Derwent Catchment Review

PART 2 Methodology and Data Analysis

Prepared for Derwent Catchment Review Steering Committee June, 2011

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Technical Advice on Water

Aquatic Science

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1 Project Methodology

A major component of the Derwent Catchment Review is to assess the various water quality data sets available, and to identify and analyse those datasets which suitably describe water quality in the Derwent at a sub-catchment and catchment scale. The scope for the project emphasised that the focus should be on long-term datasets, collected using robust methods and suitable measurement techniques, at key locations for relevant parameters.

As a starting point, the project team pursued data sets described in the comprehensive "*An Assessment of Water Quality Monitoring in the NRM South Region, Tasmania*" prepared by Hydro Tasmania Consulting (2008). Additionally, water quality monitoring locations described in the Strategic Water Information and Monitoring Plan prepared by DPIPWE through BoM funding (DPIPWE, 2010) were assessed. Discussions with stakeholders who have a key interest in water quality, revealed the existence of additional water quality data sets which were obtained where possible. The following sections outline the approach and criteria used to identify data sets for inclusion in this project.

1.1 Data priorities

The following criteria were used to prioritise inclusion of datasets in the review:

- Location of monitoring site in catchment, with priority given to sites at which flow data is also available, permitting the determination of loads;
- Length of dataset and frequency of monitoring, with a preference for data sets collected since 1990;
- Range of parameters of interest (physico-chemical, chemical, and biological) that characterise water quality changes over time;
- Quality of measurements (methods);
- Monitoring site and/or parameters are indicative of current and emerging threats to water quality on a catchment by catchment basis.

Additionally the following criteria were considered:

- Data availability and format ;
- Currency of data;
- Local or catchment activities and associated risks to water quality
- Any attached caveats on data use or sensitivity around identification of location/results/management actions.

The datasets summarised in Figure 1 were identified as of interest, based on the criteria outlined above. Data sets with both regular long-term water quality data and flow are rare in the Derwent catchment. Datasets highlighted in red in Figure 1 are used in this report, with a sub-set of locations, with sufficient flow and/or WQ data to give a picture of long-term water quality, and flow regime. More detailed maps are provided with the data analysis sections.

1.2 Data access issues

A number of issues arose from the task of collecting and collating water quality and flow data from a variety of stakeholders and data custodians. These included:

- Variable data formats: Water quality data is maintained in a variety of data bases, spreadsheets and hard copies by custodians. The integration of these multiple data types into combined data sets was extremely time intensive and provided variable results due to differences in sampling sites, parameters and sampling and analytical methodology;
- Currency of database: There were issues with both accessing old data, which was often held in differing formats, and with accessing recent data which had yet to be incorporated into databases;
- Data ownership: Some databases hold data from multiple sources, and access to data requires the approval of the original custodian or organisation. For example, the EPA holds regulatory data from Councils, water authorities, industry, and State government monitoring programs in a single database, and data cannot be accessed until the original data custodian has granted permission. This resulted in delays in accessing data, especially as the ownership of some datasets is unclear. For example, Southern Water hold some data from Councils prior to the formation of the new water authority, but ownership of the data was unclear.
- Although ownership can be an issue, multiple data sets held by a central repository is an efficient way to access information. For example, Level 2 WWTP data reported by Councils and Southern Water to the EPA was obtained from the EPA as it is maintained in a single database and therefore easier to integrate than separate reports from pre and post Southern Water formation. A similar central data repository for Level 1 data does not exist (except for data collected under programs run by the DEP), and therefore data from Level 1 premises is poorly represented in this report.
- Failure of stakeholders to engage in the project: Several key stakeholders declined to provide water quality information pertaining to their activities to the project; longer timelines or earlier consultation may have produced better outcomes.
- The provision, or export of data from databases within the short “data harvest” period allowed for in the project was found to be problematic for most stake holders. *It should be emphasized that the data presented in this section does not represent all the data available, rather it is a collation of data requested, and made available in an appropriate format during the initial data gathering stage of the project.* Some notable datasets are missing or incomplete, however a “line in the sand” was drawn to allow analysis of data within the project timeframe.
- An alternative to central repositories is being developed by the EPA. The system is a distributed database system that, like their central repository, also provides efficient data analysis and distribution. This database system was used for much of the data management within this report.

