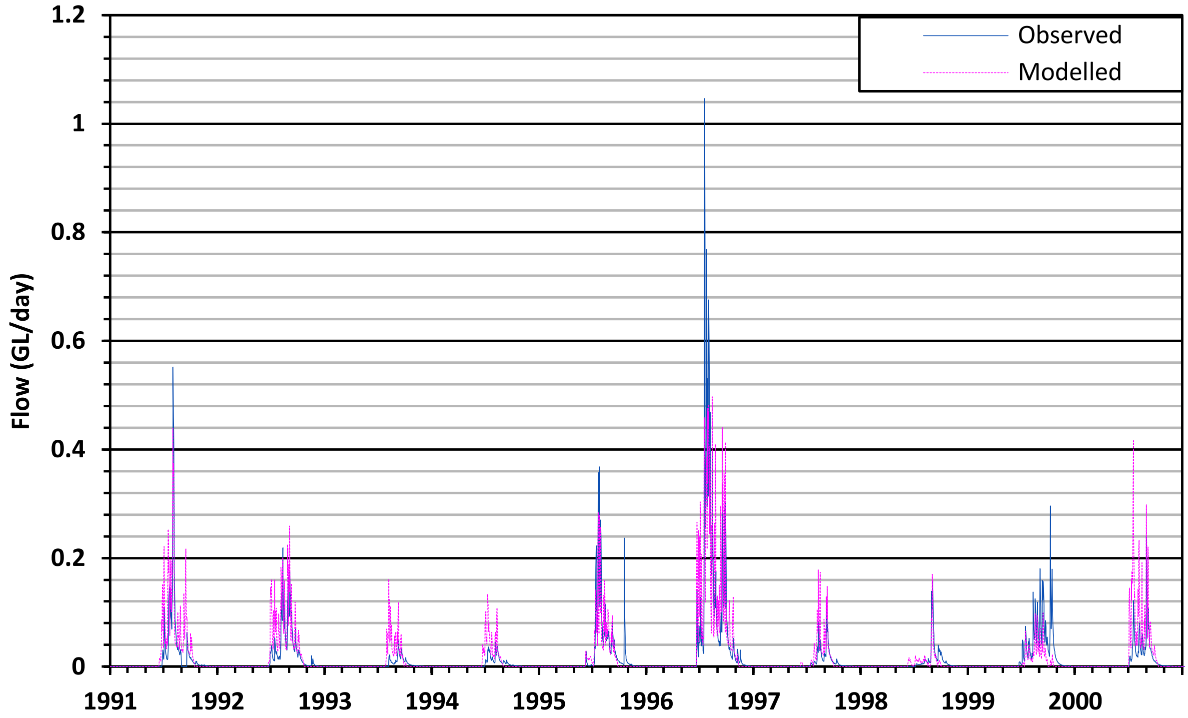


Figure D-61: Observed and modelled daily flow at Poison Lease GS (616216)

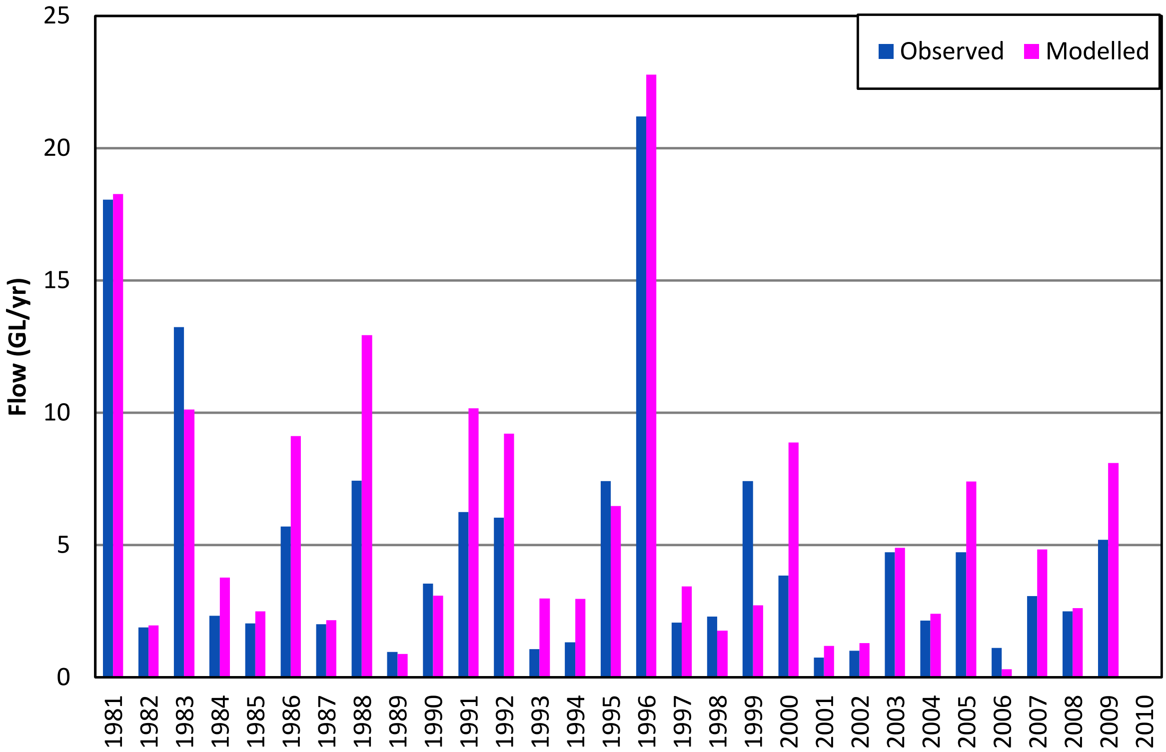


Figure D-62: Observed and modelled annual flow at Poison Lease GS (616216)

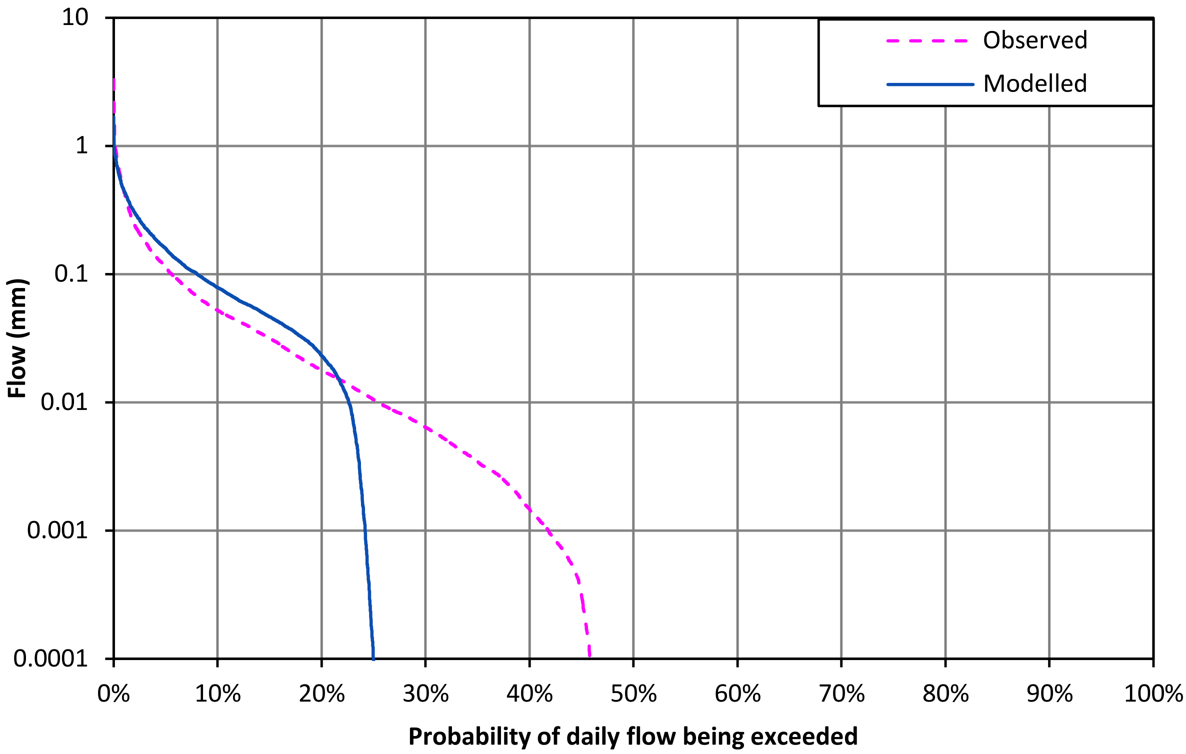


Figure D-63: Observed and modelled flow duration curves at Poison Lease GS (616216)

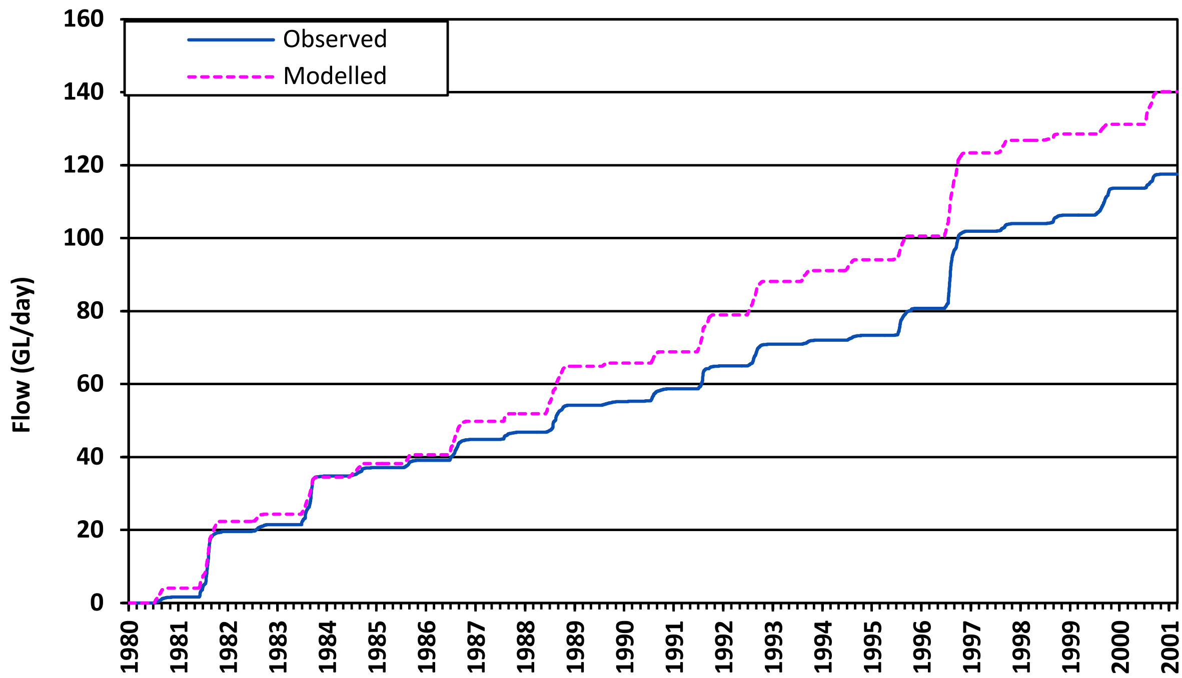


Figure D-64: Cumulative daily observed and modelled flow at Poison Lease GS (616216)

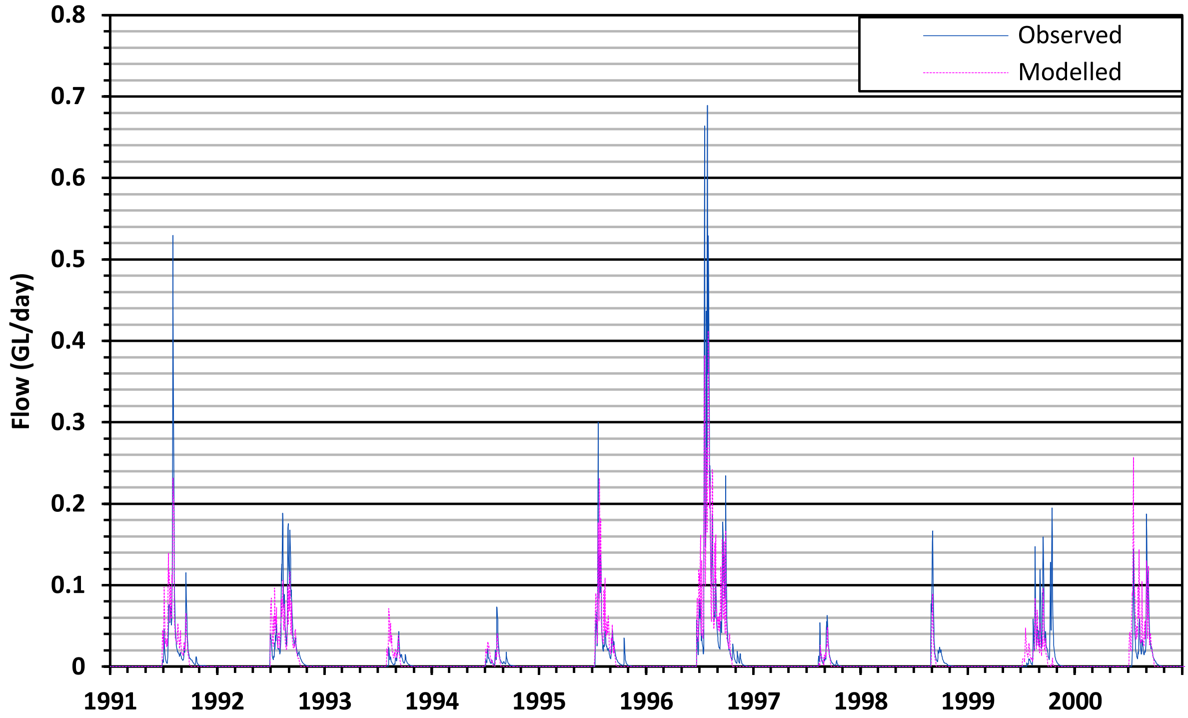


Figure D-65: Observed and modelled daily flow at pine plantation (616002)

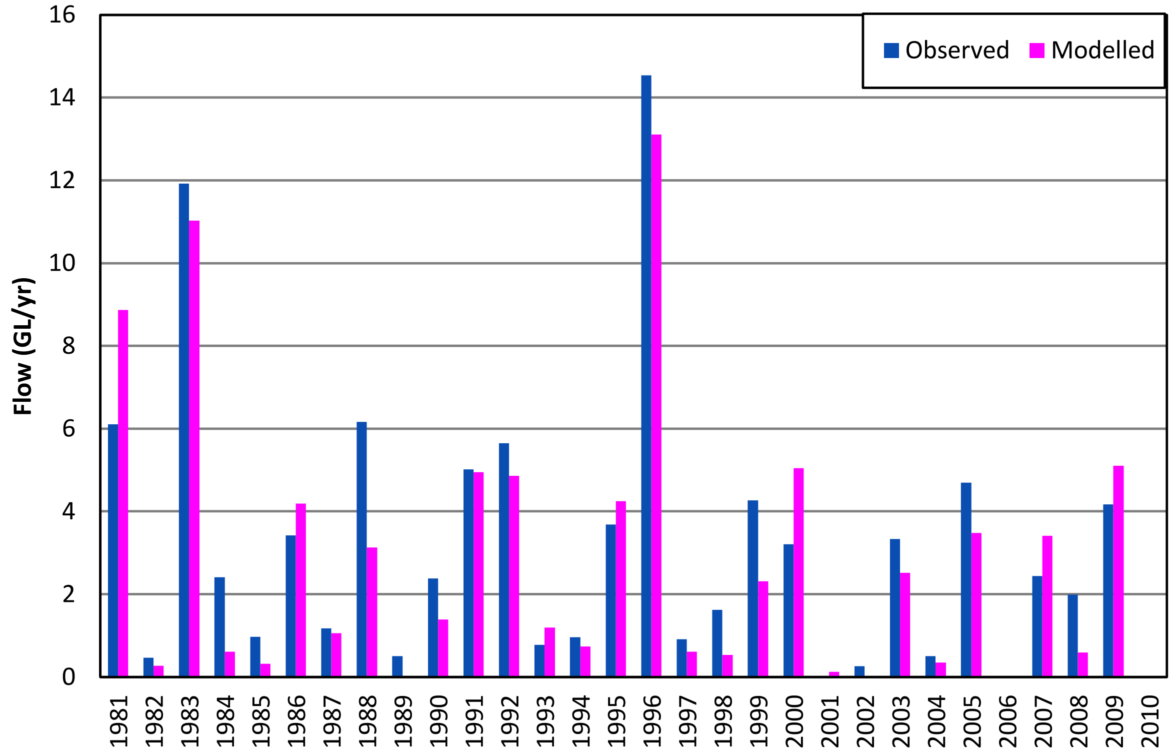


Figure D-66: Observed and modelled annual flow at pine plantation (616002)

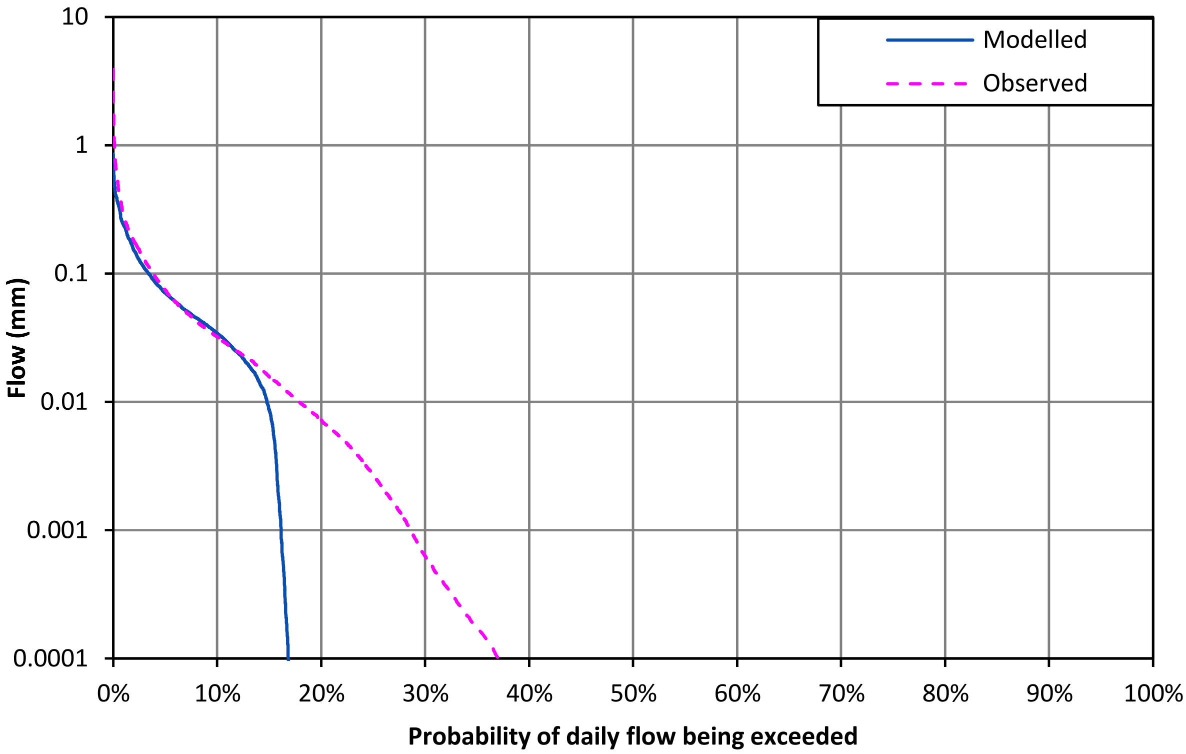


Figure D-67: Observed and modelled flow duration curves at pine plantation (616002)

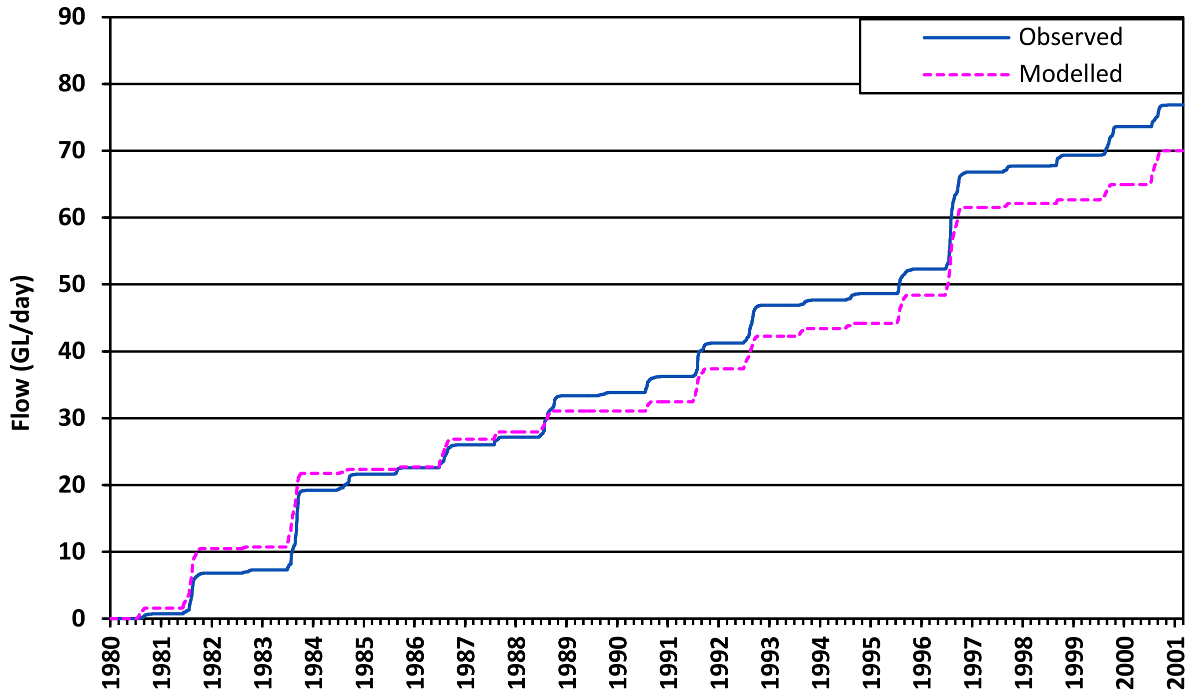


Figure D-68: Cumulative daily observed and modelled flow at pine plantation (616002)

E. Nutrient calibration and parameters

Calculating power function parameters

The calculation of power function parameters was linked to nutrient surplus data though a series of steps as follows:

1. The calculation of land-use nutrient runoff concentrations from land-use nutrient surplus, flow and a leaching factor (surplus nutrients leached to waterways). This is done within all areas upstream of a flow and nutrient sampling site.
2. Calibrate a single parameter set (a_1, b_1, c_1) to the three-year median nutrient concentrations and LOESS loads at that flow and nutrient sampling site. The modelled concentration (C_M) was noted. The value of b_1 was set for all land-use parameters and the value of c_2 was set as either an order of magnitude less than the value of a_1 or at a predetermined minimum.;

Land-use runoff concentrations (C_L) were then converted to a_2 parameter values using the following:

1.

$$Modelled\ concentration = a_1 flow^{b_1} + c_1$$

2.

$$a_2 = \frac{a_1 C_M}{a_1 flow^{b_1} + c_2}$$

The conversion between land-use runoff concentrations and '*a'* parameter values was simplified by devising a 'standardisation factor' which was just the value of *'a*' divided into the land-use runoff concentration. Power function parameters were adjusted during the calibration process. As a result, each land-use within each parameter set has its own standardisation factor.

Nutrient model parameters

Table E-1: Nitrogen model parameters, standardisation factors as well as land-use nutrient runoff concentrations, nutrient surplus, flow, and the leaching fraction

Base parameter set	Reporting catchment	Parameter	Native vegetation	Wheat & Sheep	Animal keeping	Horticulture	Orchard	Industry & transport	Lifestyle block	Mixed grazing	Plantation	Recreation	Residential
	Land-use runoff concentration variables	Surplus (kg/ha/yr)	3.0	35.7	52.6	107.0	20.4	4.0	36.9	61.4	9.5	55.7	55.1
		Area (ha)	78 107	19 872	860	297	840	1 869	2 091	44 907	1 300	29	16
		Runoff (ML/yr)	7 493	1 906	83	29	81	179	201	4 308	125	2.8	1.5
		Leaching fraction	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.31
		Land-use runoff Concentration (mg/L)	0.10	1.04	1.70	3.46	0.66	0.13	1.19	1.96	0.31	1.80	1.78
	Brockman	Standardisation factor	1.55	1.67	1.67	1.67	1.67	1.32	1.48	1.67	1.33	1.65	1.69
		a	0.15	1.73	2.84	5.77	1.10	0.17	1.77	3.28	0.41	2.97	3.01
		b	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
		c	0.02	0.17	0.28	0.58	0.11	0.02	0.17	0.33	0.04	0.30	0.30
	Dale	Standardisation factor	1.55	1.86	1.86	1.85	1.85	1.47	1.65	2.04	1.47	1.84	1.88
		a	0.15	1.93	3.16	6.41	1.22	0.19	1.96	4.00	0.45	3.30	3.34
		b	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
		c	0.02	0.19	0.32	0.64	0.12	0.02	0.20	0.80	0.05	0.30	0.33
	Lower Avon Middle Avon	Standardisation factor	0.86	0.98	0.98	0.98	0.98	0.99	0.99	0.99	1.00	0.97	0.99
		a	0.08	1.02	1.67	3.40	0.65	0.13	1.18	1.93	0.30	1.75	1.77
		b	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
		c	0.01	0.10	0.17	0.34	0.06	0.01	0.12	0.19	0.03	0.18	0.18
	Land-use runoff concentration variables	Surplus (kg/ha/yr)	3.0	35.7	52.6	107.0	20.4	4.0	36.9	35.7	9.5	55.7	55.1
		Area (ha)	86 663	874 281	168	4	1	13 296	175	874 281	118	182	232
		Runoff (ML/yr)	800	8 070	2	0	0	123	2	8 070	1	1.7	2.1
		Leaching fraction	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
		Land-use runoff Concentration (mg/L)	0.16	1.74	2.85	5.79	1.04	0.22	2.00	1.74	0.51	3.01	2.98
	Mortlock North Mortlock East Yilgarn Helena	Standardisation factor	1.17	1.41	1.41	1.41	1.49	1.48	1.41	1.41	1.41	1.40	1.50
		a	0.19	2.45	4.03	8.19	1.55	0.32	2.82	2.45	0.72	4.22	4.47
		b	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
		c	0.02	0.25	0.04	0.82	0.16	0.03	0.28	0.25	0.07	0.42	0.45
	Upper Avon	Standardisation factor	1.17	1.39	1.41	1.41	1.49	1.48	1.41	1.39	1.41	1.40	1.50
		a	0.19	2.42	4.03	8.19	1.55	0.32	2.82	2.42	0.72	4.22	4.47
		b	0.10	0.20	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.10
		c	0.02	0.48	0.04	0.82	0.16	0.03	0.28	0.48	0.07	0.42	0.45
	Lockhart Salt	Standardisation factor	1.17	2.88	1.41	1.41	1.49	1.48	1.41	2.88	1.41	1.40	1.50
		a	0.19	5.00	4.03	8.19	1.55	0.32	2.82	5.00	0.72	4.22	4.47
		b	0.10	0.20	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.10
		c	0.02	1.70	0.04	0.82	0.16	0.03	0.28	1.70	0.07	0.42	0.45
	Land-use runoff concentration variables	Surplus (kg/ha/yr)	3.0	35.7	52.6	107.0	20.4	4.0	36.9	61.4	9.5	55.1	55.7
		Area (ha)	25 971	816	1 591	10	251	1 592	2 003	20 788	185	94	166
		Runoff (ML/yr)	18 290	575	1 120	7	177	1 121	1 410	14 640	131	66.3	116.8
		Leaching fraction	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
		Land-use runoff Concentration (mg/L)	0.05	0.55	0.90	1.82	0.35	0.07	0.63	1.03	0.16	0.94	0.95
	Wooroloo	Standardisation factor	1.07	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08	1.08
		a	0.05	0.59	0.97	1.97	0.38	0.07	0.68	1.12	0.17	1.01	1.03
		b	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
		c	0.01	0.06	0.10	0.20	0.04	0.01	0.07	0.11	0.02	0.10	0.10

Table E-2: Phosphorus model parameters, standardisation factors as well as land-use nutrient runoff concentrations, nutrient surplus, flow, and the leaching fraction

Base parameter set	Reporting catchment	Parameter	Native vegetation	Wheat & Sheep	Animal keeping	Horticulture	Orchard	Industry & transport	Lifestyle block	Mixed grazing	Plantation	Recreation	Residential
	Land-use runoff concentration variables	Surplus (kg/ha/yr)	0.2	4.0	9.9	95.2	9.2	1.6	2.6	5.0	6.2	2.0	13.5
		Area (ha)	78 107	19 872	860	297	840	1 869	2 091	44 907	1 300	29	16
		Runoff (ML/yr)	7 493	1 906	83	29	81	179	201	4 308	125	2.8	1.5
		Leaching fraction	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
		Land-use runoff Concentration (mg/L)	0.002	0.028	0.072	0.694	0.067	0.012	0.019	0.043	0.045	0.014	0.099
	Brockman Helena	Standardisation factor	0.609	1.410	1.426	1.420	1.426	1.627	1.344	1.386	1.426	1.406	1.421
		a	0.001	0.039	0.103	0.986	0.096	0.019	0.025	0.060	0.064	0.020	0.140
		b	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160
		c	0.000	0.004	0.010	0.099	0.010	0.002	0.003	0.006	0.006	0.002	0.014
	Dale	Standardisation factor	0.609	1.823	1.426	1.420	1.426	1.627	1.344	2.280	1.426	1.406	1.421
		a	0.001	0.050	0.103	0.986	0.096	0.019	0.025	0.099	0.064	0.020	0.140
		b	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160
		c	0.000	0.005	0.010	0.099	0.010	0.002	0.003	0.010	0.006	0.002	0.014
	Lower Avon Middle Avon	Standardisation factor	0.305	0.398	0.401	0.400	0.401	0.385	0.403	0.404	0.401	0.387	0.401
		a	0.001	0.011	0.029	0.278	0.027	0.005	0.008	0.018	0.018	0.006	0.040
		b	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110	0.110
		c	0.000	0.001	0.003	0.028	0.003	0.000	0.001	0.002	0.002	0.001	0.004
	Lockhart Salt	Standardisation factor	0.609	10.850	1.426	1.420	1.426	1.627	1.344	1.386	1.426	1.406	1.421
		a	0.001	0.300	0.103	0.986	0.096	0.019	0.025	0.060	0.064	0.020	0.140
		b	0.160	0.500	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160
		c	0.000	0.027	0.010	0.099	0.010	0.002	0.003	0.006	0.006	0.002	0.014
	Upper Avon Yilgarn	Standardisation factor	0.609	2.712	1.426	1.420	1.426	1.627	1.344	0.370	1.426	1.406	1.421
		a	0.001	0.075	0.103	0.986	0.096	0.019	0.025	0.016	0.064	0.020	0.140
		b	0.160	0.140	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160	0.160
		c	0.000	0.001	0.010	0.099	0.010	0.002	0.003	0.006	0.006	0.002	0.014
	Land-use runoff concentration variables	Surplus (kg/ha/yr)	0.2	4.0	9.9	95.2	9.2	1.6	2.6	4.0	6.2	3.0	13.5
		Area (ha)	86 663	874 281	168	3.8	0.9	13 296	175	874 281	118	182	232
		Runoff (ML/yr)	800	8 070	1.5	0.04	0.01	123	1.6	8 070	1.1	1.7	2.1
		Leaching fraction	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
		Land-use runoff Concentration (mg/L)	0.005	0.090	0.236	2.269	0.207	0.038	0.061	0.090	0.147	0.072	0.322
	Mortlock North Mortlock East	Standardisation factor	1.492	1.639	1.644	1.643	1.643	0.944	1.645	1.639	1.644	1.636	1.644
		a	0.008	0.148	0.388	3.727	0.340	0.036	0.100	0.148	0.241	0.117	0.529
		b	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
		c	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	Land-use runoff concentration variables	Surplus (kg/ha/yr)	0.2	4.0	9.9	95.2	9.2	1.6	2.6	5.0	6.2	2.0	13.5
		Area (ha)	25 971	816	1 591	10	251	1 592	2 003	20 788	185	94	166
		Runoff (ML/yr)	18 290	575	1 120	7	177	1 121	1 410	14 640	131	66.3	116.8
		Leaching fraction	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
		Land-use runoff Concentration (mg/L)	0.001	0.011	0.028	0.270	0.026	0.005	0.007	0.017	0.017	0.006	0.038
	Wooroloo	Standardisation factor	0.861	0.873	0.889	0.873	0.878	0.880	0.829	0.861	0.859	0.903	0.887
		a	0.001	0.009	0.025	0.236	0.023	0.004	0.006	0.015	0.015	0.005	0.034
		b	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140	0.140
		c	0.000	0.001	0.003	0.024	0.002	0.000	0.001	0.001	0.002	0.001	0.003

Parameters for wastewater irrigation on recreation areas

Table E-3: Model parameters for wastewater irrigation on recreational areas

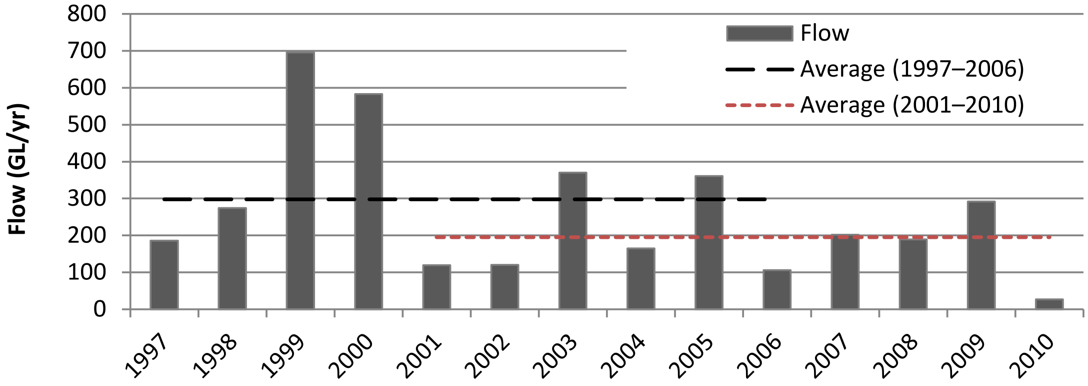
Variable	Lower Avon Middle Avon	Wooroloo	Mortlock East Yilgarn Lockhart	Lower Avon Middle Avon	Mortlock East	Wooroloo	Lockhart Yilgarn
	Nitrogen	Nitrogen	Nitrogen	Phosphorus	Phosphorus	Phosphorus	Phosphorus
Inputs (kg/ha/yr)	480	480.0	480	120	120	120	120
Surplus (kg/ha/yr)	360	360.0	360	90	90	90	90
Area (ha)	29	94	182	29	182	94	182
Runoff (ML/yr)	2.8	66	1.7	2.8	1.7	66.3	1.7
Export (%)	0.31	1.2000	0.05	0.07	0.02	0.20	0.02
Runoff Concentration (mg/L)	11.63	6.13	19.50	0.66	2.15	0.26	2.15
Standardisation factor	0.97	1.08	1.40	0.39	1.64	0.90	1.64
a	11.33	6.63	27.30	0.25	3.51	0.23	3.51
b	0.10	0.30	0.10	0.11	0.10	0.14	0.10
c	0.18	0.10	0.42	0.00	0.00	0.00	0.00

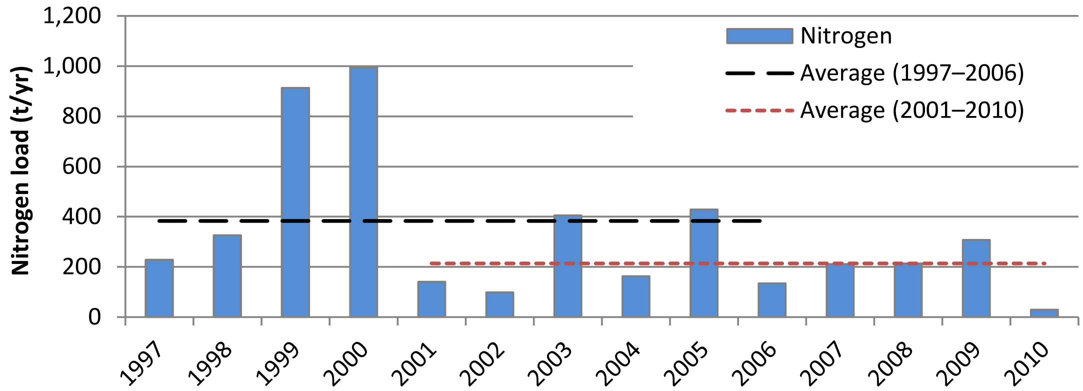
F. Reporting catchment nutrient loads, source separation and scenario results

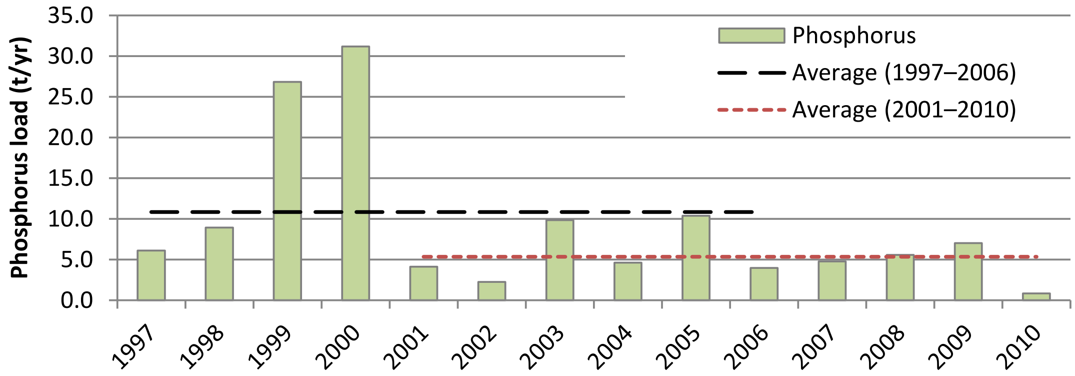
Whole catchment

Whole catchment: Annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	186	228	6.1
1998	275	327	8.9
1999	696	913	26.9
2000	583	995	31.2
2001	120	142	4.1
2002	121	99	2.3
2003	370	406	9.8
2004	165	163	4.6
2005	361	428	10.4
2006	106	135	4.0
2007	201	211	4.8
2008	189	214	5.6
2009	292	308	7.0
2010	27	29	0.8
Average (1997–2006)	**298**	**383**	**10.8**
Average (2001–2010)	**195**	**213**	**5.3**



