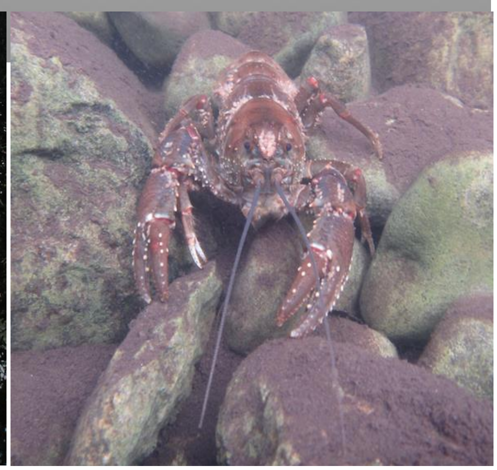
River Derwent & Catchment Tributary Water Quality Report



Bernadette Proemse, Jason Whitehead, Christine Coughanowr – July 2018

Australian Government | National Landcare Program | NRM South | Hydro Tasmania The power of natural thinking | TasWater | Derwent Estuary Program

Table of Contents

Executive Summary

The River Derwent is supplying the majority of Hobart's drinking water in addition to providing important ecosystem services, and the water quality of the River Derwent ultimately impacts on the overall health of the Derwent Estuary. Recently, there has been increasing concerns regarding the river's water quality due to observed nutrient enrichment and algal growth nuisance within the River Derwent catchment and upper Derwent estuary. Observations include:

- increasing concentrations of nutrients measured in the River Derwent at New Norfolk, notably total nitrogen and filtered phosphorus (Whitehead et al., 2016),
- taste and odour issues in the Bryn Estyn water supply, linked to algal growth on the river bed in the catchment below Meadowbank Dam (Benham, 2017), and
- macroalgal smothering of seagrass meadows in the upper Derwent estuary.

These observations appear to coincide with changes in a variety of activities in the catchment and upper Derwent estuary, such as agricultural and aquaculture intensification, growth in population centers and changes in sewage effluent and stormwater, and changes in industrial treated effluent.

In order to better document changes in catchment water quality conditions, a monitoring program was undertaken with a focus on nutrients, sediments and other standard physio-chemical parameters. From September 2015 to August 2017, water quality was monitored monthly at 5 sites along the main stem of the River Derwent and at the lower end of 9 major tributaries. Most of these sites replicated a similar monitoring program carried out in 1996/97, providing an opportunity to evaluate how catchment water quality may have changed over the last 20 years.

Water quality and flow conditions across the catchment varied considerably during the two year monitoring program. The lowest nutrient concentrations were typically observed at the sampling site below the Wayatinah power station (Wayatinah BW PS) and at the end of the Broad River tributary, both of which receive run-off from largely natural, forested catchments.
Seasonal nutrient concentration profiles revealed two groups of profiles: (1) summer time increases in nutrient concentrations in sub-catchments with aquaculture and (2) winter time increases in nutrient concentrations in sub-catchments dominated by agricultural use.
Total phosphorus concentrations were dominated by filtered phosphate in tributaries that contain fish farms (Florentine River, Tyenna River), with highest filtered phosphate concentrations observed during the late summer months (March, April) for these rivers Tributaries that have their land use dominated by agriculture (e.g. River Clyde, Ouse River) are a source of dissolved nitrate, but predominantly during the winter months.

Ammonia and ammonium concentrations were also elevated for the Florentine (site below fish farm, Florentine BW FF) and Tyenna River during the summer months. Concentrations in the Tyenna were one order of magnitude higher, and two orders of magnitude higher in the Florentine compared to elsewhere in the catchment, indicating

that land-based fish farms particularly increase concentrations of filtered (dissolved) nutrients that are readily available for primary production.
Winter time increases in total nitrogen and total phosphorus in sub-catchments dominated by agricultural use (e.g. Clyde, Ouse) are likely associated with higher winter rainfall causing increased nutrient runoff from agricultural fields and pastures.

Mass load calculations suggest that the largest source of nutrients in the catchment are from agriculture along the main stem of the River Derwent, the Ouse River and River Clyde, and from land-based fish farms.

These findings suggest that large-scale fish hatcheries, including those on the Tyenna and Florentine, are significant sources of bioavailable nutrients (particularly PO_4 and NH_4) during summer months. It is anticipated that other hatcheries not directly monitored here would follow a similar pattern. While agricultural inputs are also significant sources of nutrients (particularly NO_x), the timing of their release during winter months may occur at a time when the system is less vulnerable. That said, given the multiple storages in the catchment, there may be a lag time between winter release and downstream effects. Furthermore, management of fertilisers and animal wastes in riparian zones remains an important on-going management concern.

1 INTRODUCTION

This document summarises water quality data collected by a Derwent Catchment Water Quality Monitoring Program, undertaken by the Derwent Estuary Program (DEP) with financial support from TasWater, Hydro Tasmania, NRM South and the DEP. Monthly water quality monitoring (including field measurements, some river flow gauging, and nutrient analyses) was carried out at 14 sites (9 end-of-tributary sites, 5 sites along the River Derwent) over a 24-month period (Sept 2015 to August 2017, inclusive). This report also includes water quality data collected at a longer-term monitoring site at New Norfolk, and compares the recent data with a previous monitoring program by the DEP/DPIPWE (Feb 1996 to March 1997).

Water quality within the Derwent catchment, Tasmania, is important to numerous stakeholders that rely upon fresh surface water resources. Freshwater is a valuable natural resource, supplying the majority of Hobart’s drinking water supply as well as smaller town water supplies throughout the catchment. It is also essential for hydro-power generation, multiple irrigation schemes, large-scale fish farms and major industrial supplies (paper production). Water quality within the Derwent catchment is also important for ecosystem services in terms of recreational, cultural, and natural values. The River Derwent water quality has a direct influence on the overall health of the Derwent estuary. The River Derwent and many of its tributaries are regulated for both hydropower generation and irrigation. There are numerous river section diversions, in-stream and off-stream reservoirs, and water off-take points.
In 2011, the *Derwent Catchment Review (Eriksen et al. 2011)* reviewed existing water use and water quality information across the catchment, and identified a number of existing and potential risks including nutrient enrichment and the potential for nuisance and/or toxic algal blooms. The report noted the lack of a catchment-wide monitoring program, and recommended that the DEP 1997-1998 catchment monitoring program be revisited at 4 River Derwent and 10 end-of-tributary sites. Since then, there has been increasing evidence of nutrient enrichment within the River Derwent catchment and upper estuary, including:

- Taste and odour issues in the Bryn Estyn water supply, linked to blue-green algal growth on the river bed (Taswater; Benham, 2017)
- Increasing concentrations of nutrients in the River Derwent at New Norfolk (Whitehead et al., 2018)
- macroalgal smothering of seagrass meadows in the upper Derwent estuary, together with reported changes in recreational fisheries (Whitehead et al., 2016).

These observations have coincided with an increase, or intensification, or changes within a variety of activities in the catchment and upper estuary that may include agricultural changes (e.g. increased horticulture, dairy, and irrigation), aquaculture expansion (e.g. fish farms), growth in population centers (e.g. sewage and stormwater) and industry changes (e.g. changes in treated effluent from paper production).
Improving our knowledge of water quality in the catchment enables us to monitor and manage changes in a proactive way. This report is intended to provide water users, regulators and the wider community with a better understanding of water quality conditions and trends across the catchment, as a basis for informed management. Due to

atypical climatic and hydrological conditions during the 2015/16 monitoring period, characterised by extremely dry/low flow conditions followed by unusually wet/high flow conditions, the monitoring program was extended to a second 12 month period to provide more robust and representative results. This report documents the results from the entire two-year monitoring period from September 2015 to August 2017.

2 METHODS

2.1 Sampling Sites

A total of 14 sampling sites were established for this 2 year monitoring program, based on recommendations by Eriksen et al. (2011) and previous monitoring efforts by the DEP/DPIPWE (Coughanowr, 1997). Five of those sites are along the River Derwent main stem (Wayatinah below power station, Derwent at Glen Dhu, Derwent at Meadowbank, Derwent below Meadowbank, and Derwent at Bryn Estyn), eight sites were end-of-tributary sites (Florentine below fish farm, Broad, Dee, Ouse, Clyde, Tyenna, Styx, and Plenty), and an additional site at the Florentine above the fish farm. Exact locations are given in Table 1 and shown in Fig. 1.

Table 1: Sampling site locations and coordinates.

	Site Name	**EPA DEP Site #**	**Location**	**Description**	**Lat (WGS 84)**	**Long (WGS 84)**
1	Wayatinah BW PS	9647	Wayatinah	Below Wayatinah Power Station	42.377869	146.51066
2	Florentine AB FF	789	Florentine	Above Fish Farm	42.4418	146.50655
3	Florentine BW FF	790	Florentine	Below Fish Farm	42.438289	146.51953
4	Broad	734	Broad River	At bridge next to River Derwent	42.513644	146.65949
5	Dee	788	Dee River	At Bridge near flow station	42.49635	146.68306
6	Derwent @ GD	785	River Derwent	At Glen Dhu flow station	42.507469	146.69804
7	Ouse	768	Ouse River	Below Ouse	42.486275	146.71498
8	Clyde	692	River Clyde	Below Hamilton	42.562572	146.82677
9	Derwent @ MB	9648	River Derwent	At west end Meadowbank causeway	42.537731	146.73344
10	Derwent BW MB	787	River Derwent	Below Meadowbank dam	42.613	146.84688
11	Tyenna End	779	Tyenna River	Below Westerway Bridge	42.677908	146.86209
12	Styx	764	Styx River	Above Derwent	42.708794	146.90311
13	Plenty	763	Plenty River	At Plenty Bridge	42.738583	146.95724
14	Derwent @ BE	784, 9649	River Derwent	At Bryn Estyn inlet	42.76945	147.02613

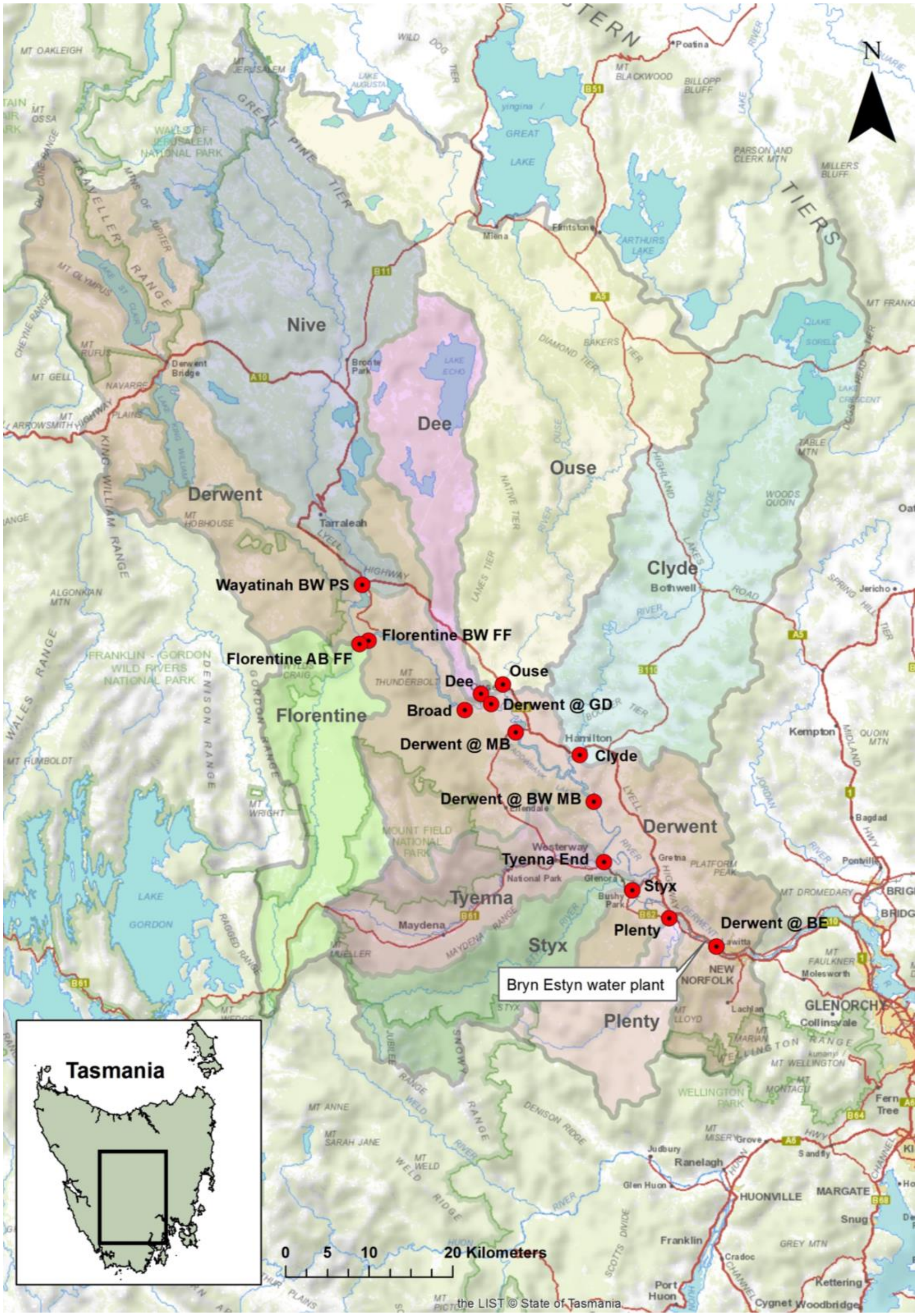


Fig. 1: River Derwent Catchment with sub-catchments and sampling sites.

All sampling sites were visited monthly, over 2-day sampling trips, typically at the 3rd Tuesday & Wednesday of the month. Field measurements were taken and samples collected for nutrients and parameters outlined in Table 2.

Table 2: Water quality parameters analysed and measured.

Parameter	Abbreviation	Units	Field measurement	Lab analysis	Detection limit
Water temperature	T	Degrees C	X		
pH		TC Units	X		
Conductivity	EC	uS/cm	X		
Salinity		ppt	X		
Dissolved oxygen	DO	% saturation and mg/L	X		
Total organic carbon (as Non-Purgable Organic Carbon)	TOC/NPOC	mg/L		X	
True colour		Hazen percentile		X	
Ammonia and Ammonium as N	NH_3/NH_4-N	µg/L		X	5
Nitrite and Nitrate as N	NO_x-N	µg/L		X	2
Nitrite as N	NO_2-N	µg/L		X	2
Nitrate as N	NO_3-N	µg/L		X	2
Total Kjeldahl Nitrogen*	TKN	µg/L		X	100
Filtered Phosphate as P (PO_4)	PO_4-P	µg/L		X	3
Total Nitrogen as N	TN	µg/L		X	100
Total Phosphorus as P	TP	µg/L		X	10
Total suspended solids (0.45µm)	TSS	mg/L		X	2
Turbidity		NTU		X	

*Total Kjeldahl Nitrogen contains organic N and inorganic ammonia and ammonium (NH_3, NH_4).

For data presentation, sites and tributaries were pooled as follows: 'Derwent sites' (Wayatinah BW PS, Derwent @ GD, Derwent @ MB, Derwent BW MB, Derwent @ BE), 'western tributaries' (Florentine AB FF, Florentine BW FF, Broad, Tyenna End, Styx, Plenty) and 'eastern tributaries' (Dee, Ouse, Clyde), based on their orientation and and land use (eastern sub-catchments are dominated by agriculture whereas forestry and National Parks are situated in the western sub-catchments, Fig. 2).

2.2 Field Measurements

Water temperature, pH, conductivity, salinity and dissolved oxygen were measured *in-situ* using a Hydrolab Quanta with calibrations conducted within 24 hours prior to sampling. Manual flow measurements were taken when safe to do so, using a Sontek® FlowTracker handheld-ADV hired from Macquarie Franklin (see 2.4).

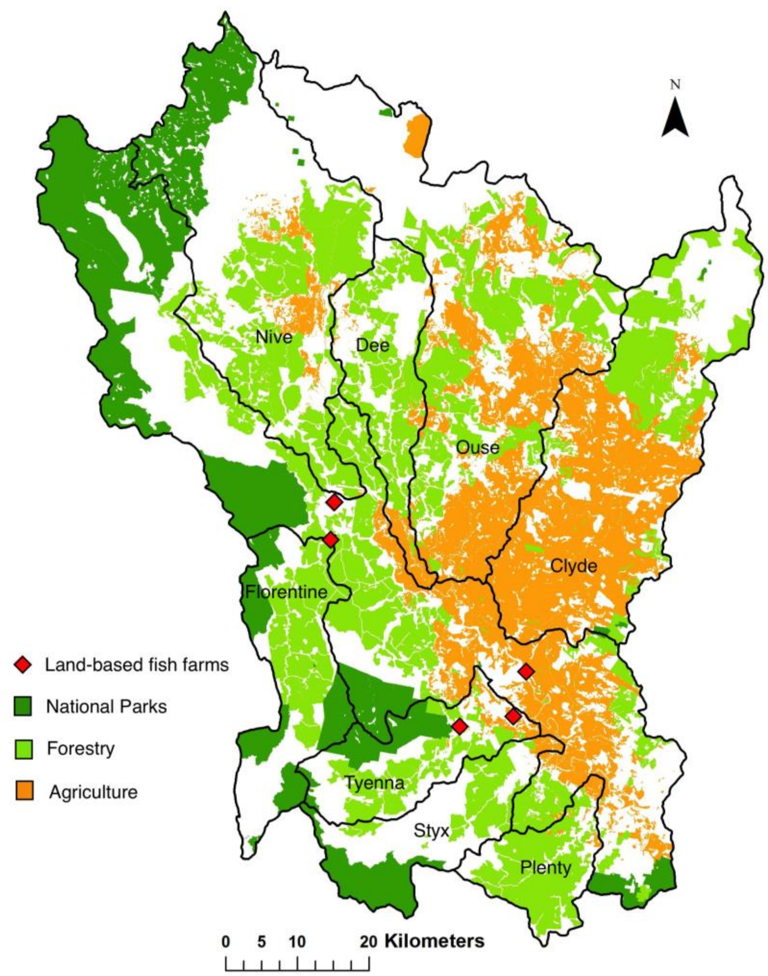


Fig. 2: Land use in the Derwent catchment, based on 2013 land use data (NRM), grouped as follows: 'National Parks', including Wilderness area and strict nature reserves; 'Forestry', including hardwood and softwood plantation, production and plantation forestry; 'Agriculture', including all pastures, irrigated and non-irrigated crops, horticulture, livestock and dairy farming. Land-based fish farms are also shown.

2.3 Laboratory analyses

All analytical work was carried out at Analytical Services Tasmania (AST), New Town. Detection limits are shown in Table 2. Field duplicates were taken at Derwent @ Bryn Estyn during each sampling event and analysed for the same parameters above. Results of a relative percentage difference (RPD) analysis of primary and duplicate sample are given in Appendix 1.

2.4 Flow Data and Measurements

River flow data was available from a number of Hydro Tasmania flow stations via the Bureau of Meteorology (BoM) website (BoM, 2018a). Data from an additional flow station further upstream of the Clyde River (Bothwell) was also available. The gauging sites typically provide continuous flow data in 15 minute intervals. In addition, manual measurements were taken using a Sontek® FlowTracker handheld-ADV hired from Macquarie Franklin. The FlowTracker was deployed in an area of laminar flow, if possible, for approximately 10 measurements per site. Due to high (or too low) flows, manual measurements were not always possible and data gaps are indicated in Table 3 as n=number of measurements out of 24 observations.

Table 3: River flow measurements and gauging sites.

Sampling site	**Flow monitoring site (number of observations/24)**
Wayatinah BW PS	Hydro: Wayatinah power station flow data (includes Nive and Derwent headwater flow)
Florentine AB FF	[Nearest: Hydro: Site 40]
Florentine BW FF	Hydro: Site 40
Broad	Manual measurement (12/24)
Dee	Hydro: Site 141
Derwent @ GD	Hydro: Site 140
Ouse	Manual measurement (13/24), Hydro: Site 826
Clyde	Manual measurement (14/24), Bothwell Hydro: Site 54
Derwent @ MB	-
Derwent BW MB	Hydro: Site 715
Tyenna End	Manual measurement (11/24), Hydro: Site 499
Styx	Manual measurement (12/24)
Plenty	-
Derwent @ BE	-

2.5 Mass Load Calculations

As shown in Table 3, For the following sites, continuous flow data was available through BoM/Hydro: Wayatinah, Florentine AB and BW FF, Dee, Derwent @ GD, and Derwent BW MB, Tyenna, and Ouse. Flow was measured in 15 min intervals, except for Dee, Ouse, and Derwent @ GD for which only daily flow was available. In order to calculate mass loads for each sampling event ('instantaneous load'), flow rates 30 min before and after the sampling time were averaged to obtain flow in liters per second and multiplied by the nutrient concentration (mg/l). This value was then extrapolated into a daily load (kg/day).

When continuous flow data was not available, the manual flow measurements were used when possible to calculate loads (Broad, Clyde, Styx). When neither continuous flow data nor manual measurements were available, flow was estimated as follows:

- Clyde: Flow was calculated by comparing continuous flow measurements at Bothwell (Hydro site 54) with historical data when flow was measured at Hamilton
- Plenty, Broad, Styx: using continuous flow measurements from the Tyenna extrapolated to catchment size
- Derwent @ Bryn Estyn can be calculated using the following equation, and this estimate include Styx and Plenty inputs (B. Graham, DPIPWE):

  *Modelled Flow = A + 4.89*B*

  A = flow at Derwent below Meadowbank gauge

  B = flow at Tyenna gauge

The site Derwent @ Meadowbank was ignored for mass load calculations because it is located near the dam and not representative of flowing river conditions.