1.3 Data analysis issues

Once data sets were identified and obtained, producing a coherent picture of water quality in the Derwent catchment was complicated by several factors as described below:

- In general there is a lack of long-term continuous water quality data sets available, and even fewer for which water quality and flow are available.
- Several data sets contained intermittent water quality results over extended periods of time, but at different monitoring locations within the same water body. Frequently sites with different names were in similar locations, and the data sets could be combined into an episodic extended time-series. Sorting out the distribution of sites, and identifying if sites were compatible for merging data sets was, at times, a subjective exercise;
- Within data sets from the same monitoring site, the parameters monitored , the methods used to determine the parameters, and / or the monitoring frequency varied over time, compounding identification of catchment trends;
- Some databases contained multiple parameter names for the same parameter which required the extraction and evaluation of multiple data sets before deciding which were most suitable for analysis;
- General discrepancies in data bases, such as duplicate entries, internally inconsistent data, and missing information such as site locations, units of measurement, depth of sample or purpose of monitoring also presented challenges;
- Some datasets were collected to investigate specific issues over a limited timeframe, and need to be considered within this context. For example Hydro Tasmania monitored many lakes in the Derwent during 2007–2008, with the aim to document water quality issues associated with low lake levels and drought conditions. This data set presents a good snapshot of water quality under these conditions, but as there are not similar, recent data sets reflecting ‘normal’ or ‘wet’ conditions it is not possible to quantify impacts from the drought.
- A few very large data sets (Lagoon of Islands, Shannon Lagoon) were not included for analysis in this project, as these data sets have been collected as part of long-term-investigations linked to the development and implementation of management strategies by Hydro Tasmania. Instead, the project has focused on the impact of discharges from the water bodies on the downstream waterways. The reports associated with these projects can be used to obtain an understanding of these systems.
- Data on water allocations was obtained from the WIMS and WIST databases. Data were carefully checked for duplicates, expired and cancelled allocations, however numbers did not always correspond with data published elsewhere.
- Water allocation information does not give any indication of actual water use, and therefore adds some uncertainty about the actual volumes of water extracted for each allocation.
- Dams less than 1 ML are not required to be licensed, and therefore cannot be included in water allocation analysis.

- On a positive note, data queries generated through WIST were completed without issue, in a timely manner.