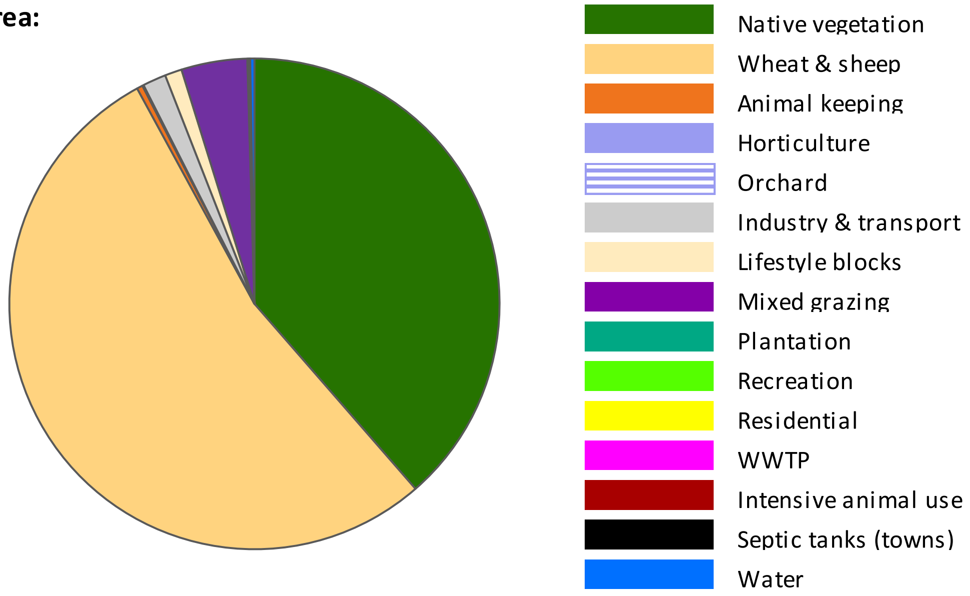




Whole catchment: Sources of nutrients

Land use	**Area**		**Nitrogen**		**Phosphorus**	
	(km^2)	**(%)**	**(t/yr)**	**(%)**	**(t/yr)**	**(%)**
Native vegetation	50 099	42	7.2	3.1	0.060	1.1
Wheat & sheep	64 619	54	139	60	3.93	69
Animal keeping	47	0.0	2.2	1.0	0.060	1.1
Horticulture	3	0.0	0.2	0.1	0.042	0.7
Orchard	13	0.0	0.2	0.1	0.019	0.3
Industry & transport	1 238	1.0	0.2	0.1	0.013	0.2
Lifestyle blocks	90	0.1	3.1	1.4	0.029	0.5
Mixed grazing	1 261	1.1	67.3	29	1.177	21
Plantation	28	0.0	0.1	0.1	0.018	0.3
Recreation	16	0.0	0.2	0.1	0.001	0.0
Residential	22	0.0	0.3	0.1	0.009	0.2
WWTPs	-	-	6.0	3	0.227	4
Septic tank (towns)	-	-	0	0	0	0
Intensive animal use	-	-	4.5	2.0	0.120	2.1
Water	1 693	1.4	-	-	-	-
Total	**119 141**		**231**		**5.71**	

Area:



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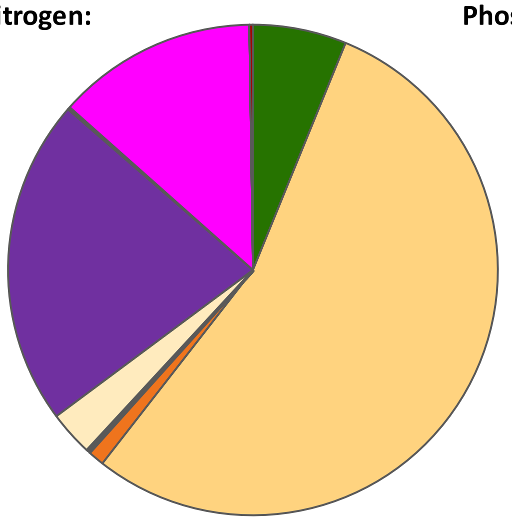

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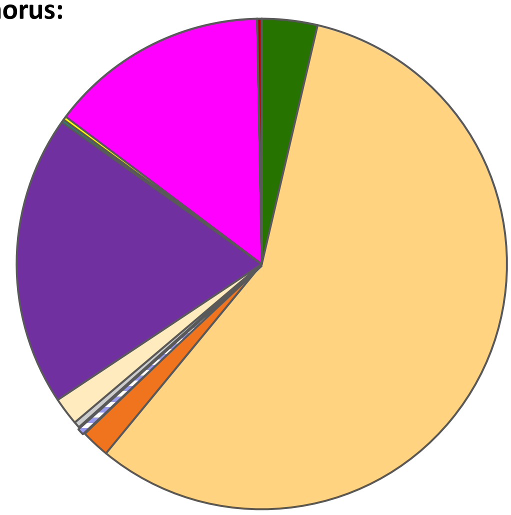
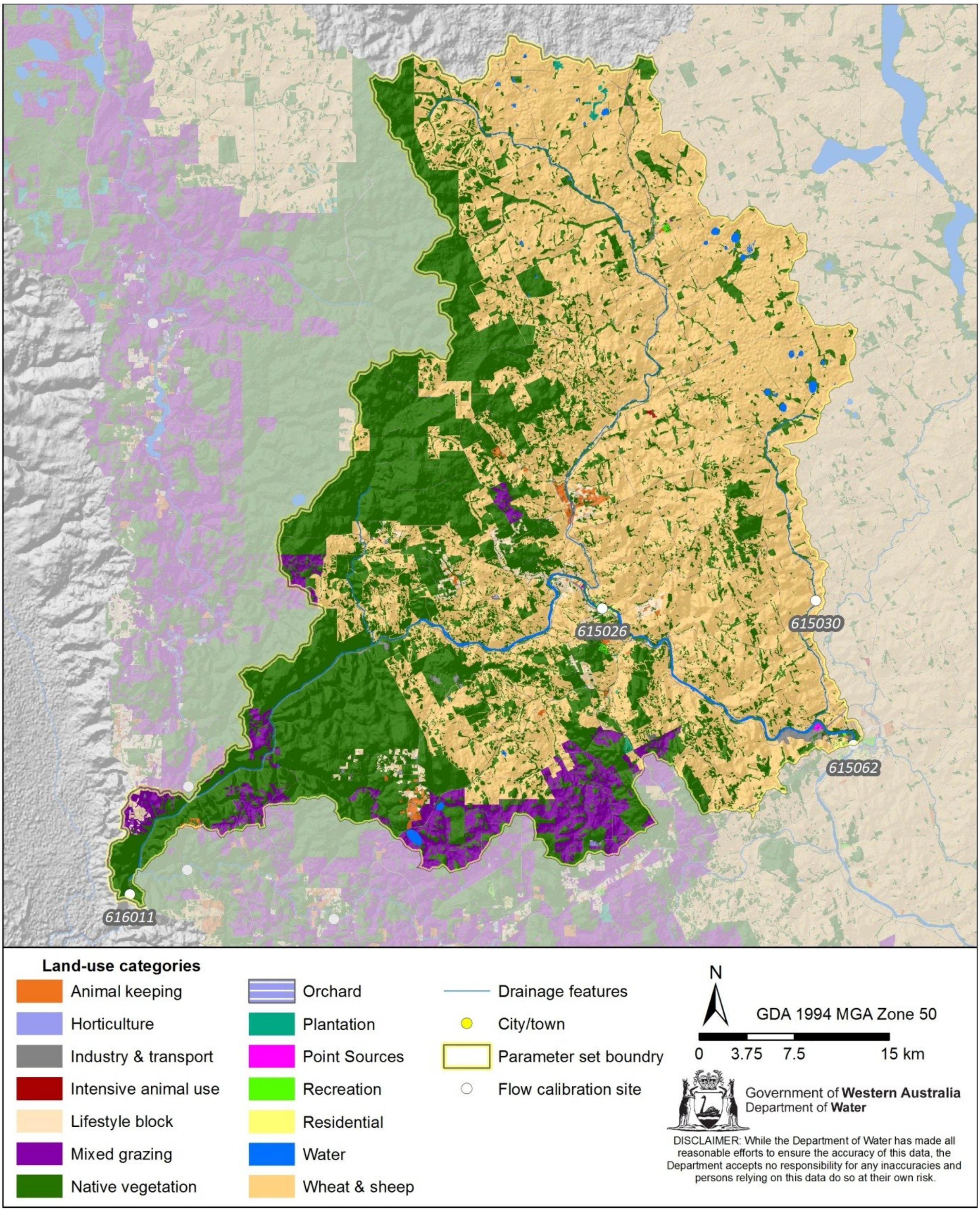


Whole catchment: all scenario results

Scenario	Flow		Nitrogen		Phosphorus	
	(GL/yr)	(% diff)	(t/yr)	(% diff)	(t/yr)	(% diff)
Base case (2001–10)	195		213		5.3	
Point source management: Town sewage management	-		207	-3	5.1	-4
Point source management: point source removal	-		203	-5	5.0	-6
Soil acidity management: 5% adoption	-		212	-0.4	5.3	-0.6
Soil acidity management: 20% adoption	-		210	-2	5.2	-3
Soil acidity management: 50% adoption	-		204	-4	5.0	-6
Soil acidity management: 100% adoption	-		195	-8	4.7	-13
Soil acidity management: No action	-		214	0.4	5.4	0.6
Farm nutrient management: 5%	-		210	-1	5.2	-3
Farm nutrient management: 20%	-		201	-6	4.7	-11
Farm nutrient management: 50%	-		183	-14	3.9	-28
Farm nutrient management: 100%	-		153	-28	2.4	-56
Riparian rehabilitation: 10 km/yr (high)	-		209	-2	5.3	-1
Riparian rehabilitation: 20 km/yr (high)	-		204	-5	5.3	-2
Riparian rehabilitation: 40 km/yr (high)	-		193	-9	5.2	-4
Riparian management: whole catchment (high)	-		135	-37	4.2	-21
Riparian rehabilitation: 10 km/yr (low)	-		209	-2	5.3	-0.3
Riparian rehabilitation: 20 km/yr (low)	-		206	-3	5.3	-1
Riparian rehabilitation: 40 km/yr (low)	-		198	-7	5.3	-2
Riparian management: whole catchment (low)	-		153	-28	4.8	-10
Land-use change: urban expansion	-		224	5	5.5	3
Current management practices	-		216	1	5.4	2
Moderate intervention	-		189	-12	4.7	-12
Large intervention	-		150	-30	2.9	-45
Revegetation: additional 5% native vegetation	190	-3%	200	-6	4.8	-10
Revegetation: additional 10% native vegetation	184	-6%	188	-12	4.4	-19
Revegetation: up to 30% native vegetation	174	-11%	168	-21	3.5	-34
Climate change: baseline climate period (1961–90)	492		638		16	
Climate change: dry (30 year period)	215	-56%	245	-62	5.9	-64
Climate change: wet (30 year period)	399	-19%	499	-22	12	-24
Climate change: dry (10 year period)	155	-20%	173	-19	4.2	-22
Climate change: wet (10 year period)	294	-40%	348	63	8.4	57

Lower Avon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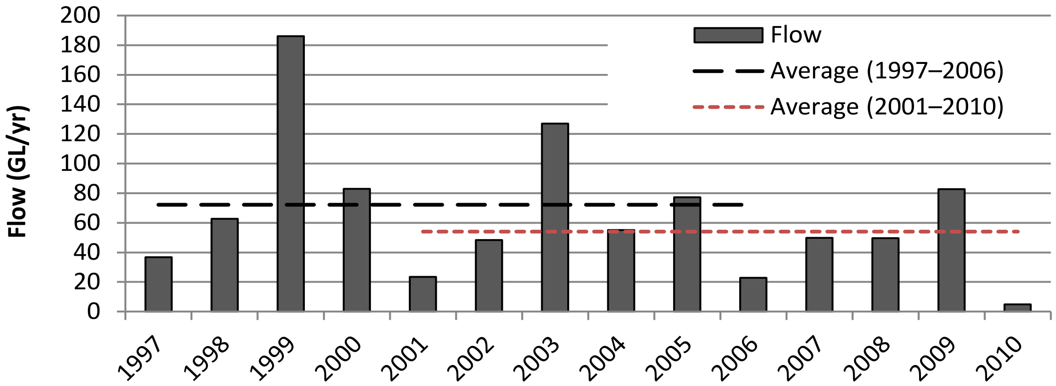
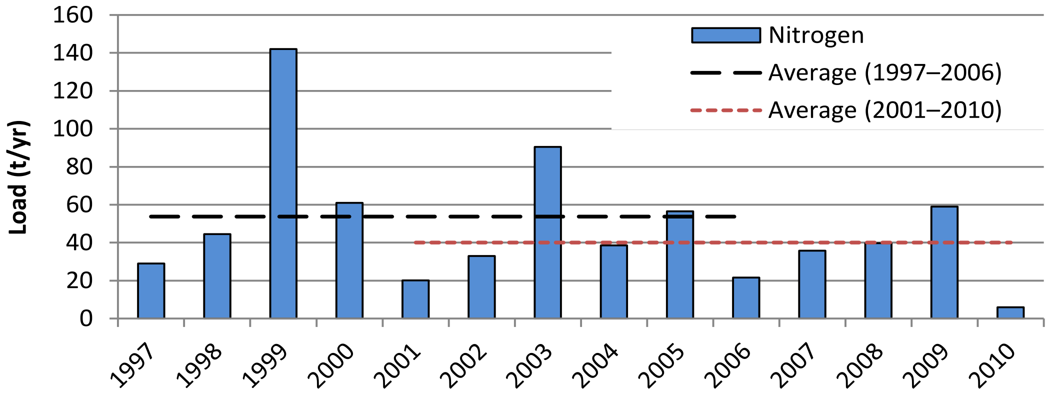
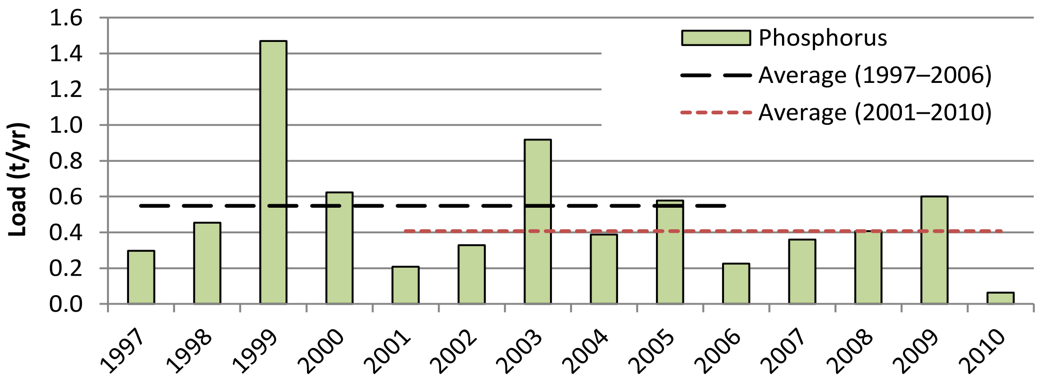
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 3.75 7.5 15 km
Government of Western Australia
Department of Water
DISCLAIMER: While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Lower Avon: Annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	37	29.0	0.30
1998	63	44.5	0.45
1999	186	142.1	1.47
2000	83	61.0	0.62
2001	23	20.2	0.21
2002	48	33.0	0.33
2003	127	90.4	0.92
2004	55	38.5	0.39
2005	77	56.5	0.58
2006	23	21.5	0.23
2007	50	35.8	0.36
2008	50	39.7	0.41
2009	83	59.0	0.60
2010	5	5.9	0.06
Average (1997–2006)	**72**	**53.7**	**0.55**
Average (2001–2010)	**54**	**40.0**	**0.41**



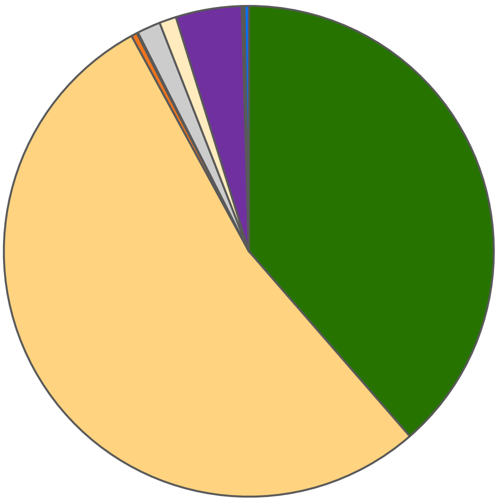




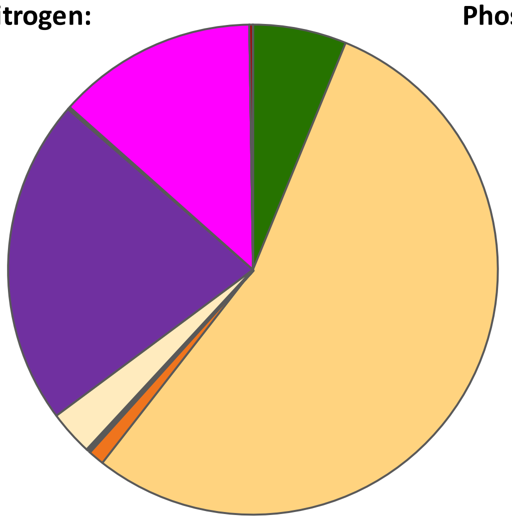
Lower Avon: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	841	56	2.5	6.2	0.015	3.7
Wheat & sheep	1165	77	22	54	0.23	57
Animal keeping	8.5	0.6	0.4	1.1	0.008	1.9
Horticulture	0.1	0.0	0.0	0.0	0.001	0.1
Orchard	1.7	0.1	0.0	0.1	0.002	0.4
Industry & transport	34	2.2	0.0	0.1	0.002	0.4
Lifestyle blocks	24	1.6	1.2	2.9	0.007	1.8
Mixed grazing	95	6.3	8.6	22	0.078	19
Plantation	2.0	0.1	0.0	0.0	0.001	0.2
Recreation	0.6	0.0	0.0	0.0	0.000	0.0
Residential	1.4	0.1	0.0	0.1	0.001	0.2
WWTPs	-	-	5.3	13	0.059	14
Septic tank (towns)	-	-	-	-	-	-
Intensive animal use	-	-	0.1	0.2	0.001	0.3
Water	6.1	0.4	-	-	-	-
Total	**1 515**		**40**	**0**	**0.41**	

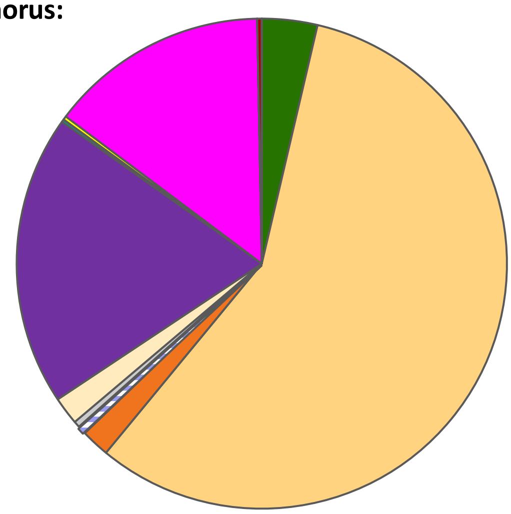
Area:



Nitrogen:



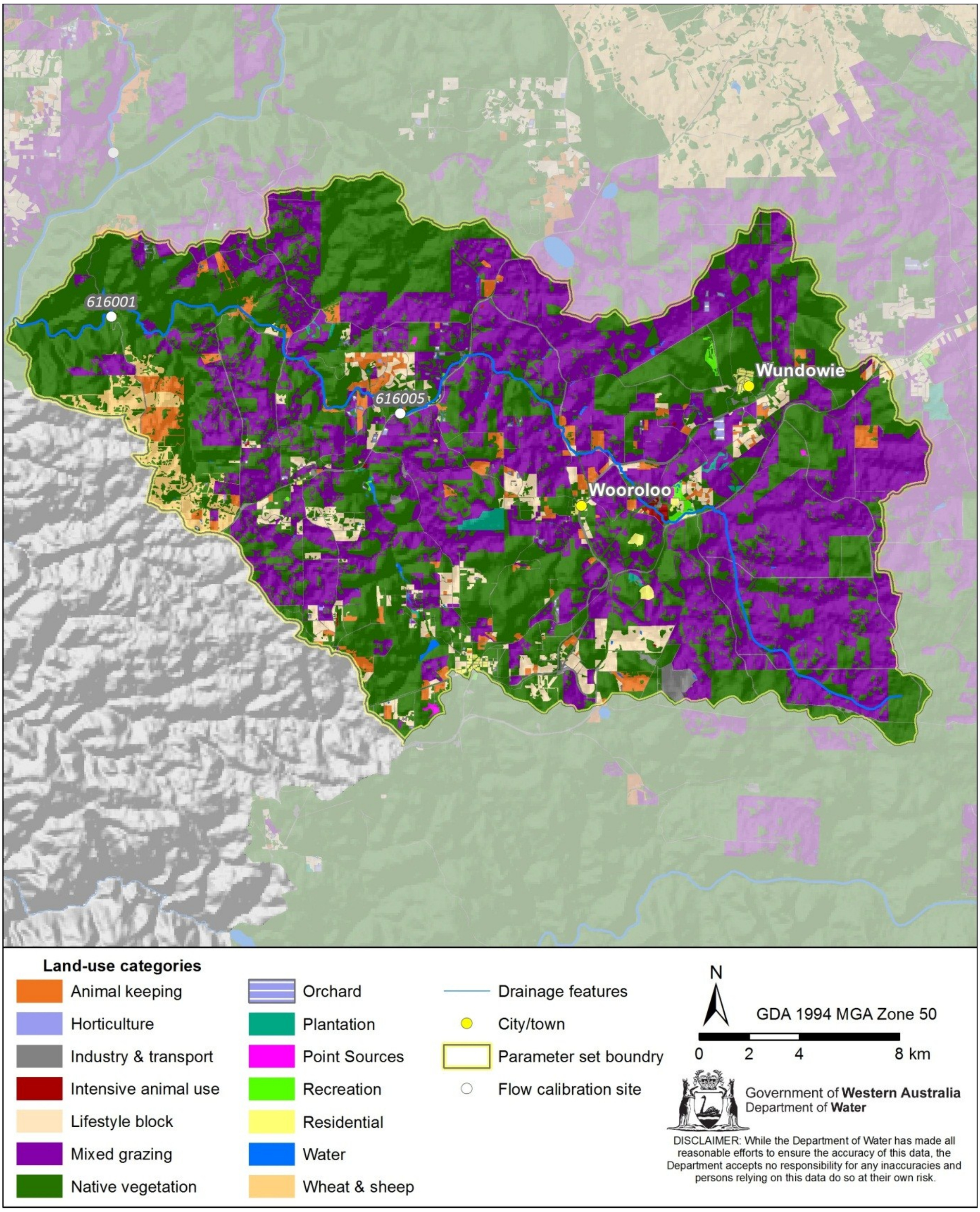
Phosphorus:



Lower Avon: all scenario results

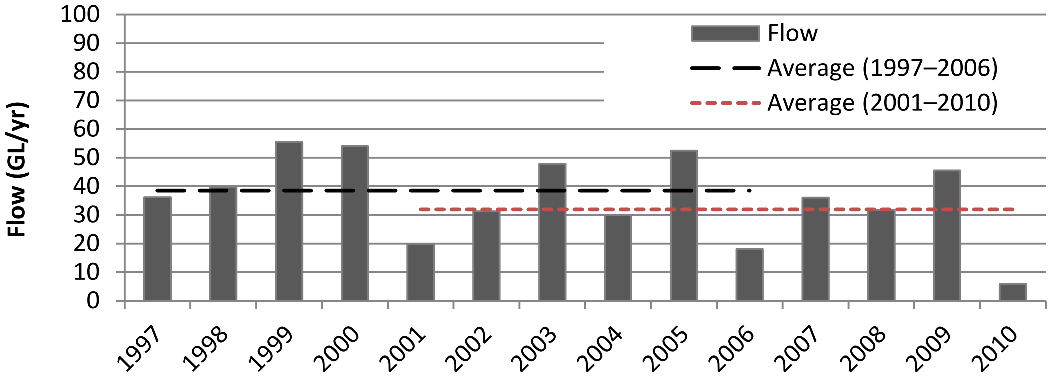
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	54		40		0.41	
Point source management: Town sewage management	-		35	-13	0.35	-14
Point source management: point source removal	-		35	-13	0.35	-15
Soil acidity management: 5% adoption	-		40	-0.4	0.41	-0.5
Soil acidity management: 20% adoption	-		39	-2	0.40	-2
Soil acidity management: 50% adoption	-		39	-4	0.39	-5
Soil acidity management: 100% adoption	-		37	-8	0.36	-11
Soil acidity management: No action	-		40	0.8	0.41	1.1
Farm nutrient management: 5%	-		40	-1	0.40	-2
Farm nutrient management: 20%	-		38	-5	0.37	-10
Farm nutrient management: 50%	-		35	-13	0.31	-24
Farm nutrient management: 100%	-		30	-25	0.21	-48
Riparian rehabilitation: 10 km/yr (high)	-		39	-2	0.40	-1
Riparian rehabilitation: 20 km/yr (high)	-		38	-4	0.40	-2
Riparian rehabilitation: 40 km/yr (high)	-		37	-9	0.39	-4
Riparian management: whole catchment (high)	-		29	-28	0.35	-15
Riparian rehabilitation: 10 km/yr (low)	-		39	-2	0.41	-0.5
Riparian rehabilitation: 20 km/yr (low)	-		39	-3	0.40	-1
Riparian rehabilitation: 40 km/yr (low)	-		37	-6	0.40	-2
Riparian management: whole catchment (low)	-		32	-21	0.38	-7
Land-use change: urban expansion	-		50	25	0.52	28
Current management practices	-		48	21	0.51	26
Moderate intervention	-		40	-1	0.42	2
Large intervention	-		33	-17	0.30	-26
Revegetation: additional 5% native vegetation	54	-1%	39	-2	0.40	-3
Revegetation: additional 10% native vegetation	51	-5%	36	-9	0.33	-18
Revegetation: up to 30% native vegetation	50	-7%	35	-12	0.32	-21
Climate change: baseline climate period (1961–90)	113		97		1.00	
Climate change: dry (30 year period)	66	-41%	51	-47	0.52	-47
Climate change: wet (30 year period)	111	-2%	84	-13	0.87	-13
Climate change: dry (10 year period)	46	-14%	36	-10	0.37	-9
Climate change: wet (10 year period)	84	-26%	63	58	0.65	59

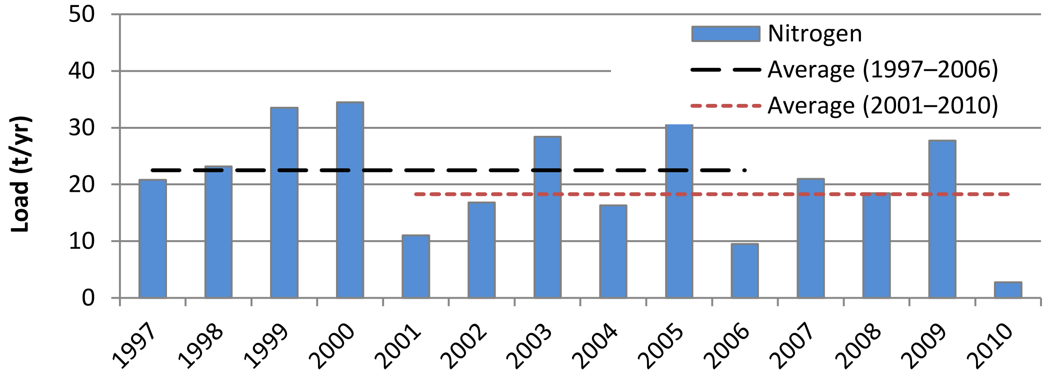
Wooroloo

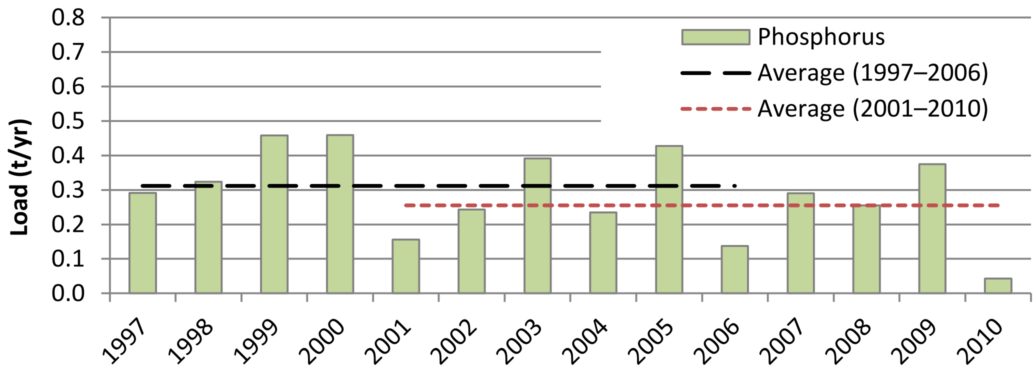

616001
616005
Wundowie
Wooroloo
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 2 4 8 km
Government of Western Australia
Department of Water
DISCLAIMER: While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Wooroloo: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	36	20.8	0.29
1998	40	23.2	0.32
1999	55	33.5	0.46
2000	54	34.5	0.46
2001	20	11.0	0.16
2002	31	16.8	0.24
2003	48	28.4	0.39
2004	30	16.3	0.23
2005	52	30.9	0.43
2006	18	9.5	0.14
2007	36	21.0	0.29
2008	32	18.4	0.26
2009	46	27.7	0.37
2010	6	2.8	0.04
Average (1997–2006)	**38**	**22.5**	**0.31**
Average (2001–2010)	**32**	**18.3**	**0.26**



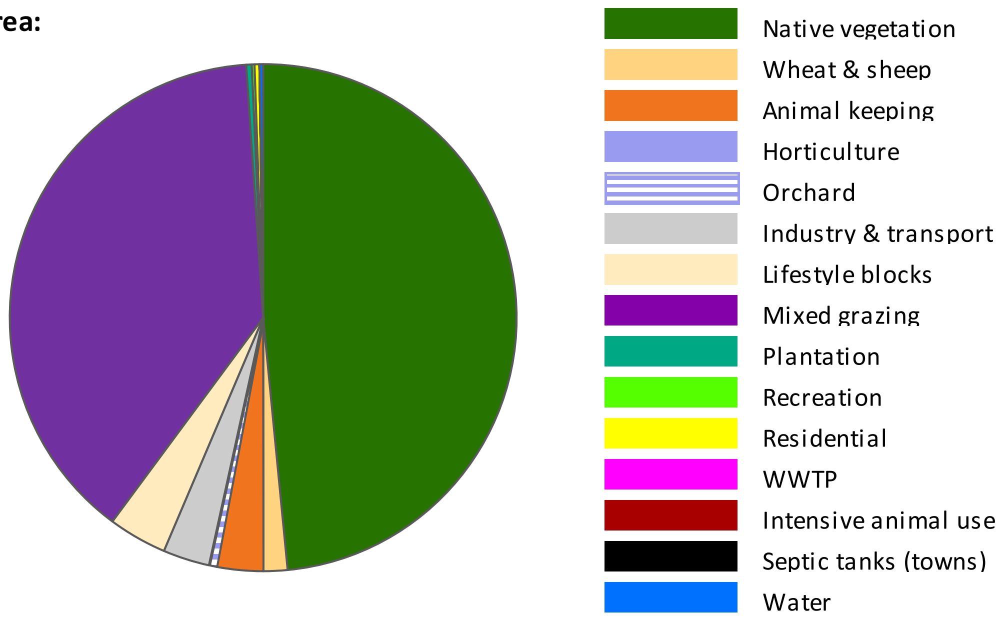




Wooroloo: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	260	48	0.9	5.2	0.009	3.7
Wheat & sheep	8.2	1.5	0.6	3.1	0.009	3.4
Animal keeping	16	3.0	1.2	6.7	0.031	12.2
Horticulture	0.1	0.0	0.0	0.1	0.002	0.6
Orchard	2.5	0.5	0.1	0.3	0.003	1.3
Industry & transport	16	3.0	0.0	0.2	0.002	0.8
Lifestyle blocks	20	3.7	1.0	5.5	0.009	3.4
Mixed grazing	208	39	14	76	0.18	72
Plantation	1.9	0.3	0.0	0.1	0.002	0.7
Recreation	0.9	0.2	0.1	0.5	0.000	0.1
Residential	1.7	0.3	0.1	0.5	0.003	1.2
WWTPs	-	-	-	-	-	-
Septic tank (towns)	-	-	0.1	0.8	0.001	0.2
Intensive animal use	-	-	0.2	0.9	0.002	0.8
Water	1.3	0.2	-	-	-	-
Total	**537**		**18**	**0**	**0.26**	

Area:



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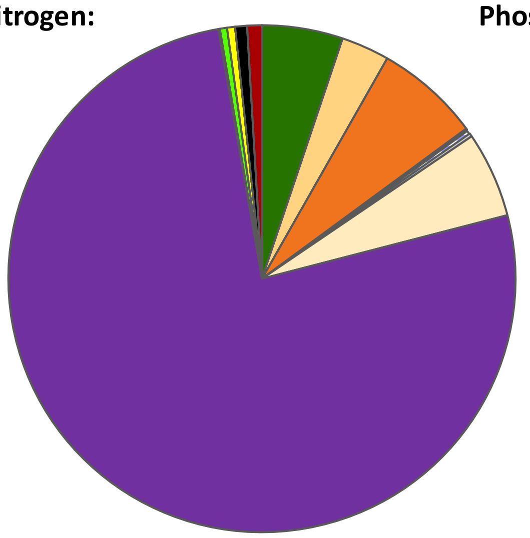
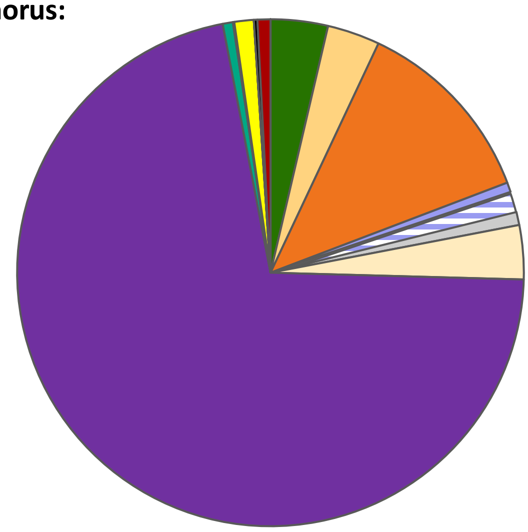


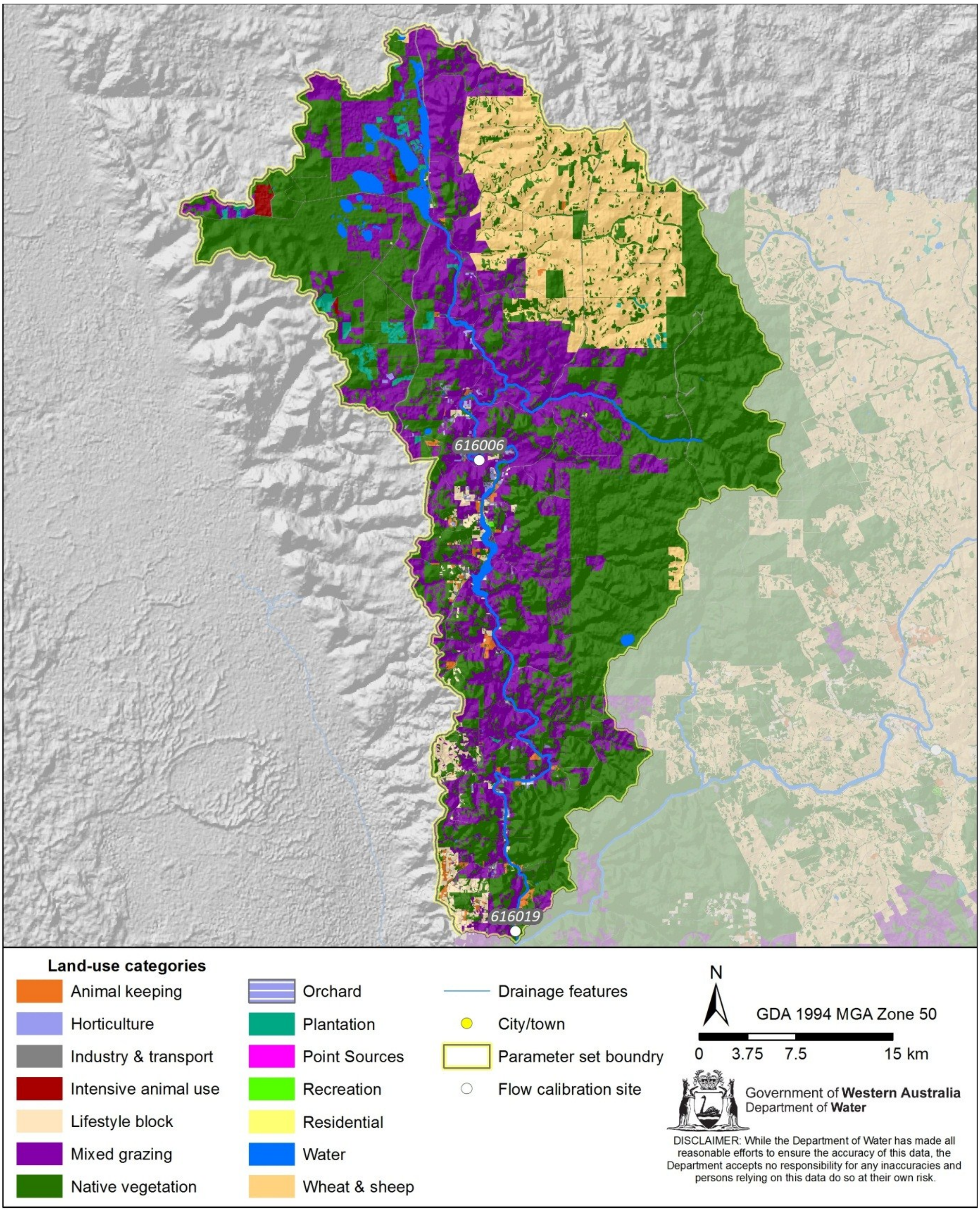
Phosphorus:



Wooroloo: all scenario results

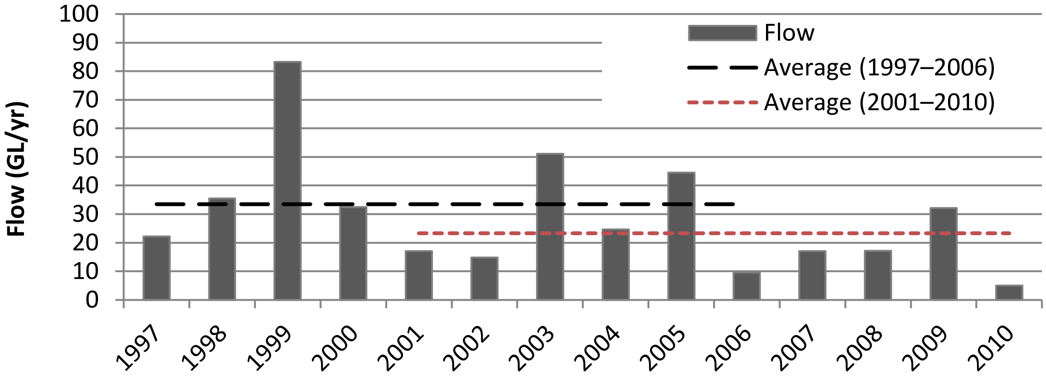
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	32		18		0.26	
Point source management: Town sewage management	-		18	-0.7	0.26	0.0
Point source management: point source removal	-		18	-2	0.25	-1
Soil acidity management: 5% adoption	-		18	-0.2	0.25	-0.4
Soil acidity management: 20% adoption	-		18	-1	0.25	-1
Soil acidity management: 50% adoption	-		18	-2	0.25	-4
Soil acidity management: 100% adoption	-		18	-4	0.24	-7
Soil acidity management: No action	-		-		-	
Farm nutrient management: 5%	-		18	-1	0.25	-2
Farm nutrient management: 20%	-		18	-3	0.24	-8
Farm nutrient management: 50%	-		17	-7	0.20	-20
Farm nutrient management: 100%	-		16	-14	0.15	-40
Riparian rehabilitation: 10 km/yr (high)	-		17	-9	0.24	-5
Riparian rehabilitation: 20 km/yr (high)	-		15	-18	0.23	-9
Riparian rehabilitation: 40 km/yr (high)	-		12	-34	0.21	-18
Riparian management: whole catchment (high)	-		12	-34	0.21	-18
Riparian rehabilitation: 10 km/yr (low)	-		17	-7	0.25	-2
Riparian rehabilitation: 20 km/yr (low)	-		16	-13	0.24	-4
Riparian rehabilitation: 40 km/yr (low)	-		14	-26	0.23	-9
Riparian management: whole catchment (low)	-		14	-26	0.23	-9
Land-use change: urban expansion	-		19	1	0.27	5
Current management practices	-		16	-14	0.25	-2
Moderate intervention	-		12	-32	0.22	-14
Large intervention	-		10	-45	0.15	-40
Revegetation: additional 5% native vegetation	-		-		-	
Revegetation: additional 10% native vegetation	-		-		-	
Revegetation: up to 30% native vegetation	-		-		-	
Climate change: baseline climate period (1961–90)	59		38		0.50	
Climate change: dry (30 year period)	31	-48%	18	-53	0.25	-50
Climate change: wet (30 year period)	49	-16%	31	-18	0.41	-17
Climate change: dry (10 year period)	23	-27%	13	-29	0.18	-28
Climate change: wet (10 year period)	40	-32%	24	32	0.33	29

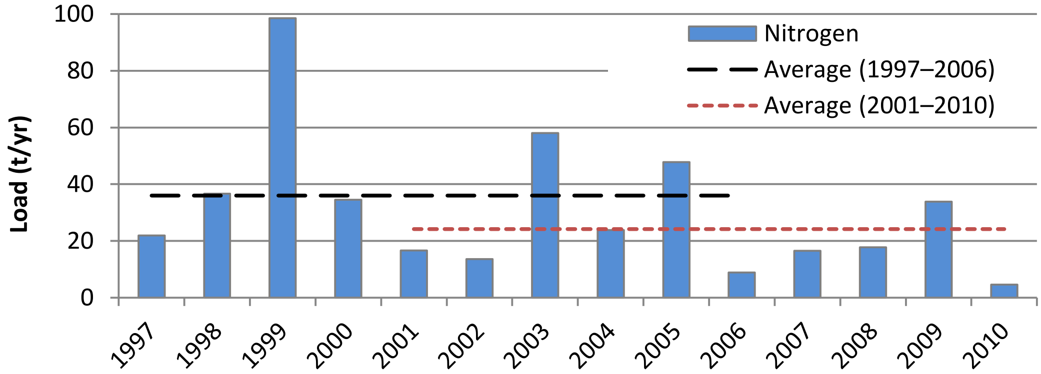
Brockman

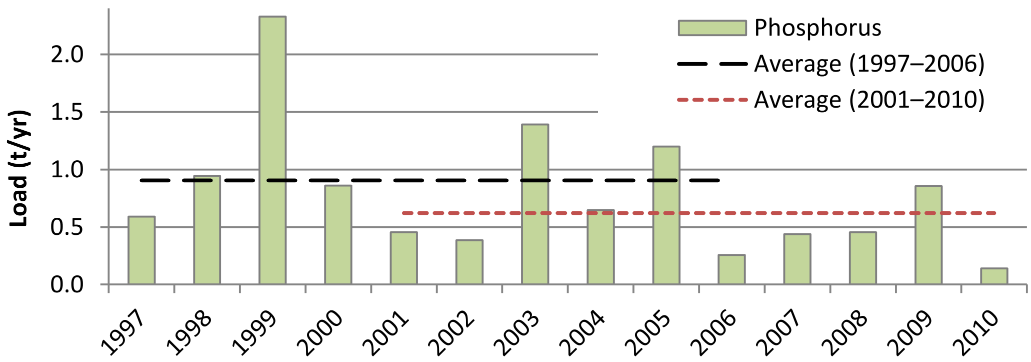

616006
616019
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 3.75 7.5 15 km
Government of Western Australia
Department of Water
DISCLAIMER: While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Brockman: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	22	21.9	0.59
1998	36	36.6	0.94
1999	83	98.5	2.33
2000	32	34.5	0.86
2001	17	16.6	0.45
2002	15	13.6	0.39
2003	51	58.0	1.39
2004	25	23.9	0.65
2005	45	47.8	1.20
2006	10	8.9	0.26
2007	17	16.5	0.44
2008	17	17.8	0.45
2009	32	33.9	0.86
2010	5	4.5	0.14
Average (1997–2006)	**33**	**36.0**	**0.91**
Average (2001–2010)	**23**	**24.1**	**0.62**



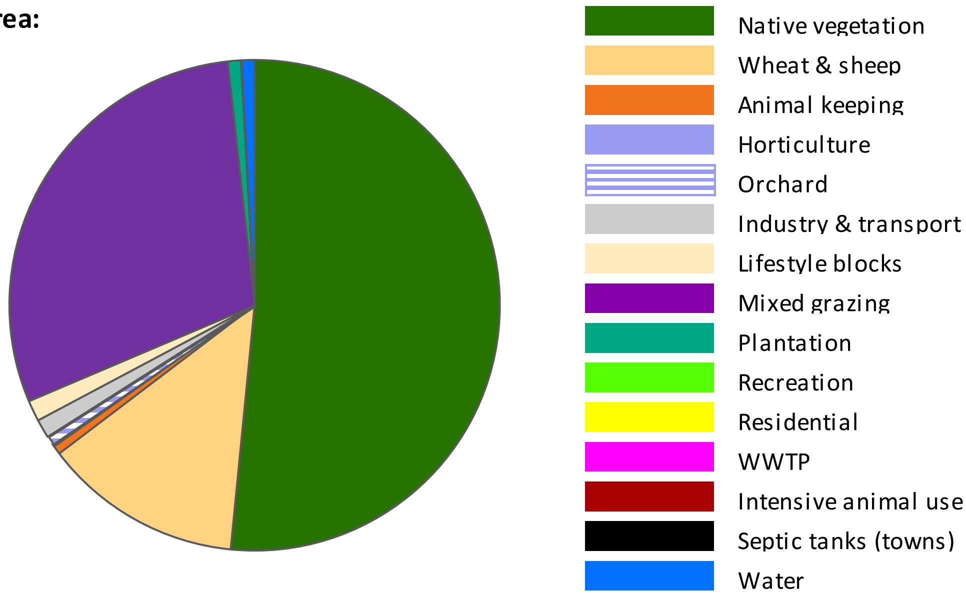




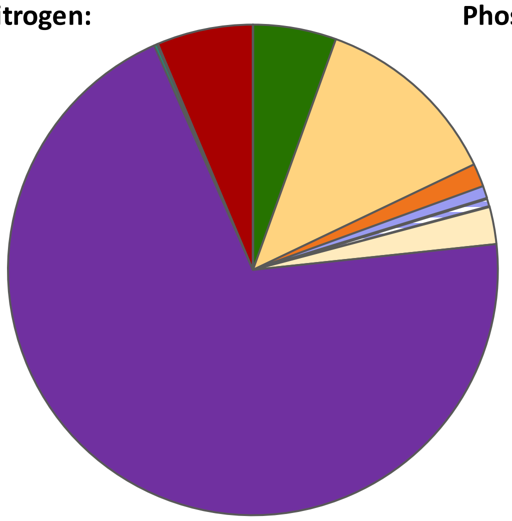
Brockman: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	781	51	1.3	5.5	0.011	1.7
Wheat & sheep	199	13	3.0	12	0.084	13
Animal keeping	8.6	0.6	0.4	1.5	0.016	2.5
Horticulture	3.0	0.2	0.2	0.8	0.040	6.4
Orchard	8.4	0.6	0.1	0.5	0.014	2.2
Industry & transport	19	1.2	0.0	0.1	0.002	0.3
Lifestyle blocks	21	1.4	0.6	2.4	0.010	1.6
Mixed grazing	449	30	17	70	0.37	60
Plantation	13	0.9	0.05	0.2	0.009	1.4
Recreation	0.3	0.0	0.02	0.1	0.000	0.0
Residential	0.2	0.0	0.00	0.0	0.000	0.0
WWTPs	-	-	-	-	0	-
Septic tank (towns)	-	-	-	-	-	-
Intensive animal use	-	-	1.5	6.3	0.065	10
Water	13	0.9	-	-	-	-
Total	**1 519**		**24**	**0**	**0.62**	

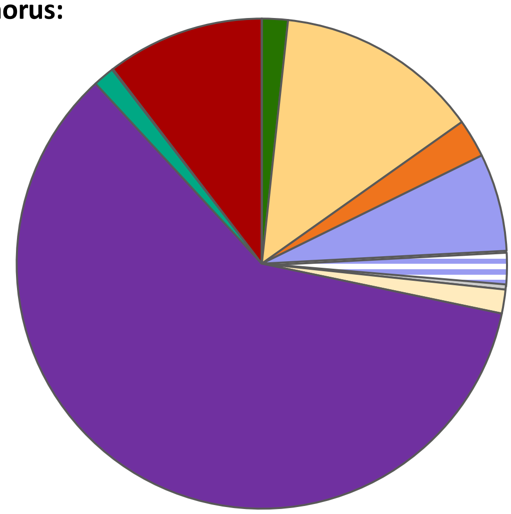
Area:



Nitrogen:



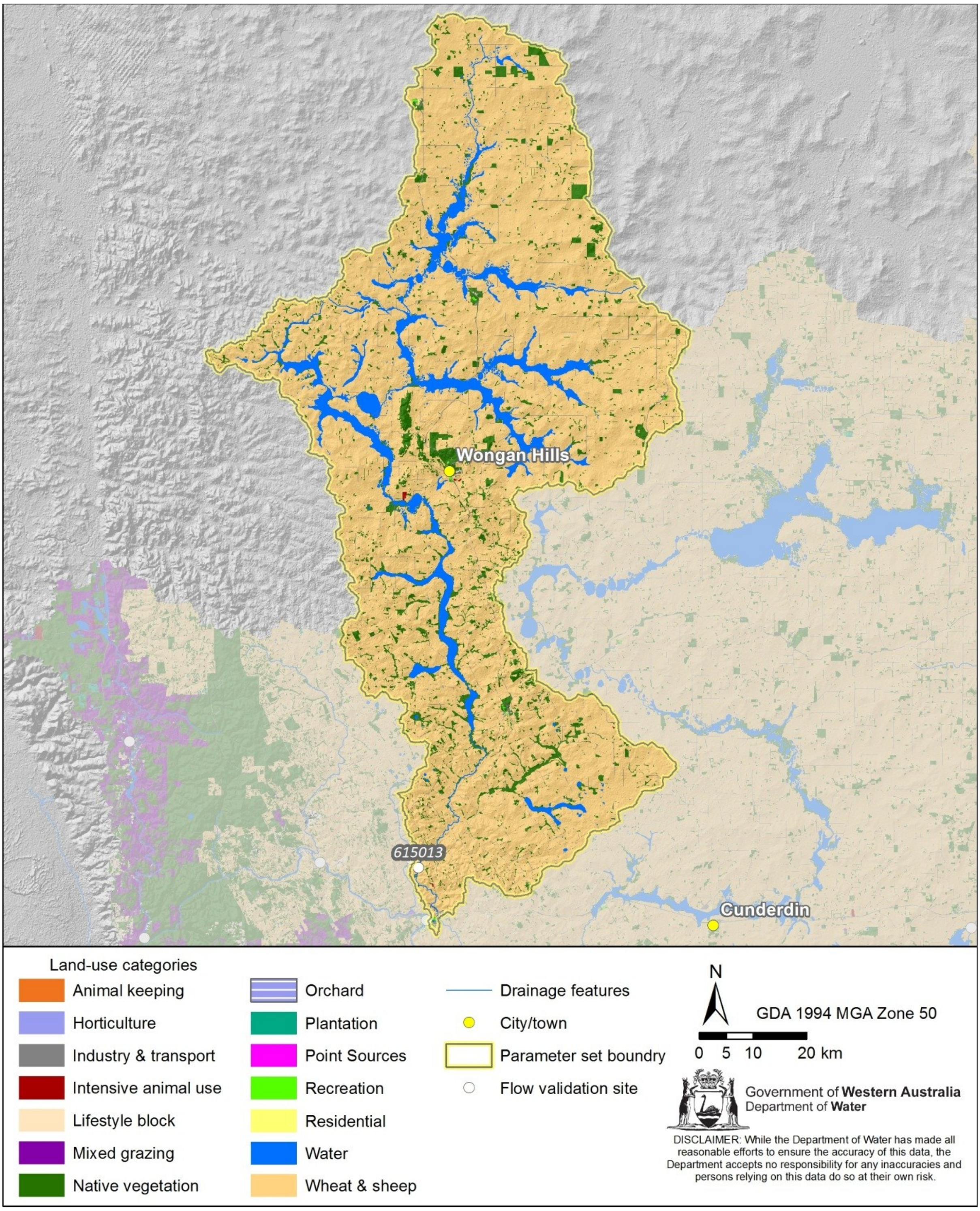
Phosphorus:



Brockman: all scenario results

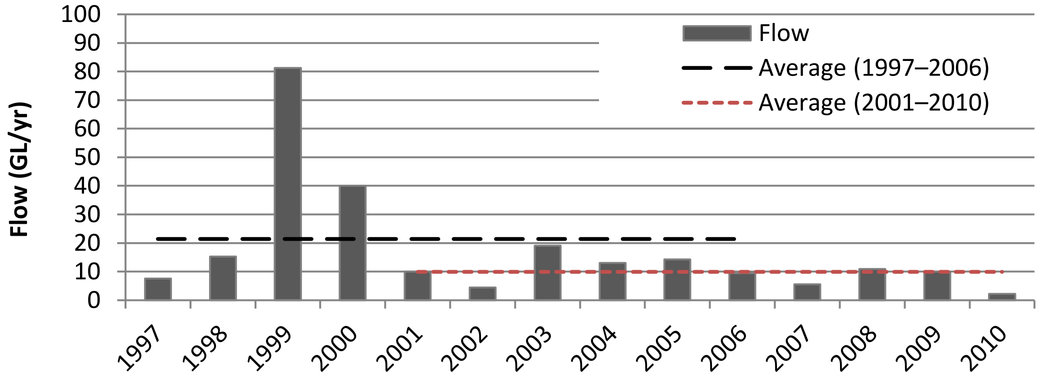
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	23		24		0.62	
Point source management: Town sewage management	-		-		-	
Point source management: point source removal	-		23	-6	0.56	-10
Soil acidity management: 5% adoption	-		24	-0.3	0.62	-0.4
Soil acidity management: 20% adoption	-		24	-1	0.61	-2
Soil acidity management: 50% adoption	-		24	-3	0.60	-4
Soil acidity management: 100% adoption	-		23	-5	0.57	-8
Soil acidity management: No action	-		-		-	
Farm nutrient management: 5%	-		24	-1	0.61	-2
Farm nutrient management: 20%	-		23	-3	0.57	-8
Farm nutrient management: 50%	-		22	-8	0.50	-20
Farm nutrient management: 100%	-		20	-17	0.37	-40
Riparian rehabilitation: 10 km/yr (high)	-		23	-4	0.61	-2
Riparian rehabilitation: 20 km/yr (high)	-		22	-8	0.60	-4
Riparian rehabilitation: 40 km/yr (high)	-		20	-15	0.57	-8
Riparian management: whole catchment (high)	-		16	-33	0.52	-17
Riparian rehabilitation: 10 km/yr (low)	-		23	-5	0.62	-1
Riparian rehabilitation: 20 km/yr (low)	-		23	-6	0.61	-2
Riparian rehabilitation: 40 km/yr (low)	-		21	-11	0.60	-4
Riparian management: whole catchment (low)	-		18	-25	0.57	-8
Land-use change: urban expansion	-		24	0.0	0.62	0.2
Current management practices	-		23	-7	0.61	-3
Moderate intervention	-		20	-17	0.55	-11
Large intervention	-		17	-28	0.40	-35
Revegetation: additional 5% native vegetation	-		-		-	
Revegetation: additional 10% native vegetation	-		-		-	
Revegetation: up to 30% native vegetation	-		-		-	
Climate change: baseline climate period (1961–90)	58		76		1.7	
Climate change: dry (30 year period)	24	-58%	28	-63	0.69	-59
Climate change: wet (30 year period)	47	-18%	60	-20	1.4	-19
Climate change: dry (10 year period)	14	-39%	14	-41	0.39	-37
Climate change: wet (10 year period)	30	-48%	33	37	0.82	32

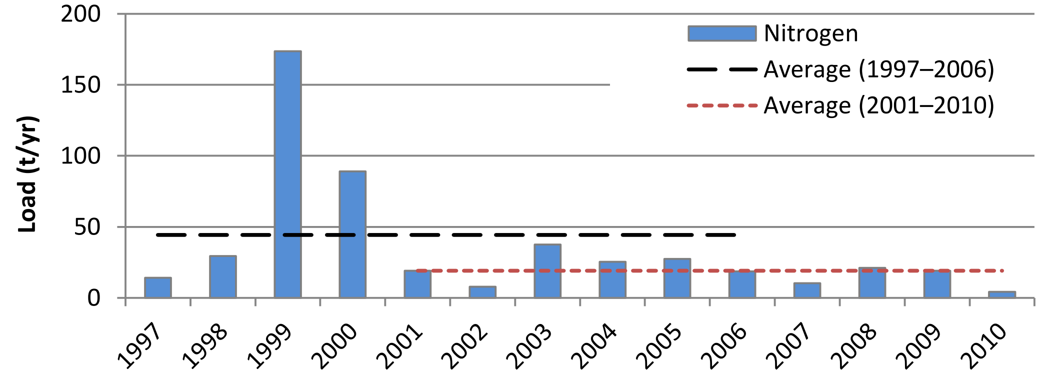
Mortlock North

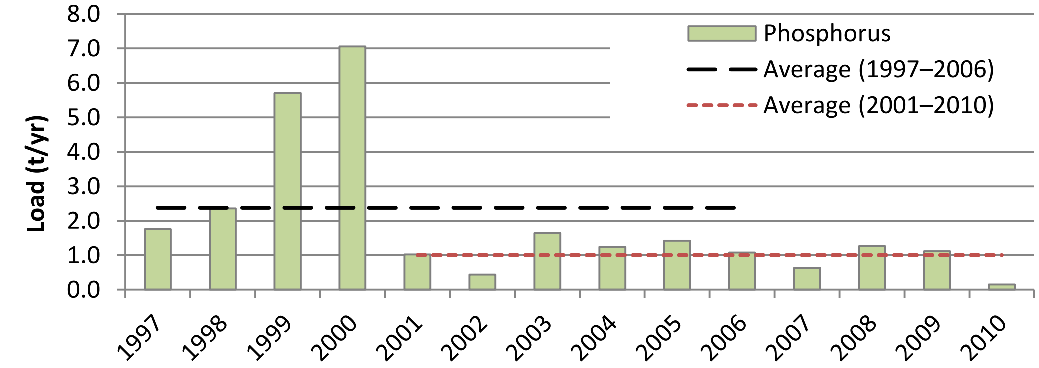


Mortlock North: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	8	14.2	1.76
1998	15	29.4	2.36
1999	81	173.7	5.70
2000	40	89.2	7.06
2001	10	19.0	1.02
2002	4	7.9	0.44
2003	19	37.6	1.64
2004	13	25.4	1.24
2005	14	27.5	1.43
2006	9	18.7	1.08
2007	6	10.3	0.63
2008	11	21.2	1.27
2009	10	19.0	1.12
2010	2	4.2	0.15
Average (1997–2006)	**21**	**44.3**	**2.37**
Average (2001–2010)	**10**	**19.1**	**1.00**



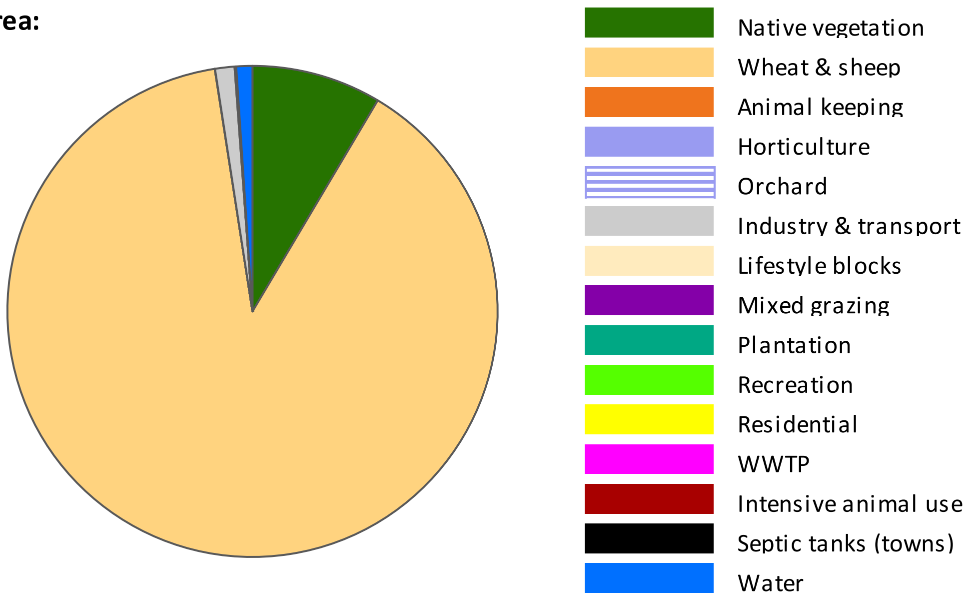




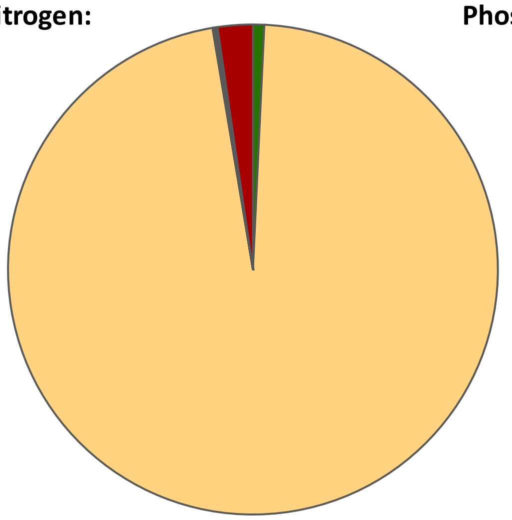
Mortlock North: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	589	8.5	0.1	0.7	0.006	0.6
Wheat & sheep	6 140	89	18.5	97	0.99	98
Animal keeping	1.3	0.02	0.0	0.1	0.001	0.1
Horticulture	-	-	-	-	-	-
Orchard	-	-	-	-	-	-
Industry & transport	88	1.3	0.0	0.1	0.002	0.2
Lifestyle blocks	2.1	0.03	0.0	0.1	0.000	0.0
Mixed grazing	-	-	-	-	-	-
Plantation	0.0	0.00	0.0	0.0	0.000	0.0
Recreation	2.7	0.04	0.0	0.1	0.000	0.0
Residential	2.6	0.04	0.0	0.1	0.001	0.1
WWTPs	-	-	-	-	-	-
Septic tank (towns)	-	-	-	-	-	-
Intensive animal use	-	-	0.4	2.3	0.007	0.7
Water	73	1.1		-	-	-
Total	**6 901**		**19**	**0**	**1.01**	

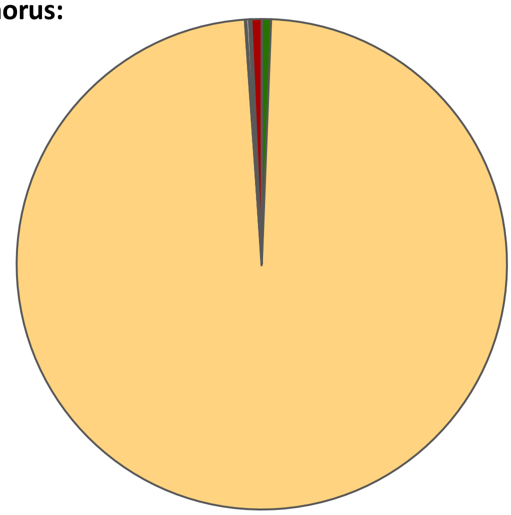
Area:



Nitrogen:



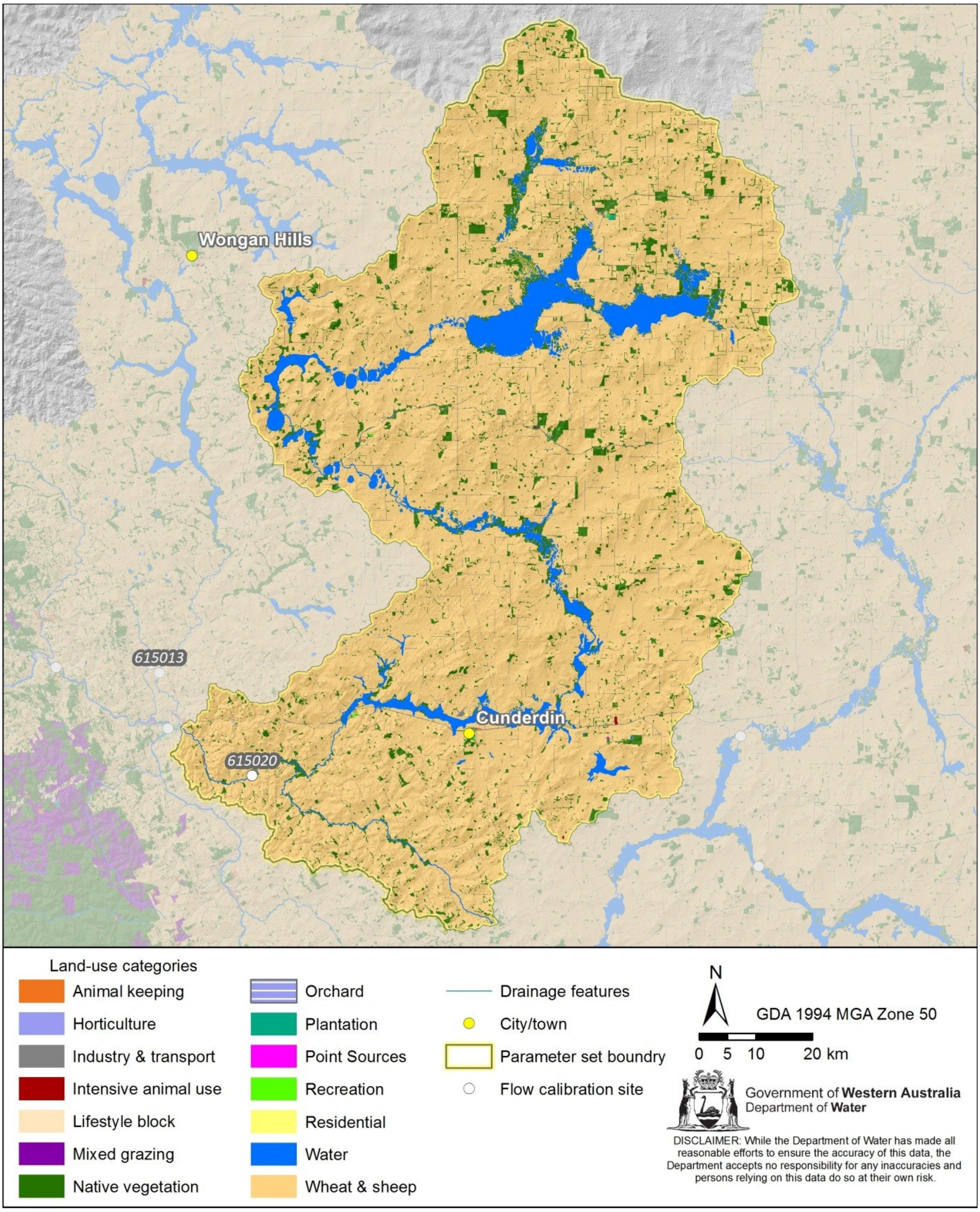
Phosphorus:



Mortlock North: all scenario results

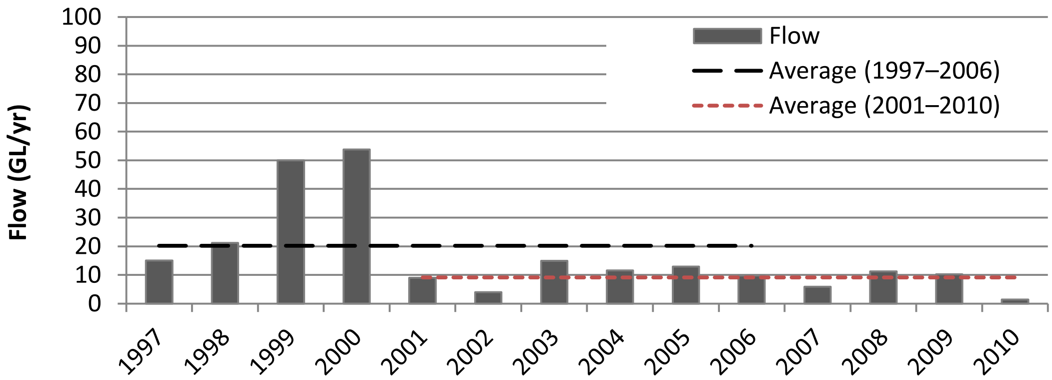
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	10		19		1.0	
Point source management: Town sewage management	-		-		-	
Point source management: point source removal	-		19	-2	1.0	-1
Soil acidity management: 5% adoption	-		19	-0.6	1.0	-0.8
Soil acidity management: 20% adoption	-		19	-2	1.0	-3
Soil acidity management: 50% adoption	-		18	-6	0.93	-8
Soil acidity management: 100% adoption	-		17	-12	0.85	-16
Soil acidity management: No action	-		19	0.1	1.0	0.1
Farm nutrient management: 5%	-		19	-2	1.0	-3
Farm nutrient management: 20%	-		18	-8	0.88	-13
Farm nutrient management: 50%	-		15	-19	0.68	-32
Farm nutrient management: 100%	-		12	-39	0.36	-64
Riparian rehabilitation: 10 km/yr (high)	-		-		-	
Riparian rehabilitation: 20 km/yr (high)	-		-		-	
Riparian rehabilitation: 40 km/yr (high)	-		-		-	
Riparian management: whole catchment (high)	-		11	-42	0.76	-25
Riparian rehabilitation: 10 km/yr (low)	-		-		-	
Riparian rehabilitation: 20 km/yr (low)	-		-		-	
Riparian rehabilitation: 40 km/yr (low)	-		-		-	
Riparian management: whole catchment (low)	-		13	-34	0.89	-12
Land-use change: urban expansion	-		19	1	1.0	1
Current management practices	-		19	1	1.0	1
Moderate intervention	-		18	-7	0.91	-10
Large intervention	-		13	-30	0.54	-46
Revegetation: additional 5% native vegetation	8.0	-20%	14	-24	0.76	-25
Revegetation: additional 10% native vegetation	6.7	-32%	12	-39	0.61	-40
Revegetation: up to 30% native vegetation	3.2	-67%	5	-74	0.25	-76
Climate change: baseline climate period (1961–90)	28		57		3.1	
Climate change: dry (30 year period)	8.7	-69%	17	-70	0.91	-71
Climate change: wet (30 year period)	20	-29%	40	-31	2.1	-31
Climate change: dry (10 year period)	6.6	-33%	13	-30	0.70	-31
Climate change: wet (10 year period)	14	-51%	27	43	1.45	44

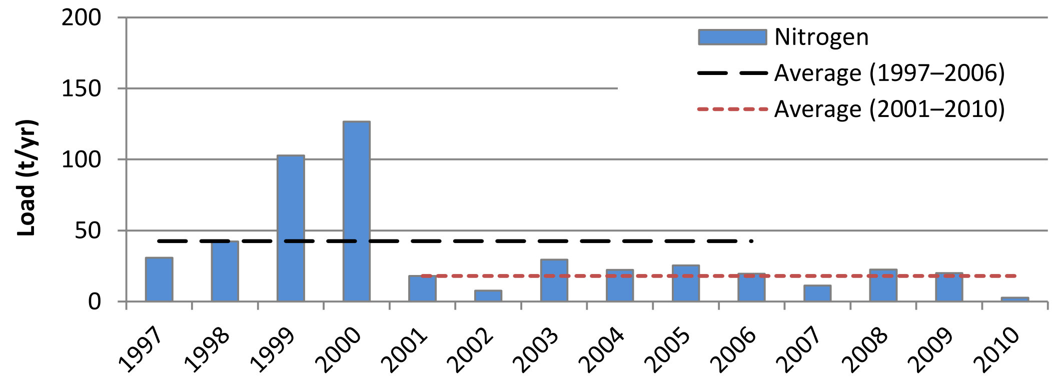
Mortlock East

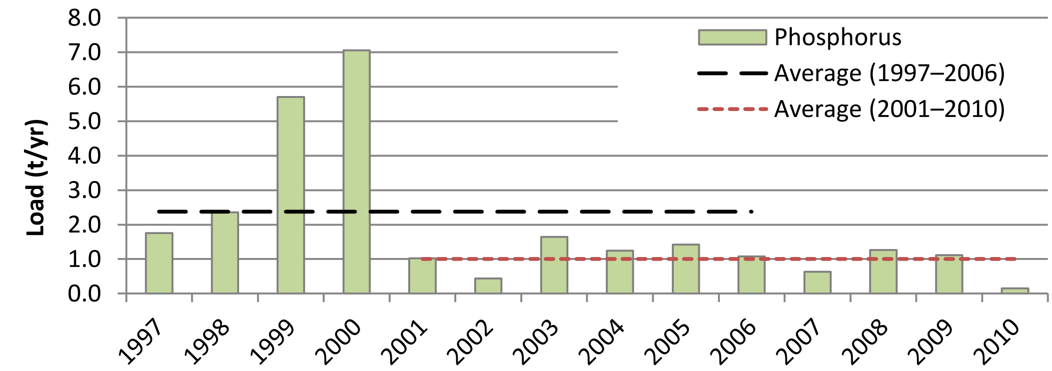


Mortlock East: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	15	30.9	1.76
1998	21	42.4	2.36
1999	50	102.9	5.70
2000	54	126.7	7.06
2001	9	18.1	1.02
2002	4	7.6	0.44
2003	15	29.4	1.64
2004	12	22.3	1.24
2005	13	25.3	1.43
2006	10	19.6	1.08
2007	6	11.3	0.63
2008	11	22.5	1.27
2009	10	20.0	1.12
2010	1	2.7	0.15
Average (1997–2006)	**20**	**42.5**	**2.37**
Average (2001–2010)	**9**	**17.9**	**1.00**



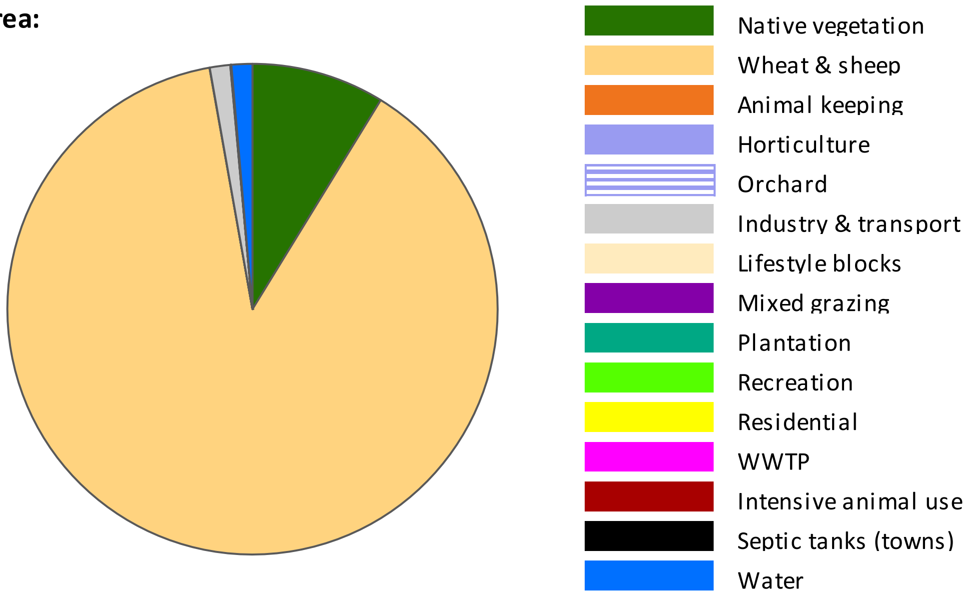




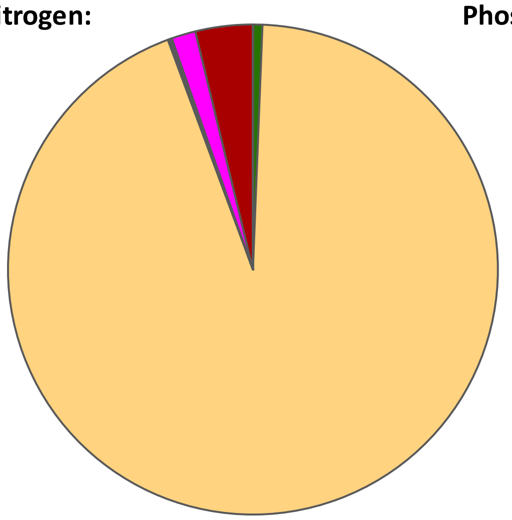
Mortlock East: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	867	8.8	0.1	0.6	0.005	0.5
Wheat & sheep	8 743	88	16.8	94	0.90	90
Animal keeping	1.7	0.0	0.01	0.1	0.001	0.1
Horticulture	-	-	-	-	-	-
Orchard	-	-	-	-	-	-
Industry & transport	133	1.3	0.01	0.1	0.002	0.2
Lifestyle blocks	1.8	0.0	0.01	0.0	0.000	0.0
Mixed grazing	-	-	-	-	-	-
Plantation	1.2	0.0	0.00	0.0	0.000	0.0
Recreation	1.8	0.0	0.01	0.0	0.000	0.0
Residential	2.3	0.0	0.01	0.1	0.001	0.1
WWTPs	-	-	0.29	1.6	0.085	8.5
Septic tank (towns)	-	-	0.00	0.0	0.000	0.0
Intensive animal use	-	-	0.68	3.8	0.008	0.8
Water	136	1.4	-	-	-	-
Total	**9 889**		**18**	**0**	**1.00**	