For the calculation of annual loads of TN and TP, the average daily load was taken and multiplied by 365 days. Because 55% of TP measurements were below detection limits, the detection limit itself (10 µg/L) was used in those instances to calculated daily loads. The daily and annual loads of TP may therefore present over-estimates, particularly for the Broad River and for Derwent @ GD, where all values fell below detection limit, and for Wayatinah BW PS, Plenty, Styx, and the Florentine AB FF, where the majority of values were below detection limit. Less than 4% of TN data were below detection limit, with 12/24 measurements below detection limit for the Broad River, indicating that Broad River TN loads are also likely over-estimated.

No considerations were made regarding the timing of a sampling event, i.e. if nutrient concentrations were representative with respect to flow conditions (e.g. 'first flush' or dilution), and whether the sampling occurred at the rising or descending limb of the hydrograph.

2.6 Historical/Other Catchment Data

2.6.1 Derwent Catchment Data 1996/97

Nutrient monitoring in the catchment was first conducted by Coughanowr (1997), starting on a monthly basis in February 1996, and continuing to April 1998. Fig. 3 shows the average daily flow at Bryn Estyn (flow calculated according to equation above, see 2.5) for the sampling years Sept 1996 to Aug 1997, Sept 2015 to Aug 2016, Sept 2016 to Aug 2017. Flow during winter and spring appears highly variable, with values orders of magnitude higher for the 2015/16 and 2016/17 monitoring program compared to the 1996/97 flow. Thus the relative time series are not comparable in terms of catchment river flows. This report therefore only compares data from the summer months (December to March) between the three years (1996/97, 2015/16, 2016/17). The samples taken in 1996/97 were also analysed by AST, however, it is important to note that detection limits have changed over the years, with lower detection limits for 1996/97 samples.

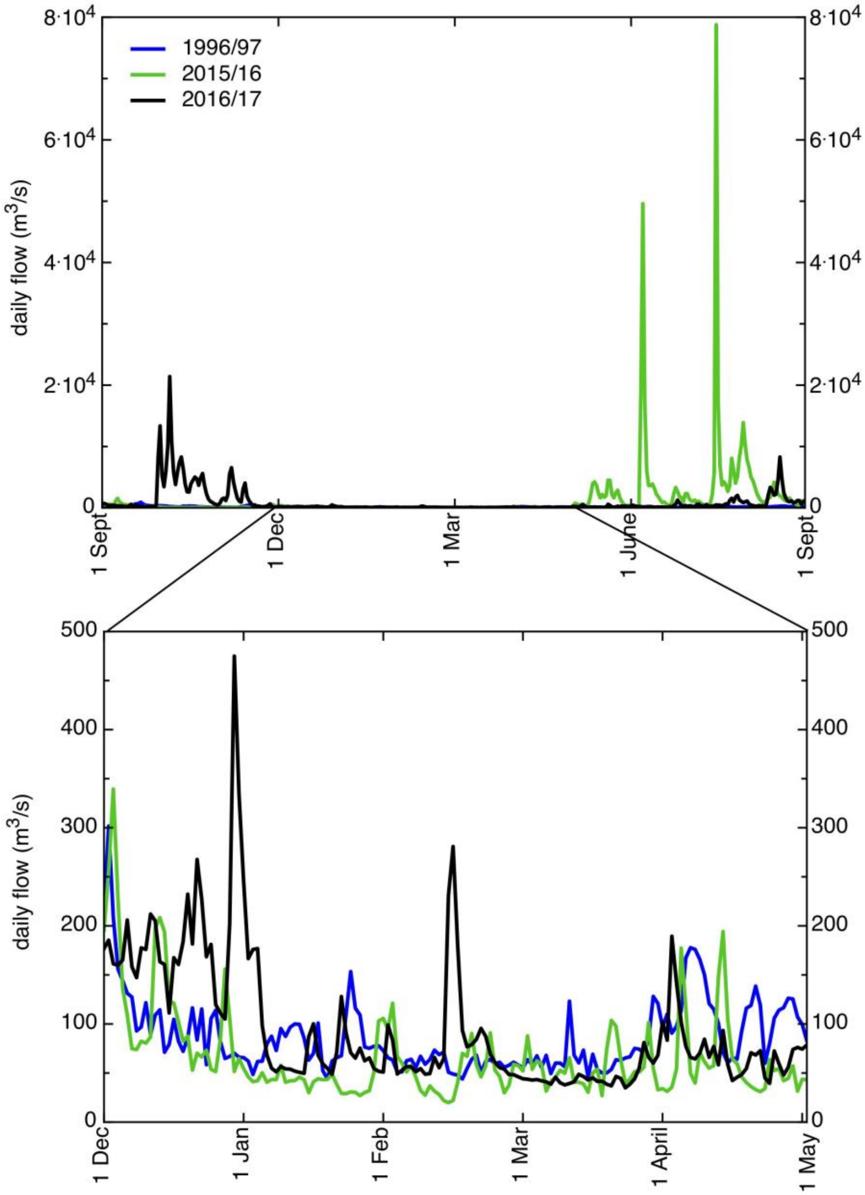


Fig. 3: Average daily flow at Bryn Estyn estimated for the 1996/97 monitoring program and the recent two-year monitoring program (2015/16 and 2016/17) for the full year (top diagram) and Dec-May only (lower diagram).

2.6.2 Continuous nutrient observations at Bryn Estyn

From July 2012 to January 2013, a Systea Water *in-situ* analyser was installed in the River Derwent at the Bryn Estyn water treatment plant with the aim to provide data for a 3D biogeochemical estuary model (Wild-Allen & Rayner, 2014). The analyser measured nitrate, nitrite, and phosphate spectrophotometrically, and ammonia fluorometrically every 4 hours. Detection limits were PO_4-P 2 µg/L, NH_3-N 4 µg/L, and NO_3-N 7 µg/L.

System maintenance tasks and operational issues caused several data gaps (e.g. no data available between 09/10/2012 and 10/12/2012). The data was assessed against flow estimates for Bryn Estyn using above equation (see 2.5) to evaluate any relationship between discharge and nutrient concentrations that could potentially be used to determine mass loads more accurately on a better time resolution compared to the monthly grab samples.

2.6.3 Long-term monitoring site New Norfolk

The Derwent Estuary Program has a long term data set from New Norfolk (site NN) from which surface water samples have been collected and analysed monthly since 2007, enabling comparison of the relationship between various water quality parameters and any long term trends. Measured parameters include, among others, ammonium and ammonia as N, nitrate and nitrite as N, total nitrogen, filtered phosphate, total phosphorus, total suspended solids and total organic carbon, also analysed by Analytical Services Tasmania (AST). Some measurements go back as far as 1990, but not on a monthly basis. Continuous monthly sampling started in 2007, and the period analysed in this report spans from 2007 to 2017. A more detailed statistical assessment of the 2007 to 2016 data at New Norfolk is given in Whitehead et al. (2016) and Whitehead et al. (2018).

3 RESULTS

3.1 Climate and runoff during study period

The estimated River Derwent flow at Bryn Estyn from September 2015 to August 2017 is presented in Fig. 4. As illustrated in this figure, the climatic and hydrological conditions during the 2015/16 monitoring period were characterised by extremely dry/low flow conditions during spring and summer, followed by unusually wet/high flow conditions starting in May 2016. During the second year of monitoring, 2016/17, high rainfall during winter and spring resulted in a more typical hydrograph. It is noteworthy that sampling during this program was scheduled monthly, irrespective of hydrological conditions, and as such flood events were not targeted.

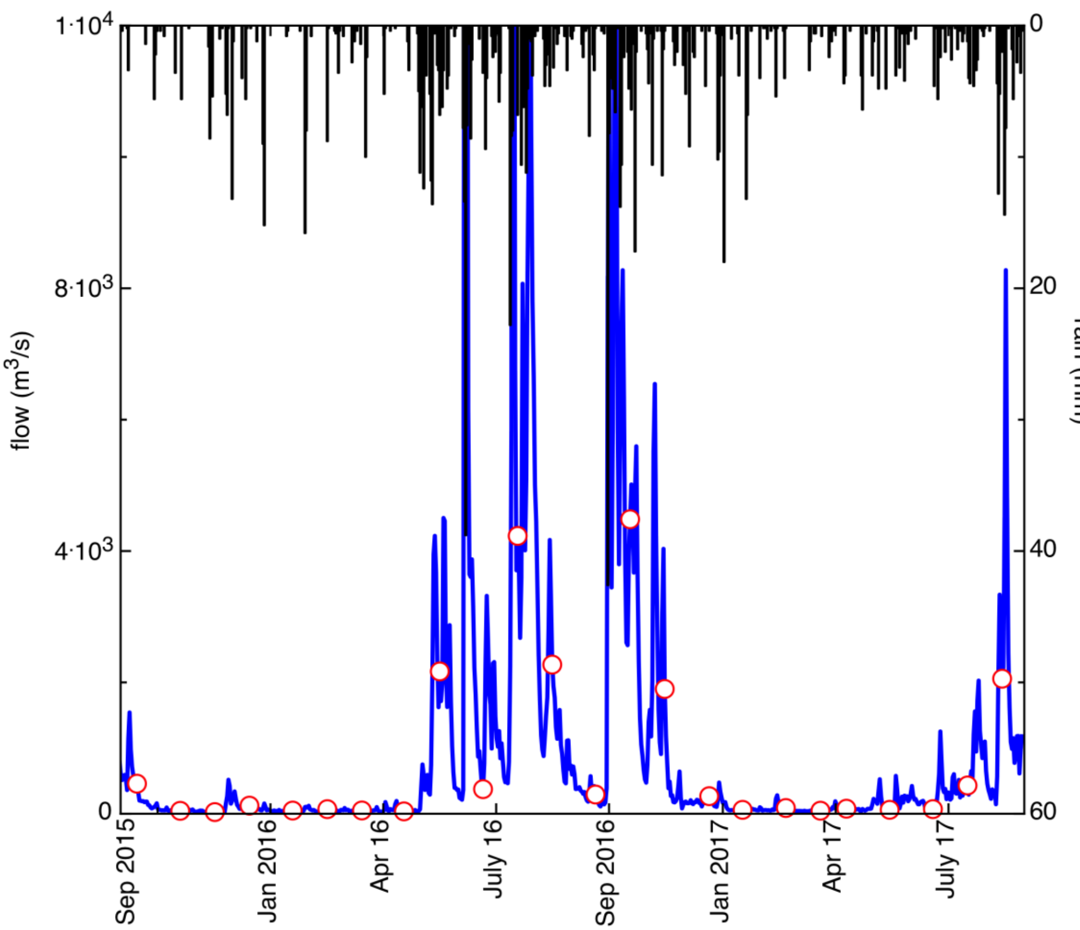


Fig. 4: Average daily flow estimates for Bryn Estyn (blue) and daily rainfall (black) recorded at New Norfolk (BoM, 2018b). Sampling events are also shown on the hydrograph (red circles).

3.2 Physical properties

3.2.1 Temperature

The water temperature of all Derwent sites and tributaries follow the seasonal cycle of air temperature (data from BoM, 2018b), with maxima in December, January and February, and with an offset of approximately 5 °C (e.g. 3-9 °C at Derwent BW Meadowbank) colder in the river water compared to air (Fig. 5). The tributaries Broad, Styx, and Tyenna have lower temperatures during the summer months compared to the Derwent sites. The Derwent at Wayatinah below power station typically has the lowest temperatures of all Derwent sites with the river water warming up towards Bryn Estyn where temperatures were up to 5.7 °C higher.

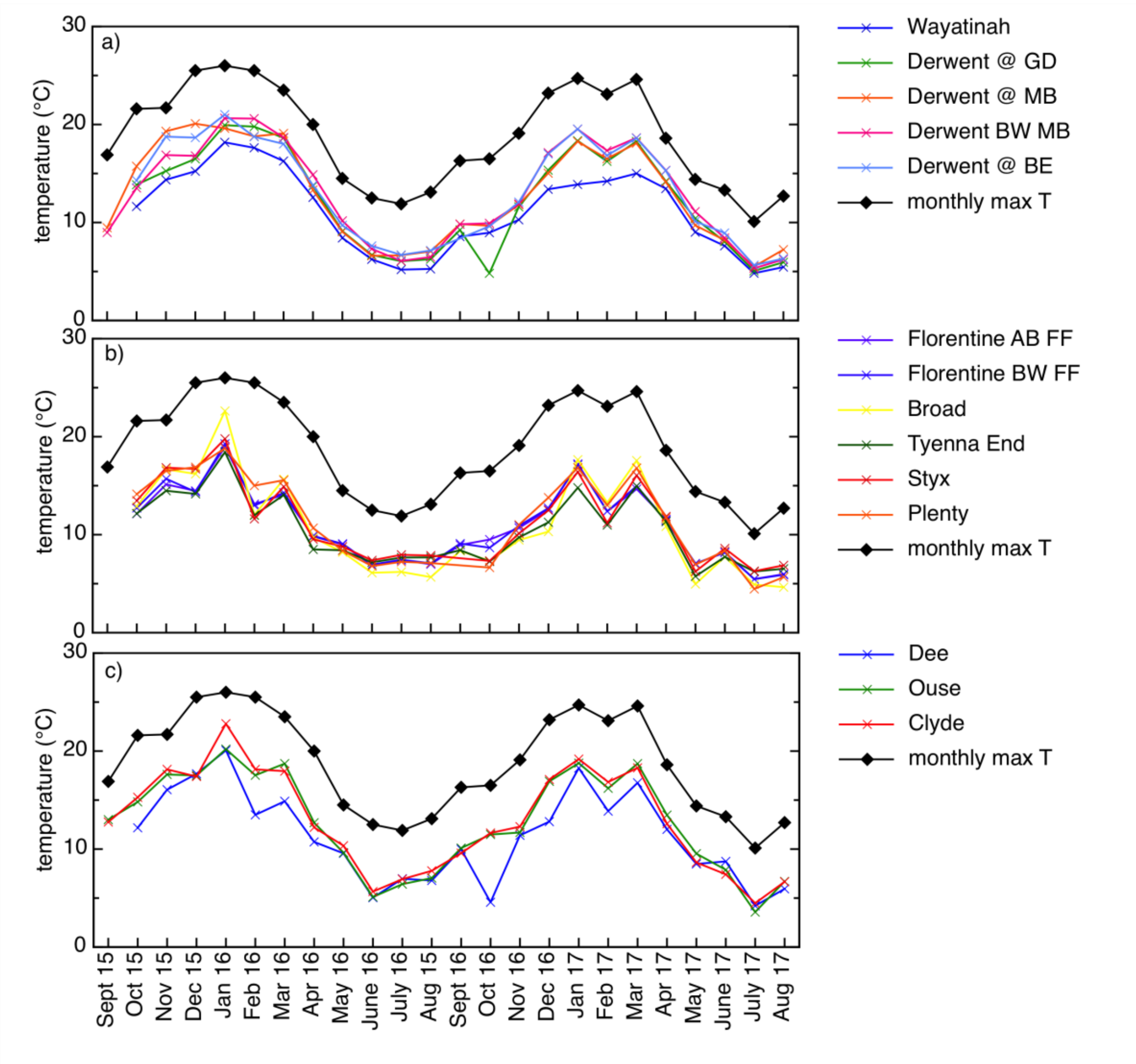


Fig. 5: Water temperatures for the Derwent sites (a), western (b) and eastern (c) tri-butaries over the study period in comparison to the mean monthly maximum temperature for Ouse (Ouse Fire Station, data from BoM 2018b).

3.2.2 pH

The highest pH values throughout the study period were observed for the Florentine, which is unsurprising considering the extent of karst in this catchment (Eriksen, 2011). The Florentine pH values were followed by Tyenna and Styx, where karst also occurs in the upper parts of the catchments (Eriksen, 2011). The largest variability in pH was observed at Wayatinah BW PS (pH 5.5-8.4) and Derwent BW MB (pH 4.8-7.4). Most variability in pH values can likely be explained by mixing of streamwater, groundwater influences and rainwater (pH 5.6). However, it is noteworthy that Florentine BW FF showed consistently lower pH values compared to Florentine AB FF, differing by up to 0.7 (Fig. 6).

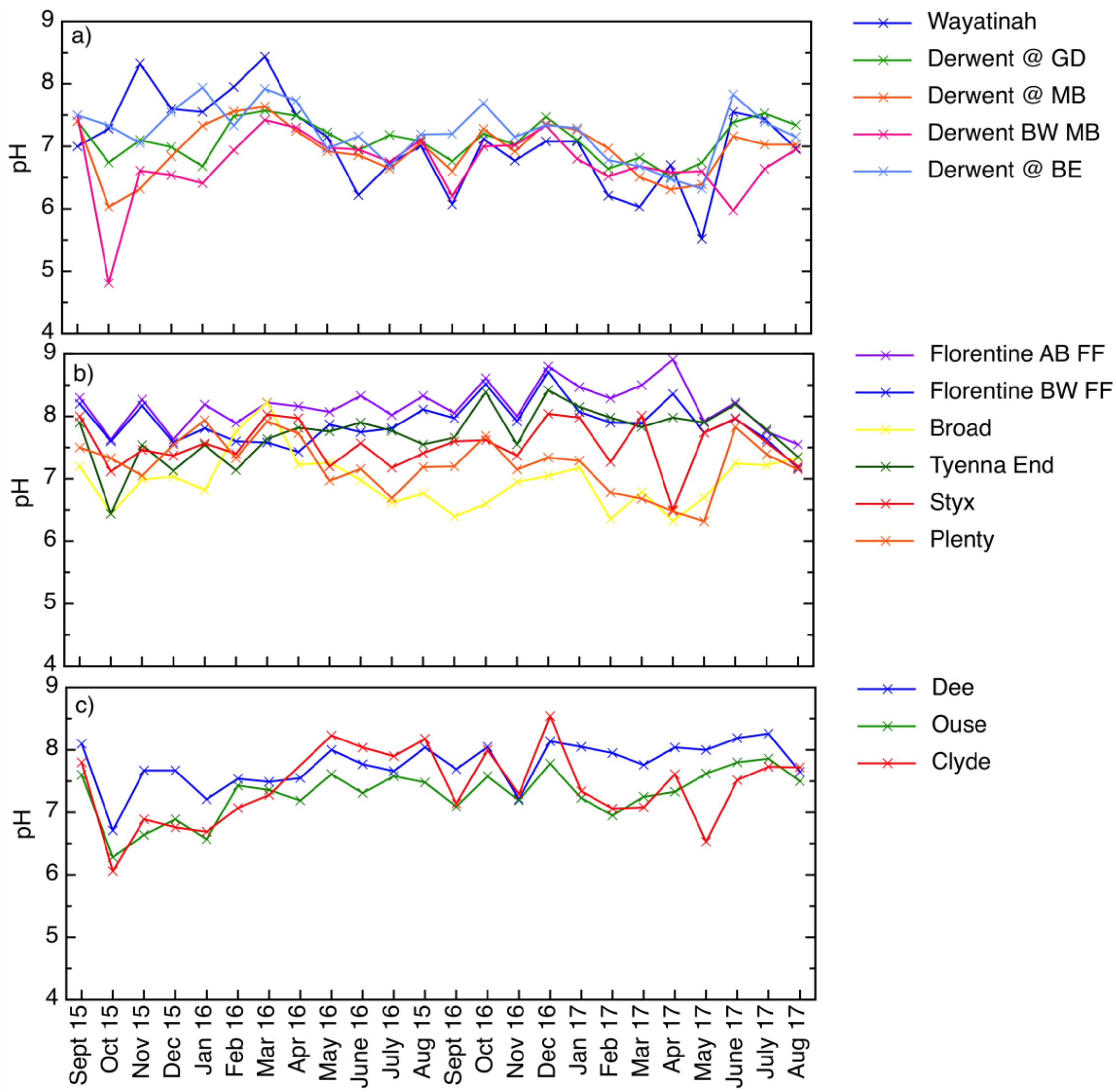


Fig. 6: pH values over the study period for Derwent sites (a), western (b) and eastern (c) tributaries

3.2.3 Conductivity

Conductivity (Fig. 7) at the Derwent sites remained relatively constant throughout the study period, with the lowest conductivity values recorded for Wayatinah BW PS (29±2 µS/cm). Eastern catchments (Clyde, Ouse, Dee) generally showed higher conductivity values and higher variability throughout the study period. Lowest conductivity in western catchments were observed for Broad, followed by Plenty, and Styx. Interestingly, the conductivity in the Clyde continued to increase beyond the low flow summer months in 2017, approaching 1200 µS/cm.