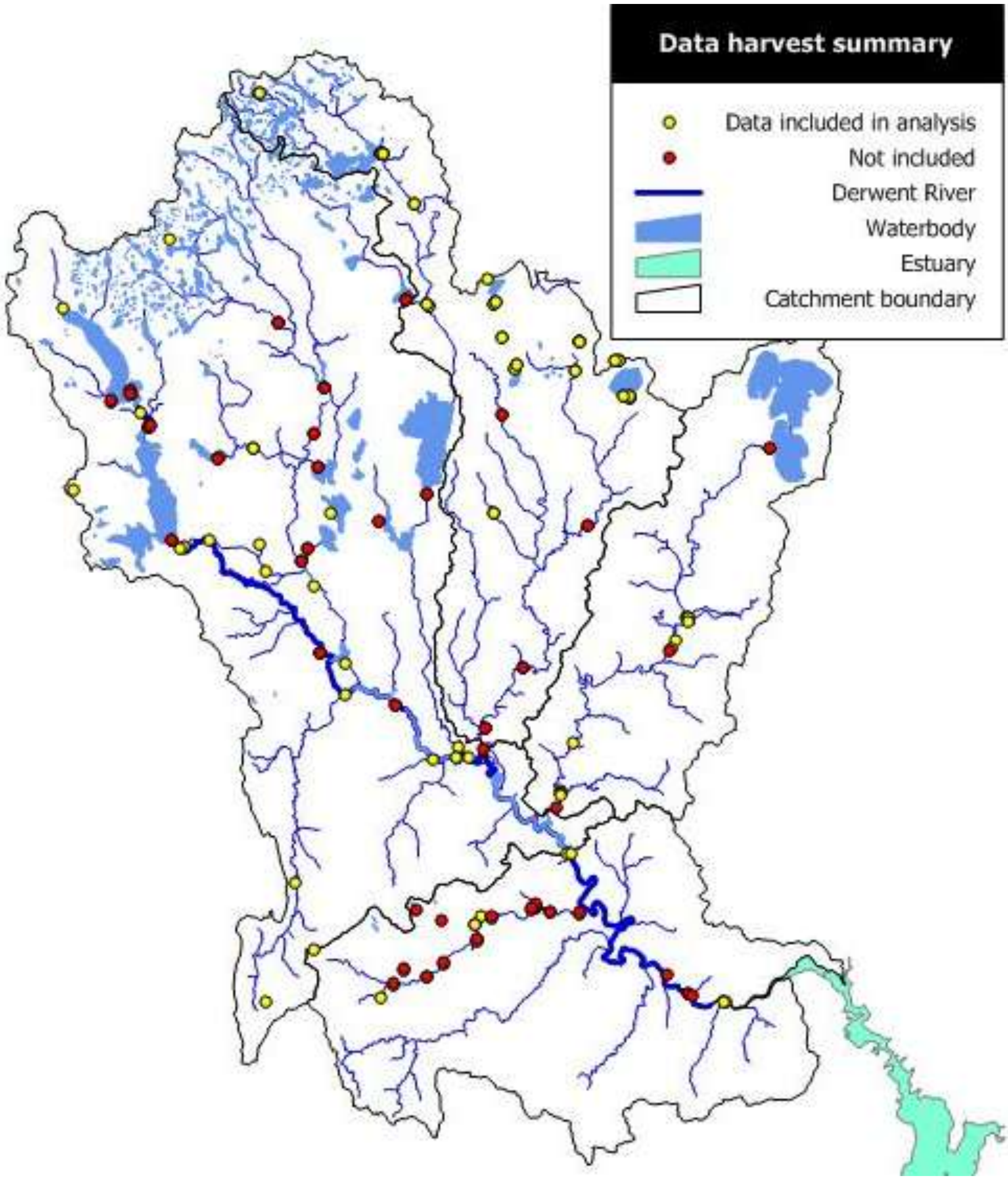


Figure 1 Summary of water quality and quantity locations within the Derwent catchment study area, considered and/or included in the data analysis sections. Base layer by CFEV, the LIST © State of Tasmania.

2 Ambient water quality

Data analysis is divided into 5 sections, largely based on the grouping of waterways within the power generation scheme, as this is one of the most significant influences on water movement in the Derwent catchment. Groups are illustrated in Figure 10 (PART1), and include:

- The Upper Derwent headwaters of the Central Plateau which have been developed into the Upper Derwent Power Scheme. This group includes the upper Derwent (Lake St Clair through to Tungatinah, the Clarence, Nive and upper Dee Rivers which flow to Tungatinah, and Lake Liapootah;
- The Lower Derwent Power Scheme Lakes, downstream of Lake Liapootah, including, Wayatinah and Cluny Lagoons, and Lakes Catagunya, Repulse, and Meadowbank;
- Western inflows to the Derwent River (Florentine, Broad, Tyenna, Styx and Plenty Rivers);
- Eastern inflows to the Derwent (Dee, Ouse and Clyde Rivers); and
- Derwent below Meadowbank to New Norfolk Bridge, including the intake for the Bryn Estyn Drinking Water Treatment Plant.

2.1 Derwent Headwaters – Central Plateau

Summary of hydrology and regulation

The headwaters of the Derwent River are a highly modified, regulated and managed flow network owing to the development of the Upper Derwent Power scheme. Figure 9 (PART 1) shows a simplified schematic of the area, omitting canals and diversion structures. As shown in Figure 9 and 10 (PART 1), the Upper Derwent region consists of two major arms, the Upper Derwent River, including Lake St Clair and Lake King William, which feeds the Tarraleah Power Station; and the Clarence, Pine, Nive, upper Dee and upper Ouse Rivers which have been highly modified to provide inflow to the Tungatinah Power Station. The combined flow from these power stations enters Lake Liapootah, from which flow is directed into the Lower Derwent Power Scheme.

Summary of data sources presented

The majority of water quality information available for this region is from Hydro Tasmania. Continuous monitoring of temperature, pH, EC, DO and turbidity occur in the Upper Nive River at Gowan Brae, on the Nive River at the Lyell Highway, and in Dee Lagoon near the outflow to Bradys Lake. Under Hydro Tasmania's Waterway Health Monitoring Program, lakes were periodically monitored on a bi-monthly basis for a 1 year period. This program terminated in the early 2000s, and since then, the Hydro monitoring in the Upper Derwent has focused on specific water quality issues and risks primarily related to periods of low lake levels associated with drought conditions. Additional water quality information is available upstream and downstream of the Waste Water Treatment Plant at Derwent Bridge, which discharges into the waterway connecting Lake St Clair and Lake King William; from a water quality survey completed by Davies and Driessen (1997), and the Upper Derwent Nutrient Study (1996-1997; Coughanowr, 2001).