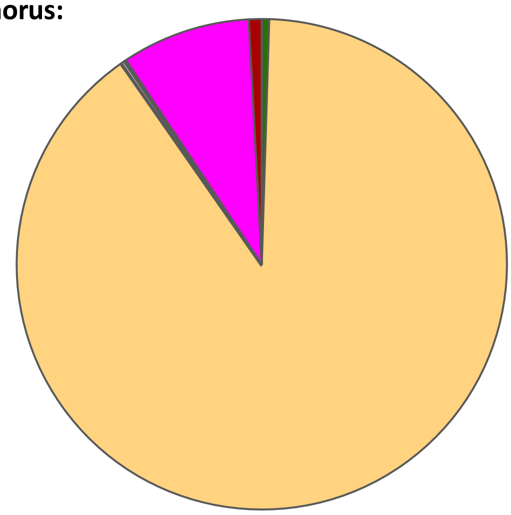
Area:



Nitrogen:



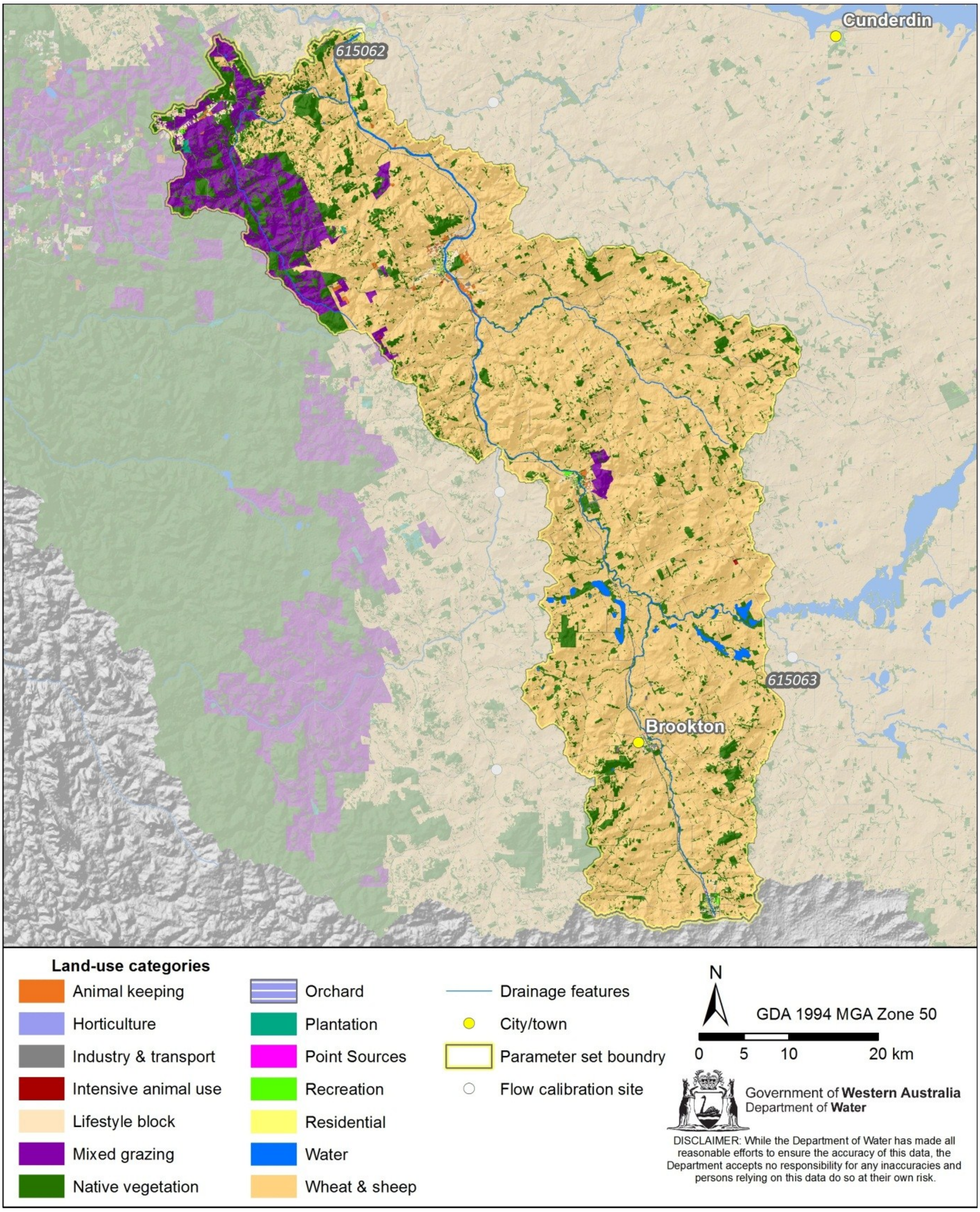
Phosphorus:



Mortlock East: all scenario results

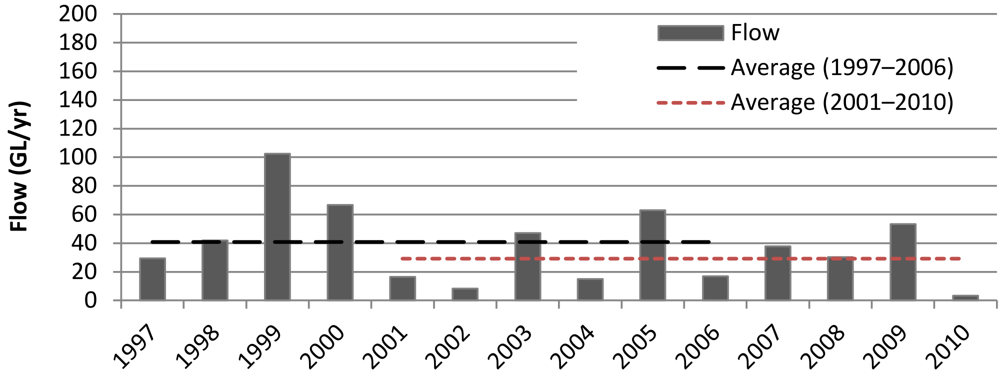
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	9.1		18		1.00	
Point source management: Town sewage management	-		18	-1	0.92	-8
Point source management: point source removal	-		17	-5	0.91	-9
Soil acidity management: 5% adoption	-		18	-0.6	0.99	-0.7
Soil acidity management: 20% adoption	-		17	-2	0.97	-3
Soil acidity management: 50% adoption	-		17	-6	0.93	-7
Soil acidity management: 100% adoption	-		16	-11	0.86	-14
Soil acidity management: No action	-		18	2	1.02	2
Farm nutrient management: 5%	-		18	-2	0.97	-3
Farm nutrient management: 20%	-		17	-7	0.88	-12
Farm nutrient management: 50%	-		15	-19	0.71	-29
Farm nutrient management: 100%	-		11	-37	0.41	-59
Riparian rehabilitation: 10 km/yr (high)	-		-		-	
Riparian rehabilitation: 20 km/yr (high)	-		-		-	
Riparian rehabilitation: 40 km/yr (high)	-		-		-	
Riparian management: whole catchment (high)	-		10	-44	0.76	-25
Riparian rehabilitation: 10 km/yr (low)	-		-		-	
Riparian rehabilitation: 20 km/yr (low)	-		-		-	
Riparian rehabilitation: 40 km/yr (low)	-		-		-	
Riparian management: whole catchment (low)	-		12	-35	0.88	-12
Land-use change: urban expansion	-		18	0.3	1.0	0.8
Current management practices	-		18	0.3	1.0	0.8
Moderate intervention	-		16	-9	0.83	-17
Large intervention	-		12	-31	0.49	-51
Revegetation: additional 5% native vegetation	7.4	-18%	14	-22	0.79	-21
Revegetation: additional 10% native vegetation	6.2	-32%	11	-38	0.63	-37
Revegetation: up to 30% native vegetation	3.1	-66%	5.2	-71	0.32	-68
Climate change: baseline climate period (1961–90)	32		68		3.8	
Climate change: dry (30 year period)	10	-70%	20	-70	1.2	-69
Climate change: wet (30 year period)	23	-28%	48	-29	2.7	-29
Climate change: dry (10 year period)	5.9	-35%	12	-33	0.70	-30
Climate change: wet (10 year period)	14	-57%	27	53	1.5	53

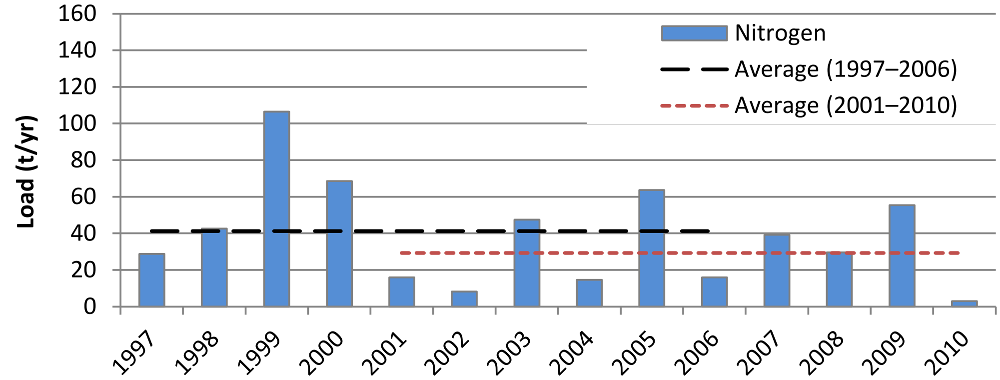
Middle Avon

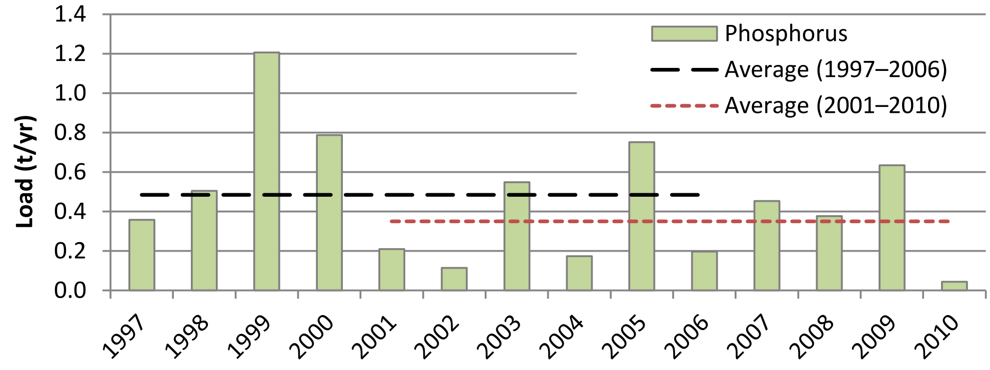

Cunderdin
615062
615063
Brookton
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 5 10 20 km
Government of Western Australia
Department of Water
DISCLAIMER: While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Middle Avon: annual flow, nitrogen and phosphorus loads

Year	**Flow (GL/yr)**	**Nitrogen (t/yr)**	**Phosphorus (t/yr)**
1997	29	28.7	0.36
1998	42	42.6	0.50
1999	102	106.5	1.21
2000	67	68.5	0.79
2001	16	15.9	0.21
2002	8	8.2	0.11
2003	47	47.6	0.55
2004	15	14.6	0.17
2005	63	63.7	0.75
2006	17	16.0	0.20
2007	38	39.2	0.45
2008	30	29.7	0.38
2009	53	55.4	0.63
2010	3	3.0	0.04
Average (1997–2006)	**41**	**41.2**	**0.48**
Average (2001–2010)	**29**	**29.3**	**0.35**



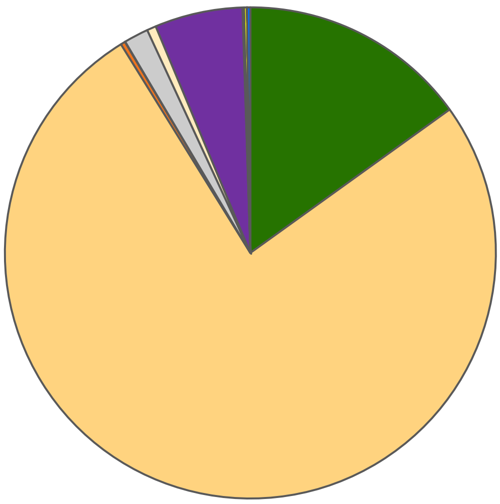




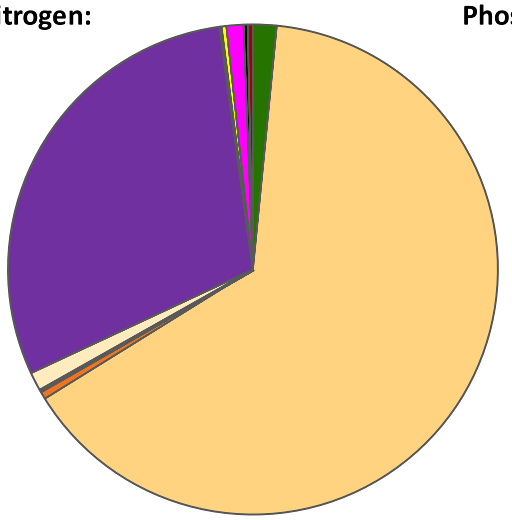
Middle Avon: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	432	15.1	0.5	1.6	0.003	0.8
Wheat & sheep	2 179	76	19.0	65	0.20	58
Animal keeping	8.7	0.3	0.16	0.6	0.003	0.8
Horticulture	-	-	-	-	-	-
Orchard	0.6	0.0	0.00	0.0	0.000	0.0
Industry & transport	46	1.6	0.03	0.1	0.001	0.3
Lifestyle blocks	17	0.6	0.36	1.2	0.002	0.6
Mixed grazing	166	6	8.73	30	0.079	23
Plantation	1.2	0.0	0.01	0.0	0.001	0.1
Recreation	1.7	0.1	0.04	0.1	0.000	0.0
Residential	5.6	0.2	0.09	0.3	0.002	0.6
WWTPs	-	-	0.33	1.1	0.056	16.1
Septic tank (towns)	-	-	0.08	0.3	0.000	0.0
Intensive animal use	-	-	0.10	0.3	0.001	0.2
Water	6.2	0.2	-	-	-	-
Total	**2 864**		**29**	**0**	**0.35**	

Area:



Nitrogen:



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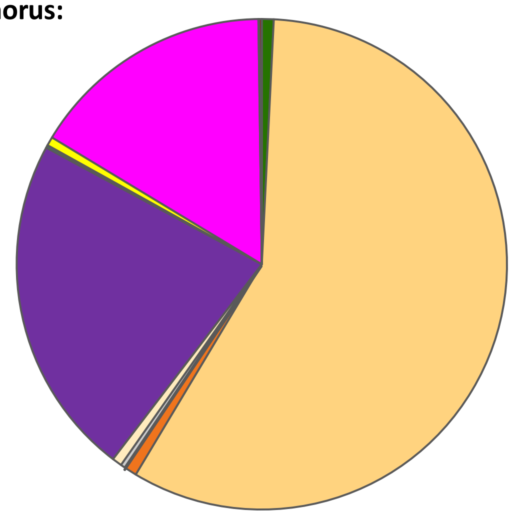
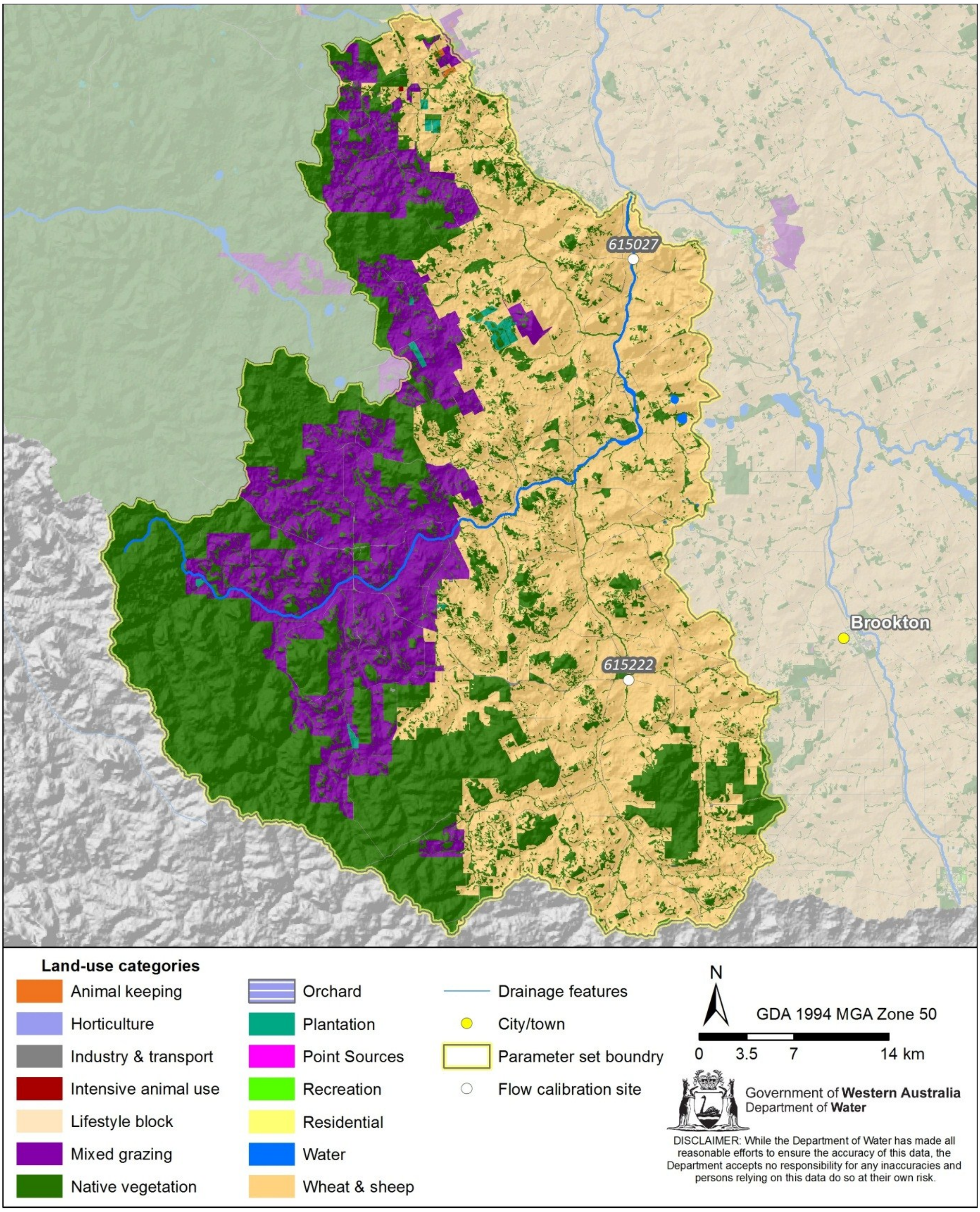


Middle Avon: all scenario results

Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	29		29		0.35	
Point source management: Town sewage management	-		29	-1	0.30	-15
Point source management: point source removal	-		29	-2	0.29	-16
Soil acidity management: 5% adoption	-		29	-0.5	0.35	-0.6
Soil acidity management: 20% adoption	-		29	-2	0.34	-2
Soil acidity management: 50% adoption	-		28	-5	0.33	-6
Soil acidity management: 100% adoption	-		27	-9	0.31	-11
Soil acidity management: No action	-		30	1.1	0.35	1.3
Farm nutrient management: 5%	-		29	-2	0.34	-2
Farm nutrient management: 20%	-		28	-6	0.32	-10
Farm nutrient management: 50%	-		25	-15	0.26	-25
Farm nutrient management: 100%	-		20	-31	0.18	-50
Riparian rehabilitation: 10 km/yr (high)	-		29	-1	0.35	-1
Riparian rehabilitation: 20 km/yr (high)	-		29	-3	0.35	-1
Riparian rehabilitation: 40 km/yr (high)	-		28	-5	0.34	-3
Riparian management: whole catchment (high)	-		17	-42	0.28	-20
Riparian rehabilitation: 10 km/yr (low)	-		29	-1	0.35	-0.3
Riparian rehabilitation: 20 km/yr (low)	-		29	-2	0.35	-1
Riparian rehabilitation: 40 km/yr (low)	-		28	-4	0.35	-1
Riparian management: whole catchment (low)	-		20	-33	0.32	-10
Land-use change: urban expansion	-		30	2	0.36	4
Current management practices	-		29	-1	0.36	3
Moderate intervention	-		26	-10	0.28	-21
Large intervention	-		21	-29	0.17	-50
Revegetation: additional 5% native vegetation	28	-3%	28	-4	0.34	-2
Revegetation: additional 10% native vegetation	28	-5%	26	-10	0.32	-10
Revegetation: up to 30% native vegetation	26	-11%	24	-19	0.29	-18
Climate change: baseline climate period (1961–90)	71		86		0.95	
Climate change: dry (30 year period)	36	-49%	38	-56	0.45	-52
Climate change: wet (30 year period)	66	-7%	70	-18	0.79	-17
Climate change: dry (10 year period)	28	-5%	28	-3	0.35	-1
Climate change: wet (10 year period)	52	-27%	54	85	0.62	76

Dale



615027
615222
Brookton
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 3.5 7 14 km
Government of Western Australia
Department of Water
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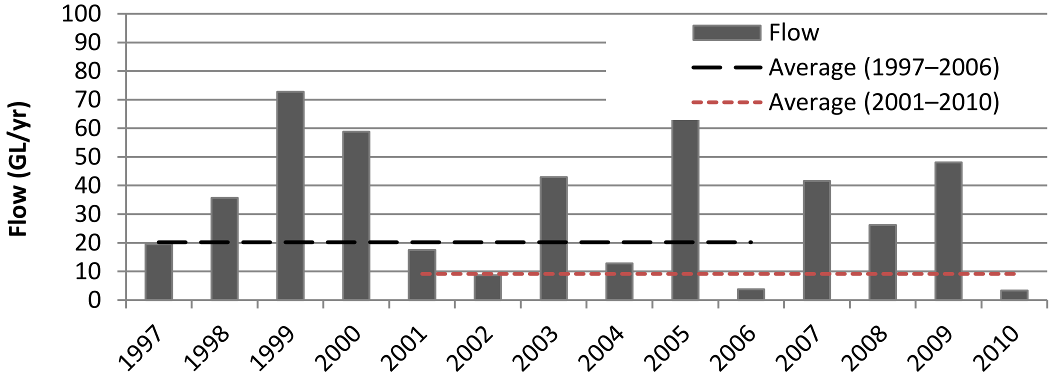
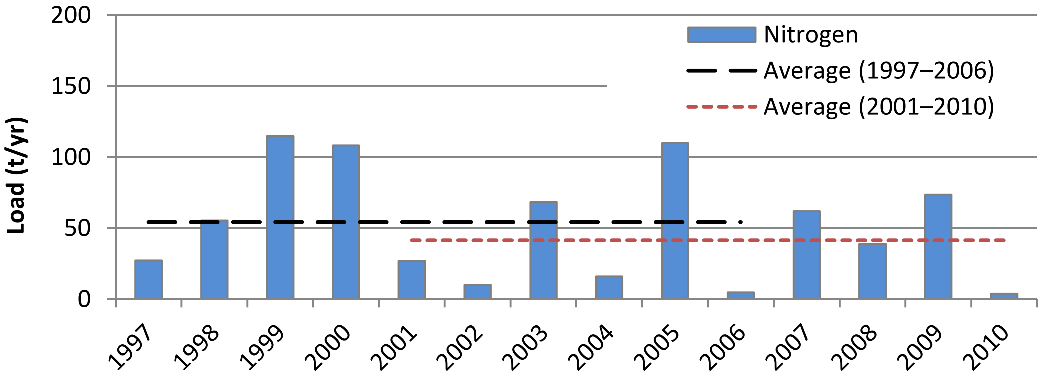
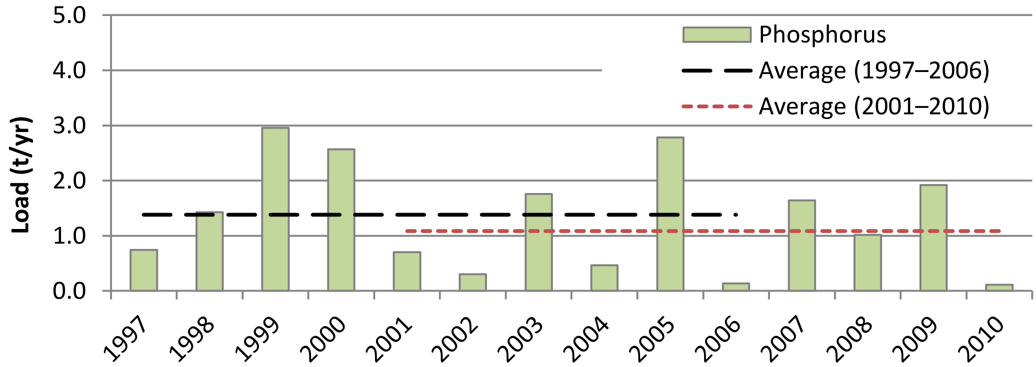
Dale: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	20	27.3	0.74
1998	36	55.3	1.43
1999	73	114.8	2.96
2000	59	108.3	2.57
2001	17	27.0	0.70
2002	9	10.1	0.30
2003	43	68.3	1.76
2004	13	16.0	0.46
2005	67	109.9	2.78
2006	4	4.7	0.14
2007	42	61.9	1.64
2008	26	38.8	1.02
2009	48	73.7	1.92
2010	3	3.8	0.11
Average (1997–2006)	**34**	**54.2**	**1.38**
Average (2001–2010)	**27**	**41.4**	**1.08**



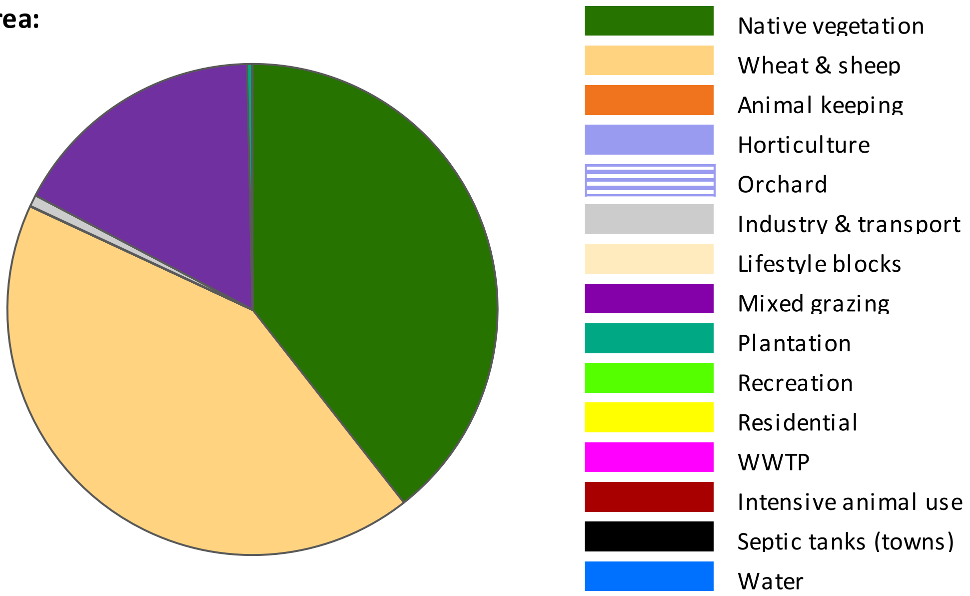




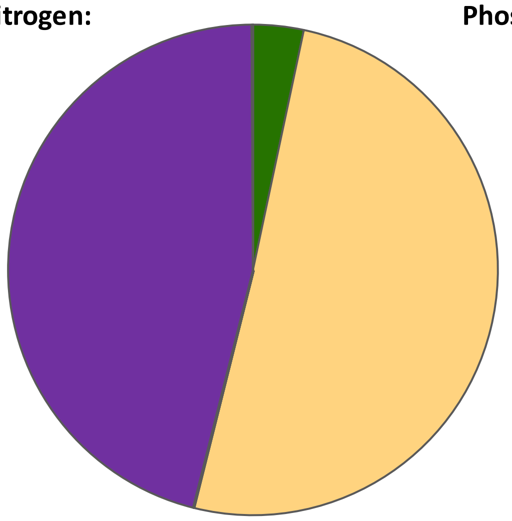
Dale: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	798	39	1.4	3.3	0.010	0.9
Wheat & sheep	861	42	21	51	0.60	55
Animal keeping	0.6	0.0	0.02	0.1	0.001	0.1
Horticulture	-	-	-	-	-	-
Orchard	0.2	0.0	0.00	0.0	0.000	0.0
Industry & transport	15	0.8	0.01	0.0	0.001	0.1
Lifestyle blocks	0.0	0.0	0.00	0.0	0.000	0.0
Mixed grazing	343.4	17	19	46	0.465	43
Plantation	6.6	0.3	0.04	0.1	0.006	0.5
Recreation	-	-	-	-	-	-
Residential	-	-	-	-	-	-
WWTPs	-	-	-	-	-	-
Septic tank (towns)	-	-	-	-	-	-
Intensive animal use	-	-	-	-	-	-
Water	0.6	0.0	-	-	-	-
Total	**2 026**		**41**	**0**	**1.08**	

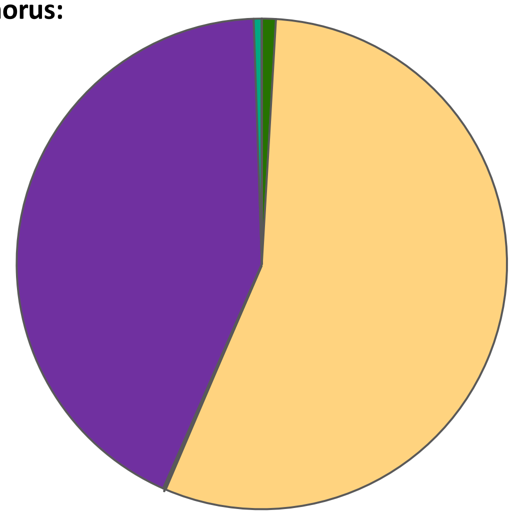
Area:



Nitrogen:



Phosphorus:



Dale: all scenario results

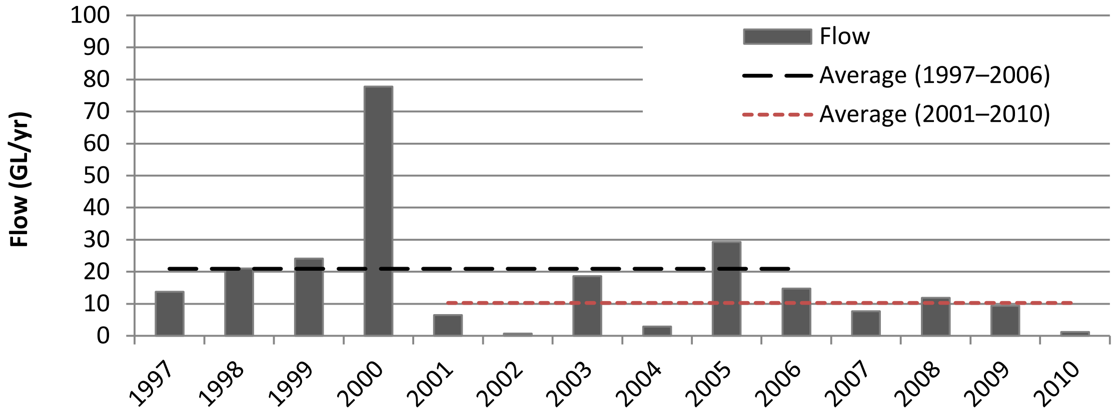
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	27		41		1.1	
Point source management: Town sewage management	-		-		-	
Point source management: point source removal	-		-		-	
Soil acidity management: 5% adoption	-		41	-0.4	1.1	-0.6
Soil acidity management: 20% adoption	-		41	-2	1.1	-3
Soil acidity management: 50% adoption	-		40	-4	1.0	-6
Soil acidity management: 100% adoption	-		38	-8	0.94	-13
Soil acidity management: No action	-		41	0.0	1.1	0.0
Farm nutrient management: 5%	-		41	-1	1.1	-3
Farm nutrient management: 20%	-		39	-6	0.96	-12
Farm nutrient management: 50%	-		36	-14	0.76	-29
Farm nutrient management: 100%	-		30	-28	0.45	-59
Riparian rehabilitation: 10 km/yr (high)	-		40	-3	1.1	-1
Riparian rehabilitation: 20 km/yr (high)	-		39	-5	1.1	-3
Riparian rehabilitation: 40 km/yr (high)	-		36	-13	1.0	-7
Riparian management: whole catchment (high)	-		27	-35	0.9	-19
Riparian rehabilitation: 10 km/yr (low)	-		41	-2	1.1	-1
Riparian rehabilitation: 20 km/yr (low)	-		40	-4	1.1	-1
Riparian rehabilitation: 40 km/yr (low)	-		37	-10	1.05	-3
Riparian management: whole catchment (low)	-		30	-27	0.99	-9
Land-use change: urban expansion	-		-		-	
Current management practices	-		40	-4	1.1	-2
Moderate intervention	-		34	-17	0.93	-14
Large intervention	-		27	-35	0.55	-49
Revegetation: additional 5% native vegetation	27	-0.2%	41	-0.3	1.1	-0.4
Revegetation: additional 10% native vegetation	27	-0.4%	41	-0.6	1.1	-0.7
Revegetation: up to 30% native vegetation	27	-0.8%	41	-1.3	1.1	-1.4
Climate change: baseline climate period (1961–90)	69		122		3.0	
Climate change: dry (30 year period)	28	-60%	43	-65	1.1	-62
Climate change: wet (30 year period)	55	-21%	94	-23	2.3	-22
Climate change: dry (10 year period)	23	-17%	33	-20	0.88	-19
Climate change: wet (10 year period)	44	-36%	70	69	1.8	65

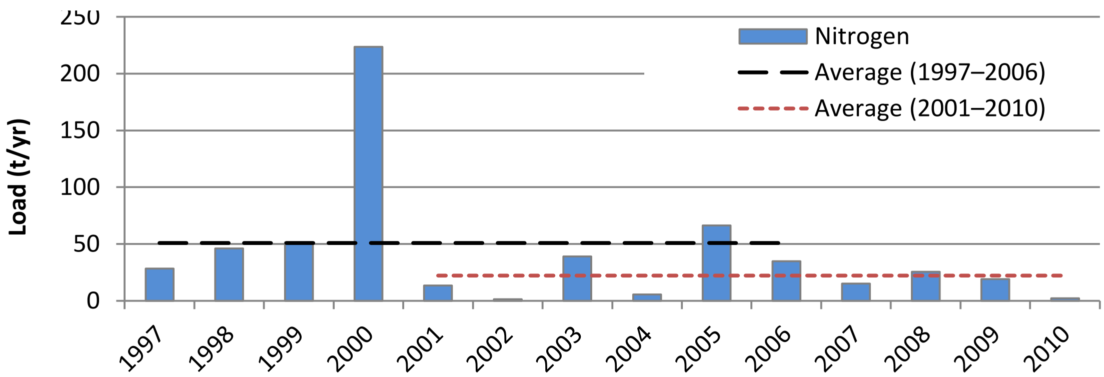
Upper Avon

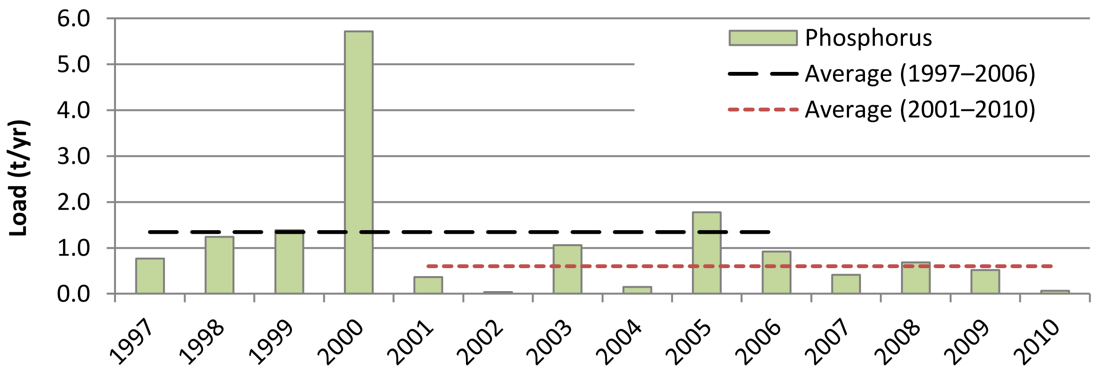

615063
Corrigin
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 4.5 9 18 km
Government of Western Australia
Department of Water
DISCLAIMER: While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Upper Avon: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	14	28.3	0.77
1998	21	46.1	1.24
1999	24	51.4	1.39
2000	78	223.6	5.72
2001	7	13.4	0.36
2002	1	1.3	0.04
2003	19	39.2	1.06
2004	3	5.5	0.15
2005	29	66.4	1.77
2006	15	34.7	0.92
2007	8	15.2	0.41
2008	12	25.5	0.69
2009	9	19.0	0.52
2010	1	2.4	0.06
Average (1997–2006)	**21**	**51.0**	**1.34**
Average (2001–2010)	**10**	**22.3**	**0.60**



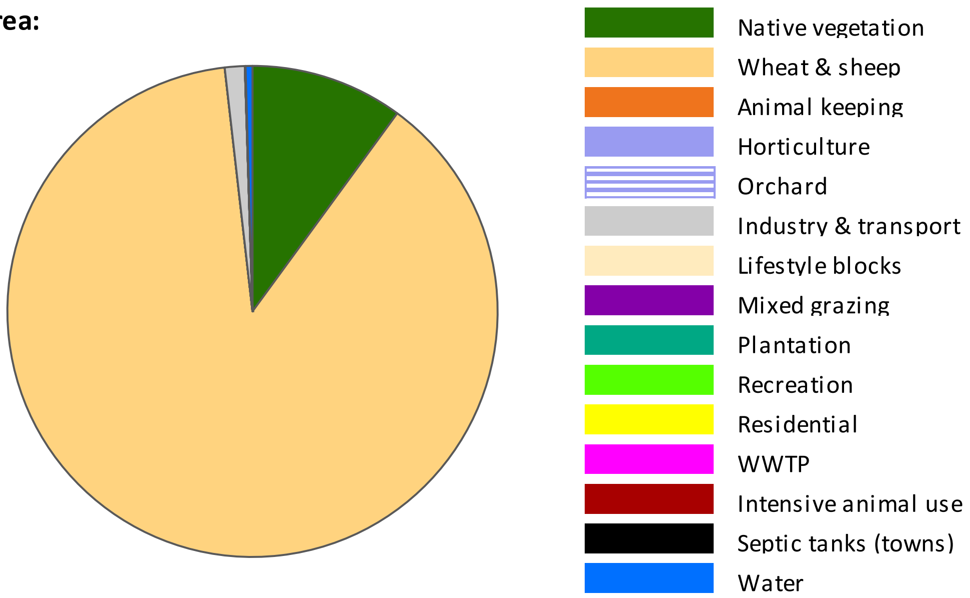




Upper Avon: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	320	10.1	0.2	0.8	0.001	0.1
Wheat & sheep	2 802	88	21.0	95	0.57	95
Animal keeping	0.1	0.0	0.00	0.0	0.000	0.0
Horticulture	-	-	-	-	-	-
Orchard	-	-	-	-	-	-
Industry & transport	42	1.3	0.01	0.1	0.001	0.1
Lifestyle blocks	0.1	0.0	0.00	0.0	0.000	0.0
Mixed grazing	-	-	-	-	-	-
Plantation	0.0	0.0	0.00	0.0	0.000	0.0
Recreation	1.0	0.0	0.01	0.0	0.000	0.0
Residential	0.5	0.0	0.01	0.0	0.000	0.0
WWTPs	-	-	-	-	-	-
Septic tank (towns)	-	-	-	-	-	-
Intensive animal use	-	-	1	4.6	0.026	4.4
Water	14	0.5	-	-	-	-
Total	**3 180**		**22**	**0**	**0.60**	