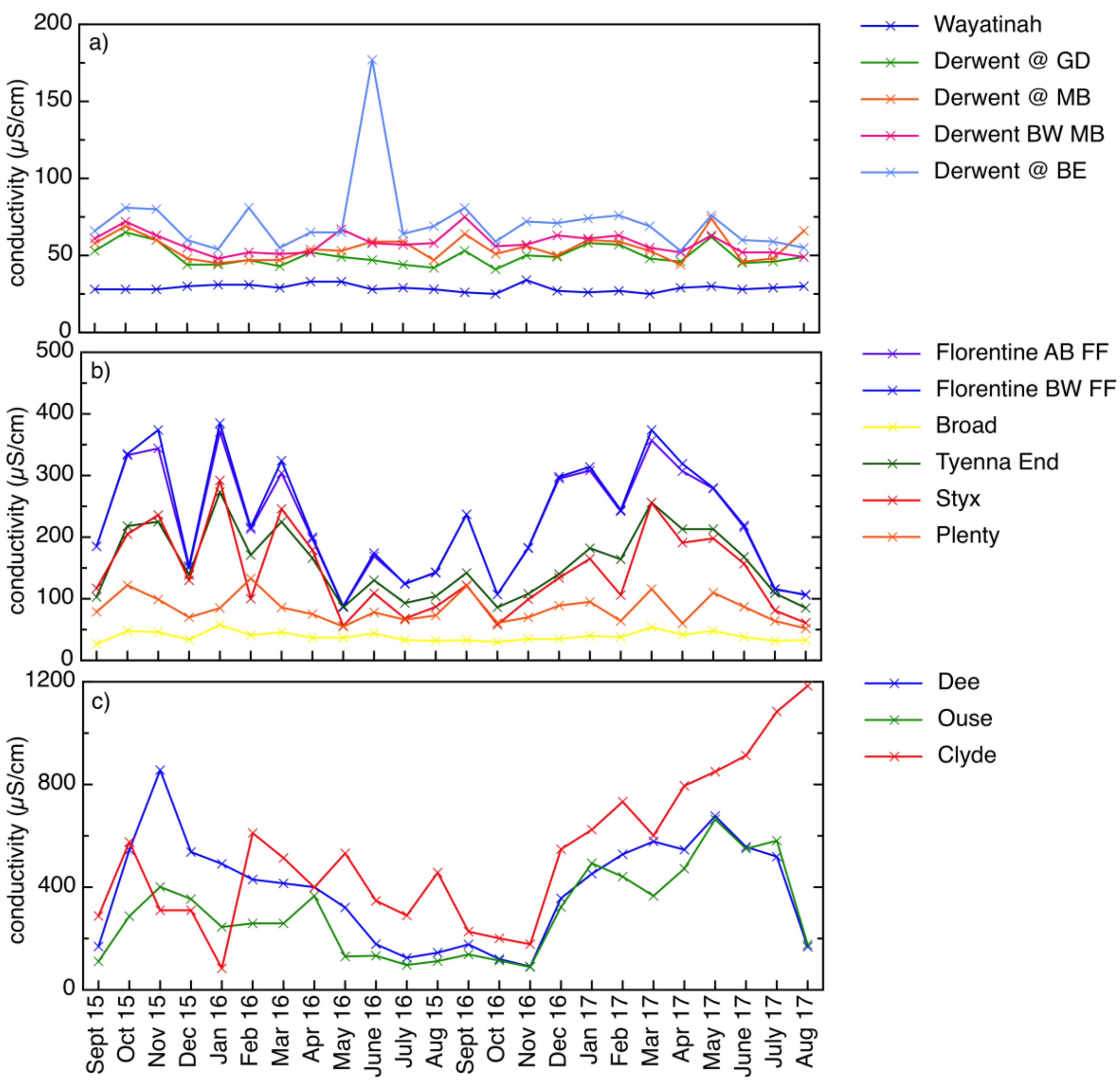


Fig. 7: Conductivity (µS/cm) measurements for Derwent sites (a), western (b) and eastern (c) catchments.

3.2.4 Salinity

Salinity is generally low throughout the entire Derwent Catchment and follows trends observed for conductivity (Fig. 8). Again, eastern catchments (Dee, Ouse, Clyde) showed highest values that correlate well with conductivity (r^2=0.977).

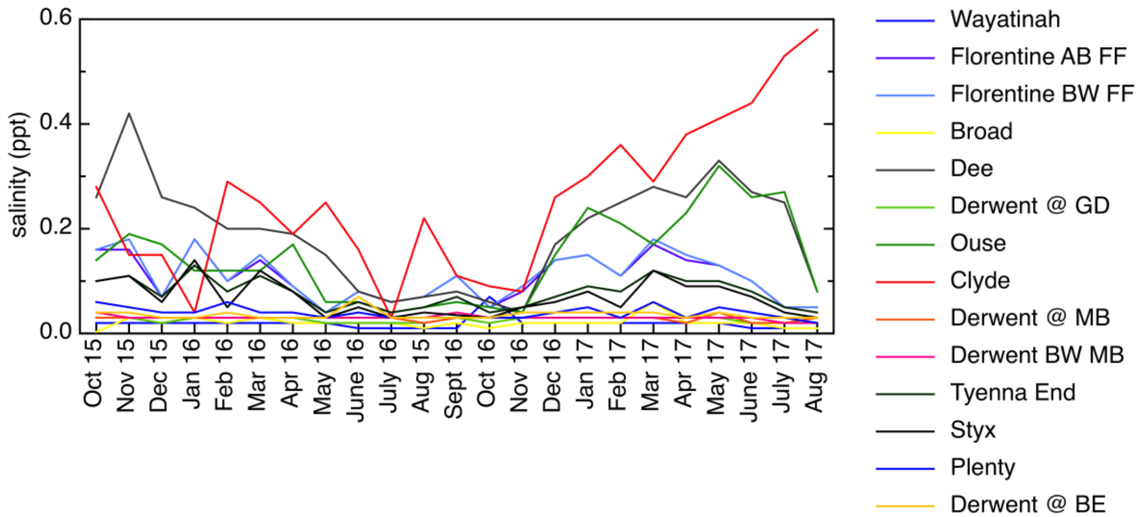


Fig. 8: Salinity for all 14 sites over the study period.

3.2.5 Dissolved Oxygen

Dissolved oxygen concentrations (Fig. 9) show typical seasonal cycles with lower concentrations during the summer months. The lowest concentrations were observed for Clyde and Ouse. Along the River Derwent, the site Derwent BW MB tended to have the lowest DO values during the summer time, lower compared to the further downstream site Derwent @ BE.

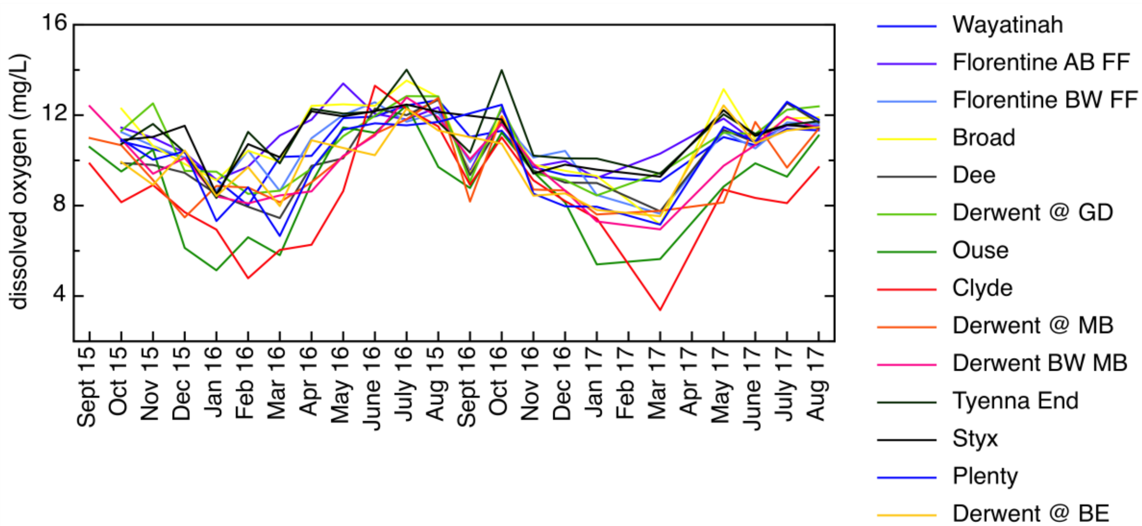


Fig. 9: Dissolved oxygen concentrations for all 14 sites over the study period.

3.3 Turbidity and Total Suspended Solids

Water clarity in the Derwent catchment is good, generally below 10 NTU which is comparable to other Tasmanian lakes and streams. The variability in turbidity further downstream of the River Derwent and in the River Clyde, Ouse River and Dee River appears to be primarily driven by rainfall-runoff events. Fig. 10 shows the turbidities over the study period for all sites in relation to rainfall recorded at New Norfolk West, Bushy Park Estates, and Ouse Fire Station (BoM, 2018b). Note that rainfall variability in the catchment is high (Appendix 2), and observed turbidity depends on the timing of sampling with respect to flow (rainfall-runoff events). Total suspended solids (TSS) concentrations were extremely low with 55% of data below detection limit (2 mg/L). TSS-turbidity relationships could therefore only be investigated for Tyenna (r^2=0.49, $p<0.05$), Clyde (r^2=0.67, $p<0.05$), and Ouse (r^2=0.63, $p<0.05$) and are shown in Fig. 11.

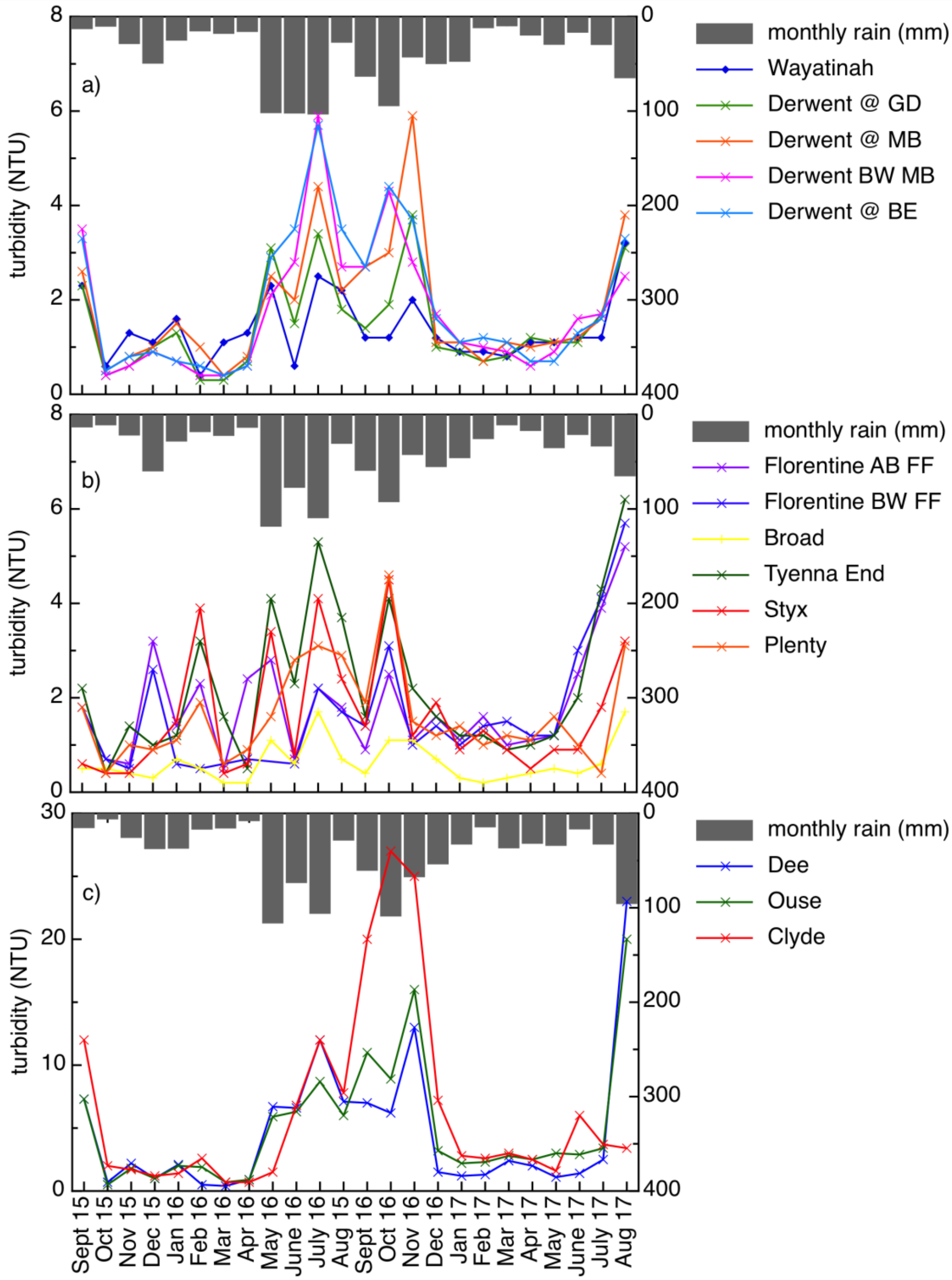


Fig. 10: Turbidity (NTU) at Derwent sites (a), western (b) and eastern (c) tributaries. Average monthly rainfall is also shown for BoM sites New Norfolk West (a), Bushy Park Estates (b), and Ouse Fire Station (c).

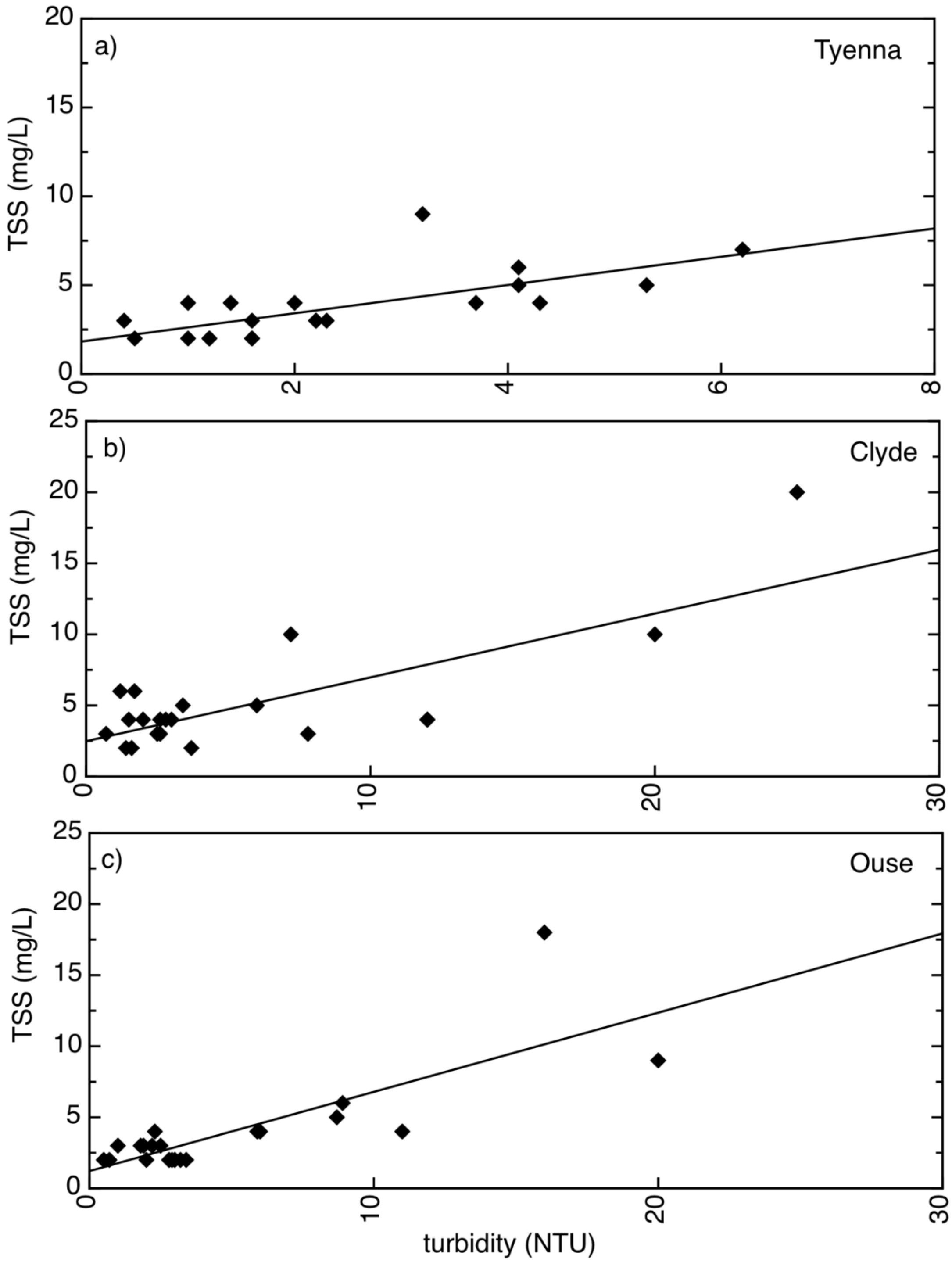


Fig. 11: Total suspended solids (TSS) to turbidity (NTU) relationship for Tyenna (a), Clyde (b), and Ouse (c).

3.4 Nutrient concentrations

3.4.1 Total phosphorus

Total phosphorus (TP) concentrations were low, with 55% of all data below detection limit (DL, 10 µg/L), which makes it challenging to assess any trends within the catchment. For instance, the Broad and Derwent @ GD revealed no data above detection limit during the study period. Limited measurements above DL for Wayatinah (n=3), Florentine AB FF (n=3), Derwent BL MB (n=3), and Styx (n=4) do not allow for any interpretation of seasonal patterns and are not displayed below. Only the River Clyde had measureable amounts of TP for every sampling event. The Clyde (n=24), Florentine BW FF (n=23), and Tyenna (n=22) showed elevated TP values during March and April in both 2016 and 2017 (Fig. 12), with the highest value recorded for the Florentine BW FF (160 µg/L in March 2016). While Florentine AB FF was almost always below or near detection limit, the downstream site Florentine BW FF showed considerable TP concentrations.

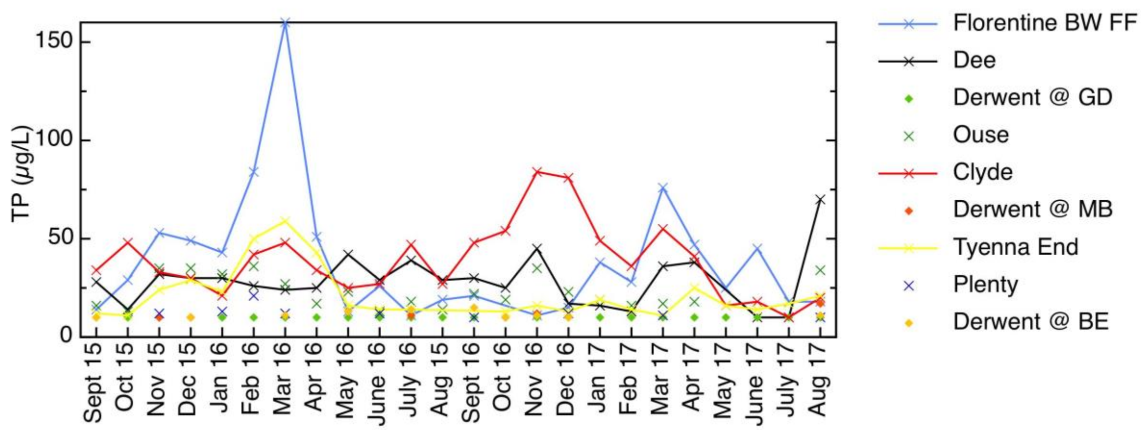


Fig. 12: Total phosphorus concentrations (TP) at sites with quantifiable amounts of TP.

3.4.2 Filtered phosphate

Filtered phosphate concentrations were low (generally <6 µg/L) and near detection limit for the Derwent sites, the Styx, Plenty, and Broad (Fig. 13). Elevated concentrations could be observed during the summer months of both years at the Tyenna and Florentine BW FF. The eastern tributaries (Dee, Ouse, Clyde) did not show similar seasonal patterns. There was a significant increase in phosphate concentrations at Florentine BW FF compared to its upstream site Florentine AB FF.

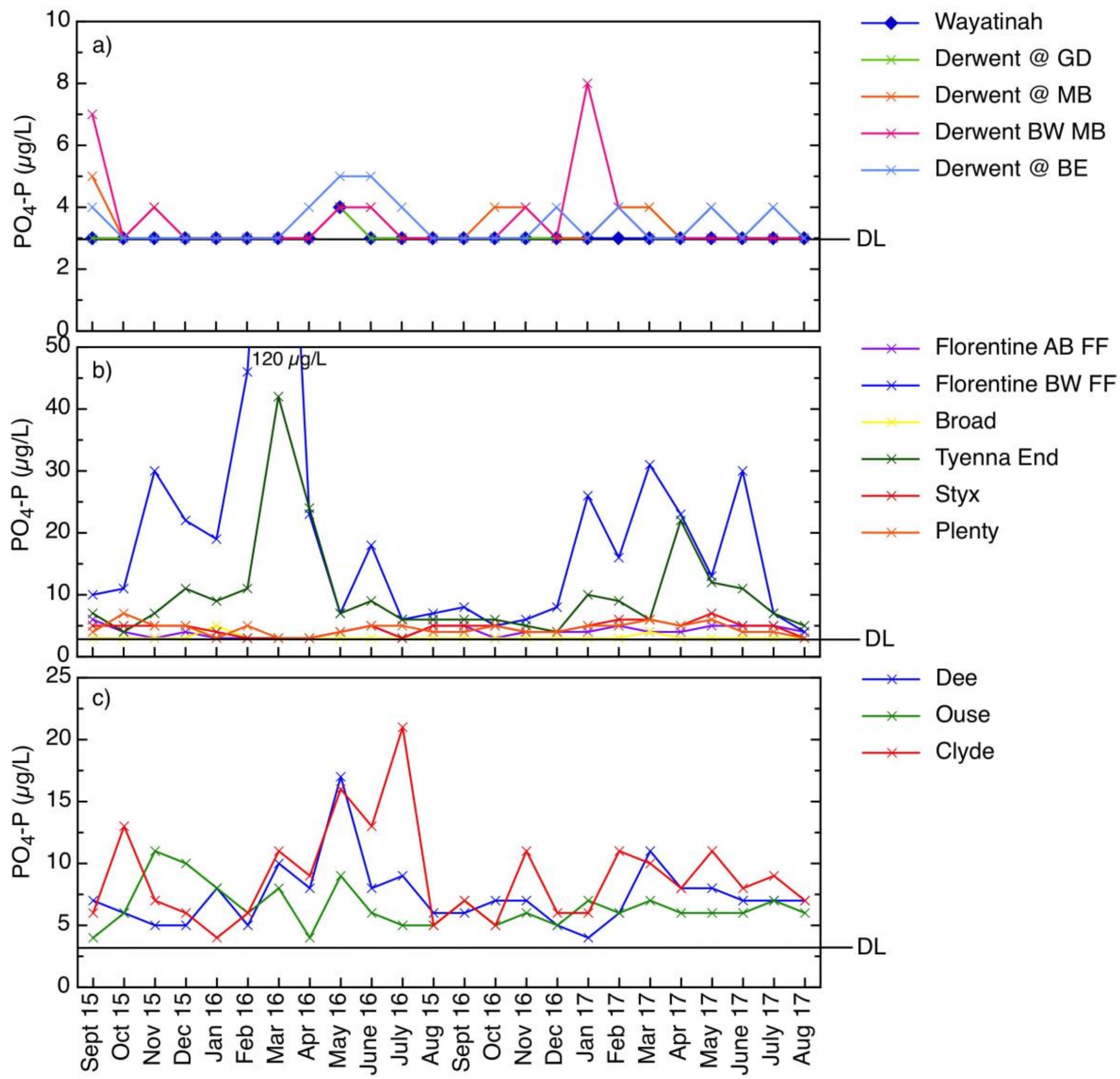


Fig. 13: Filtered phosphate (PO_4-P) for the Derwent sites (a), western (b) and eastern (c) tributaries over study period. Note the different scales for phosphate concentrations.