Spatial & temporal trends

This section summarises the continuous recording results, and water quality information from Lake St Clair, Lake King William, Upper Nive River, Bronte Lagoon, Lake Echo, Dee Lagoon Tungatinah Lagoon and Lake Liapootah, as these sites reflect the major storages and provide information about water quality from all river systems in the Upper Derwent. These sites are shown in Figure 2. Water quality has been monitored by Hydro Tasmania in other impoundments in the Derwent Headwaters (Laughing Jack Lagoon, Little Pine Lagoon, Pine Tier Lagoon, Bradys Lake, and Lake Binney). Each of these flow into one of the lakes included in the analysis so are reflected on a sub-catchment basis.

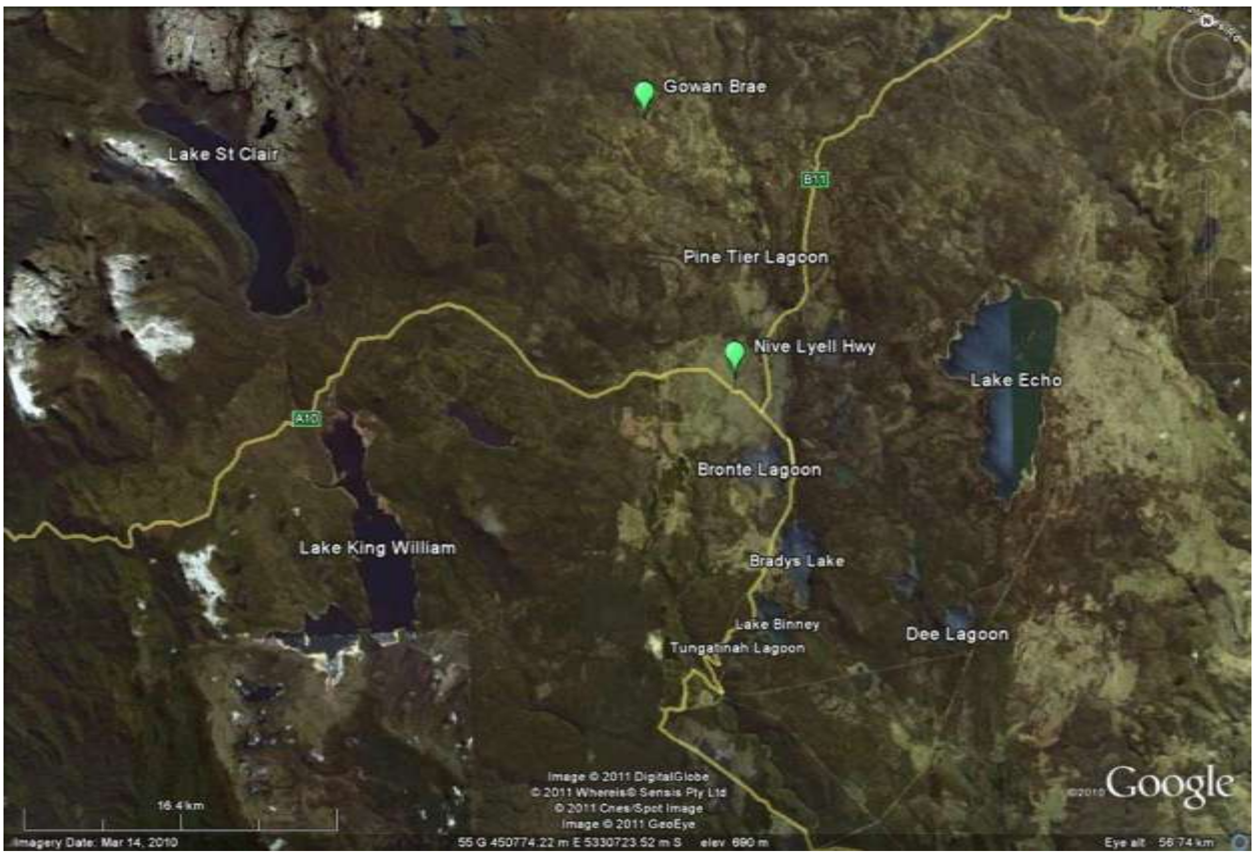


Figure 2. Google Earth image of the headwaters of the Derwent River on the Central Plateau showing monitoring locations discussed in this review.