Area:



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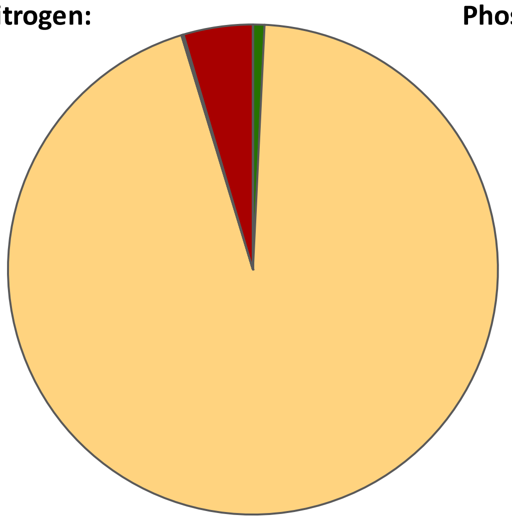
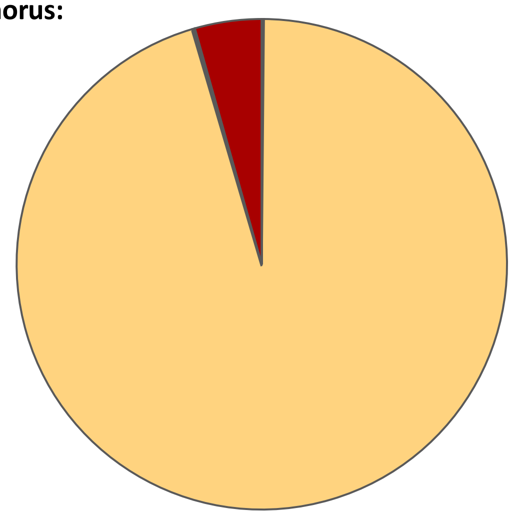


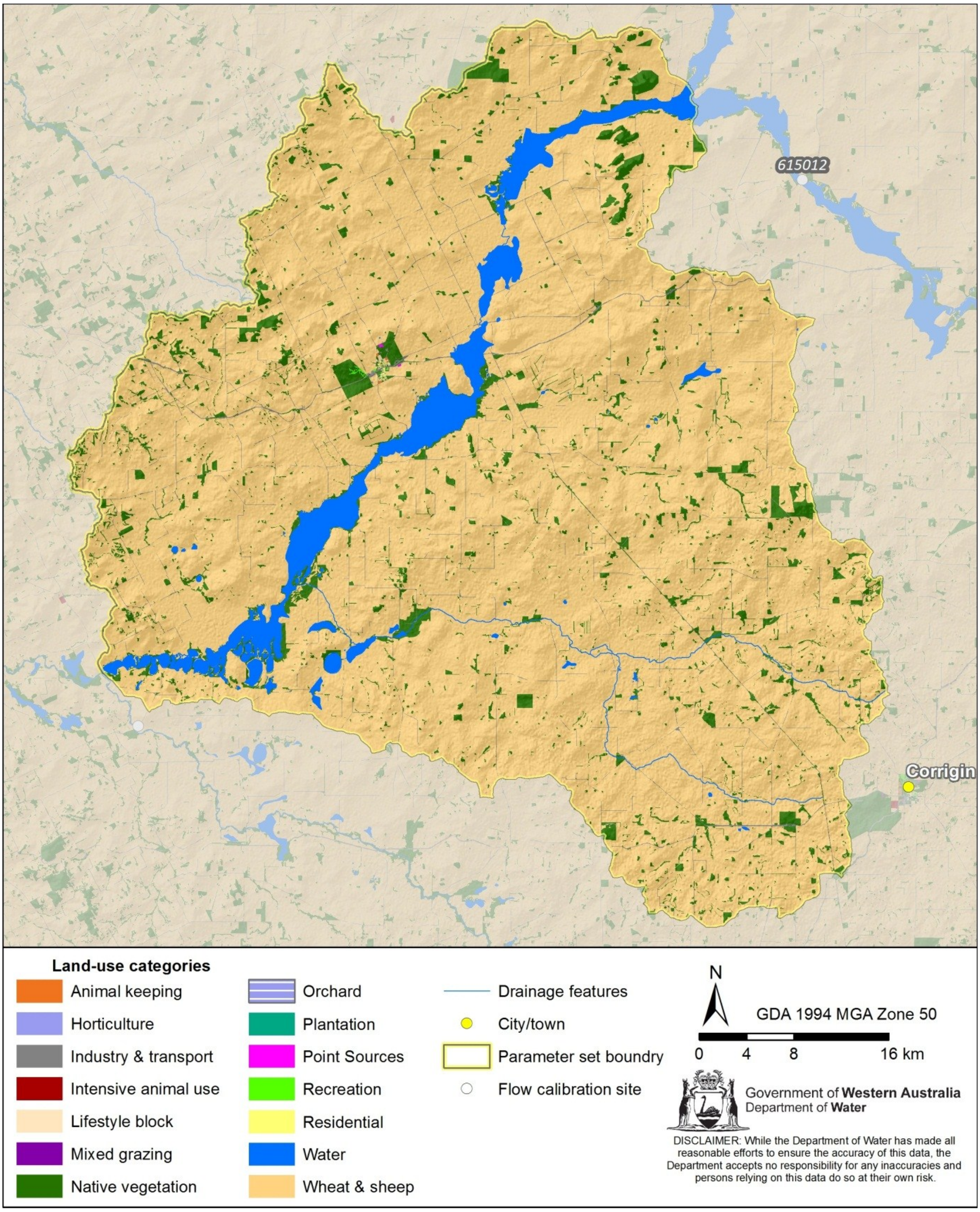
Phosphorus:



Upper Avon: all scenario results

Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	10		22		0.60	
Point source management: Town sewage management	-		-		-	
Point source management: point source removal	-		21	-5	0.57	-4
Soil acidity management: 5% adoption	-		22	-0.6	0.59	-0.8
Soil acidity management: 20% adoption	-		22	-2	0.58	-3
Soil acidity management: 50% adoption	-		21	-6	0.55	-8
Soil acidity management: 100% adoption	-		20	-11	0.51	-15
Soil acidity management: No action	-		-		-	
Farm nutrient management: 5%	-		22	-2	0.58	-3
Farm nutrient management: 20%	-		21	-8	0.52	-12
Farm nutrient management: 50%	-		18	-19	0.41	-31
Farm nutrient management: 100%	-		14	-38	0.23	-62
Riparian rehabilitation: 10 km/yr (high)	-		-		-	
Riparian rehabilitation: 20 km/yr (high)	-		-		-	
Riparian rehabilitation: 40 km/yr (high)	-		-		-	
Riparian management: whole catchment (high)	-		13	-42	0.45	-24
Riparian rehabilitation: 10 km/yr (low)	-		-		-	
Riparian rehabilitation: 20 km/yr (low)	-		-		-	
Riparian rehabilitation: 40 km/yr (low)	-		-		-	
Riparian management: whole catchment (low)	-		15	-33	0.53	-12
Land-use change: urban expansion	-		22	0	0.60	0
Current management practices	-		-		-	
Moderate intervention	-		21	-8	0.53	-11
Large intervention	-		16	-30	0.32	-46
Revegetation: additional 5% native vegetation	10	-3%	20	-8	0.55	-8
Revegetation: additional 10% native vegetation	10	-6%	19	-15	0.51	-15
Revegetation: up to 30% native vegetation	9.0	-13%	16	-30	0.41	-31
Climate change: baseline climate period (1961–90)	27		63		1.7	
Climate change: dry (30 year period)	11	-60%	24	-62	0.64	-62
Climate change: wet (30 year period)	22	-19%	51	-20	1.3	-20
Climate change: dry (10 year period)	8.3	-19%	19	-13	0.51	-15
Climate change: wet (10 year period)	15	-43%	36	60	0.94	58

Salt


615012
Corrigin
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 4 8 16 km
Government of Western Australia
Department of Water
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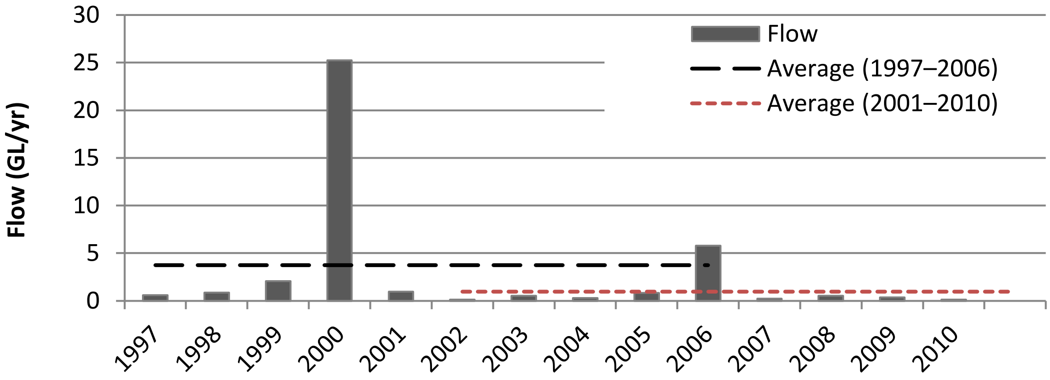
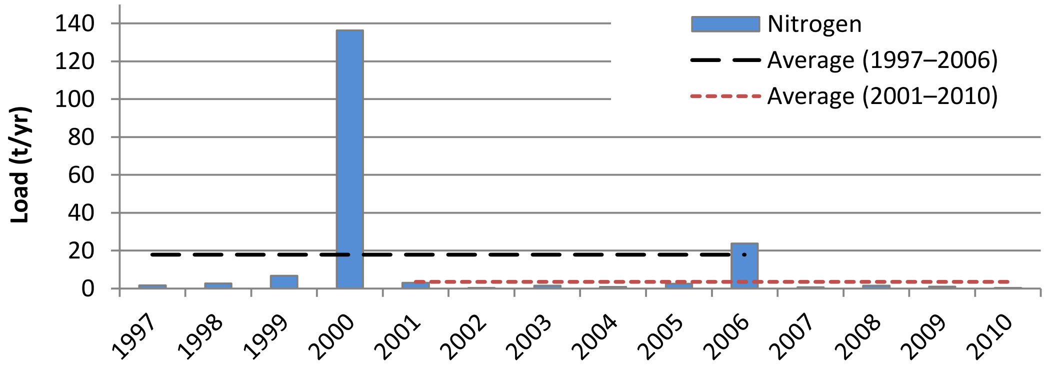
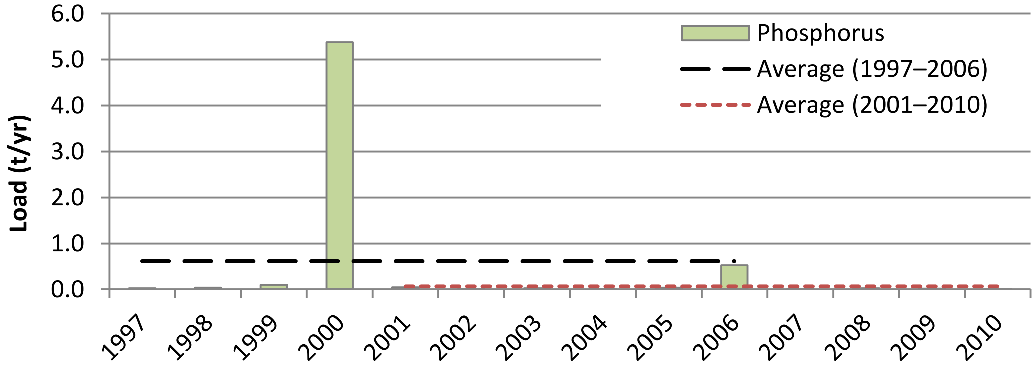
Salt: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	1	1.7	0.02
1998	1	2.6	0.04
1999	2	6.7	0.10
2000	25	136.4	5.38
2001	1	3.0	0.04
2002	0	0.3	0.00
2003	1	1.5	0.02
2004	0	0.8	0.01
2005	1	2.5	0.04
2006	6	23.8	0.52
2007	0	0.6	0.01
2008	1	1.5	0.02
2009	0	1.1	0.01
2010	0	0.3	0.00
Average (1997–2006)	**4**	**17.9**	**0.62**
Average (2001–2010)	**1**	**3.5**	**0.07**



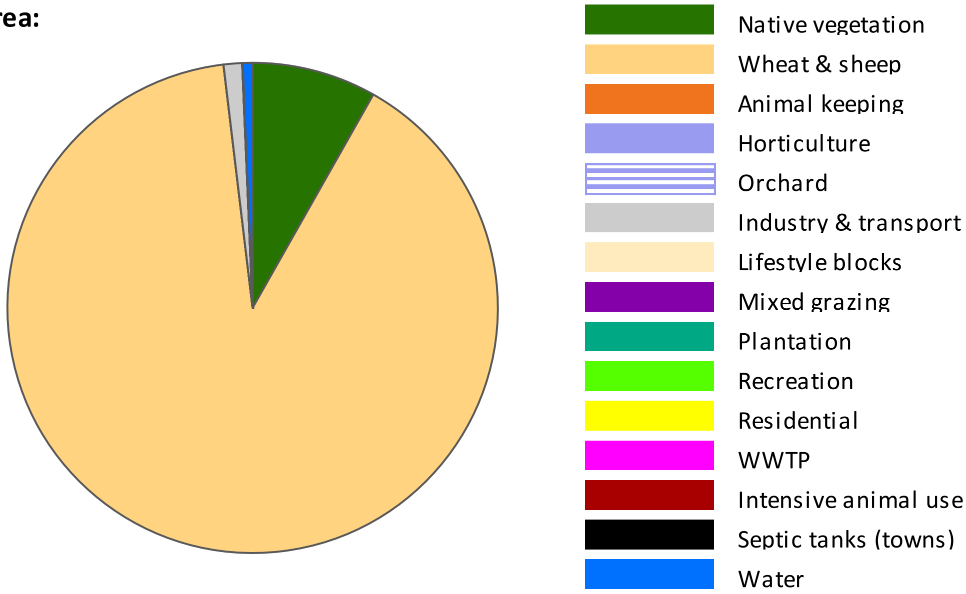




Salt: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	268	8.2	0.0	0.3	0.000	0.1
Wheat & sheep	2 939	90	3.5	99	0.068	99
Animal keeping	0.1	0.0	0.00	0.0	0.000	0.0
Horticulture	-	-	-	-	-	-
Orchard	-	-	-	-	-	-
Industry & transport	40	1.2	0.00	0.0	0.000	0.1
Lifestyle blocks	0.2	0.0	0.00	0.0	0.000	0.0
Mixed grazing	-	-	-	-	-	-
Plantation	-	-	-	-	-	-
Recreation	0.4	0.0	0.00	0.0	0.000	0.0
Residential	0.6	0.0	0.00	0.0	0.000	0.0
WWTPs	-	-	-	-	-	-
Septic tank (towns)	-	-	-	-	-	-
Intensive animal use	-	-	-	-	-	-
Water	21	0.6	-	-	-	-
Total	**3 270**		**4**	**0**	**0.07**	

Area:



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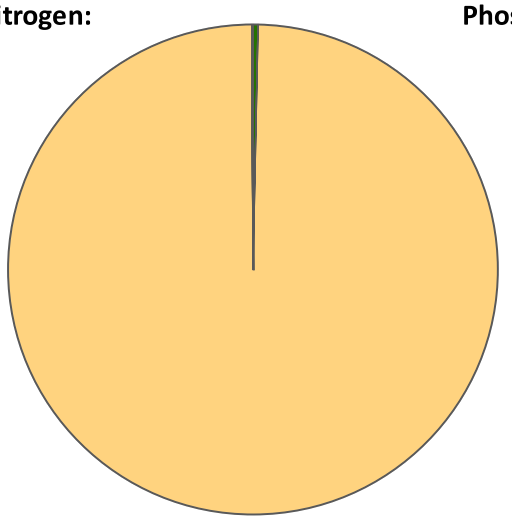

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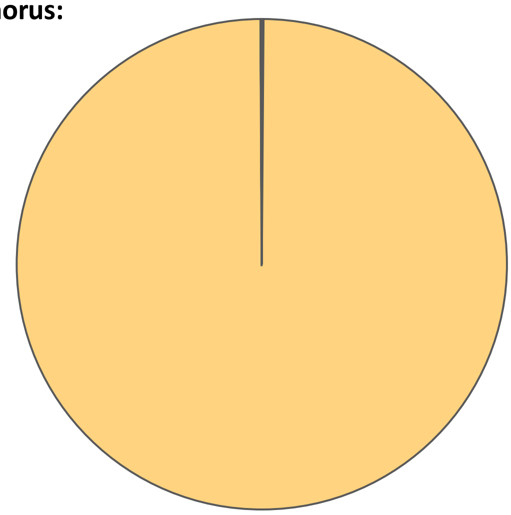


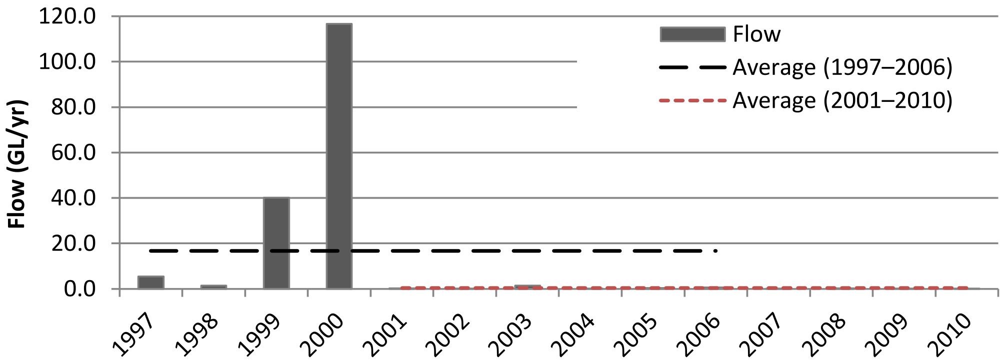
Salt: all scenario results

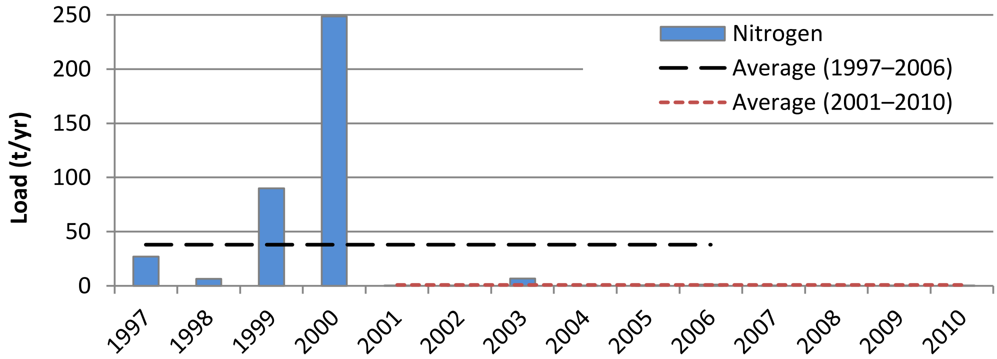
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	1.0		3.5		0.07	
Point source management: Town sewage management	-		-		-	
Point source management: point source removal	-		-		-	
Soil acidity management: 5% adoption	-		3.5	-0.6	0.07	-0.8
Soil acidity management: 20% adoption	-		3.5	-2	0.07	-3
Soil acidity management: 50% adoption	-		3.3	-6	0.06	-8
Soil acidity management: 100% adoption	-		3.1	-12	0.06	-16
Soil acidity management: No action	-		3.6	1	0.07	1
Farm nutrient management: 5%	-		3.5	-2	0.07	-3
Farm nutrient management: 20%	-		3.3	-8	0.06	-13
Farm nutrient management: 50%	-		2.8	-20	0.05	-32
Farm nutrient management: 100%	-		2.1	-39	0.02	-65
Riparian rehabilitation: 10 km/yr (high)	-		-		-	
Riparian rehabilitation: 20 km/yr (high)	-		-		-	
Riparian rehabilitation: 40 km/yr (high)	-		-		-	
Riparian management: whole catchment (high)	-		1.9	-46	0.05	-27
Riparian rehabilitation: 10 km/yr (low)	-		-		-	
Riparian rehabilitation: 20 km/yr (low)	-		-		-	
Riparian rehabilitation: 40 km/yr (low)	-		-		-	
Riparian management: whole catchment (low)	-		2.3	-36	0.06	-13
Land-use change: urban expansion	-		-		-	
Current management practices	-		-		-	
Moderate intervention	-		3.3	-8	0.06	-11
Large intervention	-		2.4	-32	0.04	-48
Revegetation: additional 5% native vegetation	0.8	-15%	2.8	-20	0.05	-20
Revegetation: additional 10% native vegetation	0.7	-27%	2.3	-34	0.04	-34
Revegetation: up to 30% native vegetation	0.4	-54%	1.2	-65	0.02	-65
Climate change: baseline climate period (1961–90)	1.6		5.5		0.09	
Climate change: dry (30 year period)	0.5	-72%	1.5	-74	0.02	-76
Climate change: wet (30 year period)	1.1	-32%	3.6	-34	0.06	-37
Climate change: dry (10 year period)	0.5	-44%	1.8	-49	0.03	-56
Climate change: wet (10 year period)	1.1	-35%	3.6	0.4	0.06	-12

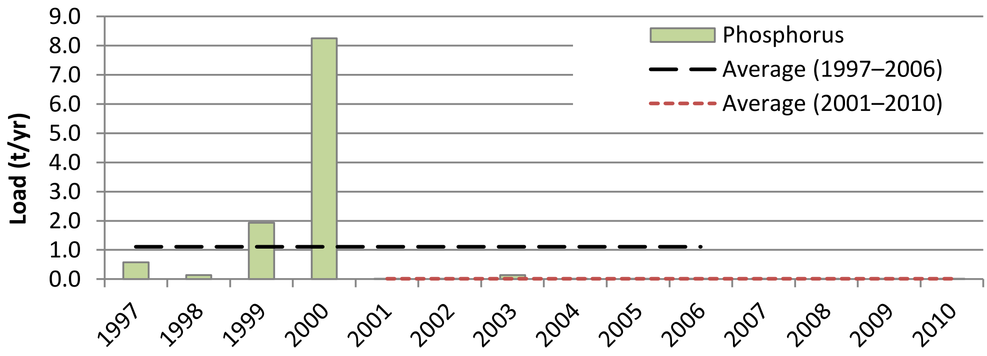
Yenyening Lakes overflow

Yenyening Lakes overflow: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	5.5	27	0.58
1998	1.4	6.4	0.13
1999	40	90	1.93
2000	117	249	8.25
2001	0.2	0.3	0.00
2002	0.0	0.0	0.00
2003	1.4	6.7	0.14
2004	0.1	0.1	0.00
2005	0.4	0.5	0.01
2006	0.6	1.0	0.02
2007	0.1	0.1	0.00
2008	0.2	0.2	0.00
2009	0.1	0.1	0.00
2010	0.1	0.1	0.00
Average (1997–2006)	**17**	**38.1**	**1.11**
Average (2001–2010)	**0.3**	**0.9**	**0.02**



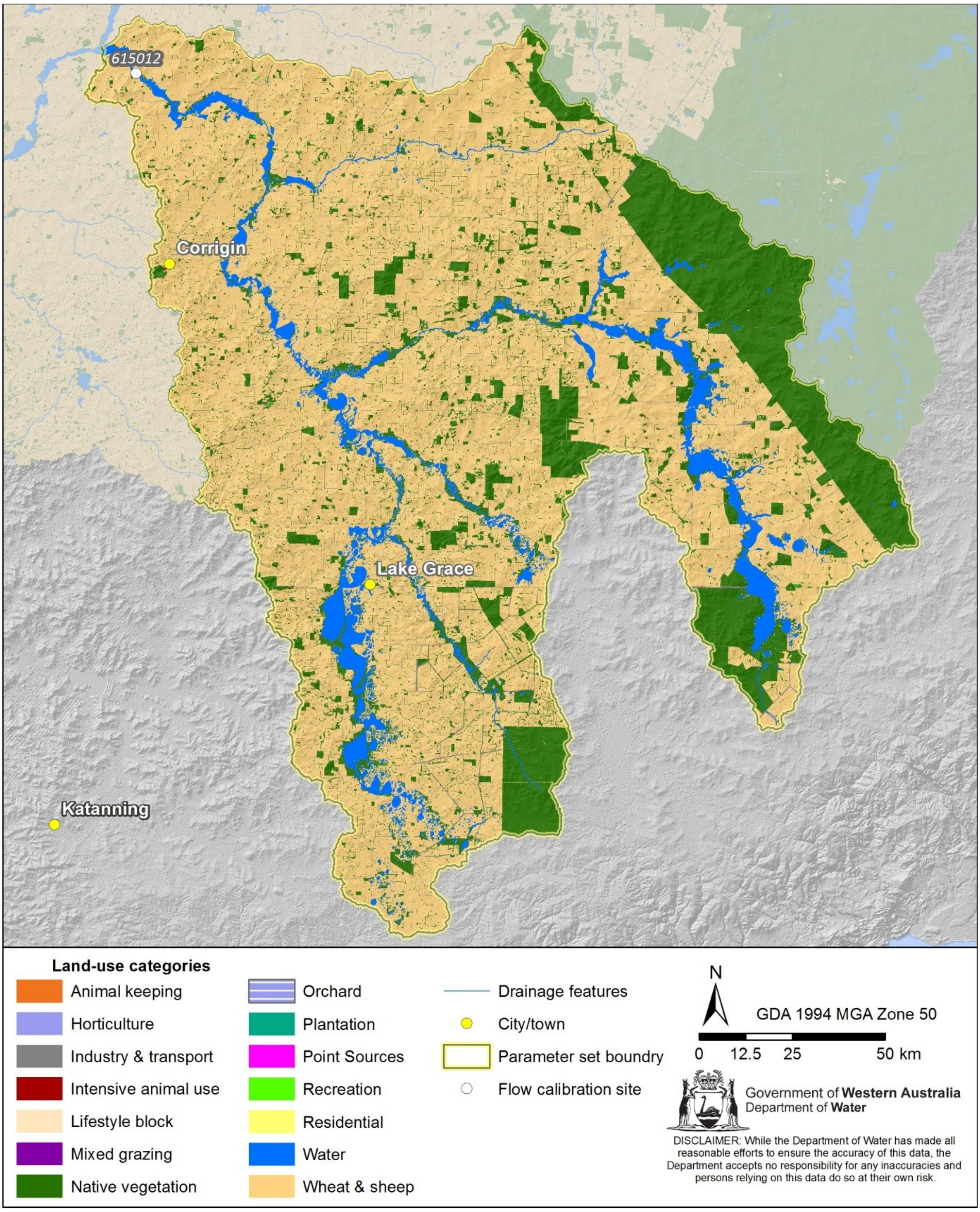




Yenyening Lakes overflow: all scenario results

Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	0.31		0.92		0.02	
Point source management: Town sewage management	-		0.91	-1	0.02	-8
Point source management: point source removal	-		0.89	-3	0.02	-9
Soil acidity management: 5% adoption	-		0.91	-0.6	0.02	-0.7
Soil acidity management: 20% adoption	-		0.90	-2	0.02	-3
Soil acidity management: 50% adoption	-		0.87	-6	0.02	-7
Soil acidity management: 100% adoption	-		0.81	-11	0.02	-13
Soil acidity management: No action	-		0.93	1	0.02	1
Farm nutrient management: 5%	-		0.90	-2	0.02	-3
Farm nutrient management: 20%	-		0.85	-8	0.02	-11
Farm nutrient management: 50%	-		0.74	-19	0.01	-27
Farm nutrient management: 100%	-		0.57	-38	0.01	-55
Riparian rehabilitation: 10 km/yr (high)	-		-		-	
Riparian rehabilitation: 20 km/yr (high)	-		-		-	
Riparian rehabilitation: 40 km/yr (high)	-		-		-	
Riparian management: whole catchment (high)	-		0.54	-41	0.01	-20
Riparian rehabilitation: 10 km/yr (low)	-		-		-	
Riparian rehabilitation: 20 km/yr (low)	-		-		-	
Riparian rehabilitation: 40 km/yr (low)	-		-		-	
Riparian management: whole catchment (low)	-		0.63	-32	0.02	-9
Land-use change: urban expansion	-		-		-	
Current management practices	-		-		-	
Moderate intervention	-		0.84	-8	0.01	-17
Large intervention	-		0.63	-31	0.01	-49
Revegetation: additional 5% native vegetation	0.15	-52%	0.20	-78	0.00	-83
Revegetation: additional 10% native vegetation	0.12	-61%	0.16	-83	0.00	-87
Revegetation: up to 30% native vegetation	0.07	-79%	0.08	-92	0.00	-94
Climate change: baseline climate period (1961–90)	13		31		0.65	
Climate change: dry (30 year period)	1.0	-92%	5.4	-82	0.12	-81
Climate change: wet (30 year period)	7.1	-44%	20	-35	0.43	-35
Climate change: dry (10 year period)	0.45	44%	4.0	334	0.09	429
Climate change: wet (10 year period)	1.8	-86%	13	1365	0.29	1528

Lockhart


615012
Corrigin
Lake Grace
Katanning
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 12.5 25 50 km
Government of Western Australia
Department of Water
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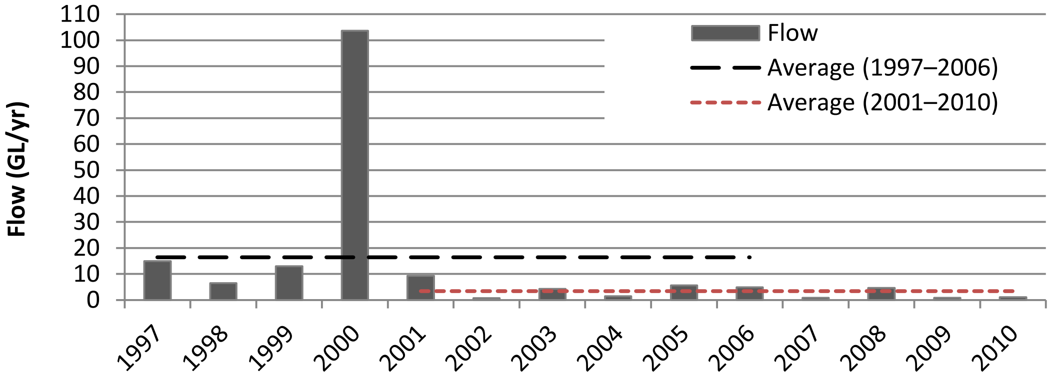
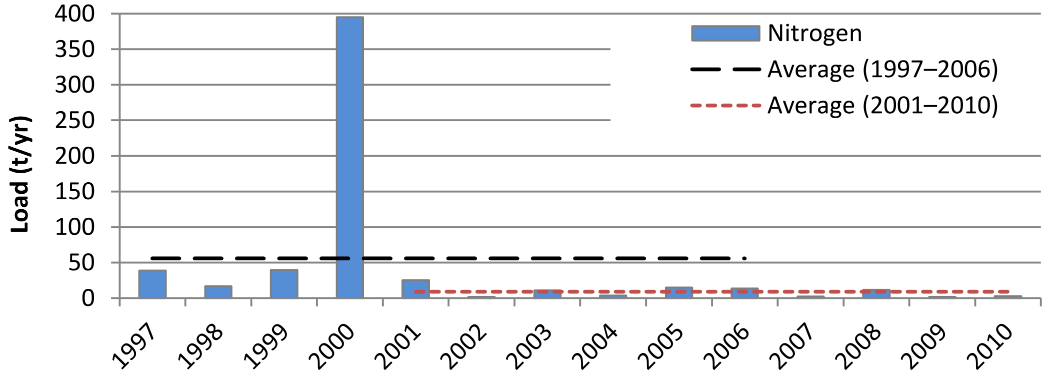
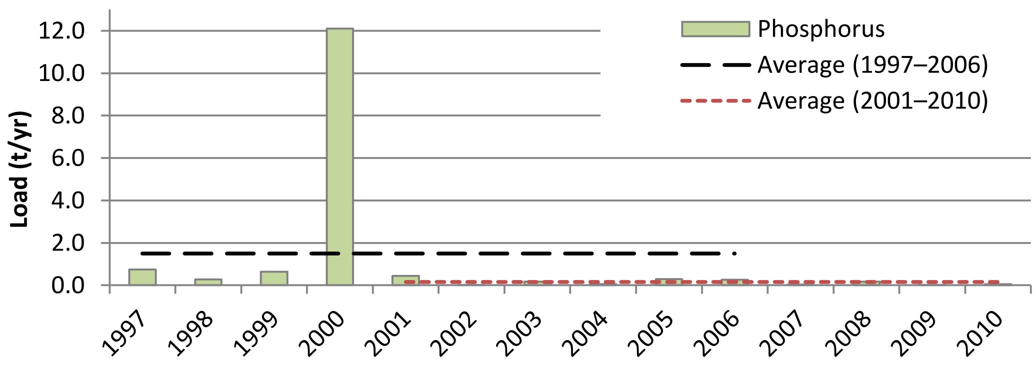
Lockhart: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	15	38.8	0.74
1998	6	16.5	0.28
1999	13	39.4	0.64
2000	104	395.1	12.10
2001	9	25.2	0.44
2002	1	1.6	0.02
2003	4	10.7	0.16
2004	1	3.4	0.05
2005	6	15.0	0.28
2006	5	13.3	0.26
2007	1	2.0	0.03
2008	5	11.4	0.17
2009	1	1.9	0.02
2010	1	2.7	0.04
Average (1997–2006)	**16**	**55.9**	**1.50**
Average (2001–2010)	**3**	**8.7**	**0.15**



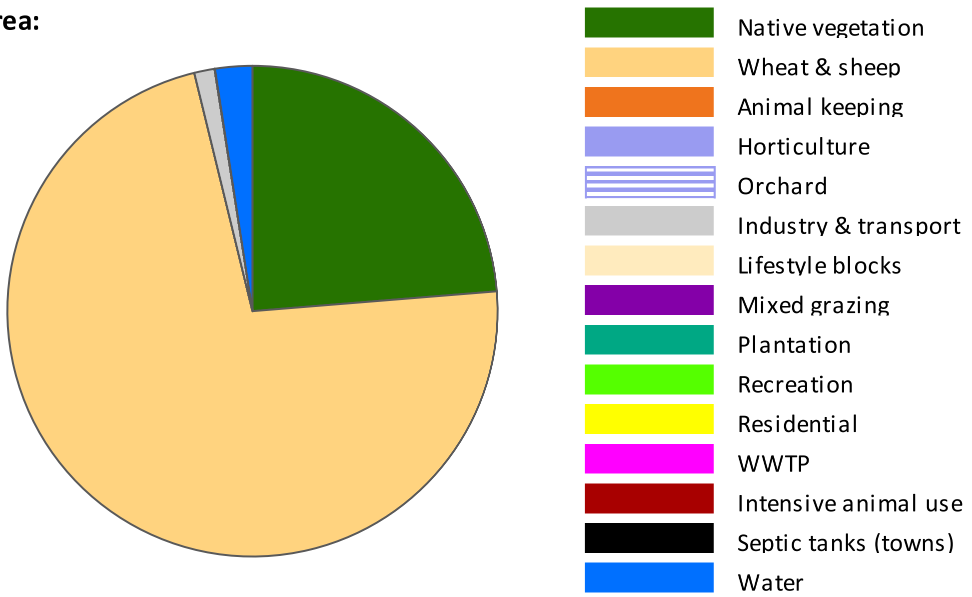




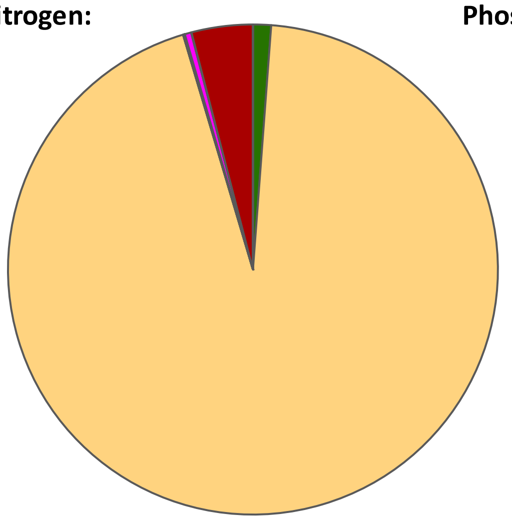
Lockhart: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	6 732	23.7	0.1	1.2	0.001	0.4
Wheat & sheep	20 573	72	8.2	94	0.12	77
Animal keeping	0.4	0.0	0.00	0.0	0.000	0.0
Horticulture	0.1	0.0	0.00	0.0	0.000	0.0
Orchard	-	-	-	-	-	-
Industry & transport	381	1.3	0.01	0.1	0.000	0.2
Lifestyle blocks	1.0	0.0	0.00	0.0	0.000	0.0
Mixed grazing	-	-	-	-	-	-
Plantation	-	-	-	-	-	-
Recreation	4.0	0.0	0.00	0.0	0.000	0.0
Residential	3.1	0.0	0.00	0.0	0.000	0.0
WWTPs	-	-	0.04	0.4	0.024	16
Septic tank (towns)	-	-	0.00	0.0	0.000	0.0
Intensive animal use	-	-	0.35	4.0	0.009	5.7
Water	695	2.4	-	-	-	-
Total	**28 391**		**9**	**0**	**0.15**	

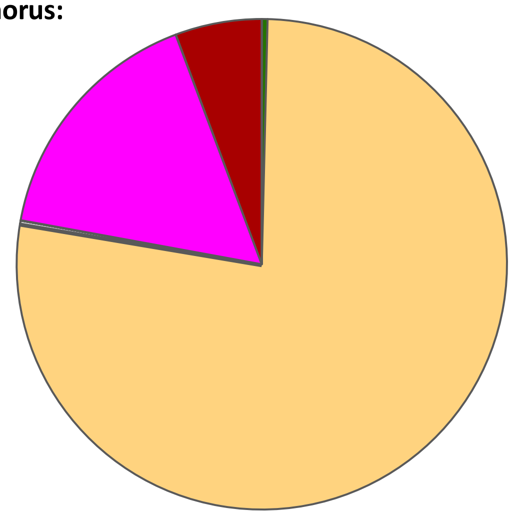
Area:



Nitrogen:



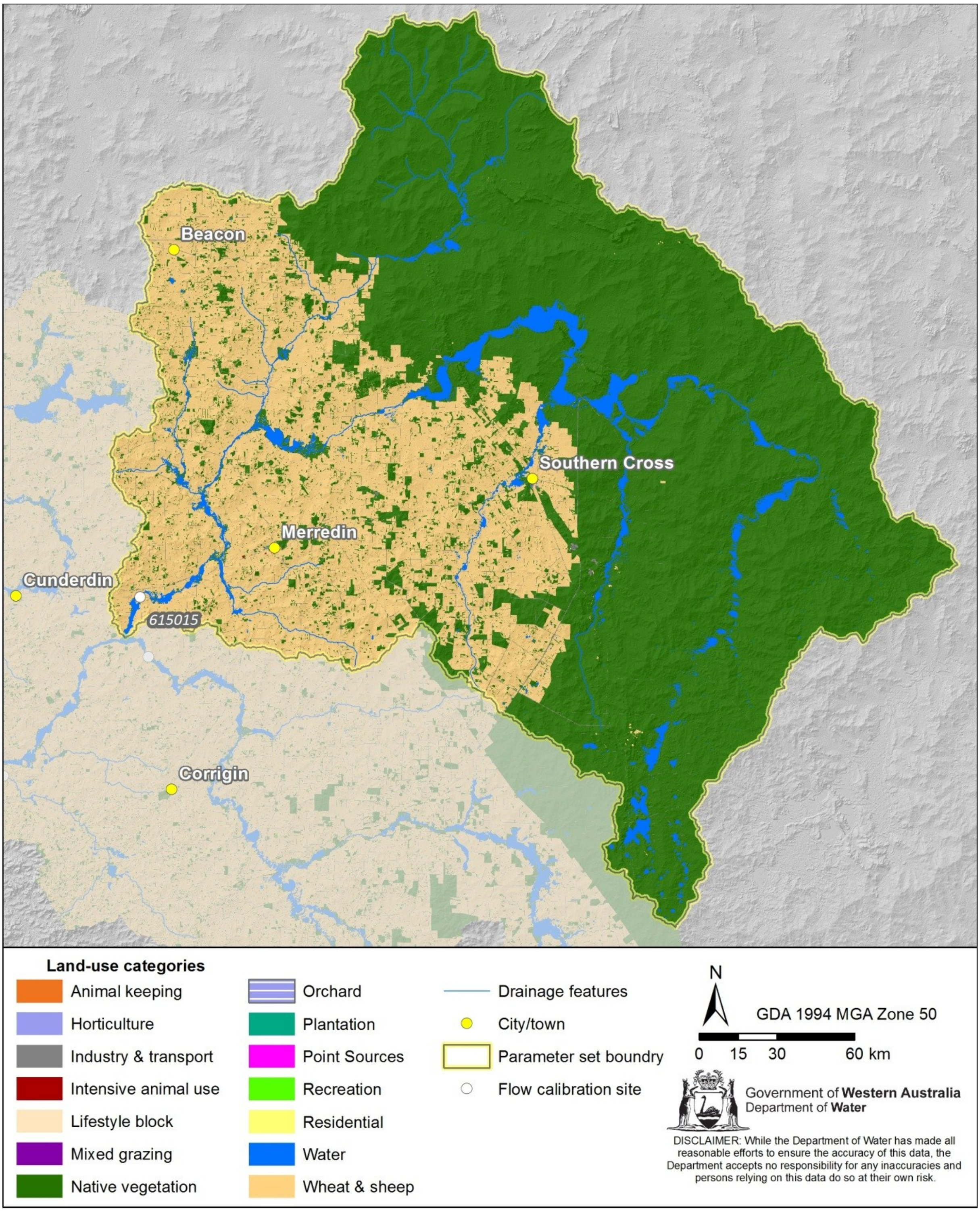
Phosphorus:



Lockhart: all scenario results

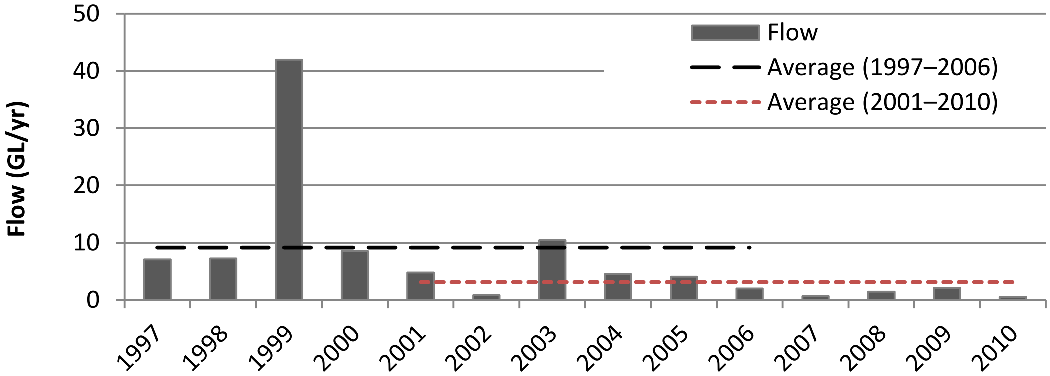
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	3.4		8.7		0.15	
Point source management: Town sewage management	-		8.6	-1	0.12	-20
Point source management: point source removal	-		8.3	-4	0.12	-22
Soil acidity management: 5% adoption	-		8.7	-0.6	0.15	-0.6
Soil acidity management: 20% adoption	-		8.5	-2	0.15	-2
Soil acidity management: 50% adoption	-		8.2	-6	0.14	-6
Soil acidity management: 100% adoption	-		7.8	-11	0.13	-12
Soil acidity management: No action	-		8.9	2	0.15	2
Farm nutrient management: 5%	-		8.6	-2	0.15	-3
Farm nutrient management: 20%	-		8.1	-7	0.13	-10
Farm nutrient management: 50%	-		7.1	-19	0.11	-25
Farm nutrient management: 100%	-		5.5	-37	0.07	-50
Riparian rehabilitation: 10 km/yr (high)	-		-		-	
Riparian rehabilitation: 20 km/yr (high)	-		-		-	
Riparian rehabilitation: 40 km/yr (high)	-		-		-	
Riparian management: whole catchment (high)	-		5.2	-40	0.12	-18
Riparian rehabilitation: 10 km/yr (low)	-		-		-	
Riparian rehabilitation: 20 km/yr (low)	-		-		-	
Riparian rehabilitation: 40 km/yr (low)	-		-		-	
Riparian management: whole catchment (low)	-		6.0	-31	0.14	-9
Land-use change: urban expansion	-		-		-	
Current management practices	-		-		-	
Moderate intervention	-		7.9	-9	0.11	-28
Large intervention	-		6.0	-31	0.06	-57
Revegetation: additional 5% native vegetation	2.7	-19%	6.8	-23	0.12	-19
Revegetation: additional 10% native vegetation	2.4	-28%	5.7	-34	0.11	-28
Revegetation: up to 30% native vegetation	1.7	-49%	4.0	-55	0.08	-45
Climate change: baseline climate period (1961–90)	11		34		0.63	
Climate change: dry (30 year period)	4.0	-65%	12	-65	0.24	-61
Climate change: wet (30 year period)	8.5	-26%	25	-27	0.46	-26
Climate change: dry (10 year period)	3.4	2%	11	26	0.23	54
Climate change: wet (10 year period)	6.0	-48%	19	112	0.36	141

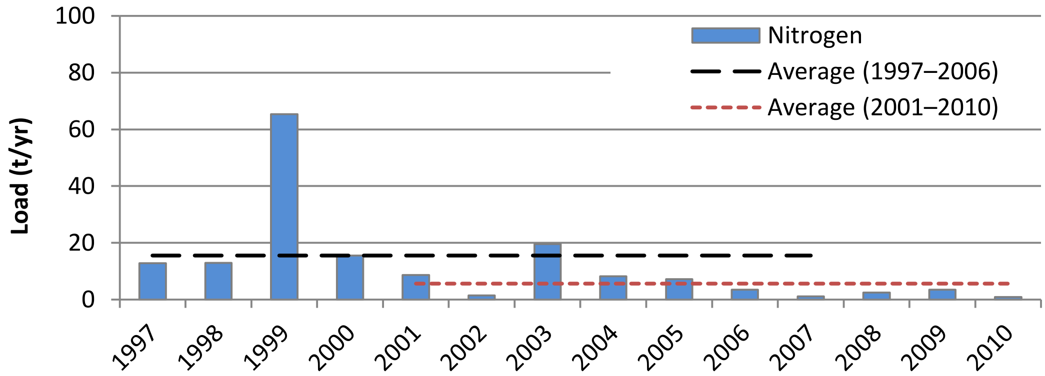
Yilgarn

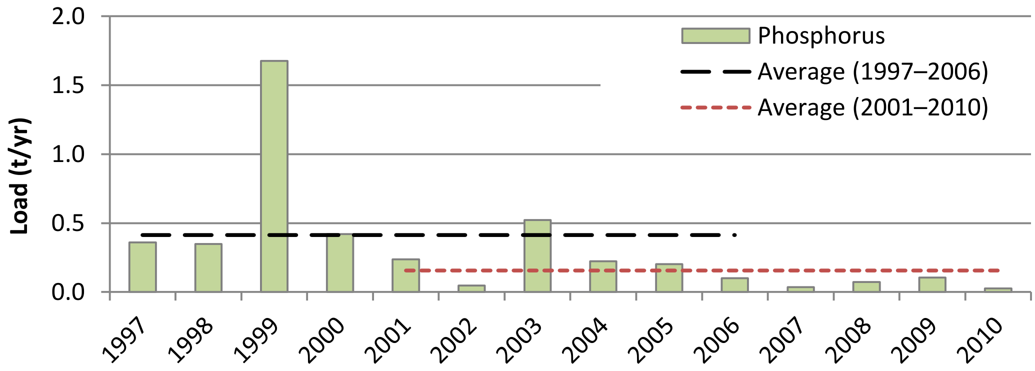

Beacon
Southern Cross
Merredin
Cunderdin
615015
Corrigin
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 15 30 60 km
Government of Western Australia
Department of Water
DISCLAIMER: While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Yilgarn: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	7	12.9	0.36
1998	7	12.9	0.35
1999	42	65.4	1.68
2000	9	15.5	0.42
2001	5	8.7	0.24
2002	1	1.4	0.05
2003	10	19.5	0.52
2004	5	8.2	0.22
2005	4	7.2	0.20
2006	2	3.5	0.10
2007	1	1.1	0.03
2008	1	2.4	0.07
2009	2	3.5	0.10
2010	1	0.9	0.03
Average (1997–2006)	**9**	**15.5**	**0.41**
Average (2001–2010)	**3**	**5.6**	**0.16**



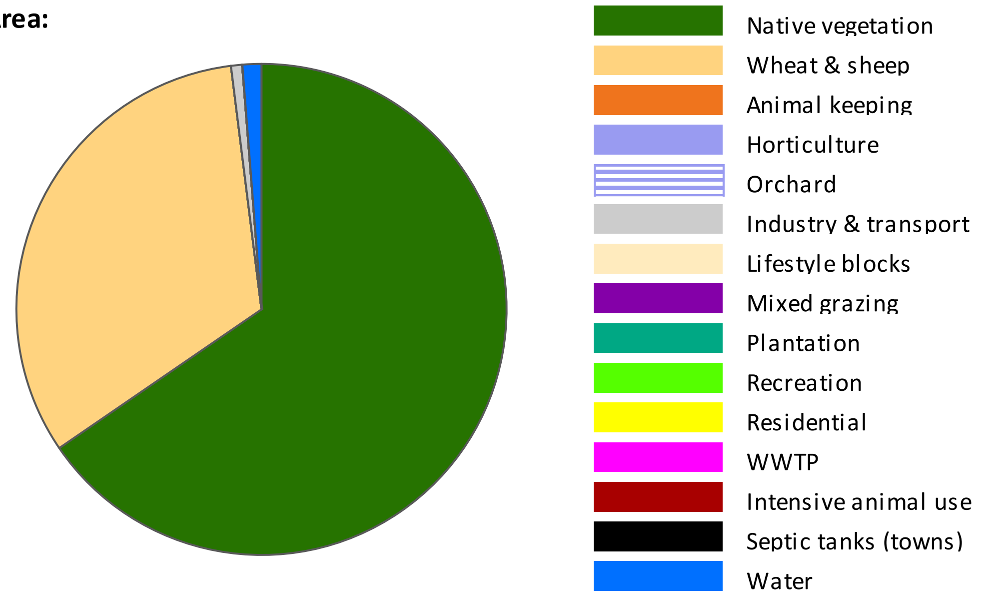




Yilgarn: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	38 211	65.4	0.1	0.9	0.000	0.1
Wheat & sheep	19 011	33	5.5	98	0.16	99
Animal keeping	1.4	0.0	0.00	0.0	0.000	0.0
Horticulture	-	-	-	-	-	-
Orchard	-	-	-	-	-	-
Industry & transport	425	0.7	0.01	0.1	0.000	0.2
Lifestyle blocks	2.0	0.0	0.00	0.0	0.000	0.0
Mixed grazing	-	-	-	-	-	-
Plantation	1.7	0.0	0.00	0.0	0.000	0.0
Recreation	2.3	0.0	0.00	0.0	0.000	0.0
Residential	4.4	0.0	0.01	0.1	0.000	0.1
WWTPs	-	-	-	-	-	-
Septic tank (towns)	-	-	-	-	-	-
Intensive animal use	-	-	0.07	1.3	0.001	0.6
Water	726	1.2	-	-	-	-
Total	**58 386**		**6**		**0.16**	

Area:



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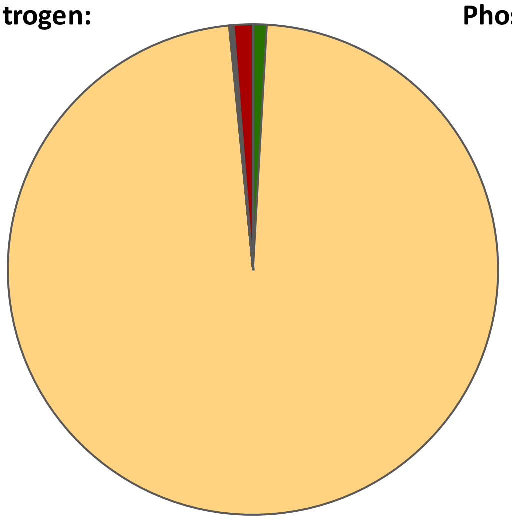
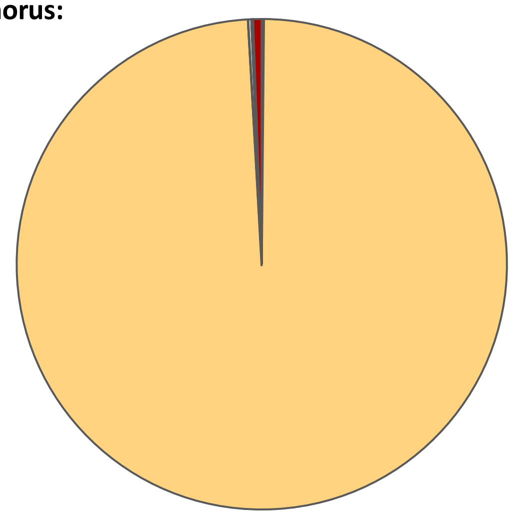


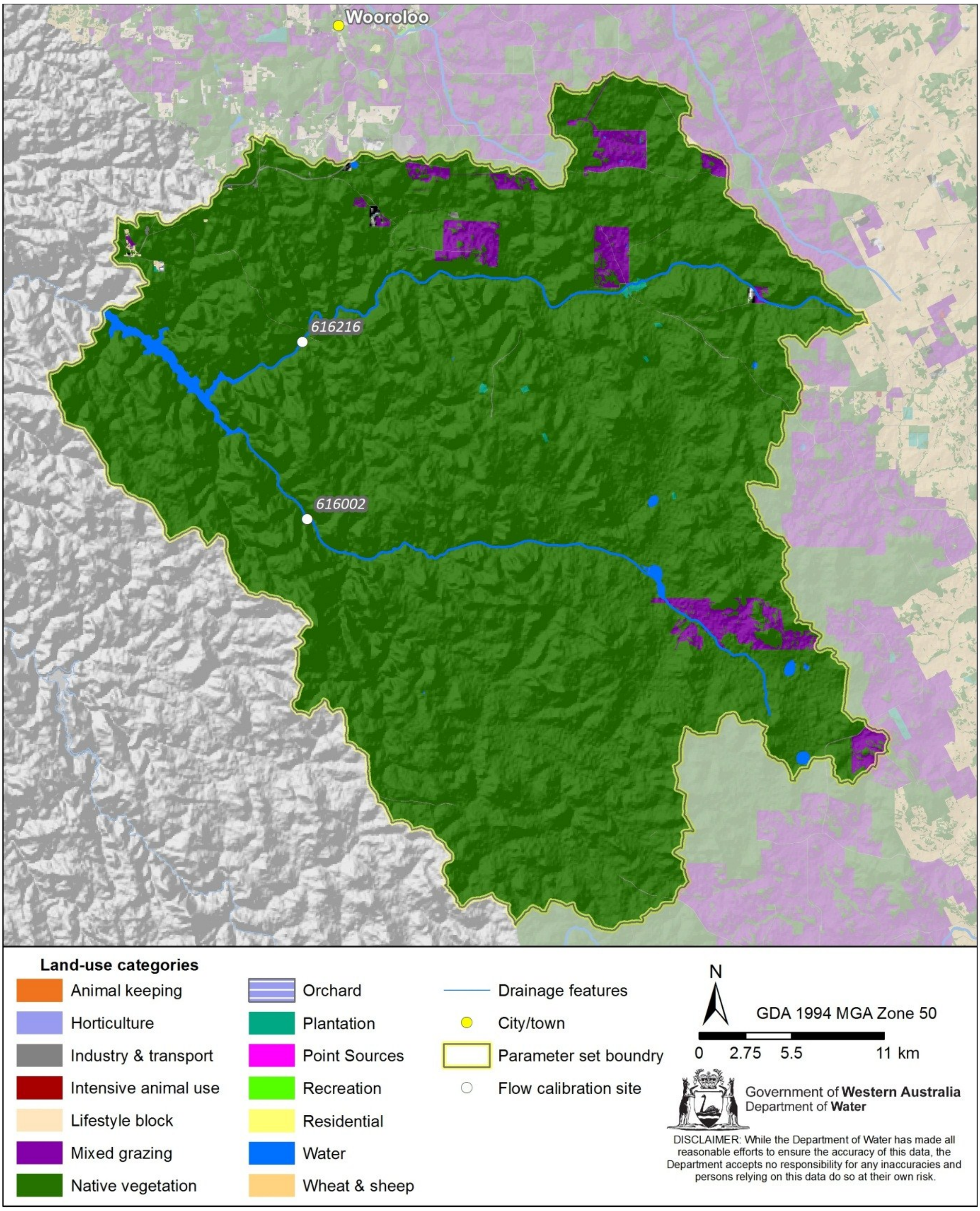
Phosphorus:



Yilgarn: all scenario results

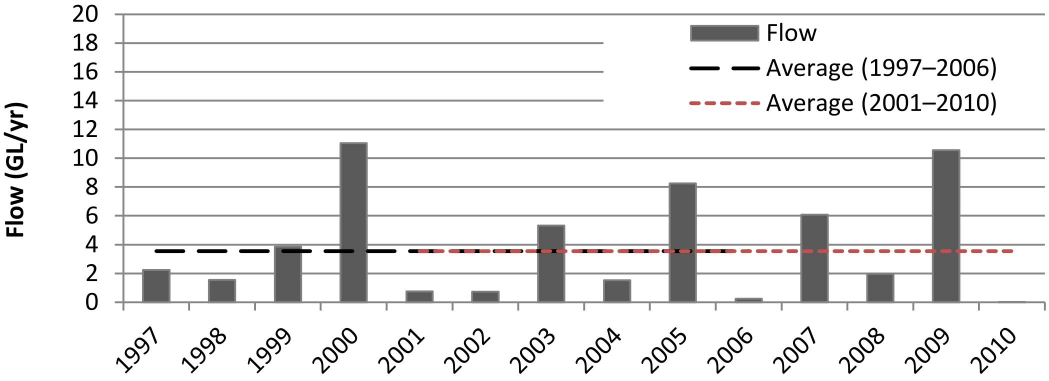
Scenario	Flow		Nitrogen		Phosphorus	
	GL/yr	% diff	t/yr	% diff	t/yr	% diff
Base case (2001–10)	3.1		5.6		0.16	
Point source management: Town sewage management	-		-		-	
Point source management: point source removal	-		5.6	-1	0.16	-0.5
Soil acidity management: 5% adoption	-		5.6	-0.6	0.16	-0.7
Soil acidity management: 20% adoption	-		5.5	-2	0.15	-3
Soil acidity management: 50% adoption	-		5.3	-6	0.15	-7
Soil acidity management: 100% adoption	-		5.0	-12	0.14	-13
Soil acidity management: No action	-		5.7	0.2	0.16	0.1
Farm nutrient management: 5%	-		5.5	-2	0.15	-3
Farm nutrient management: 20%	-		5.2	-8	0.14	-11
Farm nutrient management: 50%	-		4.6	-19	0.11	-27
Farm nutrient management: 100%	-		3.5	-39	0.07	-54
Riparian rehabilitation: 10 km/yr (high)	-		-		-	
Riparian rehabilitation: 20 km/yr (high)	-		-		-	
Riparian rehabilitation: 40 km/yr (high)	-		-		-	
Riparian management: whole catchment (high)	-		3.5	-38	0.13	-18
Riparian rehabilitation: 10 km/yr (low)	-		-		-	
Riparian rehabilitation: 20 km/yr (low)	-		-		-	
Riparian rehabilitation: 40 km/yr (low)	-		-		-	
Riparian management: whole catchment (low)	-		4.0	-29	0.14	-8
Land-use change: urban expansion	-		-		-	
Current management practices	-		-		-	
Moderate intervention	-		5.2	-8	0.14	-10
Large intervention	-		3.9	-31	0.09	-41
Revegetation: additional 5% native vegetation	1.9	-38%	3.3	-42	0.10	-36
Revegetation: additional 10% native vegetation	1.1	-64%	1.9	-67	0.07	-58
Revegetation: up to 30% native vegetation	0.3	-91%	0.5	-91	0.03	-82
Climate change: baseline climate period (1961–90)	12		23		0.62	
Climate change: dry (30 year period)	2.1	-82%	4	-83	0.13	-80
Climate change: wet (30 year period)	7.4	-36%	14	-38	0.39	-36
Climate change: dry (10 year period)	0.6	-80%	1	-80	0.05	-66
Climate change: wet (10 year period)	3.2	-73%	6	3	0.17	6

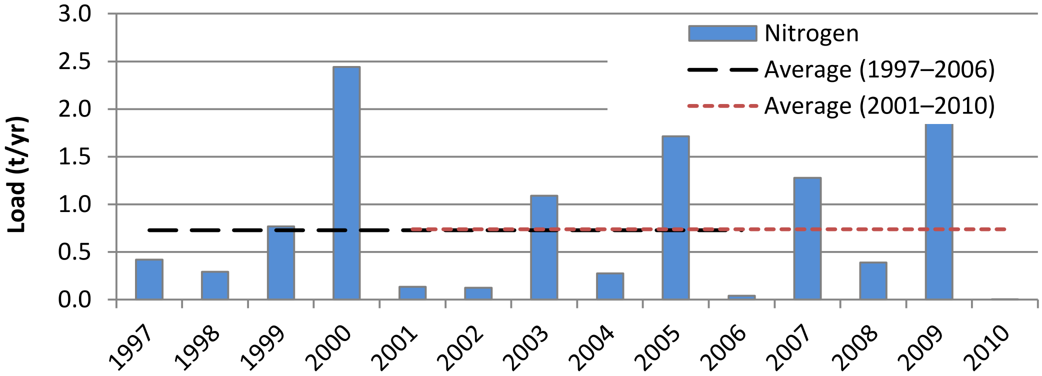
Helena

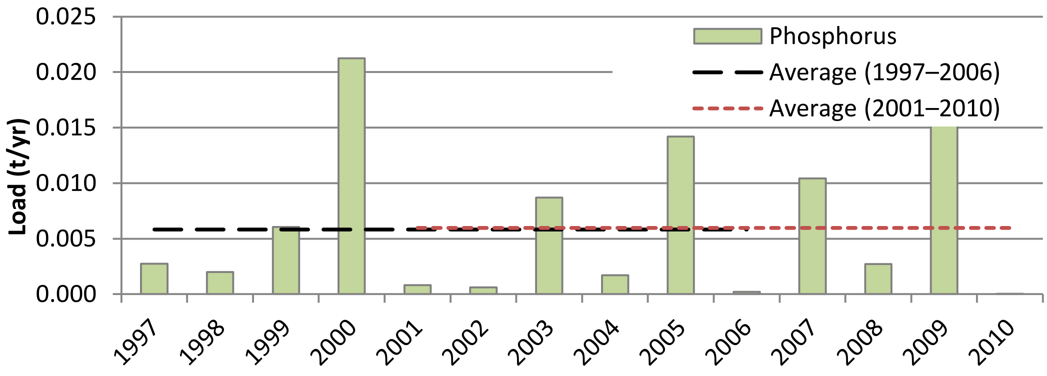

Wooroloo
616216
616002
Land-use categories
Animal keeping
Horticulture
Industry & transport
Intensive animal use
Lifestyle block
Mixed grazing
Native vegetation
Orchard
Plantation
Point Sources
Recreation
Residential
Water
Wheat & sheep
Drainage features
City/town
Parameter set boundry
Flow calibration site
N
GDA 1994 MGA Zone 50
0 2.75 5.5 11 km
Government of Western Australia
Department of Water
DISCLAIMER: While the Department of Water has made all reasonable efforts to ensure the accuracy of this data, the Department accepts no responsibility for any inaccuracies and persons relying on this data do so at their own risk.

Helena: annual flow, nitrogen and phosphorus loads

Year	Flow (GL/yr)	Nitrogen (t/yr)	Phosphorus (t/yr)
1997	2	0.4	0.00
1998	2	0.3	0.00
1999	4	0.8	0.01
2000	11	2.4	0.02
2001	1	0.1	0.00
2002	1	0.1	0.00
2003	5	1.1	0.01
2004	2	0.3	0.00
2005	8	1.7	0.01
2006	0	0.0	0.00
2007	6	1.3	0.01
2008	2	0.4	0.00
2009	11	2.3	0.02
2010	0	0.0	0.00
Average (1997–2006)	**4**	**0.7**	**0.01**
Average (2001–2010)	**4**	**0.7**	**0.01**



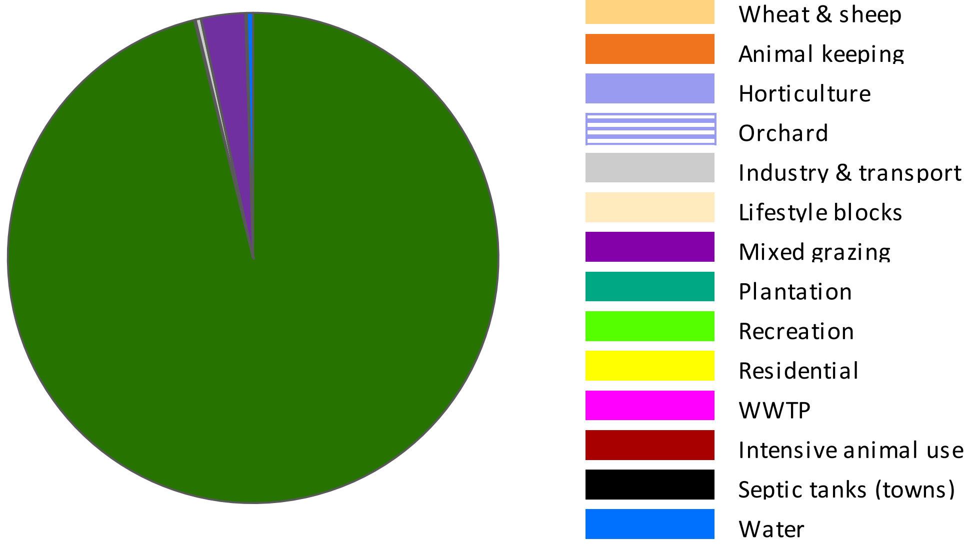




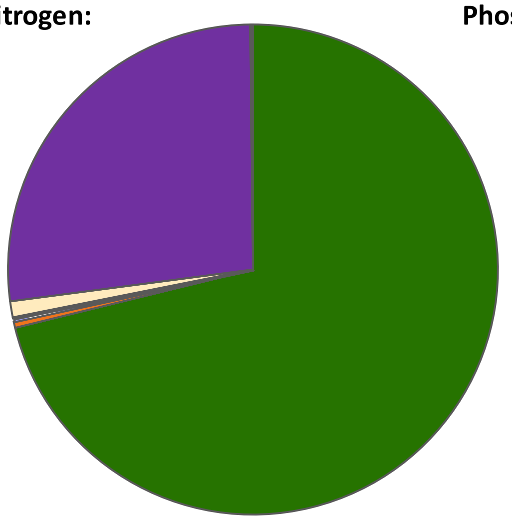
Helena: Sources of nutrients

Land use	Area		Nitrogen		Phosphorus	
	(km^2)	(%)	(t/yr)	(%)	(t/yr)	(%)
Native vegetation	1 422	96.1	0.3	71.2	0.003	46.7
Wheat & sheep	-	-	-	-	-	-
Animal keeping	1.2	0.1	0.00	0.4	0.000	1.5
Horticulture	-	-	-	-	-	-
Orchard	0.2	0.0	0.00	0.2	0.000	1.3
Industry & transport	4.9	0.3	0.00	0.1	0.000	0.9
Lifestyle blocks	0.6	0.0	0.00	1.1	0.000	1.3
Mixed grazing	43	3	0.13	27	0.003	47
Plantation	1.5	0.1	0.00	0.1	0.000	1.5
Recreation	0.1	0.0	0.00	0.0	0.000	0.0
Residential	0.0	0.0	0.00	0.1	0.000	0.3
WWTPs	-	-	-	-	-	-
Septic tank (towns)	-	-	-	-	-	-
Intensive animal use	-	-	-	-	-	-
Water	6.0	0.4	-	-	-	-
Total	**1 479**		**0**	**0**	**0.01**	

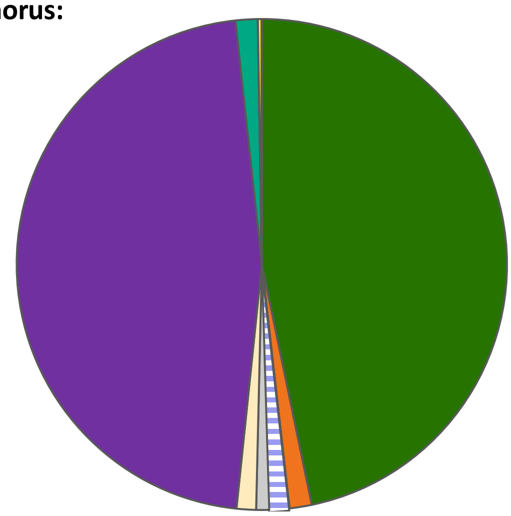
Area:



Nitrogen:



Phosphorus:



G. Riparian zone rehabilitation literature review

Wenger (1999) examined the efficiency of the removal of sediment and particulate nitrogen and phosphorus in surface flows and nitrogen losses in subsurface flows due to de-nitrification. He suggested 30 m buffers to trap sediments under most circumstances, with an absolute minimum width of 9 m. For maximum effectiveness, buffers must extent along all streams including intermittent and ephemeral streams. His reported TSS removal rates ranged from 53–95%, with low rates observed for narrow buffers with steeper slopes. Removal rates of TN and TP in surface flows were 48–74% and 46–79% respectively for 9.1 m grass buffers. Nitrate removal from subsurface flows varied from 78–99% for buffers of variable widths (16–60 m). Wenger (1999) commented that there may be no net reduction in particulate and soluble phosphorus loads that flow through riparian buffers. However, even when saturated, riparian buffers may still perform a valuable service by regulating the flow of phosphorus from the land to the stream. Sediments and organic materials that carry phosphorus in runoff during storms can be trapped by riparian vegetation. The phosphorus will slowly leak into the water, but the stream is protected from extreme nutrient pulses (Wenger 1999).

To maintain aquatic habitat 10–30 m wide native forested riparian buffers should be preserved or restored along all streams(Wenger 1999). This will provide stream temperature control and inputs of large woody debris and other organic matter necessary for aquatic organisms. Wenger (1999) also examined riparian buffer width requirements for birds and recommended some riparian tracts of at least 100 m to provide habitat for terrestrial fauna.

Mayer et al. (2005b) examined a larger number of riparian zone publications than Wenger (1999) in relation to buffer widths, vegetation cover and nitrogen removal efficiencies. The table of their data is included below. They observed that nitrogen removal efficiency was greater in subsurface flows (where de-nitrification can occur) than surface flows. Their Figure 2 is shown below. Buffers containing forest were better at removing nitrogen than grass buffers, presumably because trees intercept subsurface flows. Furthermore, mature forests were observed to be 2–5 times more effective at removing nitrogen than ‘managed’ (i.e. clear-cut or selectively thinned) forests. A small amount of variability in removal rate was attributed to buffer width. Based on their non-linear regression model, 50%, 75%, and 90% nitrogen removal efficiencies would occur in buffers approximately 3 m, 28 m, and 112 m wide, respectively.

Mayer et al. (2005b) also stated that proper design, placement, and protection of buffers was critical to buffer effectiveness. To maintain maximum effectiveness, buffer integrity should be protected against soil compaction, loss of vegetation, and stream incision. They also recommended maintaining buffers around stream headwaters (lower-order streams).

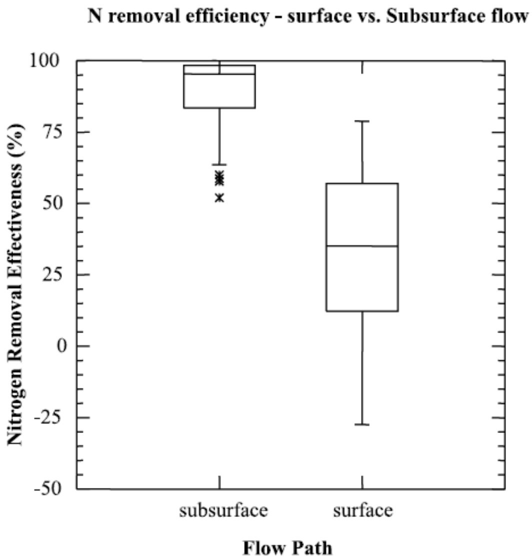


Figure 2. *Nitrogen removal effectiveness in riparian buffers by flow path. The center vertical line of the box and whisker plot marks the median of the sample. The length of each box shows the range within which the central 50% of the values fall. Box edges indicate the first and third quartiles. Whiskers show the range of observed values that fall within the midrange of the data. Asterisks indicate outside values.*

Palone & Todd (1997) studied the effectiveness of vegetated riparian zones to remove sediment, nitrogen and phosphorus in the Chesapeake Bay catchment. Estimated amounts of nutrient removal depended on geology, hydrology and buffer type. Native forest buffers were recommended due to their ability to remove sediment and nutrient and enhance ecosystem biodiversity. Although the hydro-physiographic types of the Chesapeake Bay catchment do not align with those of the Avon catchment, predicted percentage removals were influenced by whether or not water came in contact with riparian vegetation. Removal rates were high when groundwater flowed through the root zone of the riparian vegetation. Under these conditions Palone & Todd (1997) estimated removal of nitrate from groundwater to be 68–90%, removal of sediment and sediment-borne pollutants to be 65–95%, and removal of dissolved phosphorus to be 24–70%.

Palone &Todd also indicated that vegetated riparian zone buffers have greater potential for improving water quality when adjacent to low-order streams. Adjacent to first-order streams narrower buffers may be adequate to maintain the desired level of protection compared with those required on higher-order streams. They recommended a 3-zone buffer system with different zones providing different functions. Zone 1, immediately adjacent to the stream, provides bank stabilisation and habitat for aquatic fauna; Zone 2, further from the stream contains woody vegetation (trees) to strip nutrients. Zone 3 could contain a grass buffer strip to infiltrate runoff and remove nutrients and other contaminants. Minimum buffer widths were given for different objectives:

- Bank stabilisation and aquatic food web: 4–15 m
- Water temperature moderation: 4–20 m
- Nitrogen removal: 10–40 m
- Sediment removal: 15–50 m

- Flood mitigation: 20–75 m
- Wildlife habitat: 15–100 m.

Parkyn (2004) reviewed and summarised published research on the efficiency and management of riparian buffer zones with respect to the attenuation of sediment and nutrients and biodiversity enhancement for the NZ Ministry of Agriculture and Forestry. The data included in Parkyn's review is shown below. While some of Parkyn's references were included in the studies of Wenger(1999), Mayer et al. (2005b) and Palone & Todd (1997), several NZ studies were also reviewed. Parkyn deduced that sediment and total phosphorus removal rates (between 53 and 98%) increase with increasing buffer width (4.6–27 m); grass buffers, when designed sensibly, are very effective at trapping sediment particles – Neibling & Alberts (1979) found that 91% of incoming sediment to a grass filter strip was deposited in the first 0.6 m; larger particles of sediment may be removed in 5 m of grass buffer but finer particles may require 10 m. Parkyn (2004) also commented that the width required to optimise nutrient removal has been debated with little systematic study of the issue.

Almost 100% of nitrate can be removed by buffers 20–30 m wide, while examples of forested buffers of 10 m achieved over 70% removal of nitrogen (Fennessy and Cronk 1997). Nitrate removal from subsurface flows is considered to be greater in forested than grassed buffers, partly through uptake by plants, but primarily through biological denitrification (Fennessy & Cronk 1997; Martin et al. 1999). Wetlands and soils in riparian zones have been shown to have higher capacity for denitrification than terrestrial and aquatic soils (Cooper 1990). Riparian carbon inputs to streams (i.e. leaf litter and wood) can also increase the potential for stream bed denitrification. Thus, even when nitrate in groundwater passed beneath the buffer, the relatively high organic carbon in the discharge zone of those sites (derived largely from riparian vegetation) provided an environment conducive to denitrification (Spruill 2004).

Parkyn (2004) also highlighted that buffer zones could potentially become saturated with phosphorus and their ability to trap phosphorus may decline with age unless sediments or organic matter are removed from the buffer zone (Barling & Moore 1994). Harvesting production trees or plants, or fruit and nuts from trees in riparian zones can provide a mechanism where phosphorus can be removed from the riparian zone. Parkyn reiterated the increased benefits of riparian zone rehabilitation of low-order streams.

In Tasmania, Davies & Nelson (1994) found that small buffers (<10 m wide), retained after forest harvesting, did not significantly protect streams from changes in algal, macroinvertebrate and fish biomass and diversity. Buffer widths of >30 m appeared to provide protection from short-term impacts in a variety of forest types and geomorphology.

The few WA studies of effectiveness of riparian vegetation have been in the south of the state in areas with greater rainfall than the Avon catchment. McKergow et al. 2006 (Wilson inlet catchment) demonstrated the effectiveness of grass and *Eucalypyt globulus* buffers in reducing sediment and nutrient in surface flows. The grass buffer reduced TP, filterable reactive phosphorus (FRP), TN and TSS loads from surface runoff by 50 to 60%. The *E. globulus* buffer was not as effective and load reductions in surface runoff ranged between 10 and 40%. The grass buffer was efficient in removing sediment and nutrient in intense summer storms while the *E. globulus* was not. However the B-horizon (40–80 cm below ground level) subsurface flow is the dominant pathway in this location conveying approximately 20 times more flow than the surface flow path. McKergow et al. (2006) did not estimate nutrient attenuation through the subsurface flow path. However, FRP and TP concentrations were significantly lower in the B-horizon beneath the *E. globulus* buffer compared with the other surface and subsurface FRP and TP concentrations. This is consistent with observations from studies elsewhere, where deep-rooted vegetation has been shown to remove more nutrient than grass buffers in similar locations (Parkyn 2004; Mayer 2005b). Statistical analysis of TN concentration data created two groups: the first being the A-horizon (8–40 cm below ground level) and B-horizon observations under the grass buffer and the A-horizon observations under the *E. globulus* buffer, which had a median value of 5 mg/L, and the second being the observations from the *E. globulus* B-horizon and surface runoff, which had a median value of 2.5 mg/L. This also indicates that there are different processes occurring in the B-horizon under the *E. globulus* buffer from those under the grass buffer.