3.4.3 Total nitrogen and Total Kjeldahl nitrogen

Total nitrogen (TN) and total Kjeldahl nitrogen (TKN) concentrations appear to co-vary over the sampling period (Fig. 14, Fig. 15). At Florentine BW FF, concentrations were elevated for both analytes during the summer months. In contrast, the River Clyde had highest TN and TKN concentrations during the winter and spring months, similar to TP.

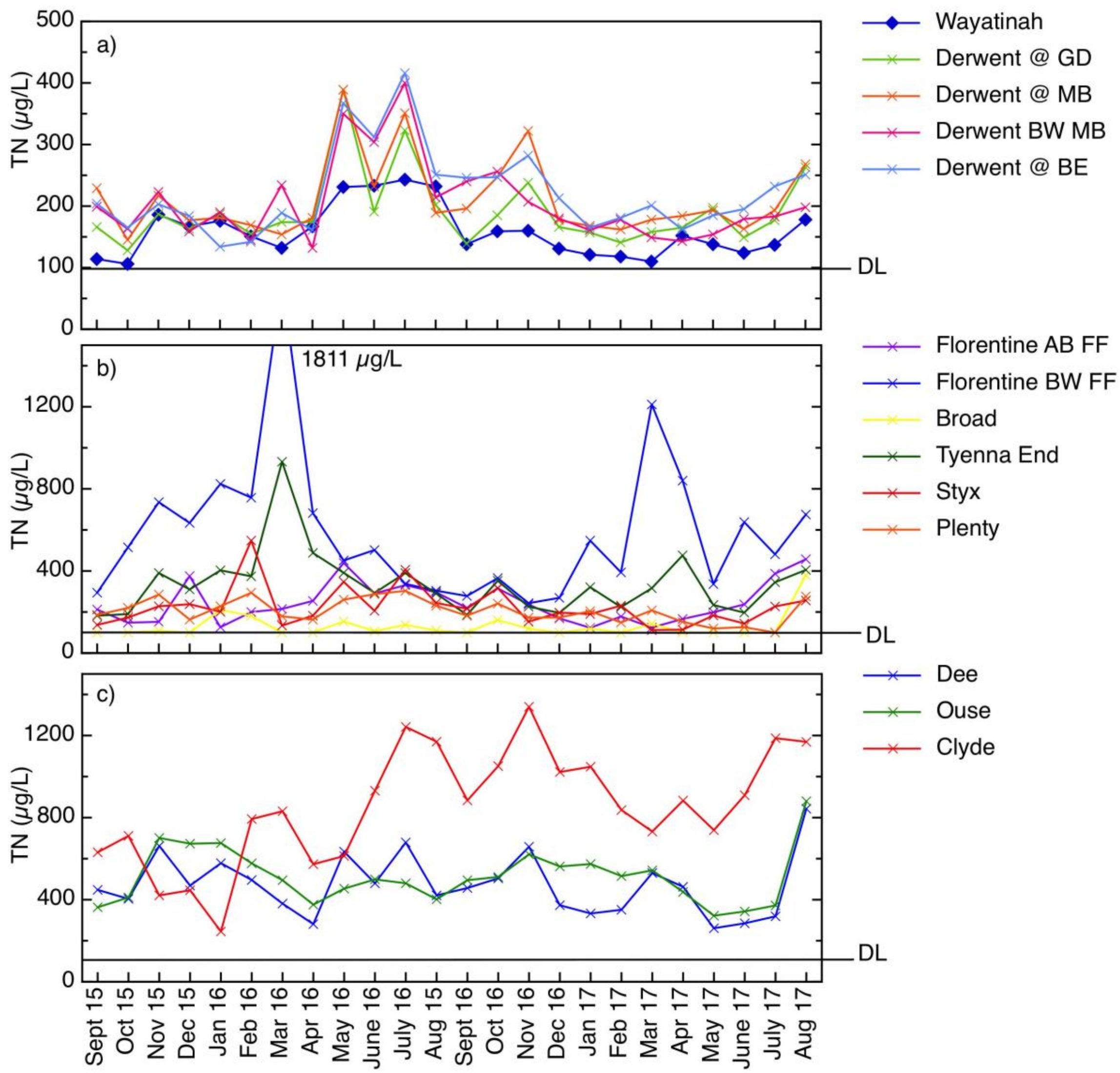


Fig. 14: Total nitrogen (TN) for the Derwent sites (a), western (b) and eastern (c) tributaries over study period. Note the different scales for TN concentrations.

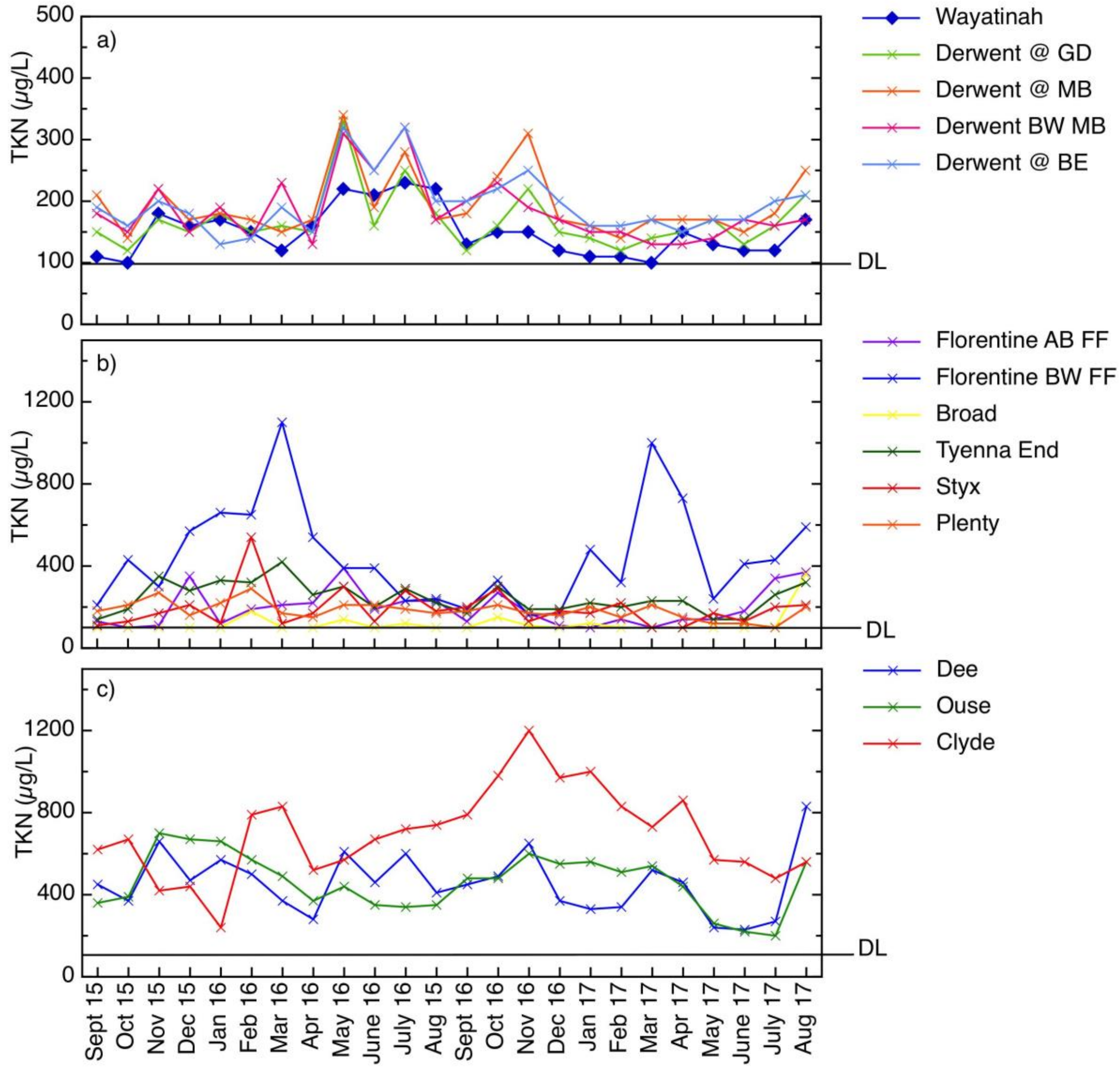


Fig. 15: Total Kjeldahl nitrogen (TKN) for the Derwent sites (a), western (b) and eastern (c) tributaries over study period. Note the different scales for TN concentrations.

3.4.4 Ammonia and ammonium

Ammonia and ammonium concentrations (NH_3+NH_4-N, often referred to as 'ammonia') did not show any apparent trend with season, except for elevated concentrations at Florentine BW FF and Tyenna during the summer months, and for Clyde during the late summer months. The site Derwent BW MB showed elevated NH_3+NH_4-N concentrations during summer 2016/17. Lowest concentrations were found in the Broad which had no value above detection limit (5 µg/L). Highest concentrations were observed at Florentine BW FF, exceeding 600 µg/L in March 2016, which is in contrast to its upstream site Florentine AB FF (Fig. 16).

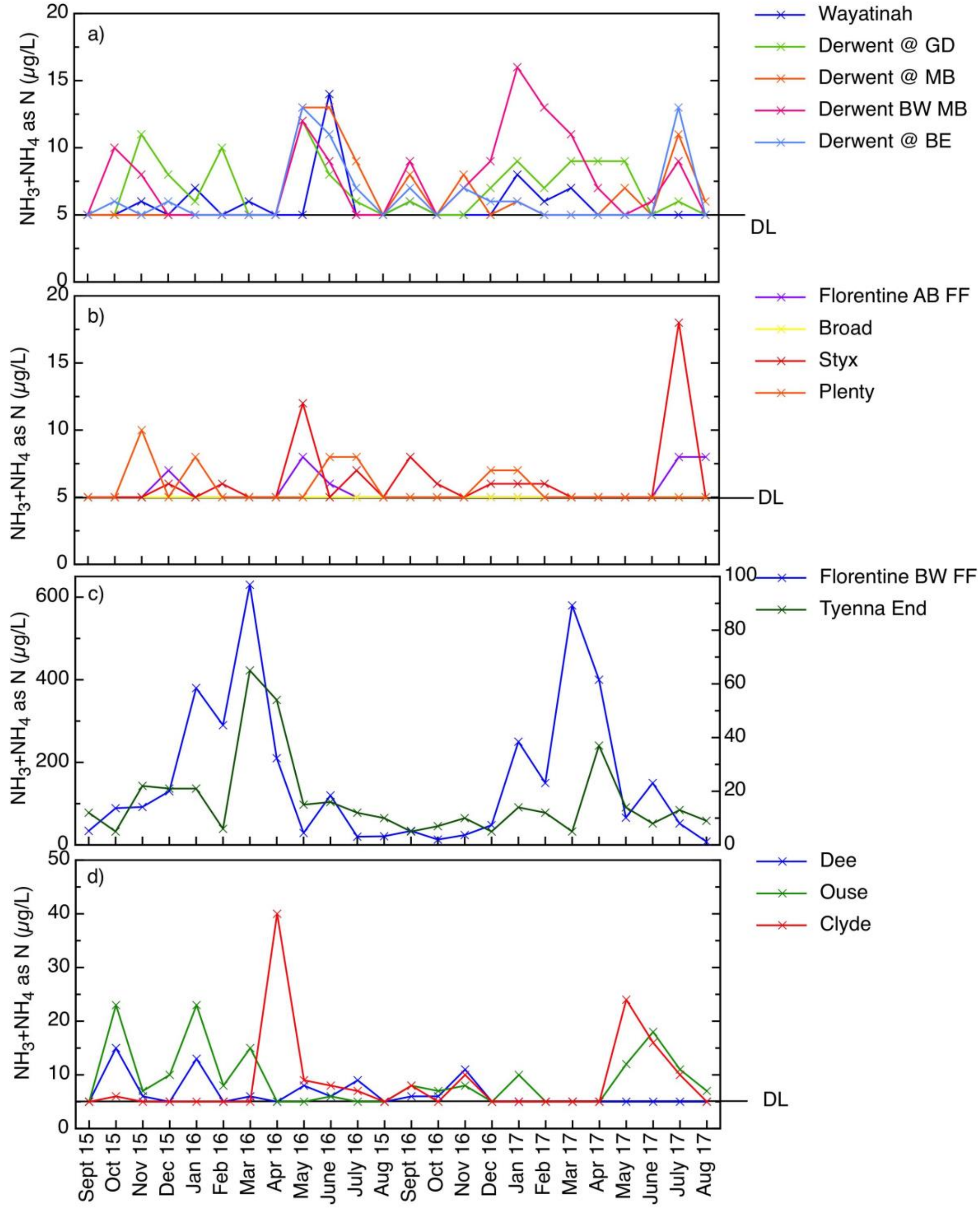


Fig. 16: Ammonia and ammonium as N for Derwent sites (a), western tributaries (b) except for Tyenna and Florentine (c), and eastern tributaries (d). Note the different scales, and the two scales for Florentine BW FF (left axis) and Tyenna (right axis) in (c).

3.4.5 Nitrate and nitrite

Nitrate (NO_3-N) concentrations are highest during winter for all Derwent sites (except Wayatinah BW PS, where concentrations are low all year round) and eastern tributaries

(Dee, Ouse, Clyde). This is in contrast to the seasonal pattern observed for the sites Florentine BW FF and Tyenna End, where concentrations tend to be elevated during spring and summer months (Fig. 17). Highest concentrations were observed for Florentine BW FF in March 2016 (680 µg/L) and Clyde in July 2017 (700 µg/L).

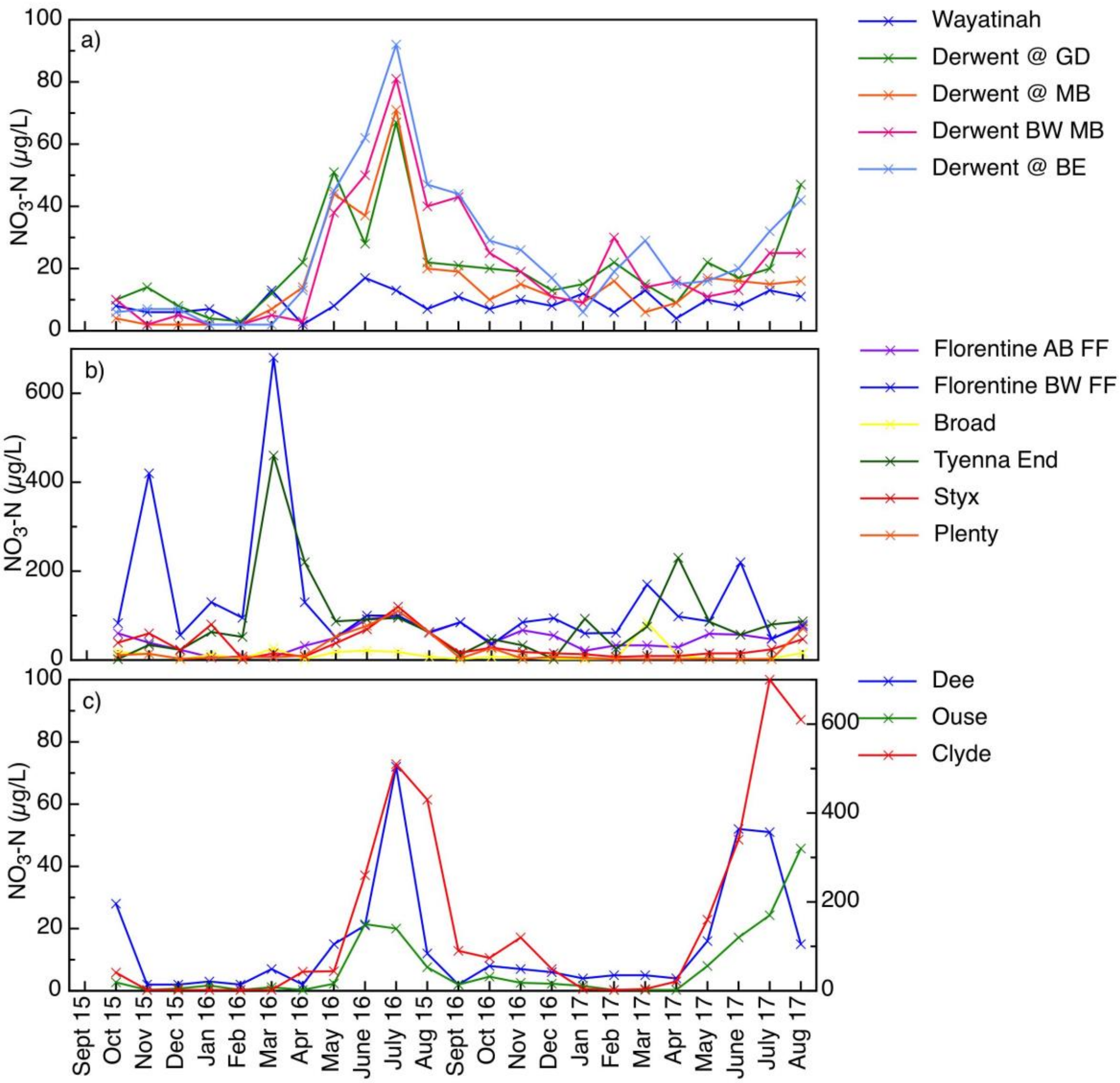


Fig. 17: Nitrate (NO_3-N) concentrations for Derwent sites (a), western tributaries (b), and eastern tributaries (d). Note the different scales in c), with Ouse and Clyde on right y-axis.

Since nitrite (NO_2-N) concentrations within the Derwent catchment are generally below detection limit (2 µg/L), the combined nitrate and nitrite concentrations (NO_x-N) are shown below (Fig. 18). However, NO_x-N concentrations follow the same patterns of NO_3-N, with similar concentrations indicating that any NO_2 readily oxidizes to NO_3 at all sites.

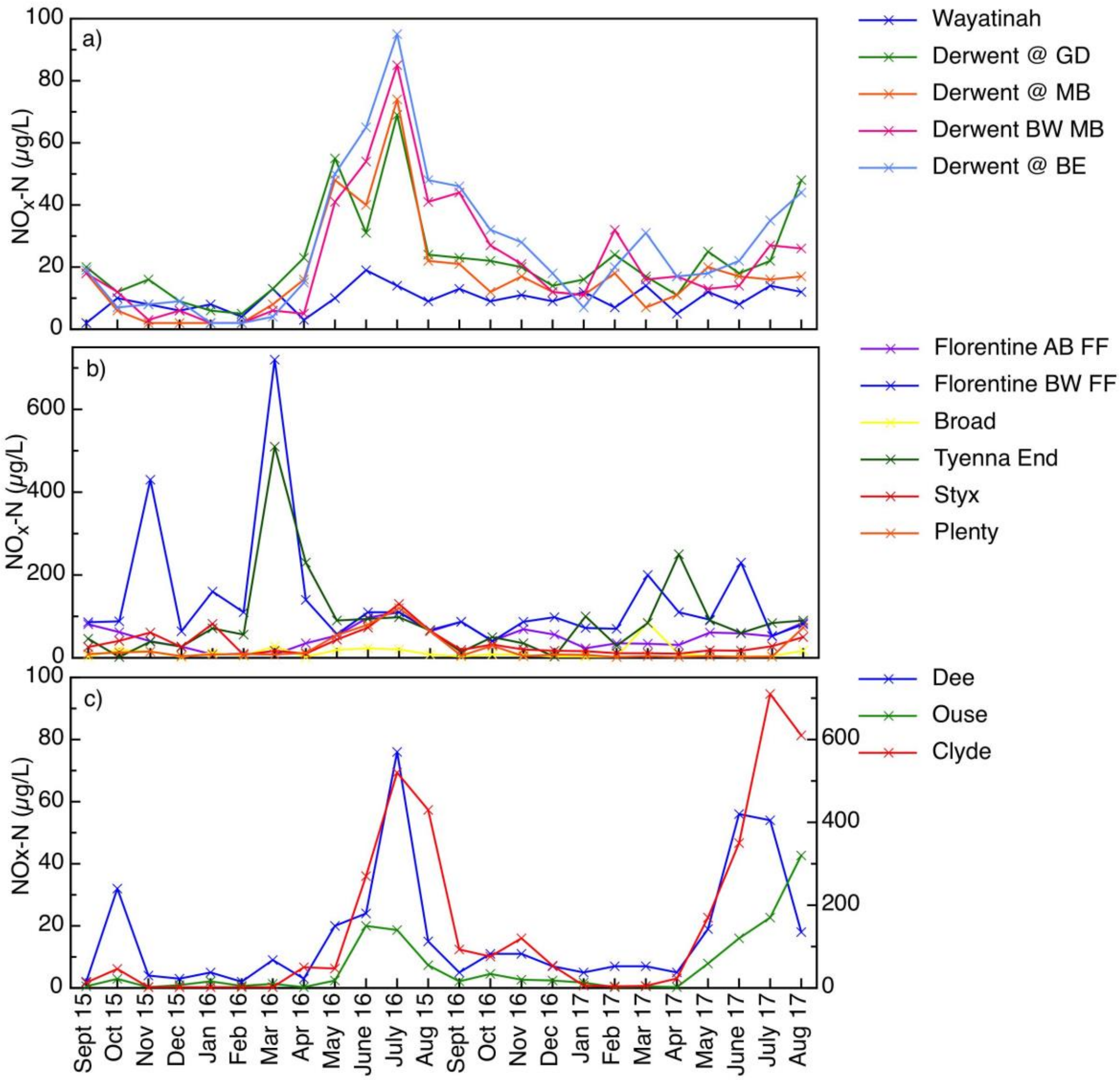


Fig. 18: Combined nitrate and nitrite (NO_x-N) concentrations for Derwent sites (a), western tributaries (b), and eastern tributaries (d). Note the different scales in c), with Ouse and Clyde on right y-axis.

3.5 Total organic carbon

Total organic carbon, or non-purgable organic carbon (NPOC) concentrations in the Derwent catchment are low and there is no apparent trend with season (Fig. 19). NPOC appears to co-vary with TN and turbidity and is highest for the Clyde, suggesting that suspended sediment containing nitrogen and carbon is either transported from upstream (Lake Crescent and Lake Sorrell) or enters the river via surface runoff.

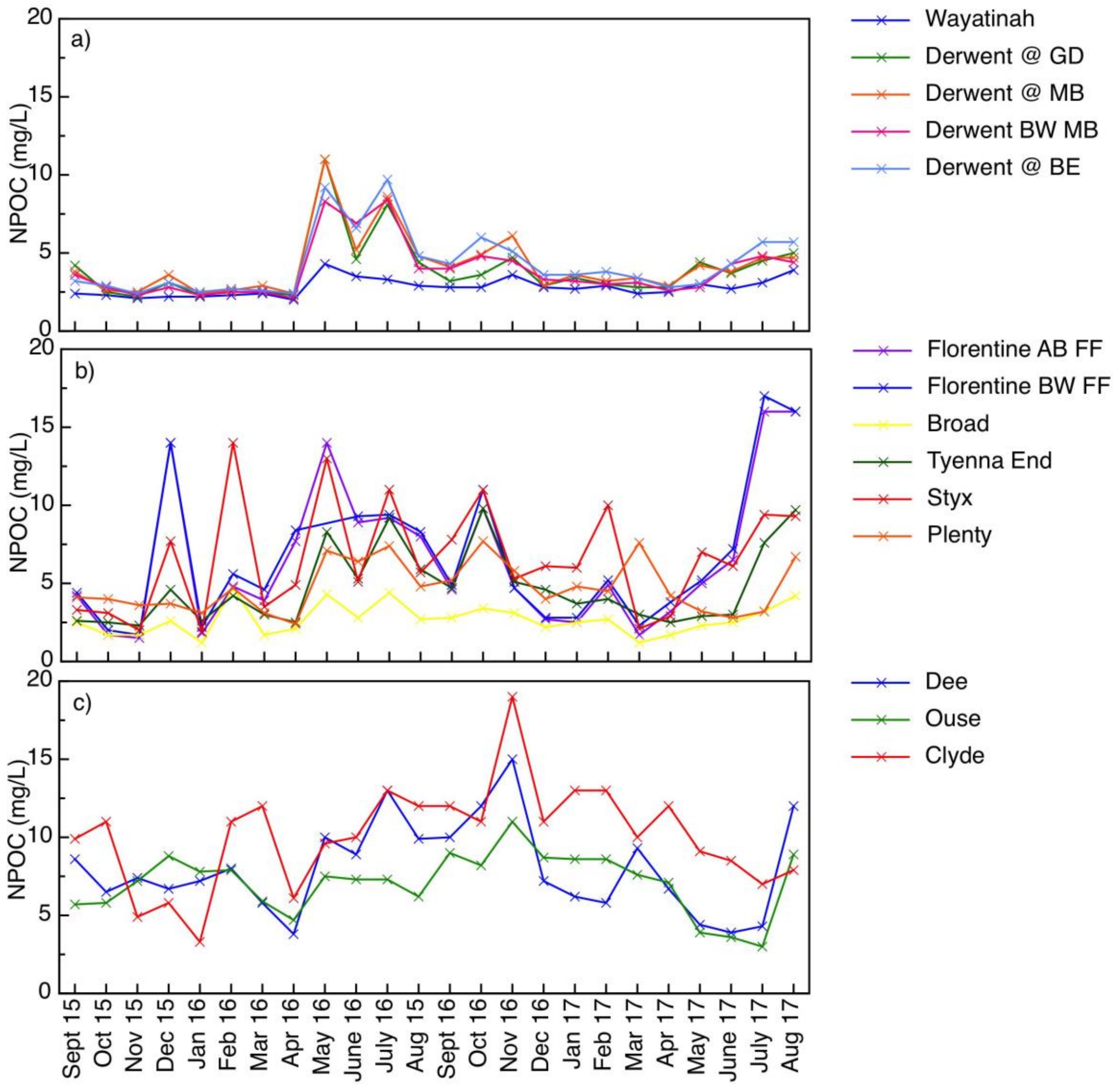


Fig. 19: Total organic carbon as non-purgable organic carbon (NPOC) for Derwent sites (a), western tributaries (b) except for Tyenna and Florentine (c), and eastern tributaries (d).

3.6 Nutrient loads

3.6.1 Phosphorus compounds

Total phosphorus (TP) loads were difficult to determine due to the lack of data (55% of values below detection limit). The daily and annual TP loads shown below use the detection limit values in the case of missing values, which likely over-estimates daily and annual loads. Particularly annual loads have to be interpreted with caution, due to their sensitivity to rainfall-runoff events that were not targeted during this monitoring program. Filtered phosphate (PO_4-P) loads were calculated also including values below the detection limit at 5 µg/L. Both TP and PO_4-P loads are shown below (Fig. 20, Fig. 21).

TP and PO_4-P loads were highest at Derwent sites compared to western and eastern tributaries, indicating the significance of flow rate for load calculations.

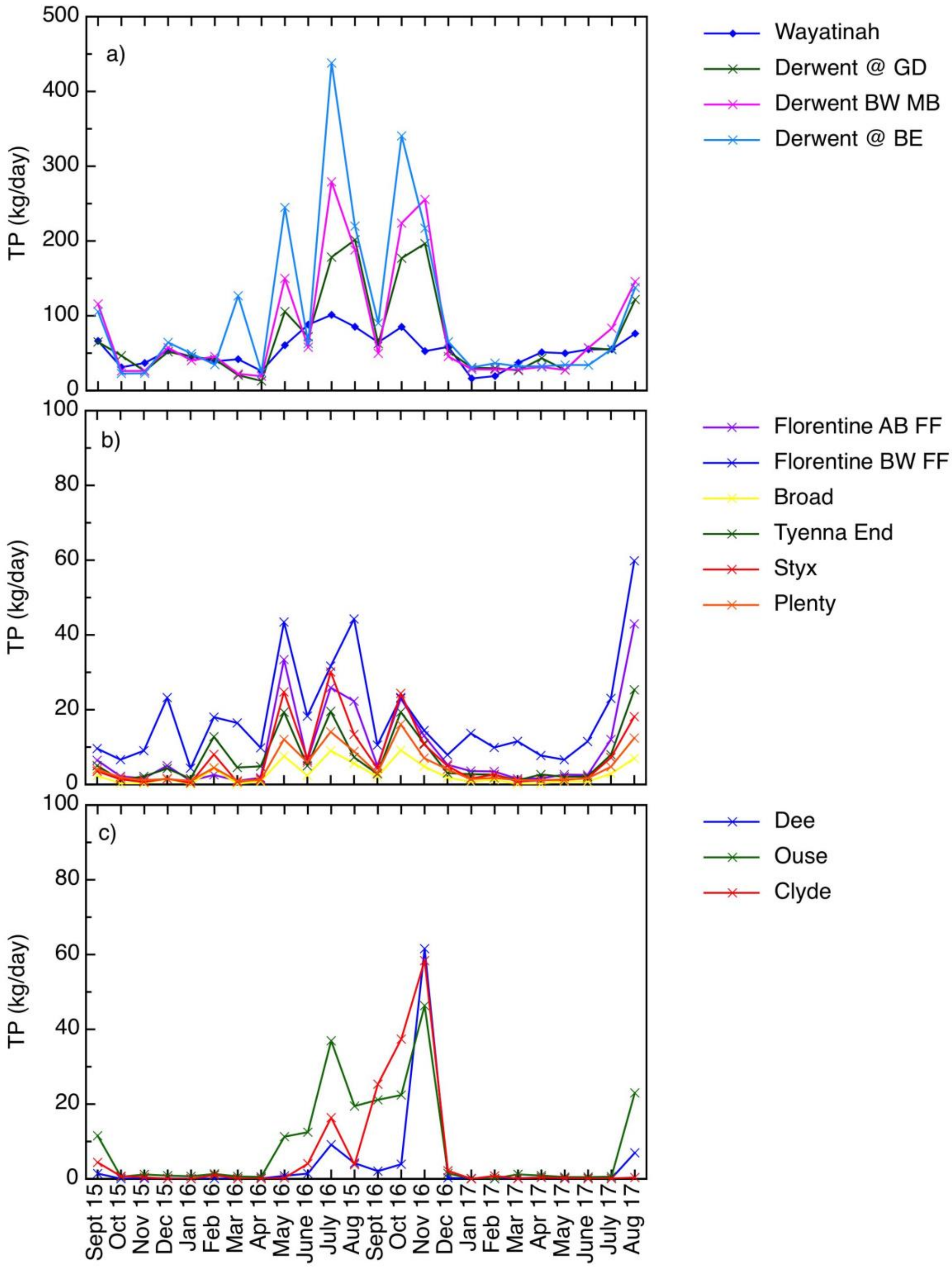


Fig. 20: Daily total phosphorus (TP) loads over the study period. Note the change in scale. Daily TP loads were highest at Derwent sites (a) compared western (b) and eastern (c) tributaries.

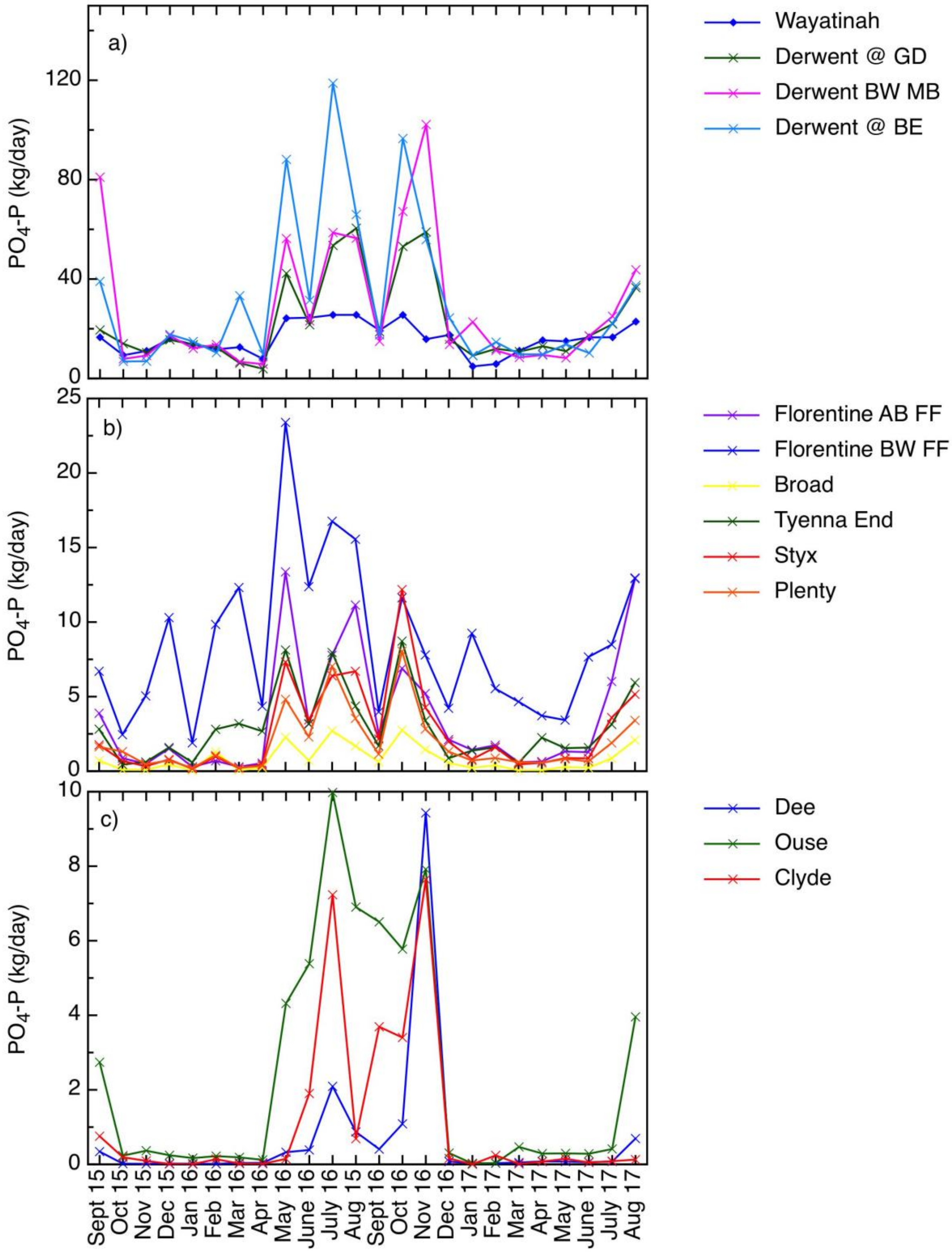


Fig. 21: Daily filtered phosphate (PO_4-P) loads over the study period. Note the change in scale. Daily PO_4-P loads were highest at Derwent sites (a) compared western (b) and eastern (c) tributaries.

3.6.2 Nitrogen compounds

Using the same approach in mass load calculations as for phosphorus, total nitrogen (TN) and nitrate (NO_3-N) loads were calculated and are shown below (Fig. 22, Fig. 23).

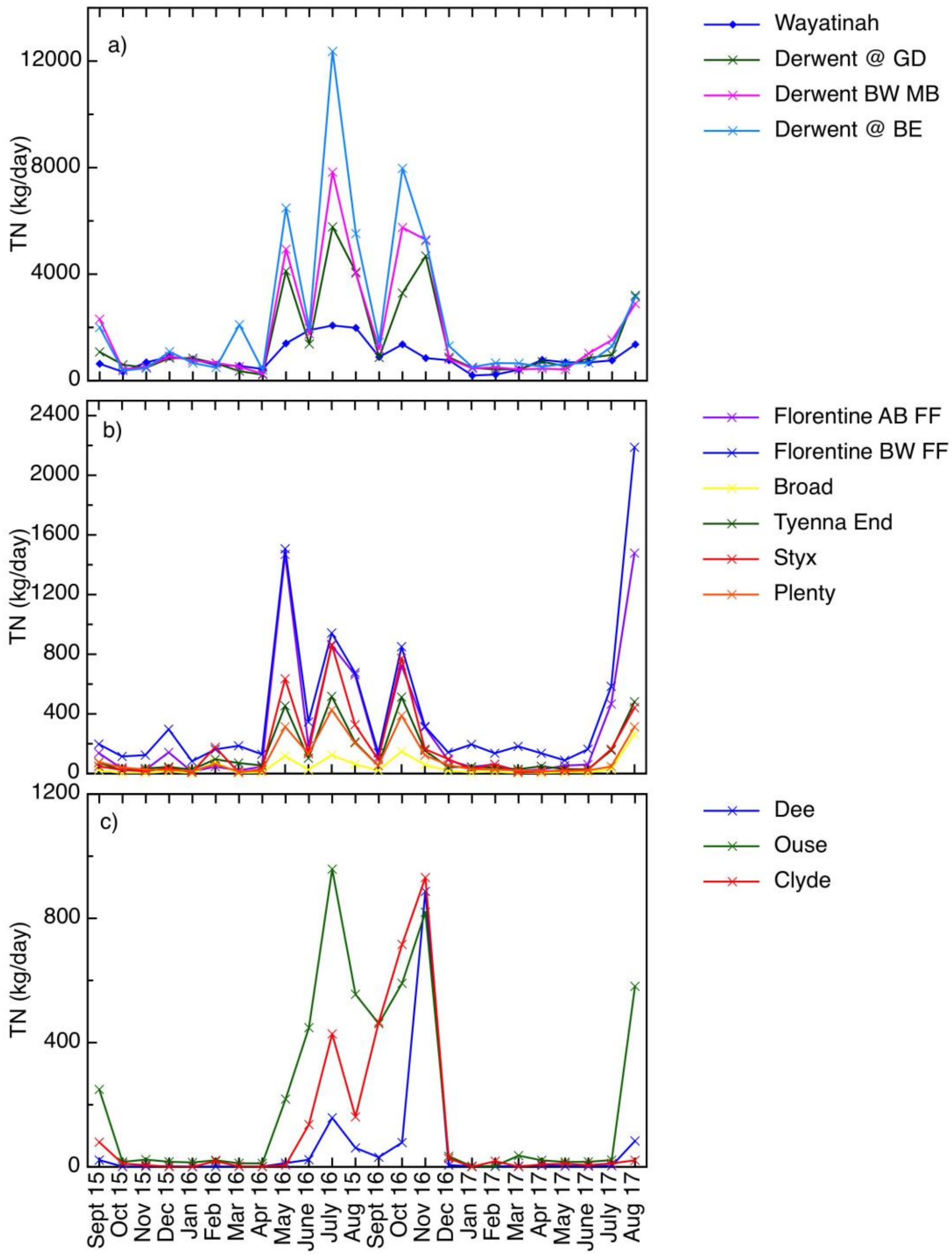


Fig. 22: Daily total nitrogen (TN) loads over the study period. Note the change in scale. Daily TN loads were highest at Derwent sites (a) compared western (b) and eastern (c) tributaries.

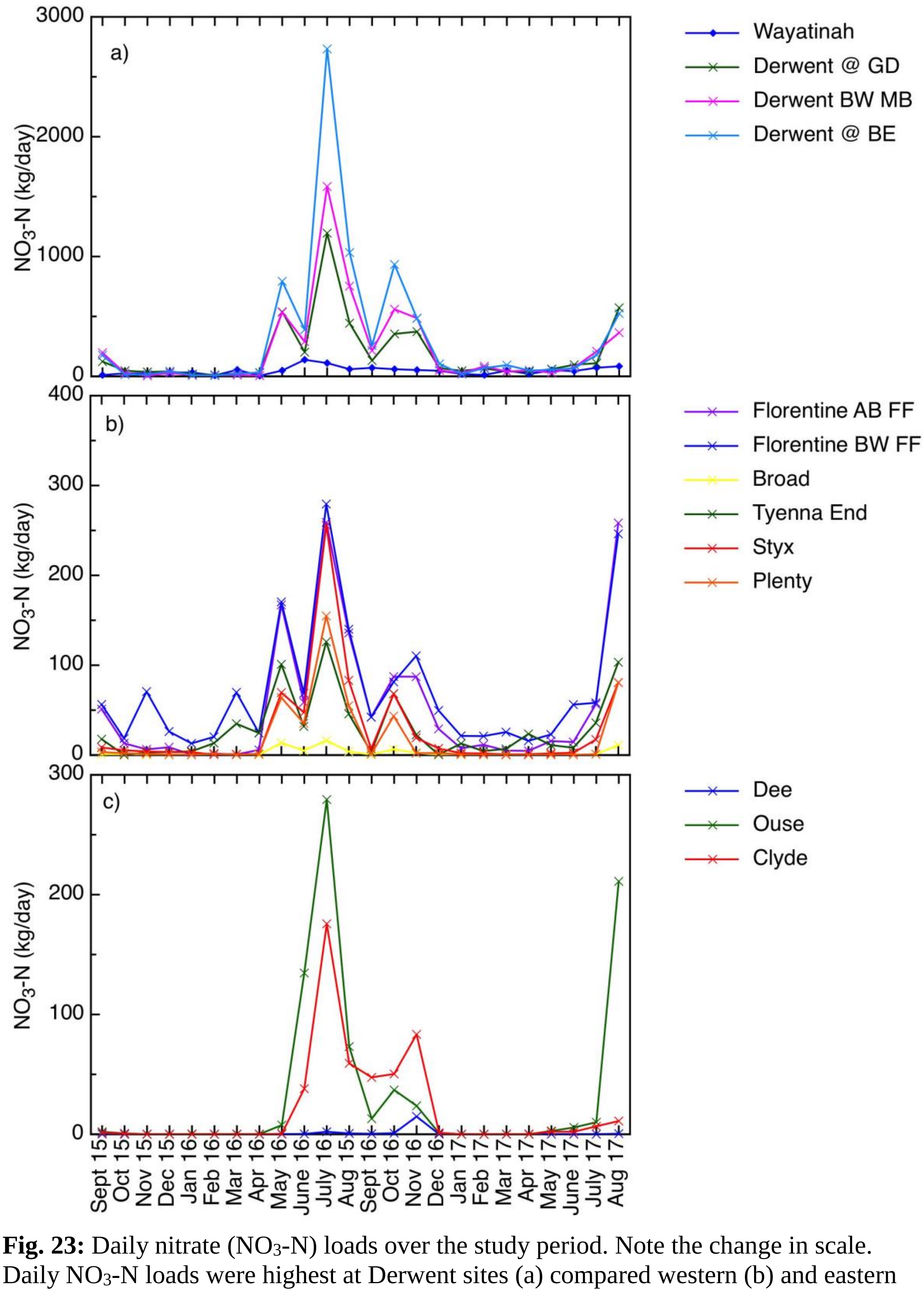


Fig. 23: Daily nitrate (NO_3-N) loads over the study period. Note the change in scale. Daily NO_3-N loads were highest at Derwent sites (a) compared western (b) and eastern (c) tributaries.