McKergow et al. (2003) examined riparian rehabilitation on a 1.7 km stream reach (catchment 5.9 km^2) in the Oyster Harbour catchment. Sediment and nutrient concentrations downstream of the stream reach were monitored over a 10-year period before and after riparian rehabilitation. Thus the impacts of the rehabilitation on both surface and subsurface flow were measured. The 93% decrease in TSS concentration was attributed to stabilisation of the banks, as surface sediment delivery in this location is small; the dominant flow path is subsurface. There was no significant reduction in TP concentration and FRP concentrations increased by 60% (ratio of FRP to TP increased from approximately 0.5 to 0.75). Before rehabilitation the FRP in subsurface flows would have adsorbed to the ready supply of stream suspended sediment. TN concentration decreased by 23%. However only high TN concentrations (associated with high flows) reduced, suggesting that denitrification had not increased following rehabilitation. Other mechanisms would have contributed to the reduction in TN: reduced surface runoff, stock exclusion (decreased animal waste deposition into the stream) and removal of pasture legumes (which may ‘bleed’ N) from the stream banks. The width of the riparian buffer was not included in the publication so it is difficult to compare these results with other studies. In addition, drains and ditches are used throughout the catchment to reduce the severity and occurrence of waterlogging, which means much of the flow to the stream reach bypasses the riparian buffer. Although deep-rooted vegetation was planted on one of the four farms abutting the stream it seems to have been insufficient to show significant nutrient uptake from the soil B-horizon. Despite the shortcomings of this study, the benefits of riparian zone rehabilitation in decreasing stream sediment loads by an order of magnitude in this location are clear.

Weaver (2010) surveyed riparian zone condition and stream order in the Oyster Harbour catchment of WA. The lower-order streams had poorer riparian zone condition and represent a greater proportion of the total catchment stream length than higher-order streams. The lower-order streams also generally had higher nutrient and TSS concentrations than higher-order streams. As similar observations can be made in the Avon catchment, restoration of lower-order streams would be more effective, as they constitute the most degraded part of the stream network and would provide the most opportunity for improvement (Weaver 2010).

Steele et al. (2009) attempted to monitor the effectiveness of riparian vegetation on water quality in the Peel-Harvey catchment. Their 2006–09 study monitored water quality and flow in a drain with a 185 ha catchment in South Coolup. They monitored 1) at the end of a 720 m section that was fenced both sides (10 m buffer) re-vegetated on one side with native trees and shrubs and with volunteer grasses on the other; and 2) at the end of a 860 m section immediately downstream, unfenced with cattle having full access to the drain. Their study was confounded by different management regimes in the properties adjacent to the drain – the property adjacent to the re-vegetated reach had higher fertiliser application rates than the property adjacent to the unfenced section; and inaccurate flow data. Although TN, FRP and TP concentrations were 'on average' greater in the vegetated portion of the drain, Steele et al. reported lower nitrogen and phosphorus loads for this section due to lower flows. A 25% lower nitrogen load was reported for the fenced and re-vegetated drain reach (3.69 kg/ha) compared with the unfenced drain reach (4.90 kg/ha). Similarly the fenced and re-vegetated drain reach had a 17% lower phosphorus load (1.21 kg/ha) than the unfenced drain reach (1.45 kg/ha). Steele et al. (2009) also observed phosphorus to have a greater proportion of FRP in the drain reach which was vegetated, similar to McKergow et al.'s (2003) study.

A conclusion from Steele et al.'s work was the benefit of fencing and re-vegetation in reducing sediment loads – the unfenced portion exported 9400 kg (118 kg/ha/yr) of sediment in the four years of the study compared with the fenced portion of the drain which exported 2700 kg (25/kg/ha/yr; 79% less sediment from the re-vegetated stream).

Buffer widths and nutrient and sediment removal rates

The effectiveness of riparian zone buffers in removing sediment and nutrient is dependent on:

- Landscape characteristics: topography, soil and hydrology
- Composition and width of the riparian buffer
- Amount and ratio of soluble and particulate fractions of nitrogen and phosphorus
- Management of the buffer.

Authors have made the following recommendations on suitable buffer widths:

- Buffers of width as narrow as 4 m have been shown to improve waterway health and stabilise banks (Palone & Todd 1997).
- Parkyn (2004) recommended a buffer width of 10–20 m as the minimum necessary to sustain indigenous vegetation with minimum weed control, and to achieve many aquatic functions (New Zealand context).
- In the *Leschenault estuary water quality improvement plan* (Hugues-dit-Ciles et al. 2012) a minimum buffer width of 15 m was recommended to achieve the stated nutrient reduction efficiencies.
- Buffer effectiveness will be influenced by vegetation density (DoW 2006b). Buffers should be progressively widened in proportion to reduced vegetation cover (i.e. doubled if only half of natural groundcover remains).
- Where feasible, riparian vegetation should be extended to the edge of the 1 in 100 year flood plain. When this is not possible, certain activities and structures should be excluded

from the floodplain because of the risk they pose to the stream. These include animal waste lagoons, animal waste spray fields, point sources, hazardous and municipal waste disposal facilities and other potential sources of severe contamination (Wenger 1999).

- Buffers should be wider if the aim is to also provide habitat for terrestrial wildlife to re-colonise or to enhance the ecological values of the waterways. In these situations riparian buffers should be no less than 100 metres (Wenger 1999; Water and Rivers Commission 2000; MacDonald 2003; Mayer et al. 2005b).
- DoW (2006b) recommend widths of 30 m along the banks of first- and second-order streams and of 50 m adjacent to the flood fringe of third- or higher-order streams (also Wenger 1999; Mayer et al. 2005b).
- For other contaminants and pollutants, buffer widths may vary.

Tables from Wenger, S 1999, A review of the scientific literature on riparian buffer width, extent and vegetation, *Office of Public Service and Outreach Institute of Ecology, University of Georgia*

Author	Width (m)	% Slope	% Removal of TSS
Dillaha et al (1988)	4.6	11	87
Dillaha et al (1988)	4.6	16	76
Dillaha et al (1988)	9.1	11	95
Dillaha et al (1988)	9.1	16	88
Dillaha et al (1989)	4.6	11	86
Dillaha et al (1989)	4.6	16	53
Dillaha et al (1989)	9.1	11	98
Dillaha et al (1989)	9.1	16	70
Magette et al (1989)	4.6	3.5	66
Magette et al (1989)	9.1	3.5	82
Peterjohn & Correll (1984)	19	5	90
Peterjohn & Correll (1984)	60	5	94
Young et al (1980)	21.3	4	75-81
Young et al (1980)	27.4	4	66-93

Table 1. Riparian Buffer Width, Slope and TSS Removal Rates.

The ability of riparian buffers to trap suspended solids is positively correlated with width and negatively correlated with slope.

Study	Total P Removal	
	4.6 m buffer	9.1 m buffer
Dillaha et al 1988	71.5%	57.5%
Dillaha et al 1989	61%	79%
Magette et al 1987	41%	53%
Magette et al 1989	18%	46%

Table 2. Removal of Total Phosphorus by Grass Buffers.

With one exception, studies by Dillaha et al and Magette et al found a positive correlation between the width of grass riparian buffers and the ability to trap total phosphorus in surface runoff.

Study	Total N Removal	
	4.6 m buffer	9.1 m buffer
Dillaha et al 1988	67%	74%
Dillaha et al 1989	54%	73%
Magette et al 1987	17%	51%
Magette et al 1989	0%	48%

Table 3. Removal of Total Nitrogen by Grass Buffers.

Studies by Dillaha et al and Magette et al found a positive correlation between the width of grass riparian buffers and the ability to trap total nitrogen in surface runoff.

		Nitrate (mg/L)	Exchangeable NH4+ (mg/L)	Particulate Org. N (mg/L)
Surface Runoff	Initial:	4.45	0.402	19.5
	Final:	0.91 (79%)	0.087 (78%)	2.67 (86%)
Subsurface Transect 1	Initial:	7.40	0.075	0.207
	Final:	0.764 (90%)	0.274 (increase)	0.267 (increase)
Subsurface Transect 2	Initial:	6.76	0.074	0.146
	Final:	0.101 (99%)	0.441 (increase)	0.243 (increase)

Table 4. Nitrogen Reductions Reported by Peterjohn and Correll (1985).

Values show initial concentration of nutrients entering the 50-m buffer and final concentrations after passing through the buffer. Values in parentheses are the percent reductions across the buffer.

	Width (m)	% Reduction	Final Conc. (mg/L)
Osborne and Kovacic (1993)	16	96	<1.0
Haycock and Pinay (1994)	16	84	N.R.
Haycock and Pinay (1994)	20	99	N.R.
Mander et al (1997)	20	81	N.R.
Mander et al (1997)	28	80	N.R.
Hubbard (1997)	30	78	9
Hanson et al (1994)	31	94	0.5
Osborne and Kovacic (1993)	39	95	<1.0
Jordan et al (1993)	60	95	0.4
Lowrance (1992)	60	94	0.81

Table 5. Nitrate Removal in Shallow Groundwater.

Studies have demonstrated consistently high removal rates for nitrate from shallow groundwater passing through riparian buffers. “Final Conc.” is the concentration of nitrate in groundwater leaving the riparian buffer. Concentrations over 10 mg/L (ppm) are considered potentially harmful.

Article	Widths Studied (m)	Min. Width Recommendation (m)
Hodges and Krementz (1996)	36-2088	100
Keller et al (1993)	25-800	100
Kilgo et al (1998)	25-500	both narrow and wide
Kinley & Newhouse (1997)	14-70	70
Smith & Schaefer (1992)	20-150	no recommendation
Spackman and Hughes (1995)	25-200	150-175
Thurmond et al (1995)	15-50	15
Triquet et al (1990)	15-23	no recommendation

Table 6. Riparian Buffer Recommendations from Avian Studies.

The recommendations of the literature on riparian corridor widths for birds are summarized here. The second column shows the range of buffer widths studied by the authors. The third column shows the authors' recommendations for the minimum corridor widths necessary to support bird populations.

Table 1 from Mayer, PM, Reynolds, SK & Canfield, TJ 2005b, Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: a review of current science and regulations, *US Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory.*

Table 1. Summary Table of Riparian Buffer Effectiveness at Removing Nitrogen by Vegetative Cover, Hydrologic Flow Path, Buffer Width and Soil Type. ("nd" = not detected; "–" = data not provided by authors)

Vegetative Cover Type	Flow Path	Buffer Width	N form	Mean Influent (pmm)	Mean Effluent (pmm)	Effectiveness(%)	Major Soil type(s)	Study
grass	surface	4.6	total N	–	–	-15	sandy loam	Magette et al. 1989
grass	surface	9.2		–	–	35		
grass	surface	7.5	total N	68	44	35	silty clay loam	Schmitt et al. 1999
grass	surface	15		68	33	51		
grass	surface	4.6	nitrate	1.86	2.37	-27	silt loam	Dillaha et al. 1988
grass	surface	9.1		1.86	2.13	-15		
grass	surface	4.6	nitrate	–	–	27	silt loam	Dillaha et al. 1989
grass	surface	9.1		–	–	57		
grass	surface	91	total N	21.6	13.3	38	–	Zirschky et al. 1989
grass	surface	27	nitrate	0.37	0.34	8	–	Young et al. 1980
grass	surface	26	NH_3	3.61	3.05	16	very fine sandy loam	Schwer and Clausen 1989
grass	surface	26	TKN	48.9	11.76	76	very fine sandy loam	Schwer and Clausen 1989
grass	subsurface	25	nitrate	15.5	6.2	60	coarse sand	Vidon and Hill 2004b
grass	subsurface	70	nitrate	1.55	0.32	80	fine sandy loam/silt loam	Martin et al. 1999
grass	subsurface	39	nitrate	16.5	3	82	silty clay loam	Osborne and Kovacic 1993
grass	subsurface	25	nitrate	12.15	1.92	84	peat/sand	Hefting and de Klein 1998
grass	subsurface	16	nitrate	2.8	0.3	89	stony clay loam	Haycock and Burt 1993
grass	subsurface	10	nitrate	7	0.3	96	entisols/histosols	Hefting et al. 2003
grass	subsurface	100	nitrate	375	<5	98	–	Prach and Rauch 1992
grass	subsurface	10	nitrate	7.54	0.05	99	silt loam	Schoonover and Williard 2003
grass	subsurface	30	nitrate	44.7	0.45	99	sand/loamy sand	Vidon and Hill 2004b
grass	subsurface	50	nitrate	6.6	0.02	100	fine sandy loam	Martin et al. 1999

Table 1. Continued.

Vegetative Cover Type	Flow Path	Buffer Width	N form	Mean Influent (pmm)	Mean Effluent (pmm)	Effectiveness(%)	Major Soil type(s)	Study
forest	subsurface	16	nitrate	6.6	0.3	95	stony clay loam	Haycock and Pinay 1993
forest	subsurface	15	nitrate	–	–	96	–	Hubbard and Sheridan 1989
forest	subsurface	165	nitrate	30.8	1	97	peat/sand	Hill et al. 2000
forest	subsurface	50	nitrate	6.26	0.15	98	peat/sand	Hefting and de Klein 1998
forest	subsurface	220	nitrate	10.8	0.22	98	peat/loamy sand	Vidon and Hill 2004b
forest	subsurface	50	nitrate	7.45	0.1	99	loamy sand	Jacobs and Gilliam 1985
forest	subsurface	10	nitrate	13	0.1	99	silt loam	Cey et al. 1999
forest	subsurface	100	nitrate	5.6	0.02	100	sandy clay/coarse sand	Spruill 2004
forest	subsurface	30	nitrate	1.32	nd	100	silt clay	Pinay and Decamps 1988
forest	subsurface	100	nitrate	12	nd	100	silt/plant debris/sand	Spruill 2004
forestwetland	surface	–	nitrate	0.34	0.07	81	sand	Yates and Sheridan 1983
forestwetland	subsurface	31	nitrate	62.7	25.9	59	sand	Hanson et al. 1994
forestwetland	subsurface	38	nitrate	30.6	6.7	78	sandy loam	Vellidis et al. 2003
forestwetland	subsurface	14.6	nitrate	–	–	84	sandy mixed mesic	Simmons et al. 1992
forestwetland	subsurface	5.8	nitrate	–	–	87	sandy mixed mesic	Simmons et al. 1992
forestwetland	subsurface	5.8	nitrate	–	–	90	sandy mixed mesic	Simmons et al. 1992
forestwetland	subsurface	6.6	nitrate	–	–	97	loamy mixed mesic	Simmons et al. 1992
forestwetland	subsurface	30	nitrate	1.06	nd	100	clay loam	Pinay et al. 1993
wetland	surface	20	nitrate	57	50	12	peat/sand	Brüsch and Nilsson 1993
wetland	surface	20		57	15	74		
wetland	subsurface	5	nitrate	6.56	1.55	76	stony silt loam	Clausen et al. 2000
wetland	subsurface	5		3	1.44	52		
wetland	subsurface	1	nitrate	1	–	96	clay loam/clay	Burns and Nguyen 2002
wetland	subsurface	200	nitrate	10.5	0.5	95	silt/sand/gravel	Fustec et al. 1991
wetland	subsurface	40	nitrate	77.48	0.31	100	fine to coarse sand	Puckett et al. 2002

Table 1. Continued.

Vegetative Cover Type	Flow Path	Buffer Width	N form	Mean Influent (pmm)	Mean Effluent (pmm)	Effectiveness(%)	Major Soil type(s)	Study
grassforest	surface	7.5	total N	68	49	28	silty clay loam	Schmitt et al. 1999
grassforest	surface	15	total N	68	40	41		
grassforest	subsurface	6	nitrate	6.17	0.56	91	loam/sandy loam	Borin and Bigon 2002
grassforest	subsurface	70	nitrate	11.98	1.09	91	loamy sand	Hubbard and Lowrance 1997
grassforest	subsurface	66	nitrate	5.8	0.17	97	gravel	Vidon and Hill 2004b
grassforest	subsurface	33	nitrate	5.7	0.11	98	sandy loam/loamy sand	Vidon and Hill 2004b
grassforest	subsurface	45	nitrate	17.8	0.18	99	peat	Vidon and Hill 2004b
grassforest	subsurface	70	nitrate	1.65	0.02	99	fine sandy loam/silt loam	Martin et al. 1999
forest	surface	30	nitrate	0.37	0.08	78	silt/stony loam	Lynch et al. 1985
forest	surface	70	nitrate	4.45	0.94	79	fine sandy loam	Peterjohn and Correll 1984
forest	subsurface	50	nitrate	26	11	58	entisols/histosols	Hefting et al. 2003
forest	subsurface	200	nitrate	11	4	64	medium-coarse sand	Spruill 2004
forest	subsurface	10	nitrate	6.29	1.15	82	silt loam	Schoonover and Williard 2003
forest	subsurface	55	nitrate	–	–	83	–	Lowrance et al. 1984
forest	subsurface	20	nitrate	–	–	83	–	Schultz et al. 1995
forest	subsurface	85	nitrate	7.08	0.43	94	fine sandy loam	Peterjohn and Correll 1984
forest	subsurface	204	nitrate	29.4	1.76	94	peat/sand/gravel	Vidon and Hill 2004b
forest	subsurface	50	nitrate	13.52	0.81	94	loamy sand	Lowrance 1992
forest	subsurface	60	nitrate	8	0.4	95	sand/gravel/clay	Jordan et al. 1993
forest	subsurface	16	nitrate	16.5	0.75	95	silty clay loam	Osborne and Kovacic 1993

Table 2. Mean and Percent Effectiveness of Riparian Buffers at Removing Nitrogen. Buffer Widths Necessary to Achieve a Given Percent Effectiveness (50%, 75%, 90%) are Approximate Values Predicted by the Non-Linear Model, y=a*ln(x)+b. Effectiveness was not predicted (np) for Models with R^2 Values <0.2

Flow Path or Vegetative cover type	N	Mean nitrogen removal effectiveness (%)	1SE	Relationship to buffer width		Approximate buffer width (m) by predicted effectiveness		
				Model	R^2	50%	75%	90%
All studies	66	74.2	4.0	y = 10.5*ln(x) + 40.5	0.137	3	28	112
Surface flow	18	33.3	7.7	y = 20.2*ln(x) – 21.3	0.292	34	118	247
Subsurface flow	48	89.6	1.8	y = 1.4*ln(x) + 84.9	0.016	np	np	np
Forest	22	90.0	2.5	y = -0.7*ln(x) + 92.5	0.003	np	np	np
Forested Wetland	7	85.0	5.2	y = -7.3*ln(x) + 104.3	0.203	np	np	np
Grass	22	53.3	8.7	y = 23.0*ln(x) – 13.6	0.277	16	47	90
Grass/forest	8	80.5	10.2	y = 18.1*ln(x) + 20.4	0.407	5	20	47
Wetland	7	72.3	11.9	y = 3.0*ln(x) + 68.9	0.005	np	np	np

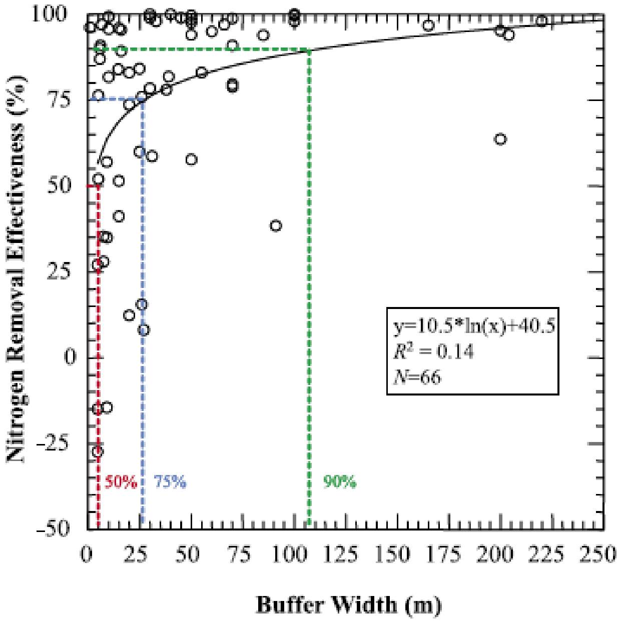


Figure 1. *Relationship of nitrogen removal effectiveness to riparian buffer width. All studies combined. Lines indicate probable 50%, 75%, and 90% nitrogen removal efficiencies based on the fitted non-linear model.*

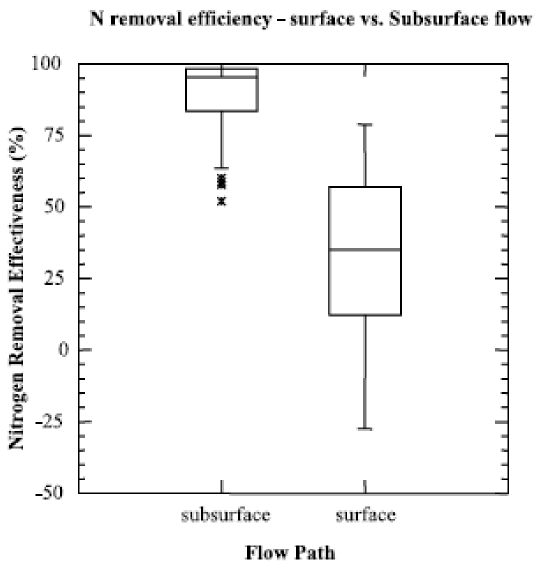


Figure 2. *Nitrogen removal effectiveness in riparian buffers by flow path. The center vertical line of the box and whisker plot marks the median of the sample. The length of each box shows the range within which the central 50% of the values fall. Box edges indicate the first and third quartiles. Whiskers show the range of observed values that fall within the midrange of the data. Asterisks indicate outside values.*

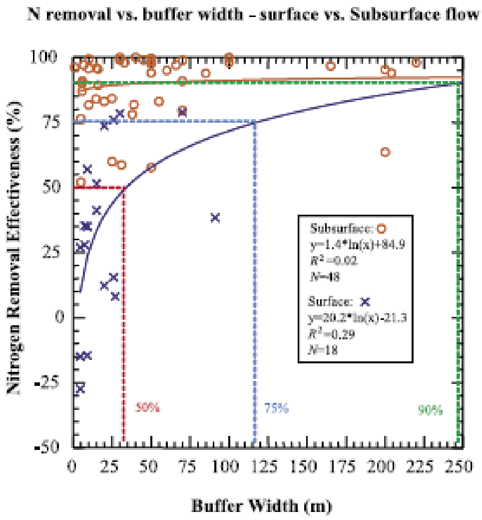


Figure 3. *Relationship of nitrogen removal effectiveness to riparian buffer width by flow path. Lines indicate probable 50%, 75%, and 90% nitrogen removal efficiencies in the surface flow path based on the fitted non-linear model.*

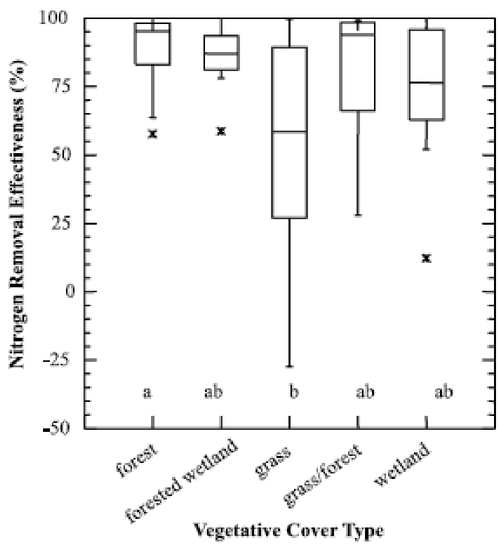


Figure 4. *Nitrogen removal effectiveness in riparian buffers by buffer vegetation type. The center vertical line of the box and whisker plot marks the median of the sample. The length of each box shows the range within which the central 50% of the values fall. Box edges indicate the first and third quartiles. Whiskers show the range of observed values that fall within the midrange of the data. Asterisks indicate outside values. Boxes identified with the same letters are not significantly different (P > 0.05).*

Figures from Palone, RS & Todd, AH 1997, Chesapeake Bay riparian handbook: A guide for establishing and maintaining riparian forest buffers, USDA Forest Service, NA-TP-02-97, Randor, PA.

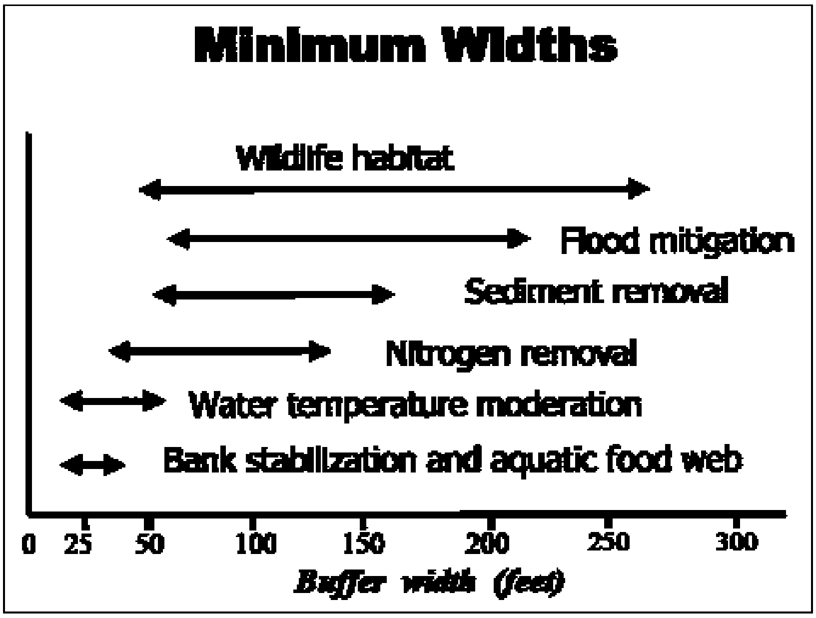


Figure 6 - 3. Range of minimum widths for meeting specific buffer objectives.

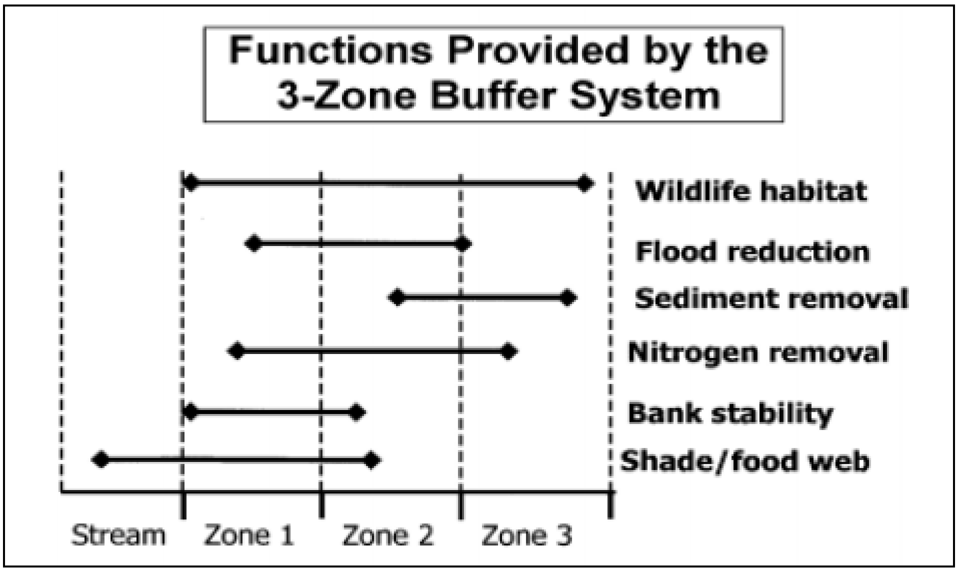


Figure 6 - 4. Each zone of the riparian forest buffer provides various functions and values to the landowner.

Tables from Parkyn, S 2004, Review of riparian buffer zone effectiveness, *MAF Technical Paper no. 2004/2005, Ministry of Agriculture and Forestry, New Zealand.*

Table 1: Contaminant removal efficiencies from references within Castelle et al. (1994) review of U.S. vegetated buffers. VFS = vegetated filter strip.

Contaminant	Buffer width	Removal (%)	Slope (%)	Farm type	Buffer type	Reference
Sediment	30.5	90	2			Wong & McCuen (1982)
Sediment	61	95	2			Wong & McCuen (1982)
Sediment	24.4	92			Veg.	Young et al. (1980)
Sediment	22.9	33		dairy	Filter strip	Schellinger & Clausen (1992)
Sediment	61	80			Grassy swale	Horner & Mar (1982)
Sediment	30	75-80		Logging activity		Lynch et al. (1985)
Sediment	9.1	85	7 and 12		Grass VFS	Ghaffarzadeh et al. (1992)
NO3-N, NH4-N, PO4-P	4.6	90%			Grass VFS	Madison et al. (1992)
NO3-N, NH4-N, PO4-P	9.1	96-99.9			Grass VFS	Madison et al. (1992)
Sediment, N, P	9.1	84, 79, 73	11-16		Grass VFS	Dillaha et al. (1989)
Sediment, N, P	4.6	70, 61, 54	11-16		Grass VFS	Dillaha et al. (1989)
NO3-N	10	99.9%			forested	Xu et al. (1992)
N, P	19	89, 80			forested	Shisler et al. (1987)

Table 2: Some New Zealand studies of efficiency.

Contaminant	Buffer width	Removal (%)	Farm type	Buffer type	Reference
Nitrate	c. 3-4m	88-97	pasture	Riparian organic soils - wetland	Cooper 1990
Nitrate	c. 3-4m	0-62	pasture	Riparian mineral soils - wetland	Cooper 1990
Nitrate		–140-91	pasture	streambed	Cooper 1990
Nitrate		32-100%	Waste water treatment	wetland	Cooper 1994
Nitrate	10-13m	67	pasture	Retired pasture	Smith 1989
Dissolved P	10-13m	55	pasture	Retired pasture	Smith 1989
Particulate P, N	10-13m	80, 85	pasture	Retired pasture	Smith 1989
Total Suspended solids	10-13m	87	pasture	Retired pasture	Smith 1989

Table 3: Experimental studies of buffer widths required for sub-surface and surface nitrate removal (from Fennessy & Cronk 1997).

Flow type	Buffer type	Buffer width (m)	N retention (%)	N inflow (mg/l)
Subsurface	Forest	9	61-97	180
	Forest	10	70-90	13.5
	Forest	10	Up to 77	0.6-2.5
	Forest	19	93	7.4
	Forest	>20	90	7.4
	Forest	>20	99	6.8
	Forest	20	Up to 87	0.6-2.5
	Forest	25	68	~2-6
	Forest	26	~100	2-9
	Forest	30	~100	5
	Forest	>10-50	94	1.8
	Forest	50	95	8
	Forest	60	~100	10
	Herbaceous	22	84	2-12
Sub- and surface	Forest	16	90	10
Surface	Forest	19	60	4.5
	Forest	>20	79	4.5
	Herbaceous	5	54	-
	Herbaceous	8	20	20
	Herbaceous	9	73	-
	Herbaceous	16	50	20
	Herbaceous	27	84	-
	Herbaceous	30	11	20

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H. Baseline period climate change modelling results

The modelling results for the World Meteorological Organisation (WMO) 'climate normal period' of 1961–90 are presented here. These results represent the 30-year averaged results from the baseline period (1961–90) and are compared to the 'dry' and 'wet' climate change scenarios, both of which are also a 30-year average. See Section 6.6 for a full description of modelling methods.

Table H-1: Average annual flows from the baseline period (1961-90), and the 30-year synthetic climate series for the wet and dry climate scenarios

Reporting catchment	Base case (1961–90) (GL/yr)	Dry (GL/yr)	Diff %	Wet (GL/yr)	Diff %
Yilgarn	12	2.1	-82	7.4	-36
Lockhart	11	4.0	-65	8.5	-26
Salt	2	0.47	-72	1.11	-32
Yenyening Lakes inflow	25	6.5	-74	17.0	-31
Yenyening Lakes outflow	13	1.0	-92	7.1	-44
Upper Avon	27	11	-60	22	-19
Dale	69	28	-60	55	-21
Middle Avon	71	36	-49	66	-7.3
Mortlock East	32	10	-70	23	-28
Mortlock North	28	8.7	-69	20	-29
Brockman	58	24	-58	47	-18
Wooroloo	59	31	-48	49	-16
Lower Avon	113	66	-41	111	-2.3
Basin outlet	492	215	-56	399	-19

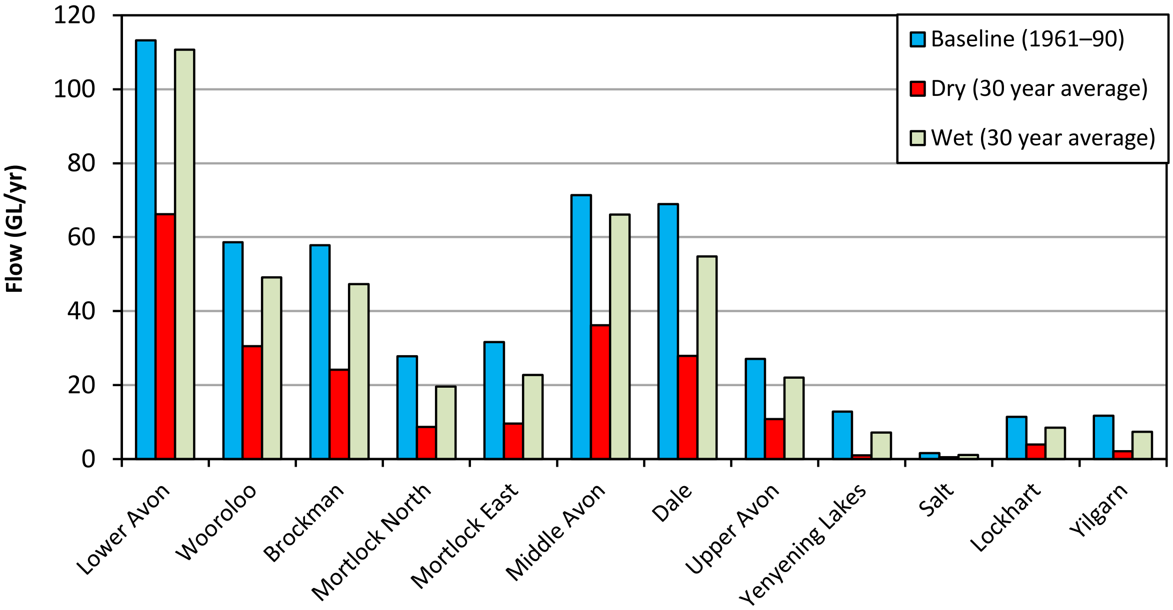

Figure H-1: Average annual flows from the baseline period (1961-90), and the 30-year synthetic climate series for the wet and dry climate scenarios

Table H-2: Average annual nitrogen loads from the baseline period (1961-90), and the 30-year synthetic climate series for the wet and dry climate scenarios

Reporting catchment	Base case (1961–90) (t/yr)	Dry (t/yr)	Diff %	Wet (t/yr)	Diff %
Yilgarn	23	3.9	-83	14	-38
Lockhart	34	12	-65	25	-27
Salt	6	1.5	-74	3.6	-34
Yenyening Lakes inflow	62	17	-73	43	-31
Yenyening Lakes outflow	31	5.4	-82	20	-35
Upper Avon	63	24	-62	51	-20
Dale	122	43	-65	94	-23
Middle Avon	86	38	-56	70	-18
Mortlock East	68	20	-70	48	-29
Mortlock North	57	17	-70	40	-31
Brockman	76	28	-63	60	-20
Wooroloo	38	18	-53	31	-18
Lower Avon	97	51	-47	84	-13
Basin outlet	638	245	-62	499	-22

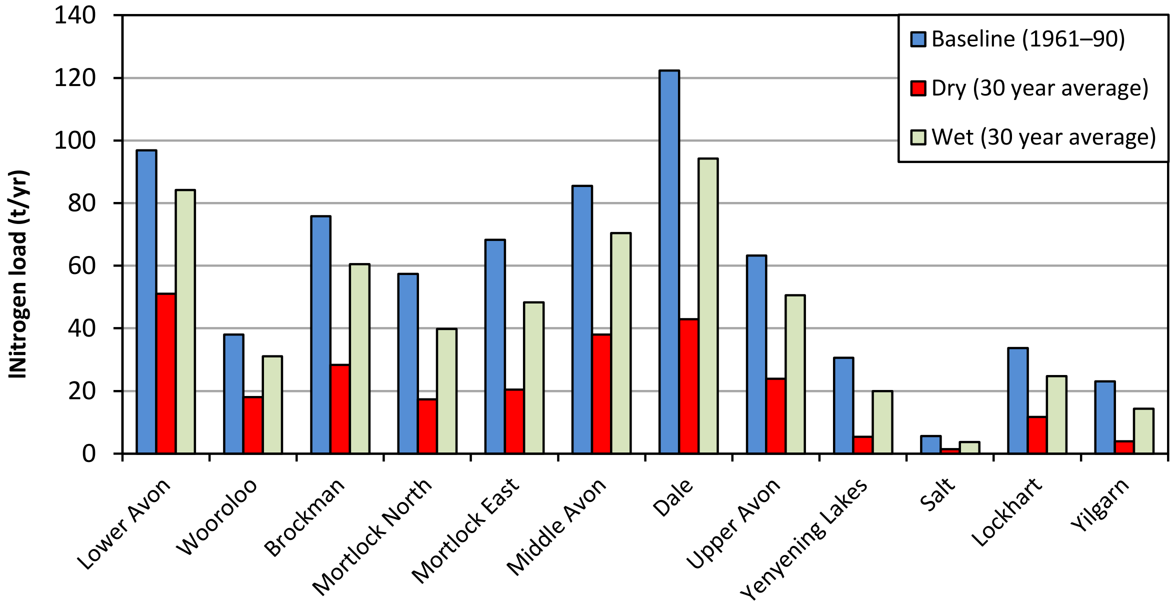

Figure H-2: Average annual nitrogen loads from the baseline period (1961-90), and the 30-year synthetic climate series for the wet and dry climate scenarios

Table H-2: Average annual phosphorus loads from the baseline period (1961-90), and the 30-year synthetic climate series for the wet and dry climate scenarios

Reporting catchment	Base case (1961–90) (t/yr)	Dry (t/yr)	Diff %	Wet (t/yr)	Diff %
Yilgarn	0.62	0.13	-80	0.39	-36
Lockhart	0.63	0.24	-61	0.46	-26
Salt	0.09	0.02	-76	0.06	-37
Yenyening Lakes inflow	1.3	0.39	-71	0.91	-32
Yenyening Lakes outflow	0.65	0.12	-81	0.43	-35
Upper Avon	1.7	0.64	-62	1.3	-20
Dale	3.0	1.1	-62	2.3	-22
Middle Avon	0.95	0.45	-52	0.79	-17
Mortlock East	3.8	1.2	-69	2.7	-29
Mortlock North	3.1	0.91	-71	2.1	-31
Brockman	1.7	0.69	-59	1.4	-19
Wooroloo	0.50	0.25	-50	0.41	-17
Lower Avon	1.00	0.52	-47	0.87	-13
Basin outlet	16	5.9	-64	12	-24