4 DISCUSSION

4.1 Physical properties

Water temperature at all sites followed a seasonal cycle correlating to that of air temperature, with highest values during the summer months. Along the River Derwent main stem, the river water warms up continuously from Wayatinah BW PS to Derwent @ BE. Water temperatures of tributaries were comparable to those of the River Derwent. The pH in the catchment is clearly influenced by its geology, with mildly alkaline values in sub-catchments with karst occurrence (Florentine, Tyenna, Styx; Eriksen, 2011). It is noteworthy that the pH at Florentine BW FF was consistently lower compared to its upstream site (Florentine AB FF). According to the Tyler corridor, surface water characteristics (pH, colour, hydrochemistry) vary depending on their location with respect to the 'Tyler Line'. West of the divine, waters are predominantly dark in colour, high in dissolved organic carbon (DOC) and have a low pH, whereas east of the divine colour and DOC are low and pH is high. According to Eriksen (2011), only a small number of streams fall into the latter group, which are predominantly in the upper Florentine catchment.

Conductivity and salinity in the catchment are low, reflecting freshwater chemical compositions. Conductivity is low at all Derwent sites, higher in summer months for tributaries and exceeding 1000 µS/cm at the Clyde (for comparison, seawater has a conductivity of around 54,000 µS/cm).

Dissolved oxygen also showed typical seasonal cycles with lower values during the summer. The lowest DO values were observed at Ouse and Clyde during the summer when flow at these tributaries is very low or intermittent (Hughes, 1987). It is noteworthy that hydrological regimes across the Derwent catchment are diverse. The River Clyde is classified as a Group 2 river (rivers that have the lowest mean annual runoff across Tasmania), while the Derwent, Nive, Florentine and Tyenna are Group 3 rivers characterised by highest mean annual runoff (Hughes, 1987).

4.2 Nutrient concentrations

Nutrient concentrations in the catchment have different seasonal cycles. TP and TN are highest during the late summer months (March, April) for tributaries influenced by fish farms (e.g. Florentine BW FF, Tyenna), but higher during the winter months at e.g. Clyde and Ouse (agriculture). In addition, dissolved nutrients play a more important role in fish farm influenced tributaries. Fig. 24 and Fig. 25 show the contributions of dissolved nutrients to total phosphorus and total nitrogen. Total phosphorus is dominated by filtered phosphate at Florentine BW FF and Tyenna, whereas filtered phosphate concentrations are relatively stable all year round in the Clyde and Ouse, irrespectively of TP variations. Similarly, nitrate and ammonia are important contributors to TN at Florentine BW FF and Tyenna. However, nitrate concentrations at the Ouse and Clyde also show a seasonal cycle, but with higher concentrations during the winter months (June, July, August). Ammonia does not play a role at the Ouse and Clyde. Summer time increases of dissolved nutrients at the Florentine and Tyenna therefore coincide with periods of stress in the River Derwent and the upper Derwent Estuary, as characterised by growth of filamentous algae, taste and odour problems and loss of seagrass beds.

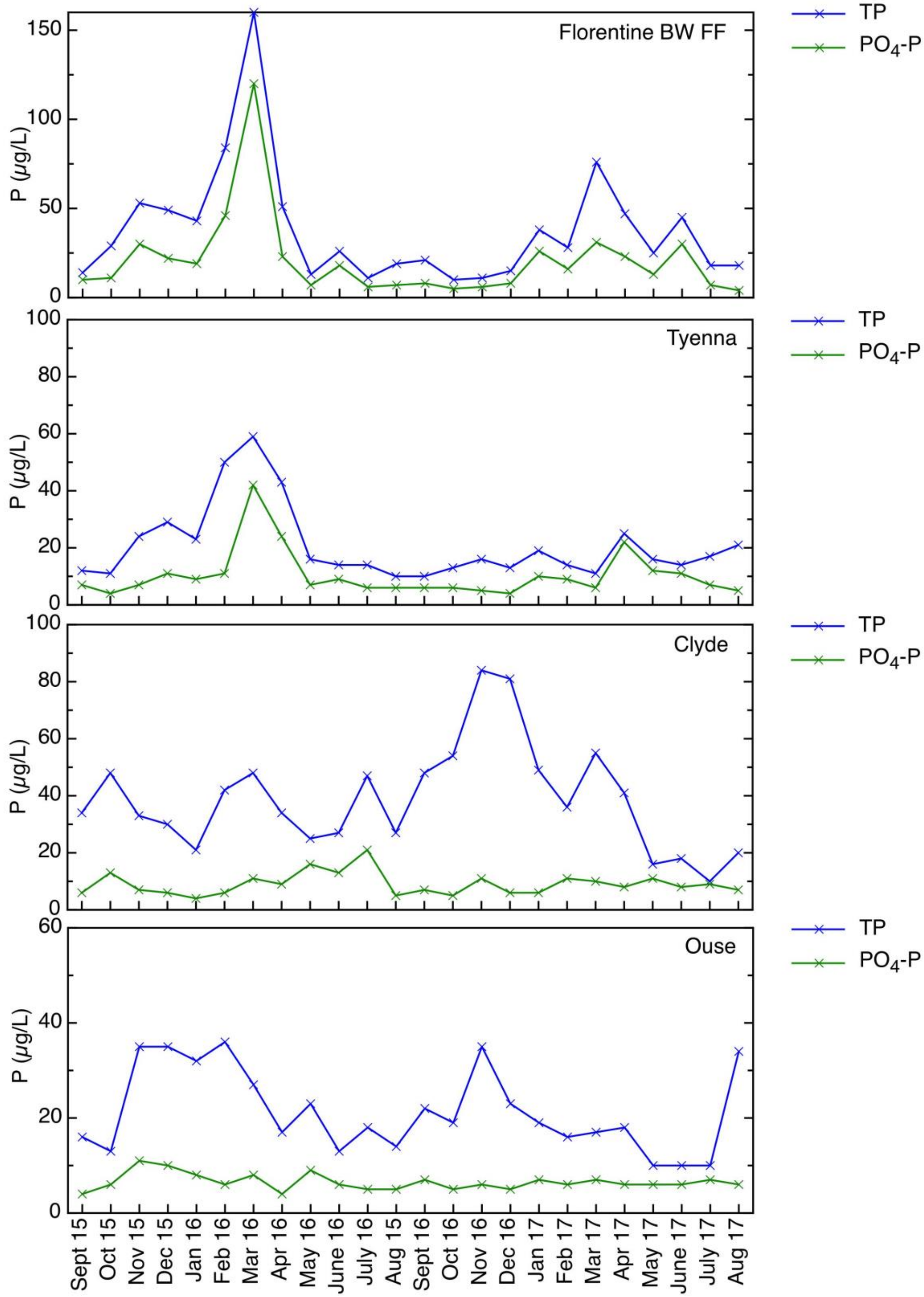


Fig. 24: Comparison of filtered phosphate to total phosphorus concentrations between fish farm influenced rivers (Florentine, Tyenna) and agriculturally dominated catchments (Clyde, Ouse).

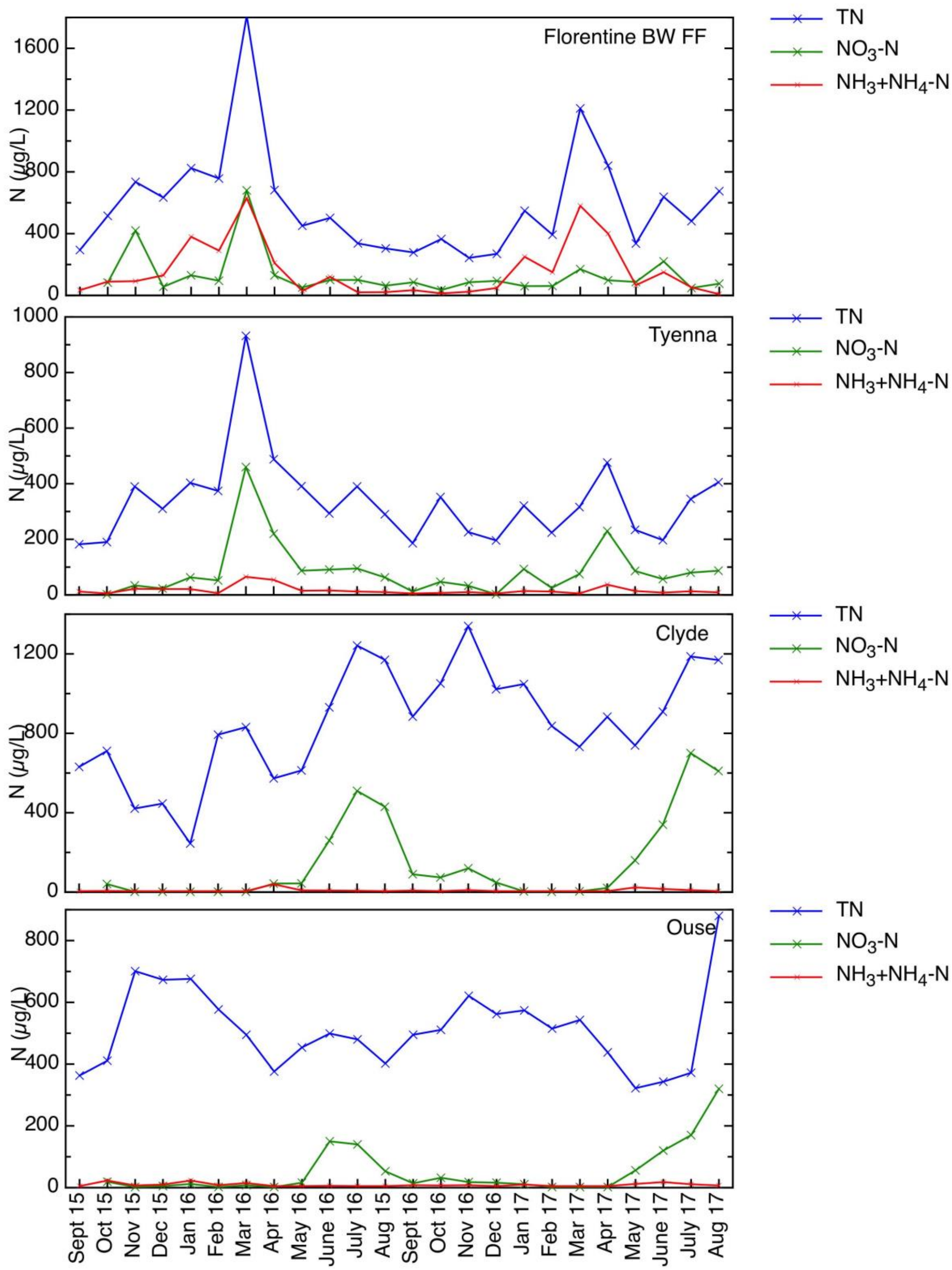


Fig. 25: Nitrate and ammonia concentrations in comparison to total nitrogen at fish farm influenced tributaries (Florentine, Tyenna) and at tributaries influenced by agriculture (Clyde, Ouse).

4.3 Nutrient limitation

Unicellular algae such as phytoplankton and benthic microalgae use light energy to fix carbon (C) which is subsequently combined with elements such as nitrogen (N) and phosphorus (P) to an elemental C:N:P ratio within their cells of 106:16:1, known as the "Redfield ratio" (Redfield et al., 1963). A more recent comparison of total nitrogen (TN) and total phosphorus (TP) measurements with contemporaneous measurements of chlorophyll a and phytoplankton nutrient deficiency across a broad range of lakes and oceans demonstrated that N-deficient growth was apparent at a molar ratio of TN:TP<20, whereas P-deficient growth consistently occurred when TN:TP>50 (Guildford & Hecky, 2000). At intermediate TN:TP ratios, either N or P can become deficient, irrespectively of the system (marine or freshwater). Molar ratios of TN to TP were therefore calculated when both TN and TP values were above the detection limit, and are shown in Fig. 26 (Broad River and Derwent @ GD are not shown due to lack of TP data). The figure shows that the majority of sites are either P limited or co-limited by N and P. Derwent sites (Fig. 26a) appear to have a tendency for P limitation, whereas eastern tributaries are more frequently co-limited by N and P. This is in contrast to marine systems that are predominantly nitrogen limited, hence both phosphorus and nitrogen are crucial nutrients to monitor in the Derwent catchment. Only at the Tyenna and Florentine BW FF nitrogen limitation occurred in Feb 2016, likely due to elevated dissolved phosphorus loads during summer time.

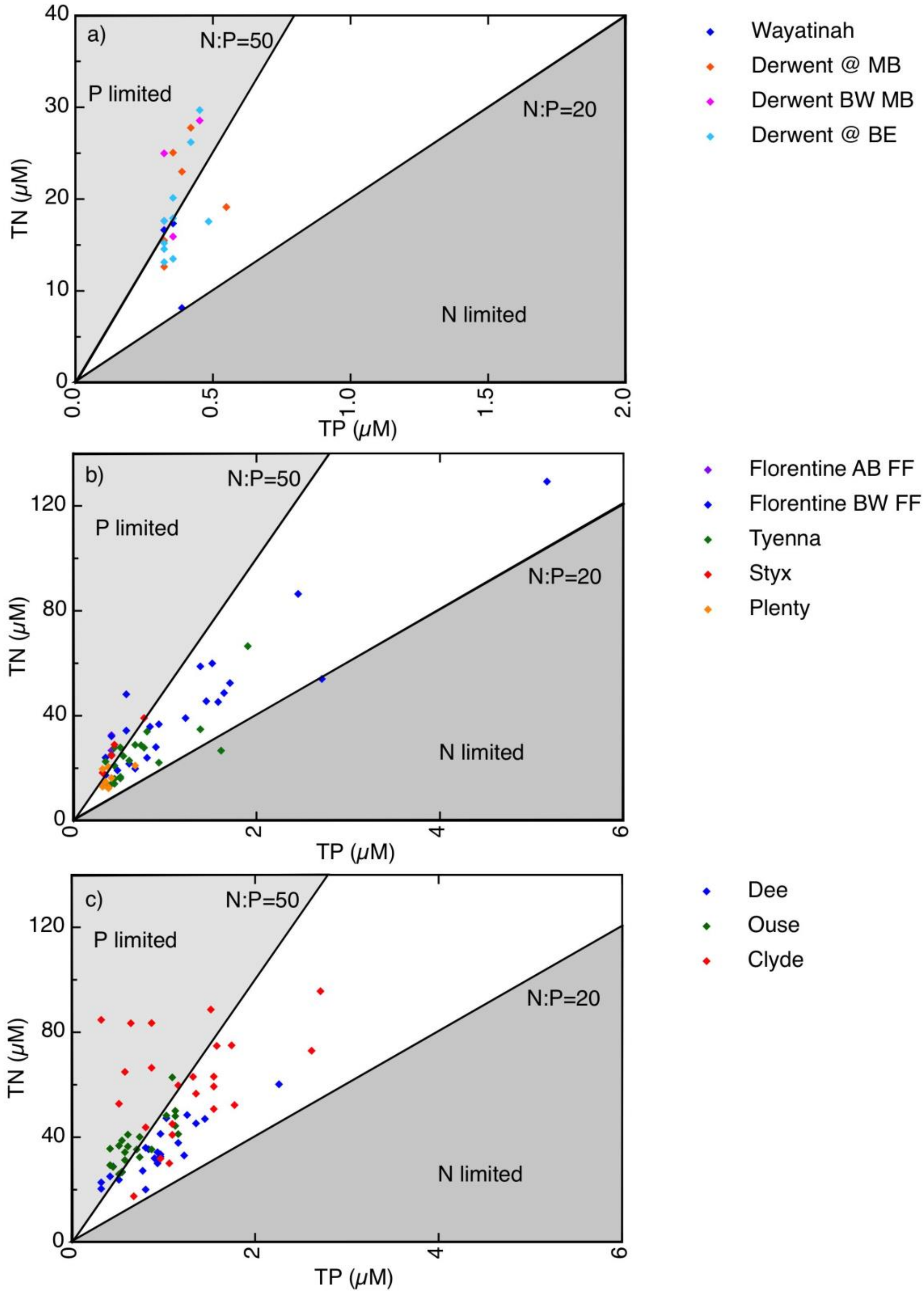


Fig. 26: Molar ratios of TN to TP for Derwent sites (a), western (b) and eastern (c) tributaries. Solid lines indicate N:P ratios of 20 and 50 which denote the ratios below and above which N and P limitation are expected to occur, respectively.

4.4 Mass loads

The monitoring sites considered for mass loads were at variable distances downstream of point sources which may cause a bias in load estimates. When nutrient concentrations were below detection limit, the detection limit itself was used, likely causing an overestimate in loads (see section 2.5). The timing of sampling (rising or descending limb of hydrograph) was not considered in the calculations.

Both total and dissolved nutrient loads increase downstream along the River Derwent (Fig. 27) and are significantly higher compared to tributary mass loads. Fig. 28 shows the relative contribution of each tributary to TN, NO_3-N, TP, and PO_4-P loads in the catchment. The Florentine BW FF is the largest contributor of TN of all tributaries, followed by the Ouse, but the majority of TN loads appears to be derived from point and diffuse sources along the River Derwent main stem. TP mass loads are also highest at the Florentine BW FF, followed by Ouse, whereas filtered phosphate loads are predominantly from Florentine BW FF and Tyenna, followed by the Styx and Ouse.

Nutrient yields (export rates, kg/ha/yr) for TP (Table 4) and TN (Table 5) were also calculated based on mass loads and catchment size (Derwent 8900 km^2, Clyde 1109 km^2, Dee 355 km^2, Florentine 436 km^2, Ouse 1735 km^2, Plenty 204 km^2, Styx 347 km^2, Tyenna 284 km^2; Eriksen, 2011). TP yields range from 0.009 to 0.164 kg/ha/yr with considerable differences between the two sampling years. The highest values for both years were observed for the Florentine, in agreement with the mass loads, followed by Tyenna, Plenty and Styx. TP yields at the Broad were higher compared to the Ouse for both years.

Total nitrogen export rates were also highest for the Florentine, and the Ouse catchment yielded lower export rates compared to the Broad due to its catchment size.

Both TN and TP annual export rates are comparable to nutrient export rates in South-east Australia (Young et al., 1996).

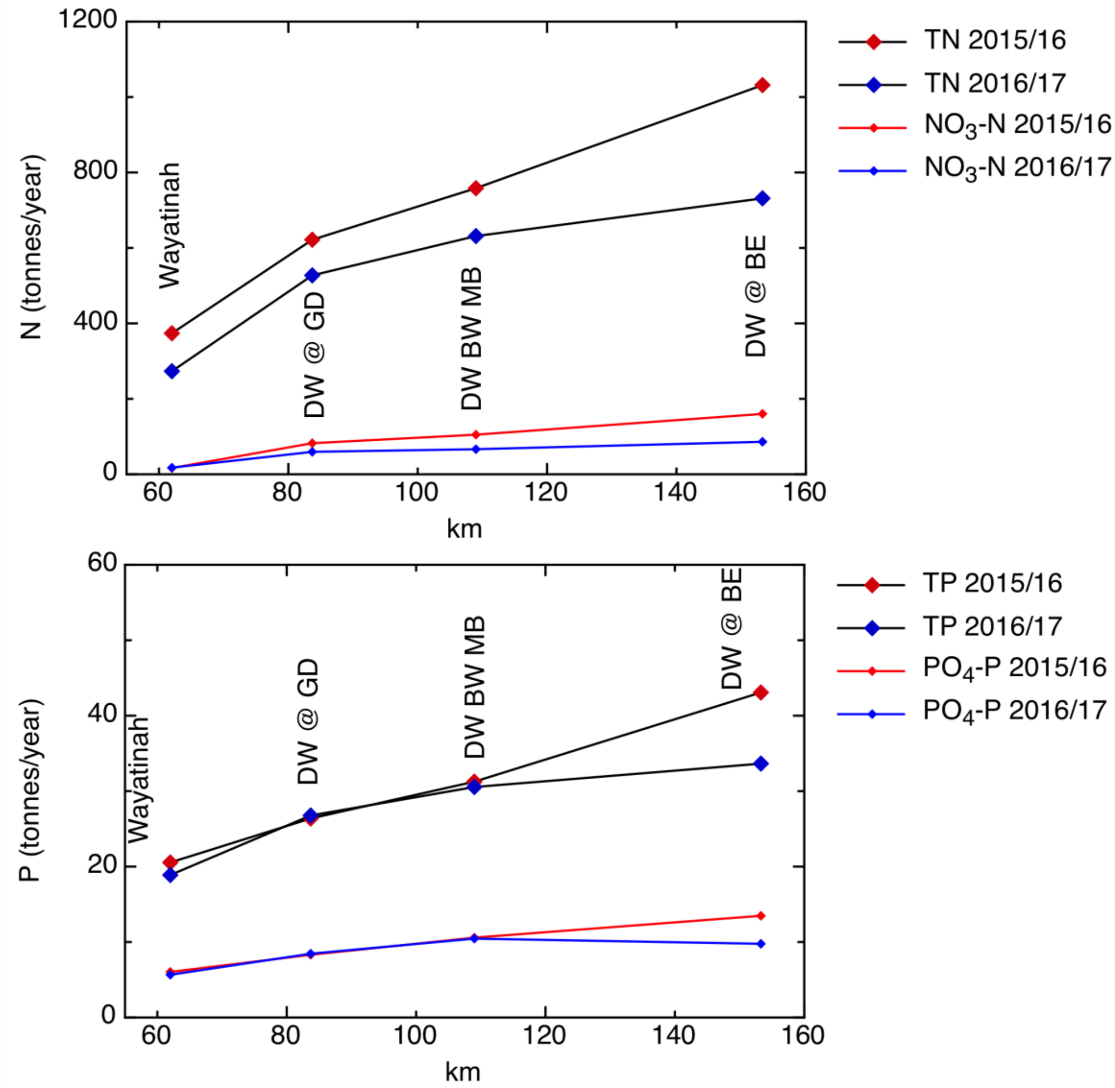


Fig. 27: Annual loads of nitrogen and phosphorus for the Derwent sites (except Derwent @ MB) for both sampling years.

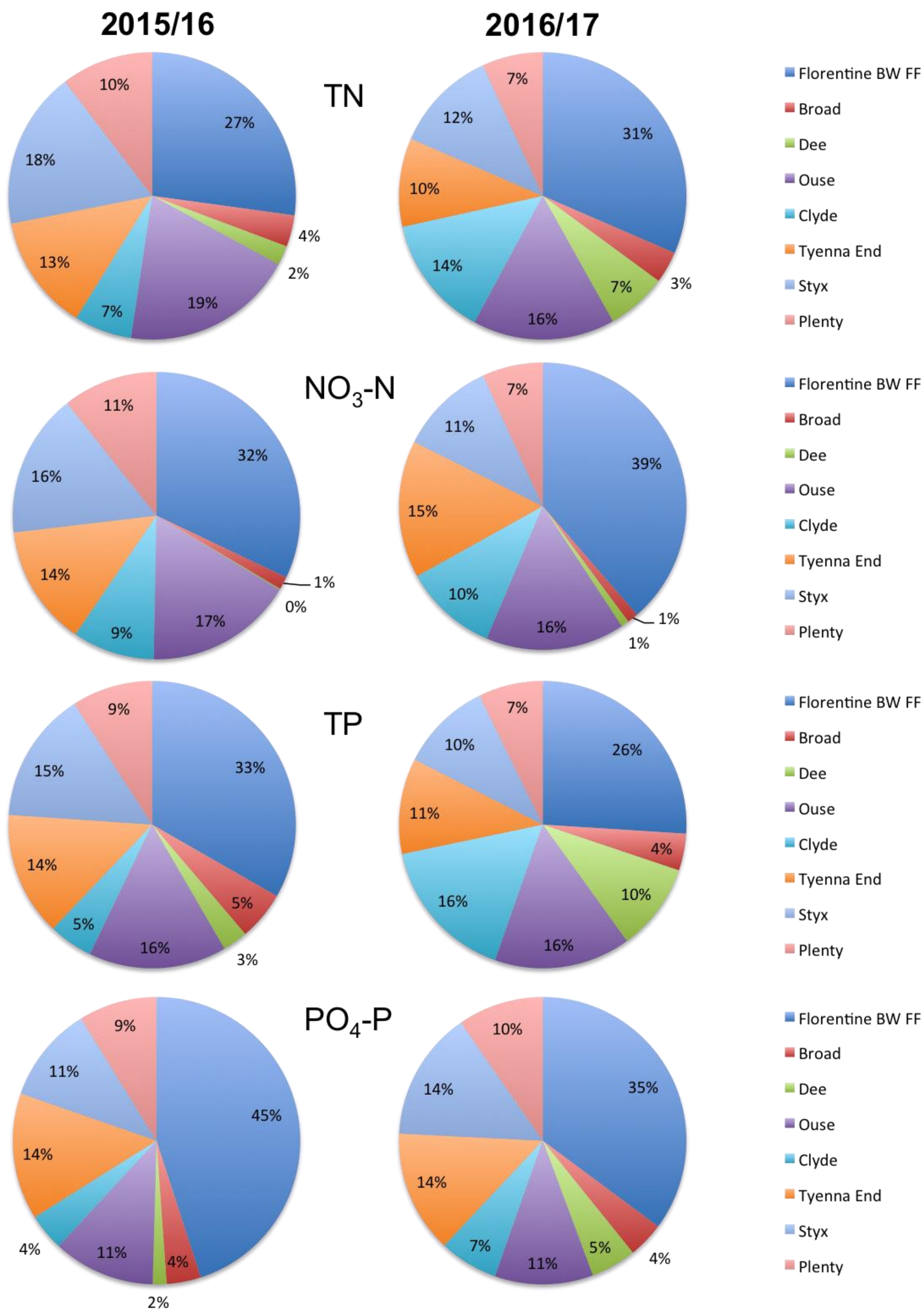


Fig. 28: Annual loads for the 2015/16 (left) and 2016/17 (right) sampling periods for TN, NO_3-N, TP and PO_4-P for all tributaries.

Table 4: Total phosphorus (TP) mass loads per catchment for each sampling year (t/yr) and corresponding yields (kg/ha/yr) based on catchment size.

Catchment	TP (t/yr)	TP (kg/ha/yr)
Derwent		
2015/16	43.1	0.048
2016/17	33.6	0.038
Clyde		
2015/16	0.9	0.009
2016/17	3.8	0.034
Dee		
2015/16	0.5	0.015
2016/17	2.3	0.065
Florentine		
2015/16	7.1	0.164
2016/17	6.1	0.139
Ouse		
2015/16	3.0	0.017
2016/17	3.6	0.021
Plenty		
2015/16	1.7	0.085
2016/17	1.7	0.083
Styx		
2015/16	2.8	0.081
2016/17	2.4	0.069
Tyenna		
2015/16	2.7	0.094
2016/17	2.5	0.089
Broad		
2015/16	1.0	0.075
2016/17	1.0	0.069

Table 5: Total nitrogen (TN) mass loads per catchment for each sampling year (t/yr) and corresponding yields (kg/ha/yr) based on catchment size.

Catchment	TN (t/yr)	TN (kg/ha/yr)
Derwent		
2015/16	1031.1	1.159
2016/17	731.5	0.822
Clyde		
2015/16	25.8	0.233
2016/17	67.4	0.608
Dee		
2015/16	8.7	0.246
2016/17	33.6	0.946
Florentine		
2015/16	144.9	3.323
2016/17	155.7	3.572
Ouse		
2015/16	77.4	0.446
2016/17	79.2	0.456
Plenty		
2015/16	41.3	2.023
2016/17	33.8	1.658
Styx		
2015/16	70.5	2.030
2016/17	57.6	1.661
Tyenna		
2015/16	51.9	1.828
2016/17	49.3	1.734
Broad		
2015/16	14.1	1.007
2016/17	17.7	1.262

4.5 Comparison to historical/other catchment data

4.5.1 Comparison to Derwent Catchment Data 1996/97

Flow conditions during the 2015-2017 and 1996/97 monitoring programs were only comparable for the summer months. The figures below therefore only show nutrient concentrations for the period December to March. Between the three summer periods, there are significant differences between the tributary concentrations. For the Florentine (BW FF) and the Tyenna, almost all observations for the nutrients TN, TP, NO_x-N, PO_4-P, and NH_3+NH_4-N were lowest during the 1996/97 summer months. Highest concentrations were typically observed during the 2015/16 summer, which followed unusually dry winter and spring months in 2015. Remarkable are the increases in filtered phosphate and ammonia concentrations compared to the 1996/97 data. In contrast, for the

Clyde and Ouse River, nutrient concentrations during the 1996/97 summer were in the same range or higher compared to 2015/16 and 2016/17 data. However, due to the small number of observations, it is difficult to determine whether the differences in absolute concentrations are statistically significant.

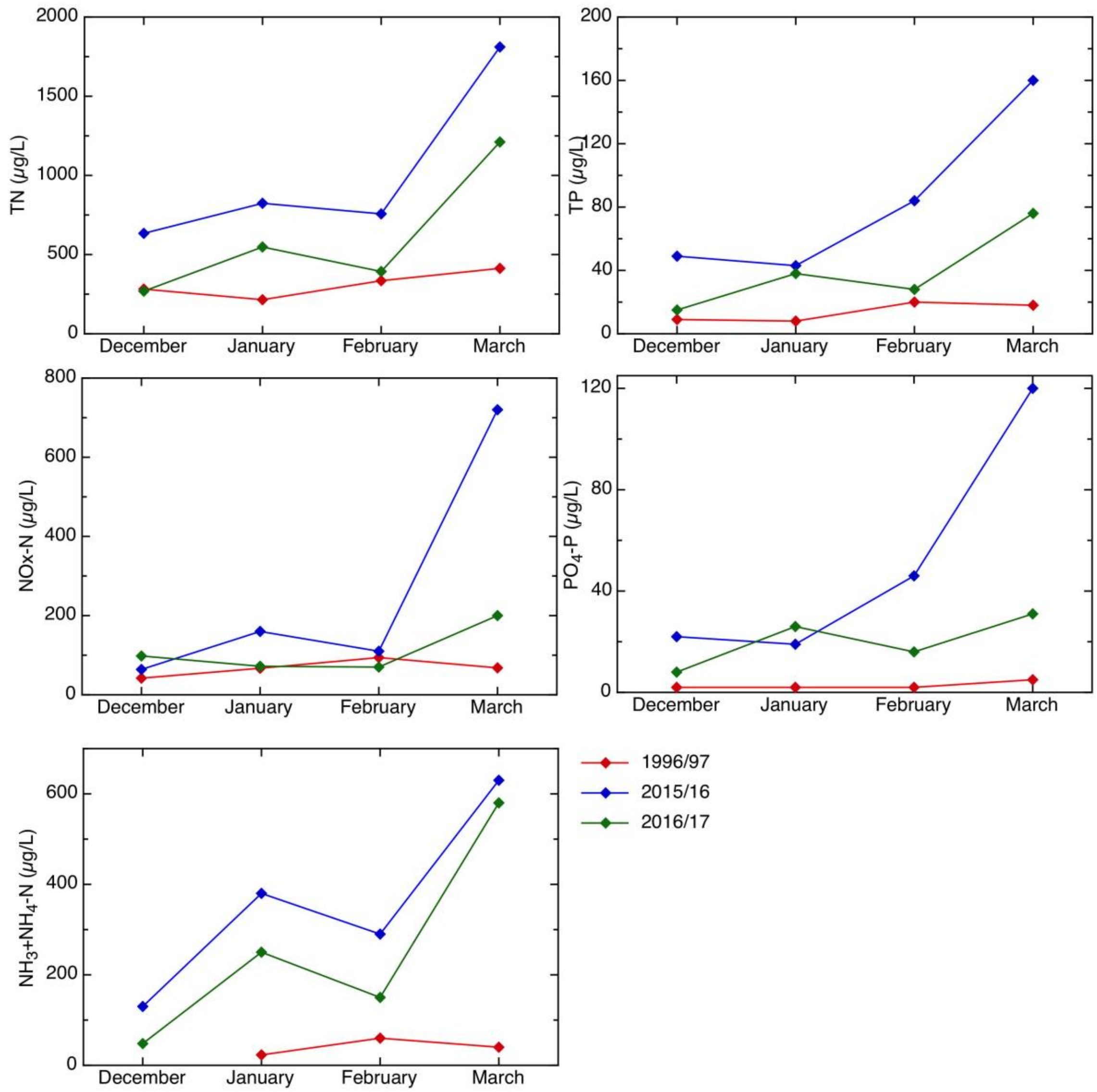


Fig. 29: Comparison of nutrient concentration observations between the three summer periods sampled in 1996/97, 2015/16 and 2016/17 for the Florentine BW FF.

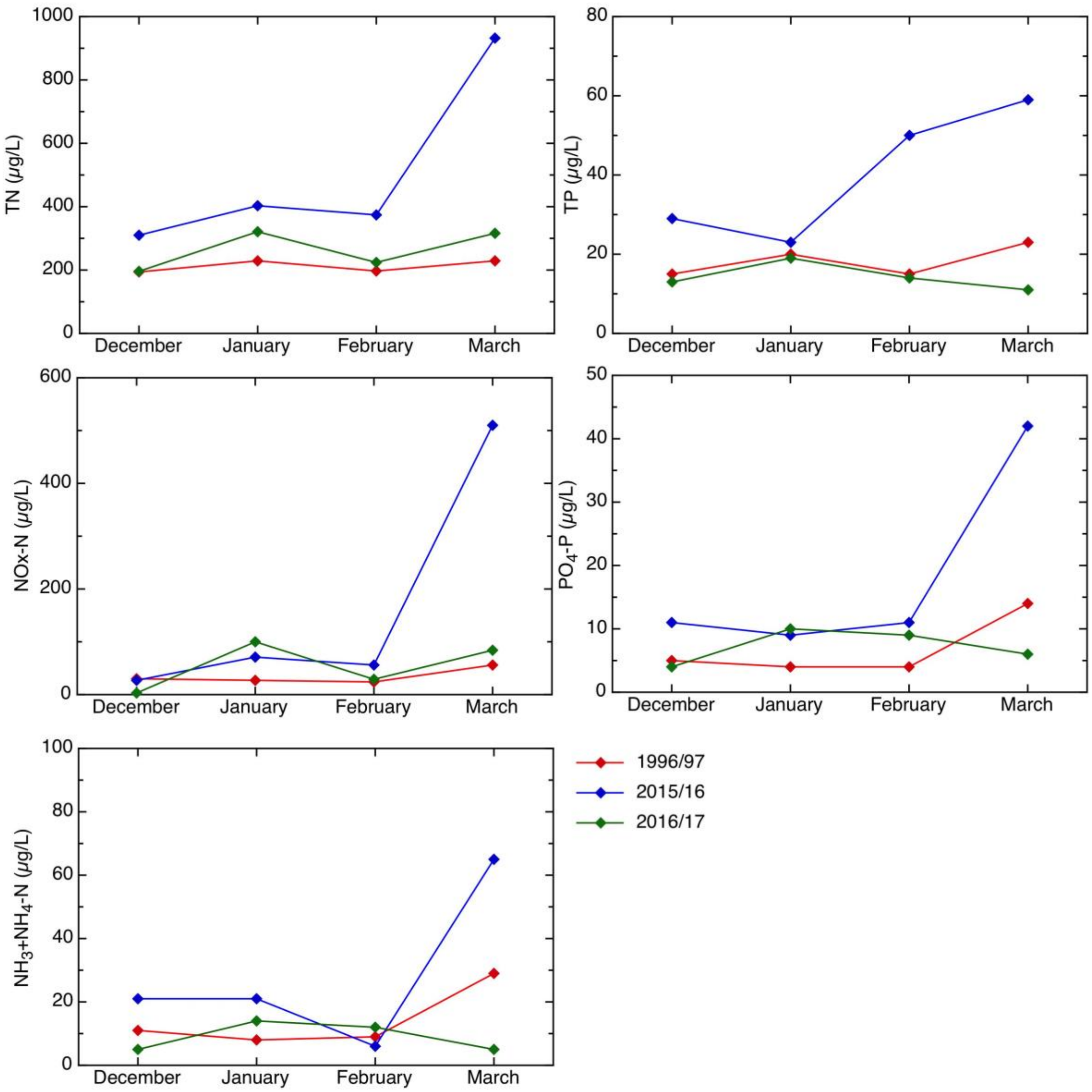


Fig. 30: Comparison of nutrient concentration observations between the three summer periods sampled in 1996/97, 2015/16 and 2016/17 for the Tyenna.

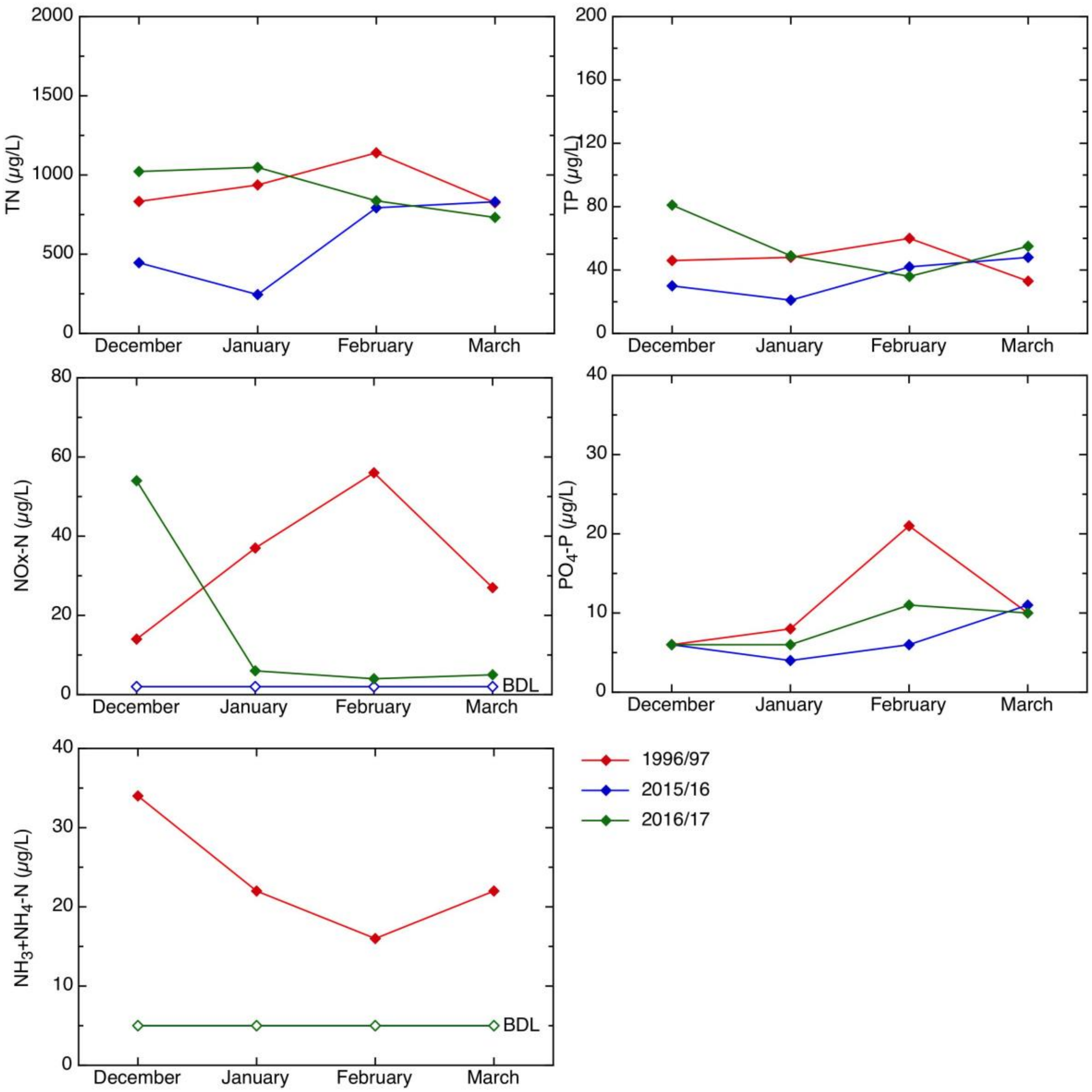


Fig. 31: Comparison of nutrient concentration observations between the three summer periods sampled in 1996/97, 2015/16 and 2016/17 for the Clyde River.