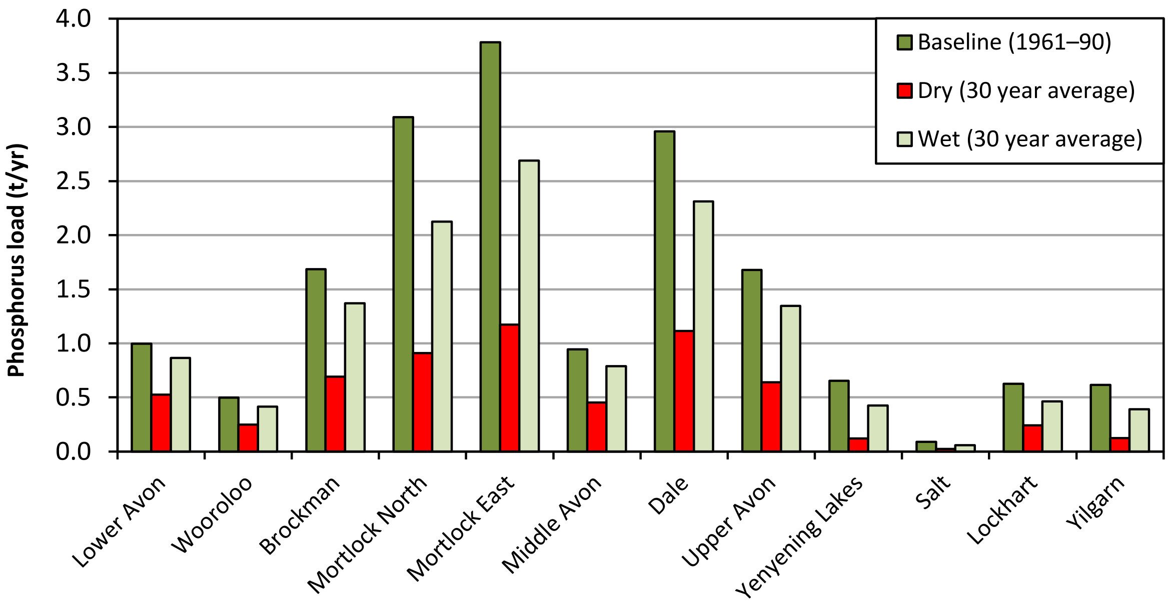

Figure H-3: Average annual phosphorus loads from the baseline period (1961-90), and the 30-year synthetic climate series for the wet and dry climate scenarios

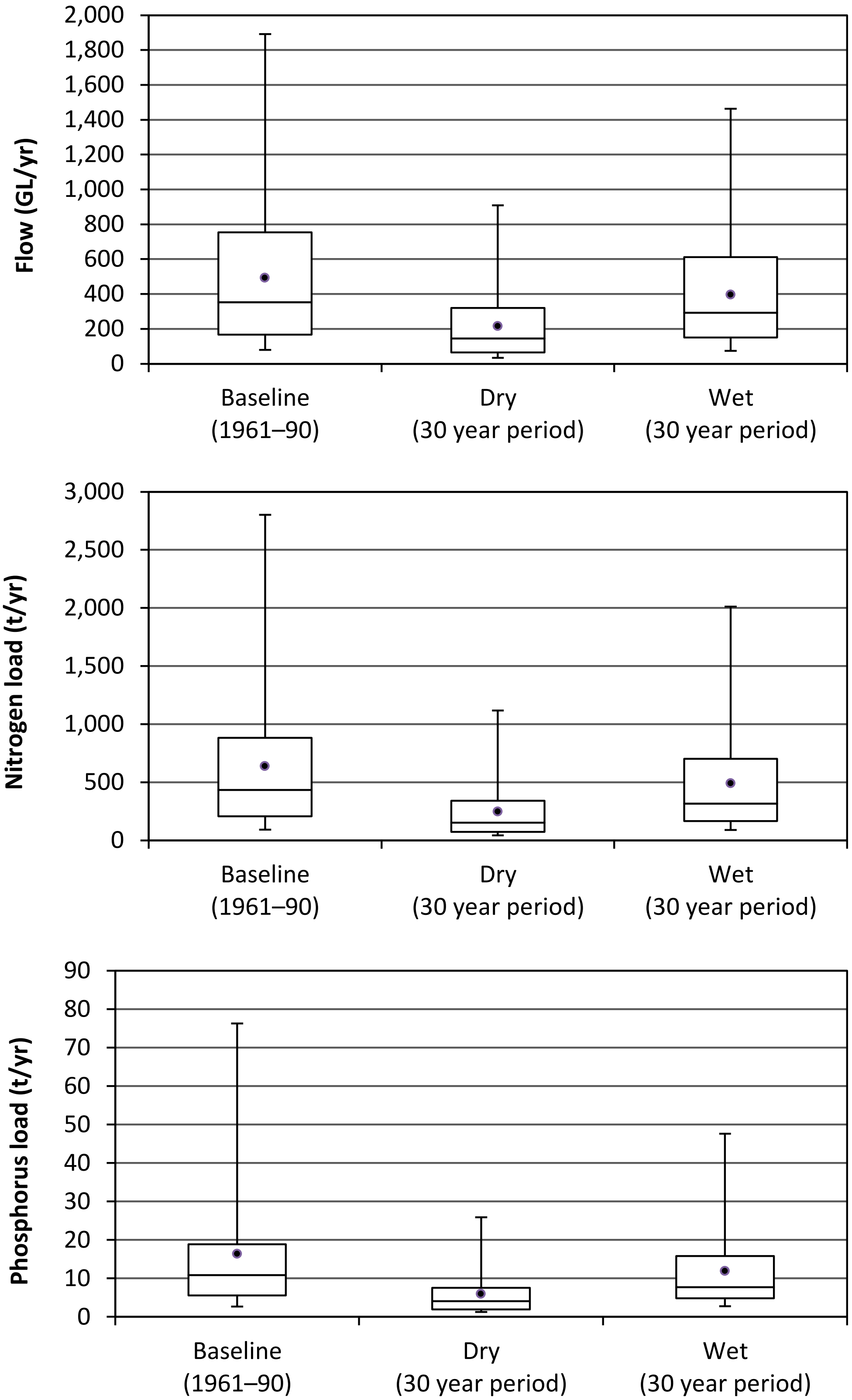

Figure H-4: Box and whisker plots showing maximum, minimum, 25th, 50th and 75th percentiles and average annual values (dot) for flow (top), nitrogen (middle) and phosphorus (bottom) loads at the basin outlet for the baseline period (1961-90) and the 30-year synthetic climate series for the wet and dry climate scenarios.

I. Peer review

Copy of peer review letter

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Our Ref: TRW: ReviewLetter.docx

21 October 2014

Water Science Branch
Department of Water
PO Box K822
Perth WA 6842

Attention: Peta Kelsey

Dear Peta

RE: PEER REVIEW - AVON BASIN HYDROLOGICAL AND NUTRIENT MODELLING

Thank you for the opportunity to review the Department of Water's report into the Avon River Basin modelling recently undertaken. Provided below is the findings of my review.

1. The authors are to be congratulated on what is an excellent report on contemporary catchment modelling approaches within a hydrologically complex system. Having authored many similar reports across Australia, I would say that this report is an exemplar of how catchment modelling should be undertaken and reported and all staff who worked on this should be congratulated for the efforts made.
2. Fundamentally, I can find no significant issues with the report, with the majority of my comments revolving around readability and minor technical issues. The modelling approach, catchment analysis, data collation, hydrologic and water quality calibration, scenarios and conclusions are all sound in their findings and outputs.
3. The general readability of the document is very good, however this may be enhanced by further figures and images to supplement some of the text. Further suggestions on this are noted below
4. In Section 2.3 on soils, mention is made on the Phosphorus Retention Index of different areas of the basin. It would be useful if there was a link or some description as to how this is used within the model itself.
5. Section 2.6 discusses point sources and the assumed nutrient export from all discharges to land being 10% of the discharge when river flows exceed 10ML/day. It would be useful to describe how this was chosen, even if it was arbitrary.
6. Figure 2.11 shows the point sources and reporting catchments. It is a little difficult to match the colours directly with the legend and it would be beneficial if the catchments were named directly on the map.
7. In Section 2.7 in the discussion of environmental degradation, some images to illustrate some of the issues noted would better help convey their impact.
8. Also within that section, discussing how the environmental degradation may have further impacted on the hydrology of the catchment would assist, especially around the impacts of sheep

C:\trw\AvonRPeerReview\ReviewLetter.docx **A part of BMT in Energy and Environment** farming on compaction and lack of infiltration in those areas which would be typical. In later sections, one of the remediation options is revegetation of the catchment, this would help restore the hydrology of those areas to that prior to grazing pressure and so drawing a link between the land use impacts and the remediation benefits is warranted.

9. Figure 2.15 shows proportional speciation of nutrients. This is valuable information and provision of the numbers or percentages on the graphs would help preserve this information for future reference.

10. Figure 3.1 contains information on average monthly flows. The Gairdners crossing information appears to have a spurious value for February, or if it is not so, some other explanation of why it was so high.

11. The description of LASCAM in Section 4.2.1 is very useful and the authors are commended for such a useful explanation.

12. Also in Section 4.2.1, some information is given on Yenyening Lakes representation as a storage within the model, however there is no real information provided on the performance of the storage node to represent this (I may have missed this in the results section). Some presentation of water level variation and spills would be useful.

13. I am interested in the use of the Leaf Area Index discussed in Section 4.4.2. Was any consideration given to using remote sensing (such as FPC) to predict this?

14. The statement in Section 4.4.2 (3rd paragraph) regarding nutrients outputs from urban lands being small is somewhat confusing. In our studies of urban runoff, nitrogen and phosphorus loads can be substantial, especially due to the increased flows from those areas.

15. Further in Section 4.4.2, discussion and presentation of N and P use efficiency, there is no discussion on the influence of the N and P fixation of various soil types, e.g. the PRI discussion note in Point 4 above. I therefore wonder whether this has been properly considered. If so, perhaps some further text describing how this is included would help the reader understand those issues. I would have thought some losses of N and P in sandy soils to groundwater (perhaps this is just a hydrologic issue to consider) would also be beneficial.

16. Section 4.5 on Model Calibration has used several criteria for acceptance of model performance. It is recommended that the authors consider the use of the criteria set out in Moriasi et al 2007 on hydrologic model performance as shown in the table below:

Table 3-1 General Performance Ratings for Model Statistics for a Monthly Time Step –Stream flow (adapted from Moriasi *et al*, 2007)

Performance Indicator	PBIAS (Stream flow)	NSE	RSR
Very good	PBIAS < ±10	0.75 < NSE ≤ 1	0 ≤ RSR ≤ 0.5
Good	±10 ≤ PBIAS < ±15	0.65 < NSE ≤ 0.75	0.5 < RSR ≤ 0.6
Satisfactory	±15 ≤ PBIAS < ±25	0.5 < NSE ≤ 0.65	0.6 < RSR ≤ 0.7
Unsatisfactory	PBIAS ≥ ±25	NSE ≤ 0.5	RSR > 0.7

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17. The calibration results are generally excellent and modellers should be very pleased with the results obtained. I was especially impressed by the water quality calibration that was undertaken and envious that sufficient data was available to do this (a rare issue in catchment modelling!).
18. In the discussion on power curve development for the Lockhart and Salt catchments, the use of a single value for setting the curve parameters is questionable, though given the likely paucity of data on event runoff, I can understand why it was used. It would be useful to have some further discussion as to whether this was the case.
19. Section 4.6 outlines the model uses. I have some concerns about the use to estimate the impacts of climate variability. One issue that arises in assessing climate variability, especially climate change, is the validity of calibration in different climatic periods. Further discussion of this is made in later dot points below.
20. In Table 5.3, the estimate of TSS loads shows average concentrations of 92 and 105 mg/L for 1999 and 2000 respectively. I believe these to be quite elevated, and while I realise there was a large event in 2000, but these averages are quite high and I question whether they are justified.
21. In Section 5.5.1 on comparison of nutrient loads with the work of Kelsey 2010a, the statement regarding the erroneous TN and TP data during periods of high river flow is somewhat confusing. I would have expected this to be typical and it may be better to discuss if this could be corrected and revised comparisons made. I realise that this may be outside the scope of the current project, however to dismiss contrary data by the claim of an error seems to not examine the issue appropriately.
22. With the second paragraph on p 103, it might be better to represent the information using a graph or two for the N and P results.
23. In the first paragraph on p 107, there is discussion of the relationship between the Avon River and coastal catchment flows, plus the impact of seasonality. It would be good to outline the implications for this in managing nutrients and algal growth in the estuary.
24. The information presented on the tidal profiles for constituents is useful, however the reference for this information should be included in each of the figures for completeness.
25. Figure 6.4 on p 138 seems to be missing one of the revegetation scenarios in the legend (Entire Basin), even though the column is shown in the graph.
26. Section 6.6 on the assessment of climate change is interesting, however some consideration of the impacts of hydrologic response of wet and dry climates, and whether the model should be recalibrated to better represent how the catchment would operate in these times, should be discussed.
27. The section of cumulative impacts is excellent and something that is rarely done in catchment modelling.

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In conclusion, prior to reading this report, I would have suggested that catchment modelling undertaken in the Reef Catchments or our work in the Tamar and Esk Rivers would have been considered "state of the art" projects. I now believe that the work undertaken in the Avon basin surpasses those projects, it has been very well developed, delivered and documented and I would strongly recommend that the authors consider publishing this to a wider audience (should the Department be acceptable).

The authors and all involved in the project should also be congratulated on such an excellent project. I would suggest though, that further engagement with community stakeholders who may be influenced or impacted by some of the recommendations of the report be undertaken so that they have the ability to discuss the findings with the authors.

I hope that this review is of benefit and I would be more than happy to discuss the findings with the authors and researchers at any stage.

Yours Faithfully
BMT WBM

Tony Weber
National Practice Leader – Water Quality

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Responses to peer review

4. In Section 2.3 on soils, mention is made on the Phosphorus Retention Index of different areas of the basin. It would be useful if there was a link or some description as to how this is used within the model itself.

Response:

PRI mapping helps understanding of TP concentrations in different areas of the Avon Basin. The TP calibrations were based on observed three-year median TP concentrations within reporting catchments and not explicitly related to PRI. PRI is discussed in the report to highlight the greater potential for phosphorus pollution in areas of low PRI soils.

5. Section 2.6 discusses point sources and the assumed nutrient export from all discharges to land being 10% of the discharge when river flows exceed 10ML/day. It would be useful to describe how this was chosen, even if it was arbitrary.

Response:

The following text was added

“These assumptions were used to account for the relatively low nutrient export (i.e. the small percentage of nutrients applied to land that reaches waterways) of the Avon Basin, and to prevent discharge at times when point sources would be hydrologically disconnected from waterways. It should be noted that these assumptions may underestimate the contributions from point sources. Table 2.7 shows the estimated nutrient loads from point sources that reach waterways.”

6. Figure 2.11 shows the point sources and reporting catchments. It is a little difficult to match the colours directly with the legend and it would be beneficial if the catchments were named directly on the map.

Response:

The symbology and symbol size of point sources was altered to improve the readability of the figure.

7. In Section 2.7 in the discussion of environmental degradation, some images to illustrate some of the issues noted would better help convey their impact.

Response:

Pictures illustrating the environmental degradation in the Avon Basin were added into this section.

8. Also within that section, discussing how the environmental degradation may have further impacted on the hydrology of the catchment would assist, especially around the impacts of *sheep farming on compaction and lack of infiltration in those areas which would be typical. In later sections, one of the remediation options is revegetation of the catchment, this would help restore the hydrology of those areas to that prior to grazing pressure and so drawing a link between the land use impacts and the remediation benefits is warranted.*

Response:

Soil compaction, increased watertable height, waterlogging and erosion will all change the hydrology of the catchment. It is difficult to quantify the impact of any of these individually because the catchment is so altered.

9. Figure 2.15 shows proportional speciation of nutrients. This is valuable information and provision of the numbers or percentages on the graphs would help preserve this information for future reference.

Response:

Done.

10. Figure 3.1 contains information on average monthly flows. The Gairdners crossing information appears to have a spurious value for February, or if it is not so, some other explanation of why it was so high.

Response:

This was checked and the following text was included:

"Gairdners Crossing discharges only 63% of its average annual flow during winter. However, the large proportion of summer flow was a result of a summer storm in February 2003, which was the largest flow event of the record, and thus skewed the average monthly summer flow at this site."

12. Also in Section 4.2.1, some information is given on Yenyening Lakes representation as a storage within the model, however there is no real information provided on the performance of the storage node to represent this (I may have missed this in the results section). Some presentation of water level variation and spills would be useful.

Response:

The following figure (Figure 4.4) was included which shows the storage volume at Yenyening Lakes.

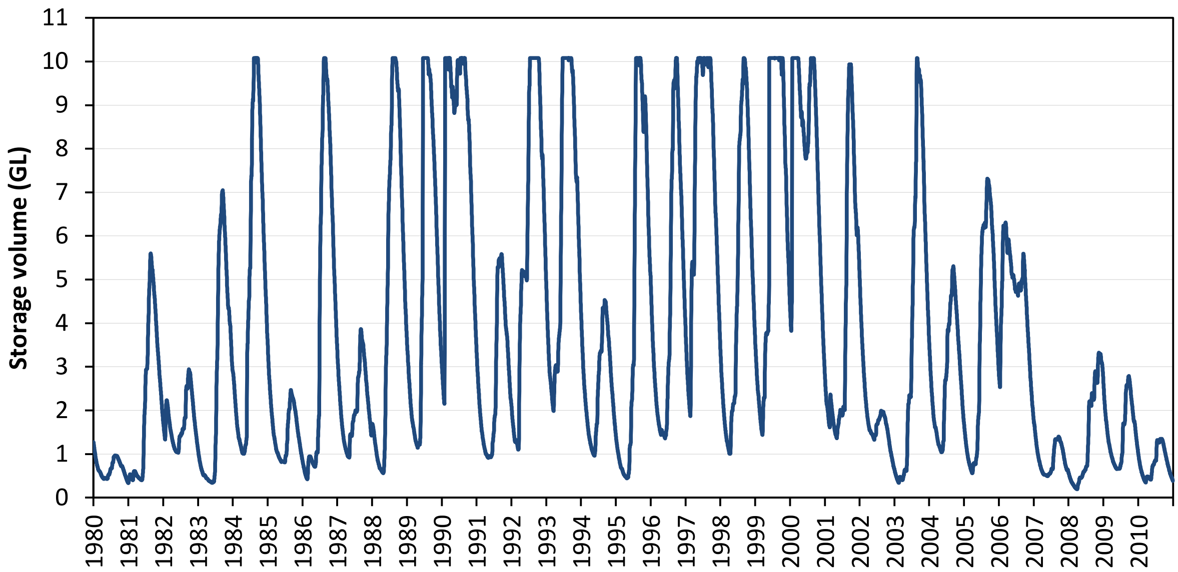

Figure 4.4: Modelled volume of the Yenyening Lakes storage node

13. I am interested in the use of the Leaf Area Index discussed in Section 4.4.2. Was any consideration given to using remote sensing (such as FPC) to predict this?

Response:

We discussed using NDVI data to calculate LAI at the beginning of the project. However, the methodology used was deemed satisfactory. It was a similar approach to other modelling undertaken in Southwest WA. In future catchment modelling projects we will investigate alternative methods, such as remote-sensed FPC.

14. The statement in Section 4.4.2 (3rd paragraph) regarding nutrients outputs from urban lands being small is somewhat confusing. In our studies of urban runoff, nitrogen and phosphorus loads can be substantial, especially due to the increased flows from those areas.

Response:

Agreed, bad wording. (This is actually in Section 4.4.3.) The text has been edited:

"The nutrient surpluses of urban land use are not known but are likely to be large as urban land uses do not remove nutrients in produce."

15. Further in Section 4.4.2, discussion and presentation of N and P use efficiency, there is no discussion on the influence of the N and P fixation of various soil types, e.g. the PRI discussion note in Point 4 above. I therefore wonder whether this has been properly considered. If so, perhaps some further text describing how this is included would help the reader understand those issues. I would have thought some losses of N and P in sandy soils to groundwater (perhaps this is just a hydrologic issue to consider) would also be beneficial.

Response:

We didn't include soil adsorption of N and P explicitly, but it is implicitly included in the nutrient calibration.

The model assumed uniform catchment-nutrient storage conditions in modelling subcatchments. Nutrient loads lost to waterways (exported) were calibrated to observed data. That is, land-use nutrient exports, were related to their catchment characteristics (such as soil type, nitrification-denitrification potential, microbial assimilation and plant uptake). Therefore, nutrient storage capacity was accounted for implicitly in the model calibration.

16. Section 4.5 on Model Calibration has used several criteria for acceptance of model performance. It is recommended that the authors consider the use of the criteria set out in Moriasi et al 2007 on hydrologic model performance as shown in the table below:

Response:

Noted. We will read the paper and consider using these general performance ratings in future work.

18. In the discussion on power curve development for the Lockhart and Salt catchments, the use of a single value for setting the curve parameters is questionable, though given the likely paucity of data on event runoff, I can understand why it was used. It would be useful to have some further discussion as to whether this was the case.

Response:

Agreed, we have included the following text:

"Although this puts great weight on data from a single large flow event, it was unavoidable due to the scarcity of data."

19. Section 4.6 outlines the model uses. I have some concerns about the use to estimate the impacts of climate variability. One issue that arises in assessing climate variability, especially climate change, is the validity of calibration in different climatic periods. Further discussion of this is made in later dot points below.

Response:

This is discussed with point 26 below.

20. In Table 5.3, the estimate of TSS loads shows average concentrations of 92 and 105 mg/L for 1999 and 2000 respectively. I believe these to be quite elevated, and while I realise there was a large event in 2000, but these averages are quite high and I question whether they are justified.

Response:

The data from 1999 and 2000 were checked. The high average TSS concentrations appear to be a result of large flows, which mobilise large amounts of TSS. Also, there were more samples taken in these years. All samples collected via the auto-sampler were excluded from the analysis (as discussed in the next point). Therefore, the TSS readings for 1999 and 2000 were considered valid. TSS increases in concentration in high flows, thus high-flow years have higher TSS loads, due both to increased flow volumes and increased TSS concentrations, as seen in Figure 5.4.

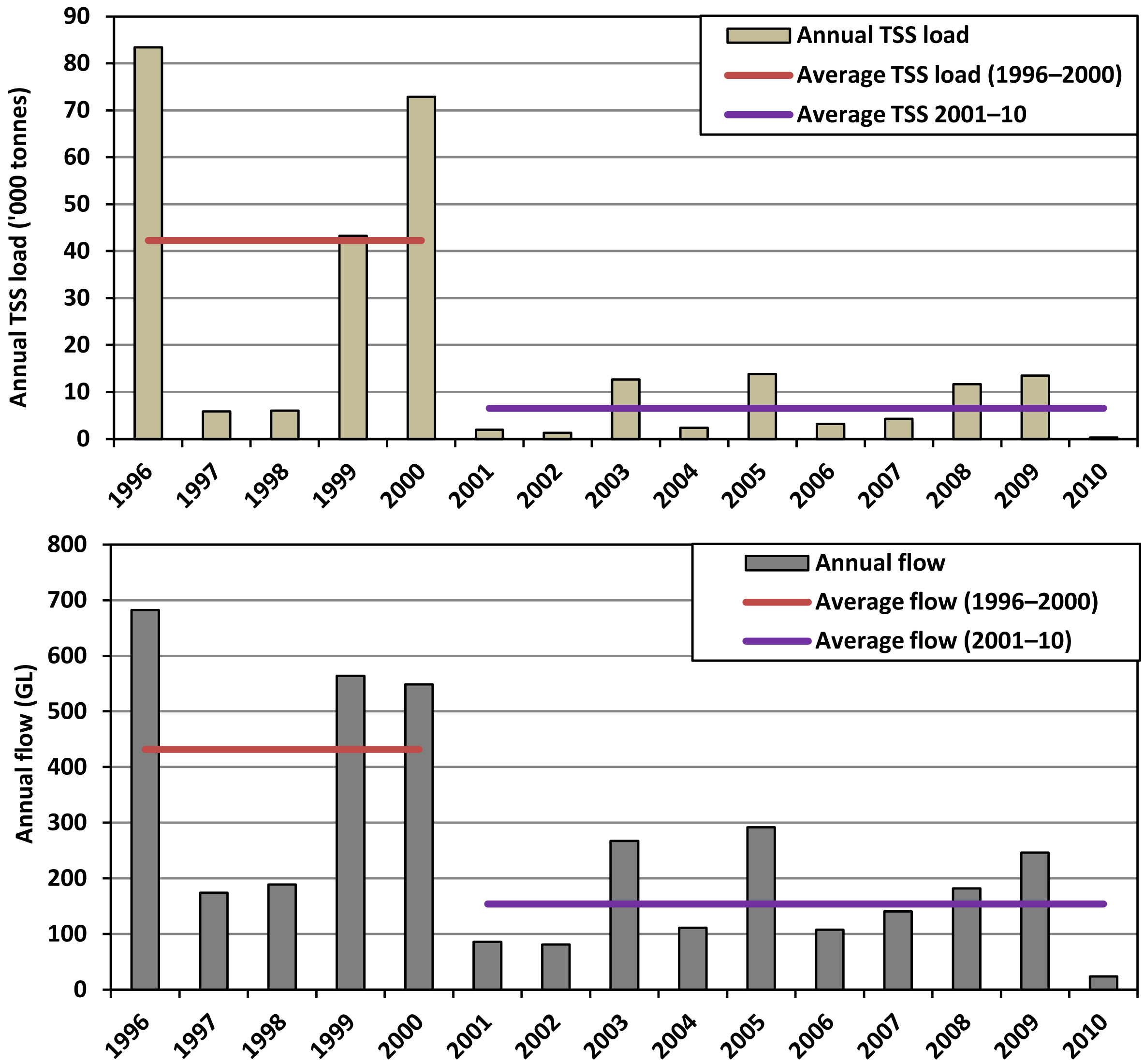

Figure 5.4: Annual flows and TSS loads at Swan River, Walyunga 616011 for the period 1996-2012

21. In Section 5.5.1 on comparison of nutrient loads with the work of Kelsey 2010a, the statement regarding the erroneous TN and TP data during periods of high river flow is somewhat confusing. I would have expected this to be typical and it may be better to discuss if this could be corrected and revised comparisons made. I realise that this may be outside *the scope of the current project, however to dismiss contrary data by the claim of an error seems to not examine the issue appropriately.*

Response:

In the Jan 2000 flood in the Avon River, the autosampler intake was too low in the river profile, due to the increased river depth. The samples collected contained a large amount of suspended sediment and organic matter, which resulted in elevated TN and TP concentrations characteristic of the nutrient concentrations of the ‘bed load’ and not typical of the ‘average’ nutrient concentration of the water profile. The inlet to the autosampler should have been raised as the water level raised. However, due to the fixed nature of sampling equipment this does not occur. This was discovered following the publication by Kelsey et al. (2010a) and the data have now been flagged appropriately.

The elevated erroneous TN and TP concentrations at high river flows led to an erroneous concentration-flow relationship which generated the erroneously large nitrogen and phosphorus loads.

The text has been edited to explain the cause of the error more fully.

22. With the second paragraph on p 103, it might be better to represent the information using a graph or two for the N and P results.

Response:

This information is given in Figure 5.10.

23. In the first paragraph on p 107, there is discussion of the relationship between the Avon River and coastal catchment flows, plus the impact of seasonality. It would be good to outline the implications for this in managing nutrients and algal growth in the estuary.

Response:

This is addressed in the final paragraph of Section 5.5.1. We have added the few words in **bold** below to make the meaning clearer.

“During the summer months of 1997 (January, February, March, November and December) there was very little input to the Swan Estuary from the Avon River and Ellen Brook but the inputs, particularly phosphorus loads from the impervious, urban coastal catchments, kept ‘dribbling in’. Nutrient inputs, particularly inorganic nitrogen and phosphorus, in summer are likely to be available for algal growth due to the strong light conditions and high temperatures. **It is, thus important to minimise nutrient inputs from the urban catchments surrounding the estuary**.”

24. The information presented on the tidal profiles for constituents is useful, however the reference for this information should be included in each of the figures for completeness.

Response:

A reference to the published vertical plots has been included.

25. Figure 6.4 on p 138 seems to be missing one of the revegetation scenarios in the legend (Entire Basin), even though the column is shown in the graph.

Response:

The legend of this figure has been amended.

26. Section 6.6 on the assessment of climate change is interesting, however some consideration of the impacts of hydrologic response of wet and dry climates, and whether the model should be recalibrated to better represent how the catchment would operate in these times, should be discussed.

Response:

Climate modelling is problematic. The errors in the future climate models are probably greater than the errors in hydrological and nutrient models, even those calibrated to a different climate regime! The Department of Water has developed a climate tool to provide future climate scenarios based on global climate models for use in hydrological modelling. In most of the state, except the south-west, the global climate models do not agree on the direction of the climate change. That is, some predict a wetter climate and some predict a drier climate. In the south-west, all the global climate models predict a drying climate, so there is greater confidence that predicted future rainfall may be a possibility.

At subcatchment 25, near Northam the dry-climate 30-year average annual rainfall predicted for 2030 (of 355 mm) is similar to the 10-year average annual rainfall for our model reporting period of 2001–10 (of 358 mm). So either the climate in south-west WA is drying faster than the climate models predict or 2001–10 was a very dry decade. This is discussed in the report.

Hydrological calibration

The observed and modelled annual flows at the catchment outlet for the period 1981–2010 (from Appendix D) are shown in Figure D-2. There is quite good agreement in the modelled and observed annual flows, except for the highest flow year of 1983. The modelled flows for the 30-year dry- and wet-climate sequences are shown in Figure 1 and Figure 2 respectively. For the dry-climate, the range of annual flows is not too different to those of the calibration period, so it is likely that the hydrological calibration is appropriate for modelling the dry climate scenario. However, it is highly likely that the high-flow years for the wet-climate scenario are being underestimated (Figure 2). This would lead also to an underestimation of the nutrient loads in these high-flow years.

Nutrient calibration

The nutrient calibration was based on 2007–09 median winter TN and TP concentrations. As stream concentrations are generally different for different flow regimes, changed flows that may eventuate from changed climate may lead to changes to median winter TN and TP concentrations.

The relationship between median TN and TP concentrations and annual flow were examined for several sites, and at most sites there was no clear relationship. Thus, the nutrient loads estimated in the climate change scenarios (except for the high-flow years of the wet climate scenario) are probably indicative of possible future loads.

However, in future modelling exercises, if similar methodology for the nutrient calibrations (i.e. power curves), is used, we will examine more closely the relationship between median TN and TP concentrations and flow, to determine likely future median concentrations for predicted future flows.

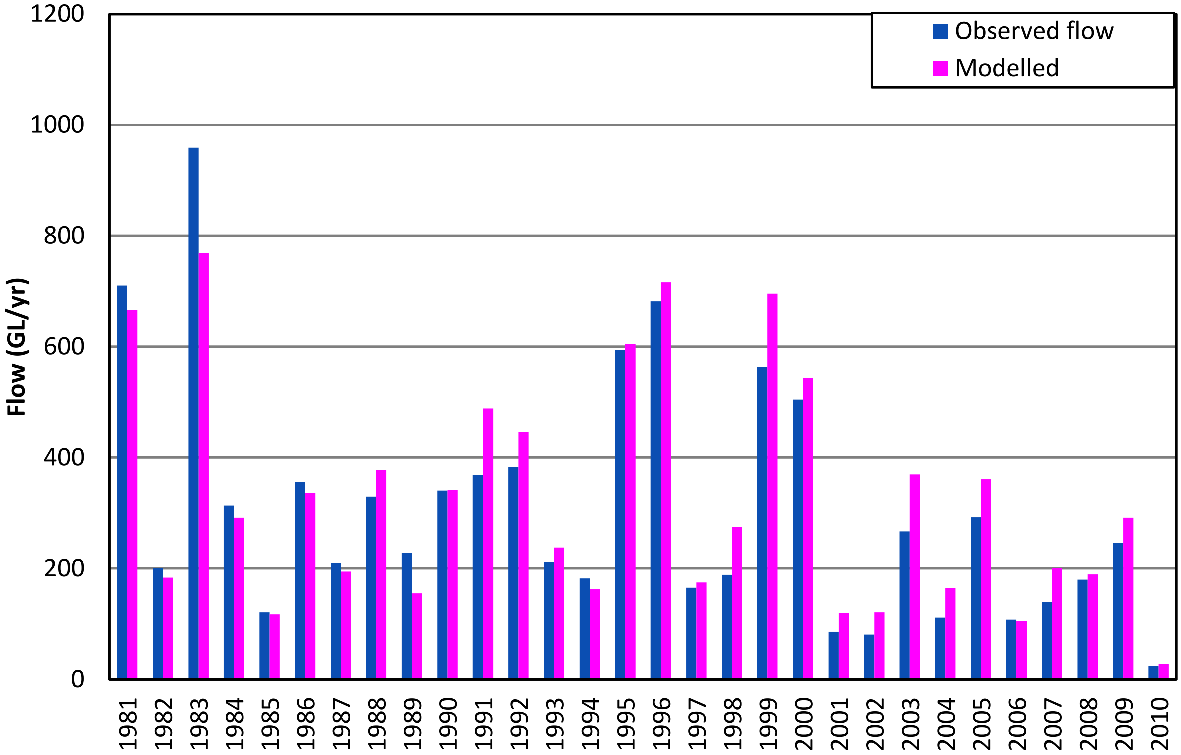

Figure D-2 from Appendix D, Figure D-2: Observed and modelled annual flows at Walyunga (616011)

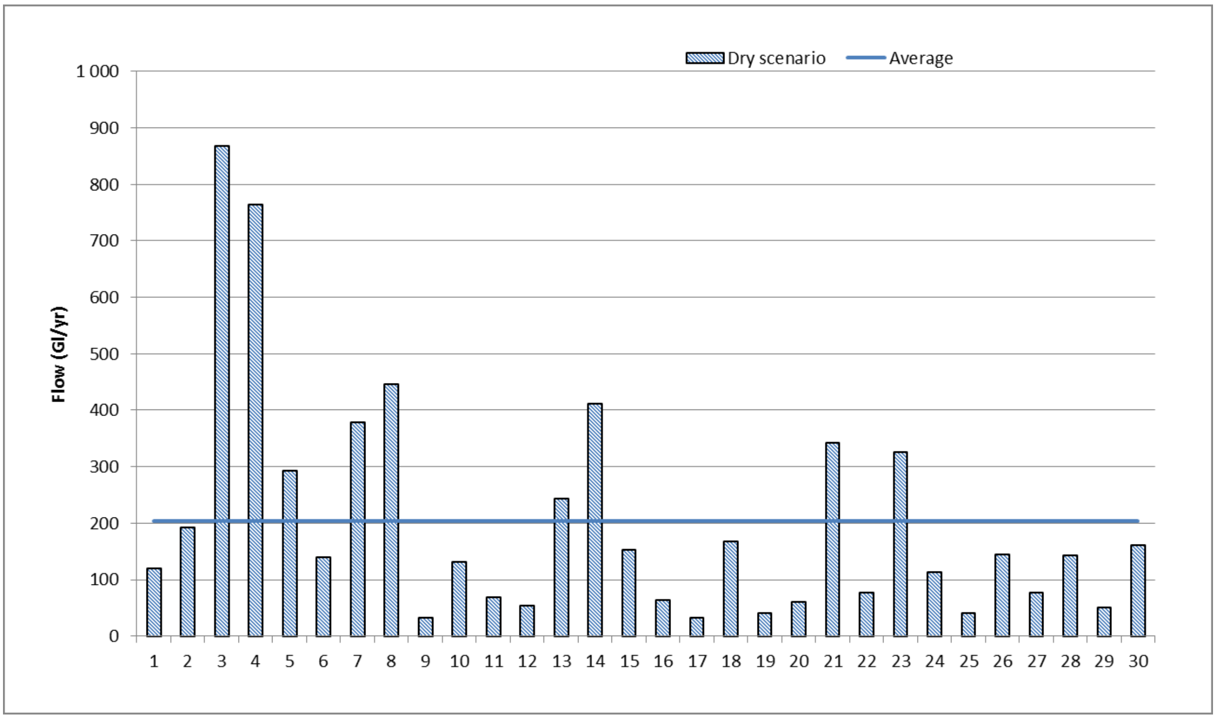

Figure 1: Modelled flows for 30-year 2030 dry-climate scenario rainfall

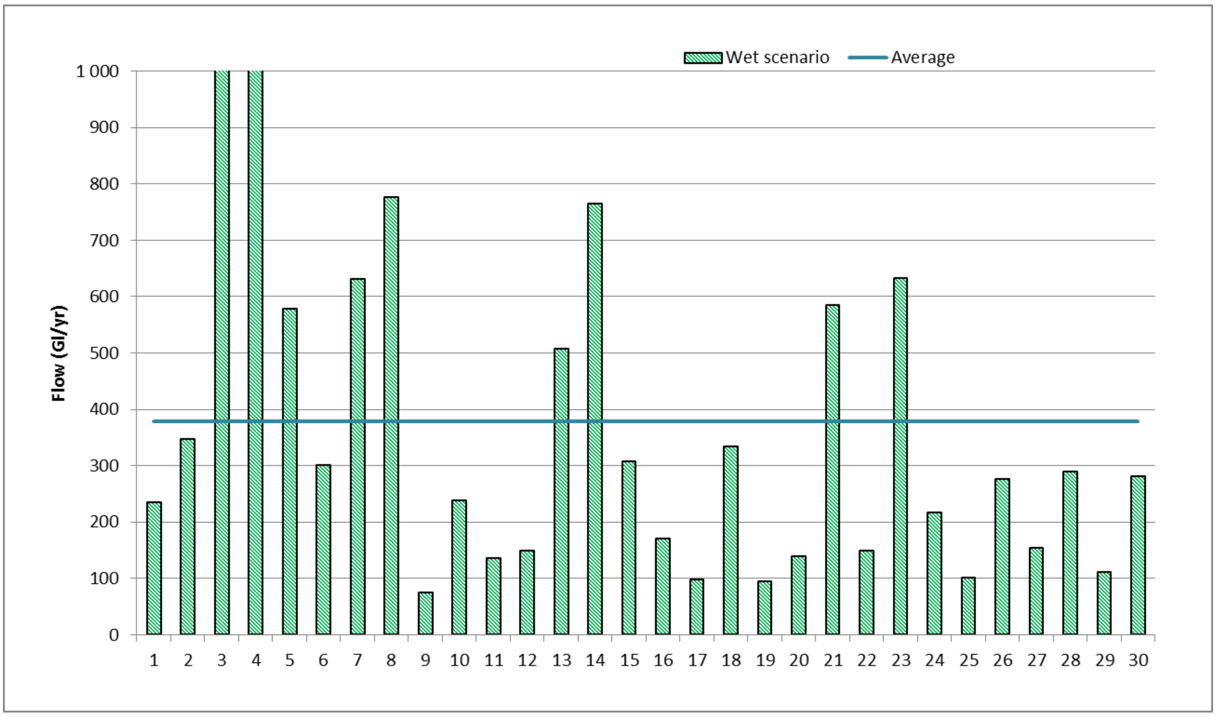

Figure 2: Modelled flows for 30-year 2030 wet-climate scenario rainfall. Years 3 and 4 have annual flows of 1415 GL and 1263 GL respectively.

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