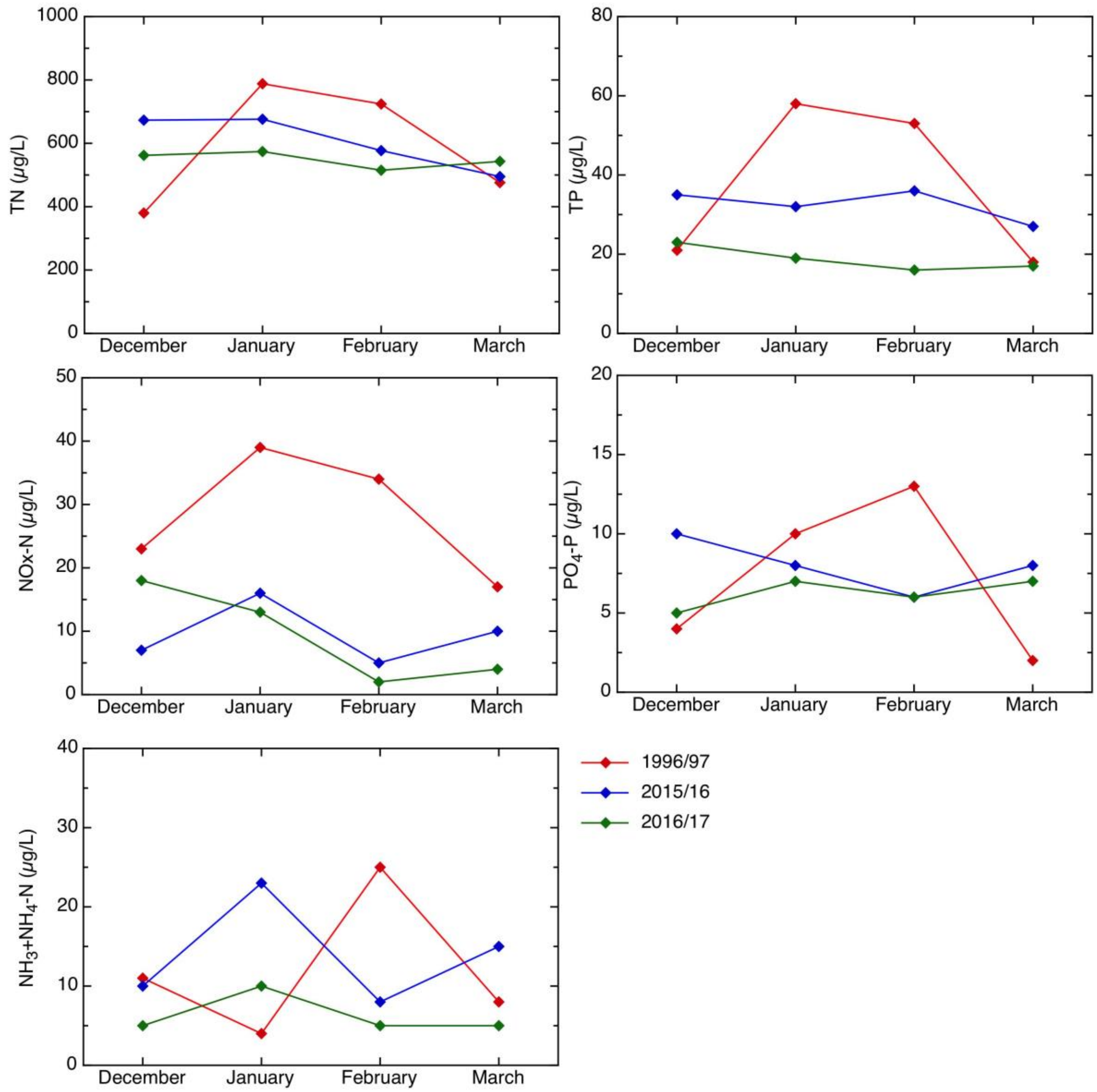


Fig. 32: Comparison of nutrient concentration observations between the three summer periods sampled in 1996/97, 2015/16 and 2016/17 for the Ouse River.

4.5.2 Bryn Estyn

The Bryn Estyn continuous nutrient analyser (Systea) data was used to investigate whether a relationship between flow and nutrient concentrations exist, so that nutrient loads can be better estimated because continuous flow data is more frequently available compared to nutrient data in the catchment. Fig. 33 shows nutrient concentrations for NH_3, NO_3, and PO_4 (in µM) versus estimated flow (in m^3/s) at Bryn Estyn. Although it appears that NH_3 concentrations decrease with increasing flow rates, there was no strong correlation between any of these nutrients and flow. However, extremely high flow rates (well above 200 m^3/s) were never associated with increased nutrient levels.

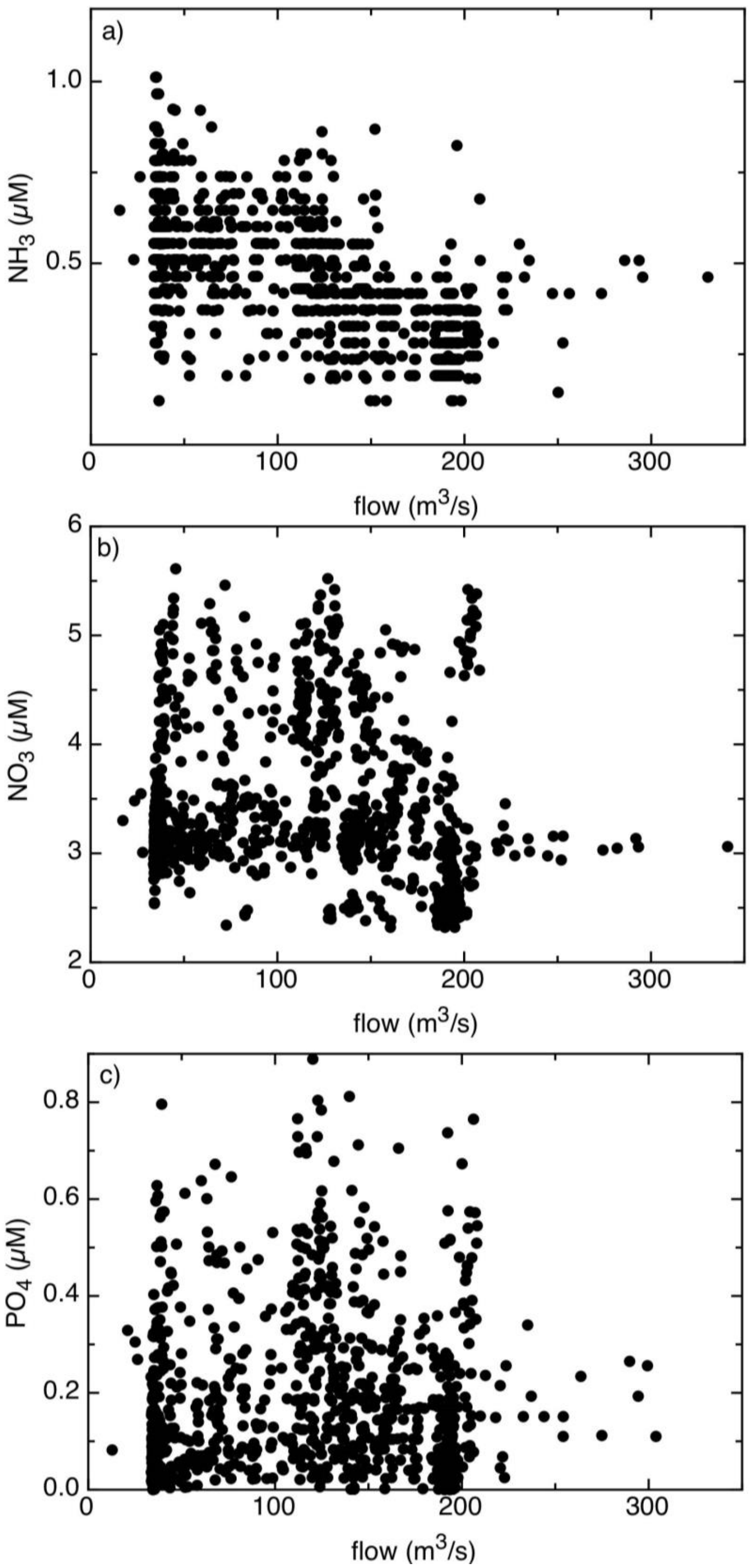


Fig. 33: Systea nutrient analyser results from Wild-Allen & Rayner (2014), versus estimated flow at Bryn Estyn. Neither NH_3 (a), NO_3 (b), nor PO_4 (c) correlated strongly with flow.

4.5.3 New Norfolk long-term record

Nutrient concentrations for the New Norfolk long-term monitoring site are shown in Fig. 34 and Fig. 35. Particularly ammonia, total phosphorus and filtered phosphate are difficult to evaluate due to the increase in detection limits. Total nitrogen and filtered phosphate increase significantly over the last 10 years (Whitehead et al., 2016).

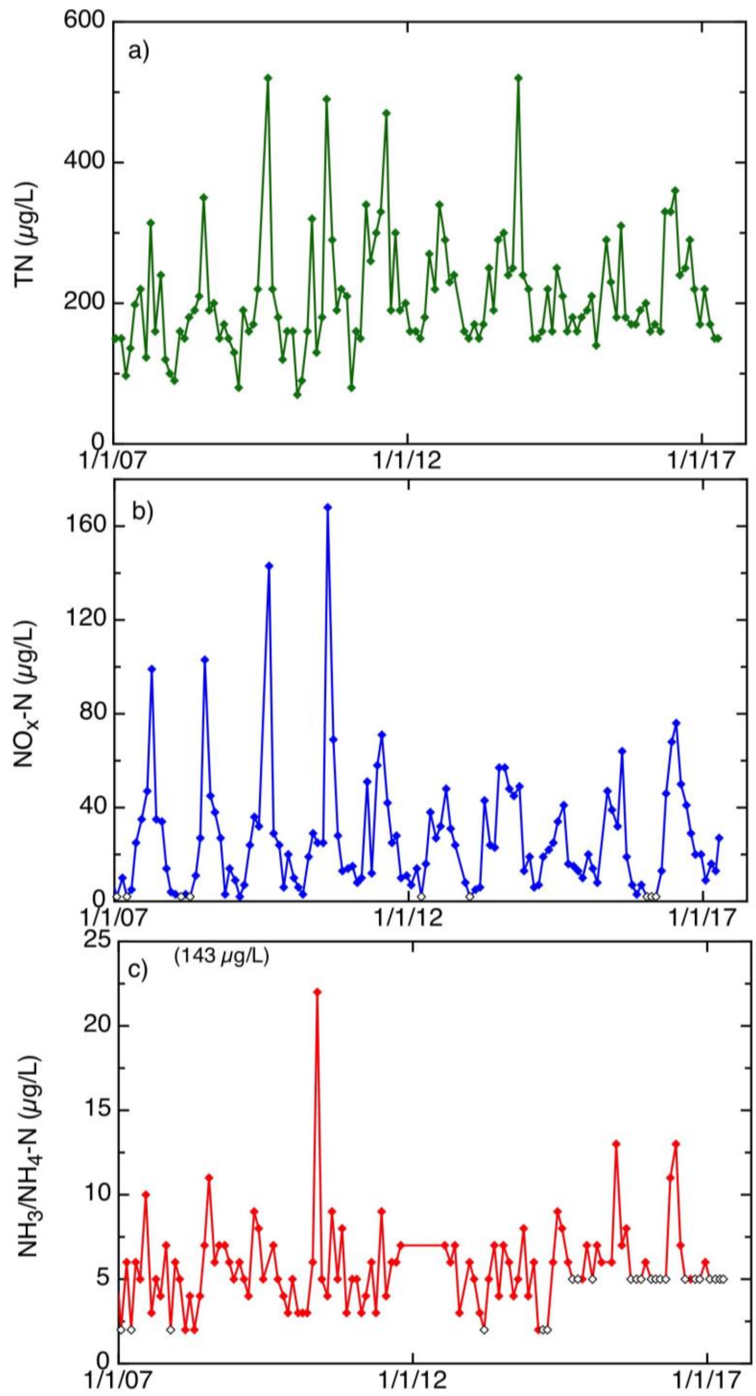


Fig. 34: Nitrogen data for the long-term monitoring site New Norfolk: a) Total nitrogen, b) nitrate and nitrite as N, and c) ammonia and ammonium as N.

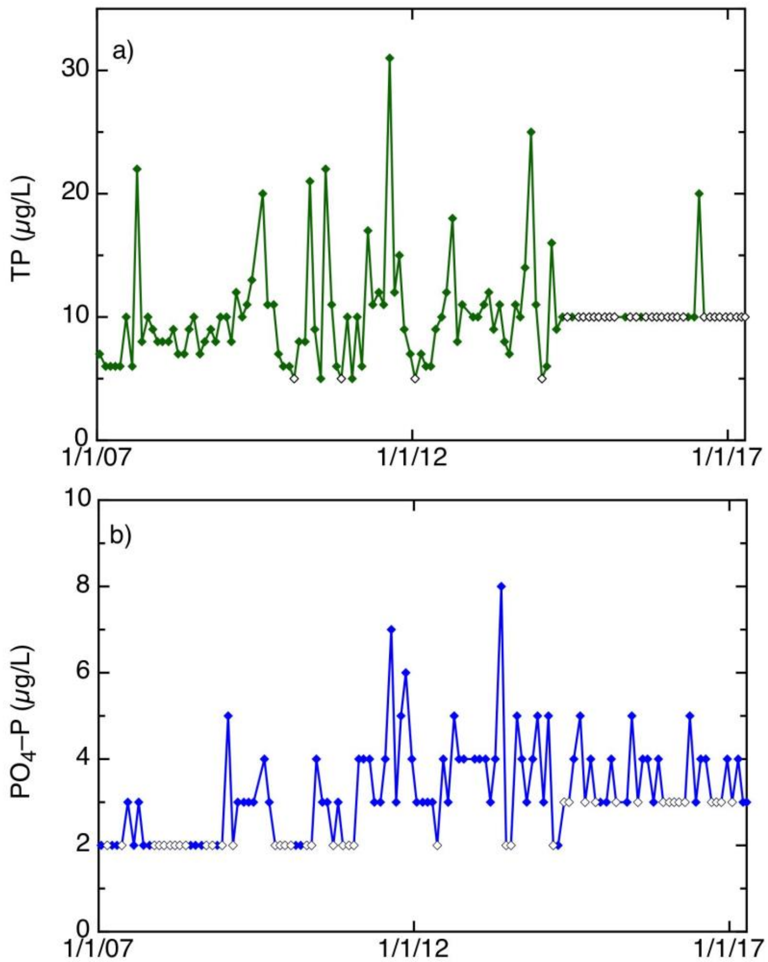


Fig. 35: Total phosphorus (a) and filtered phosphate (b) for the long-term monitoring site New Norfolk. Note the change in detection limit (values below detection limit indicated by white diamonds).

5 RECOMMENDATIONS

This two-year monitoring program revealed that nutrient concentration profiles across the Derwent catchment differ depending on the dominating landuse/activity. Overall, concentration and mass load calculations showed two major sources of nutrients at different times of the year: agriculture (along River Derwent main stem, River Clyde, Ouse River) during the winter months, and aquaculture (Florentine River, Tyenna River) during the late summer months. Periods of stress in the River Derwent and the upper Derwent Estuary, as characterised by growth of filamentous algae, taste and odour problems and loss of seagrass beds, that typically occur during the summer time, therefore coincide with elevated dissolved nutrient concentrations originating from catchments with fish farms (Florentine, Tyenna). However, there are also other fish farms along the River Derwent that were not sampled in close proximity downstream. Further monitoring would benefit from adding upstream and downstream sites of these point sources. Such information, in addition to end-of-tributary sites, would also allow for a better understanding of nutrient uptake rates along the rivers.

Winter increases in phosphorus and nitrogen concentrations from agriculturally used catchments and parts of the River Derwent main stem indicate that riparian zone management should be further improved in order to reduce diffuse nutrient runoff from agriculture to river and streams (ongoing work by Derwent catchment NRM). This includes the removal of cattle from streams and the establishment of buffer strips. In Europe for instance, fertilizers must not be applied within a certain distance to the river. The exact value varies across countries, but is generally between 10 and 50 m. The Derwent catchment would benefit from similar practices, particularly in areas were crops have established in immediate proximity to the river. Similar recommendations currently only exist for herbicide use in Tasmania (DPIPWE, 2002). Further management of dairy herds and dairy effluent is also recommended to reduce the annual nutrient loads from these catchments

Over the past few years, the detection limits at Analytical Services Tasmania have changed considerably. Filtered phosphate detection limits were increased in March 2014 from 2 to 3 µg/L, and total phosphorus from 2 to 10 µg/L. These detection limit changes are detrimental to long-term monitoring efforts such as occur at New Norfolk. For instance, total phosphorus values at New Norfolk do not exist for the past three years, despite analyses, because of the change in detection limit. In order to assess nutrient changes in the catchment over long-term records in the future, different analytical facilities or methods with lower detection limits should be considered.

Despite consulting DPIPWE, Hydro Tasmania and CSIRO, the source of the formula for flow estimates and Bryn Estyn could not be identified. It may be worthwhile to re-visit this equation and to determine its accuracy, given the site's importance for determining mass load inputs into the Derwent Estuary.

This monitoring program provides a valuable snapshot of water quality across the Derwent catchment during the period from 2015 to 2017. Given the recent and likely future changes in land and water use, as well increasing evidence of downstream impacts, it is recommended that some elements of this catchment monitoring program be continued, with support from multiple stakeholders.

6 ACKNOWLEDGEMENTS

The DEP acknowledges the assistance of the Derwent Catchment Working Group, and co-funding arrangement between the DEP, TasWater, NRM-South and Hydro Tasmania that has enabled this work to occur. Thank you to Hydro Tasmania and DPIPWE staff for provision of river flow data and Daniel Ray for support with river flow estimates for ungauged sites. Thank you also to Dr. Karen Wild-Allen for provision of Bryn Estyn nutrient analyser data, to Richard White for assistance with Arc GIS maps, and to Iain Koolhof for assistance with mass load calculations.

7 REFERENCES

Benham, A. (2017): Clear as mud: Solving the problem of MIB contamination in the Derwent River catchment, Tasmania. University of Tasmania honours thesis.

BoM (2018a): Australian Government Bureau of Meteorology, flow data accessed via http://www.bom.gov.au/waterdata/index.shtml?selected=Copyright.

BoM (2018b): Australian Government Bureau of Meteorology, climate data online accessed via http://www.bom.gov.au/climate/cdo/about/cdo-selecting-data.shtml.

Coughanowr, C. (1997): State of the Derwent Estuary: a review of environmental quality data to 1997. Supervising Scientist. Report 129. Canberra.

DPIPWE (2002): Rivercare Guideline for safe & effective herbicide use near water. Department of Primary Industries, Water and Environment, Tasmania; http://dpipwe.tas.gov.au/Documents/HerbicideGuidelines.pdf

Guildford, S.J., Hecky, R.E. (2000): Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: Is there a common relationship? Limnology and Oceanography, 45, 1213-1223.

Hughes, J.M.R. (1987): Hydrological characteristics and classification of Tasmanian rivers. Australian Geographical Studies 25, 61-82.

Redfield, A.C., Ketchum, B.H., Richards, F.A. (1963): The influence of organisms on the composition of seawater, p. 26-77. In M.N. Hill (ed.), The sea, volume 2, Interscience.

Whitehead, S., Coughanowr, C., Visby, I., Taylor, U. (2016): Annual technical report 2016, Derwent Estuary Program.

Whitehead, S., Coughanowr, C., Visby, I., Taylor, U. (2018): Annual technical report 2017, Derwent Estuary Program.

Wild-Allen, K., Rayner, M. (2014): Continuous nutrient observations capture fine-scale estuarine variability simulated by a 3D biogeochemical model. Marine Chemistry 167, 135-149.

Young, W.J., Marston, F.M., Davies, J.R. (1996): Nutrient exports and land use in Australian catchments. Journal of Environmental Management 47, 165-183.

APPENDIX

1) A relative percentage difference (RPD) analysis of duplicates was used to measure the precision of duplicate samples. The RPD was calculated as follows:
RPD(%)=100x(D1xD2)/((D1+D2)/2) where D1 is the value of the first measurement and D2 the value of the duplicate sample.

PO_4-P	0.93%
TP	-2.87%
TN	-0.37%
TKN	0.45%
NH_3+NH_4-N	-0.68%
NO_3-N	-0.43%
NO_x-N	-1.17%

2) Rainfall variability

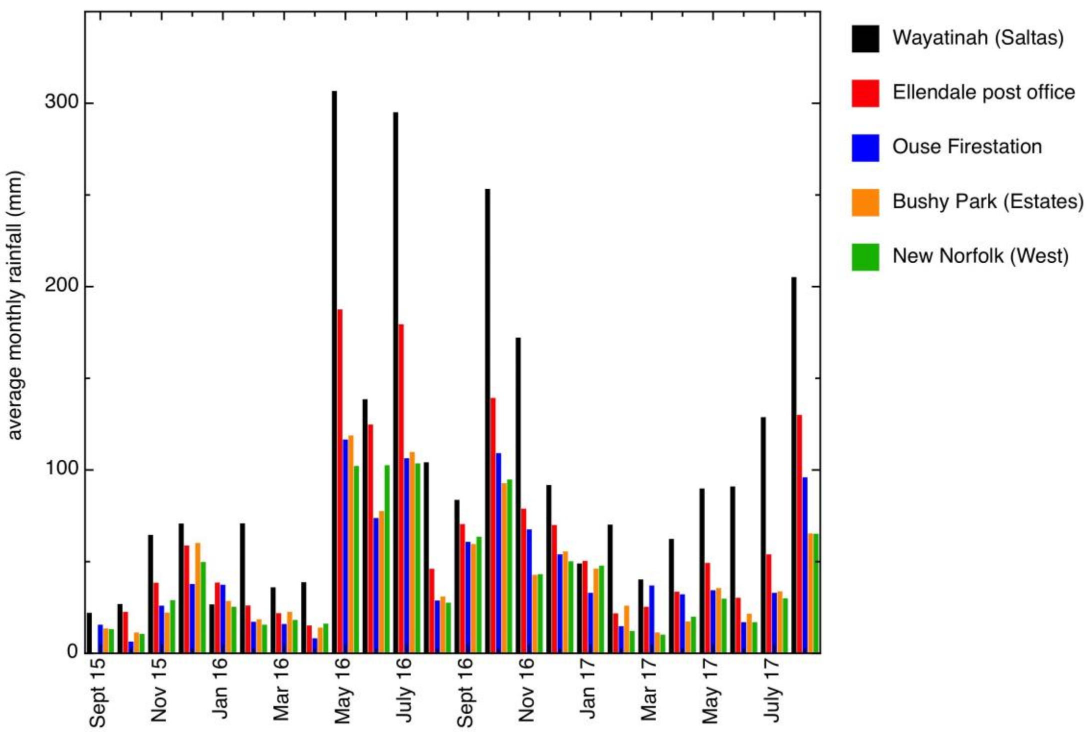


Fig. 36: Average monthly rainfall for the two monitoring years at Wayatinah, Ellendale, Ouse, Bushy Park and New Norfolk show the rainfall variability across the catchment, with average monthly rainfall decreasing from the headwaters towards the estuary.