2.1.1 Upper Derwent: Lake St Clair, Lake King William

As shown in Figure 11 (PART 1), a constant flow of between 20 – 30 cumecs enters the Tarraleah Power Station from Lake King William via the Butlers Gorge Power Station. The catchment for these lakes consists of land reserved for nature conservation, and production forestry. The lakes are near the western edge of the plateau, and drain predominantly Parmeneer sediments rather than dolerite. Hydro Tasmania monitored several locations in Lake St Clair and Butlers Gorge between 1990 – 2010, as shown on Figure 3 and Figure 16.

In Lake St Clair, monitoring was completed in the northern, central and southern lake during three periods between 1992 and 2002. One depth profile of water quality parameters is available from the 'Middle' sampling point in Lake St Clair, which was collected in March 2001, with sampling completed from the surface to a depth of 96.4 m, the length of the cable. At the time of sampling, the depth of the lake depth at the point was measured at 129 m *(P. Harding, pers. comm*.), so the profile does not capture what is occurring in the deepest waters of the lake.

Figure 3. Hydro Tasmania monitoring sites in Lake St Clair.

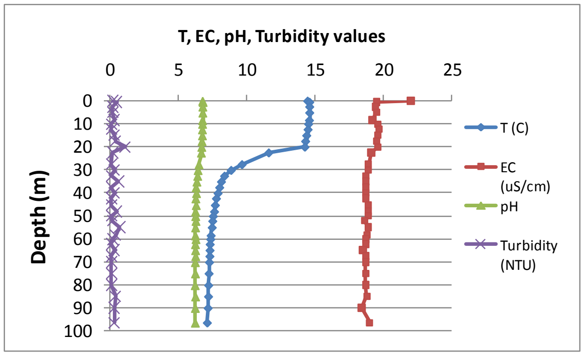


Figure 4. Temperature, EC and pH profile for "Middle" site in Lake St Clair on 14 March 2001. Data collected by Hydro Tasmania. A heroic effort by P. Harding and the IFC.

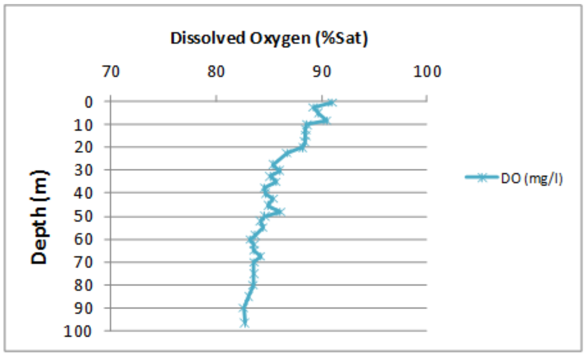


Figure 5. Dissolved oxygen (% Saturation) at Middle site in Lake St Clair 14 March 2001. Data collected by Hydro Tasmania.

The results (Figure 4 and Figure 5) show summer thermal stratification, with surface waters above 20 m depth about 7°C warmer than deeper water and the thermocline between 20 and 30 m. Turbidity and EC values are very low (Turbidity<1 NTU, EC from 18.5 to 19.5 µS/cm except for one surface value of 22 µS/cm) and show little variability over the depth of the water column. pH ranges from 6.8 to 6.2, with the higher values in the warmer surface waters. Dissolved oxygen saturation decreases slightly with depth, with the largest decrease corresponding to the thermocline, but the lake remains well oxygenated over the entire water column monitored. This suggests that the inputs/decomposition of organic matter is occurring at low rates in the water column, and / or there are sub-surface oxygenated inflows to the lake.

Information about seasonal water quality changes within Lake St Clair are available from profiles collected near Pumphouse point during 2000 – 2001 (Figure 6 through Figure 9). The temperature profiles show a uniform water column in September 2000, with initial thermal stratification recorded in November 2000 (note early profiles are shallower than summer profiles). The thermocline deepened between November and January 2001 from about 2 m to 12 m. By March, the entire water column had warmed to near the January surface values. In May 2001, the water column was cooler and uniform, suggesting that vertical mixing took place between these two sampling periods.

Dissolved oxygen and pH profiles reflect these changing thermal conditions, with DO saturation inversely proportional to temperature, as would be expected. pH values are higher during the summer months, probably reflecting increased primary production in the surface waters. Conductivity profiles show little variability over the year or with depth. Conductivities recorded are among the lowest in Tasmania and probably Australia, reflecting the weathered catchment geology and lack of disturbance in the tributaries of the lake.

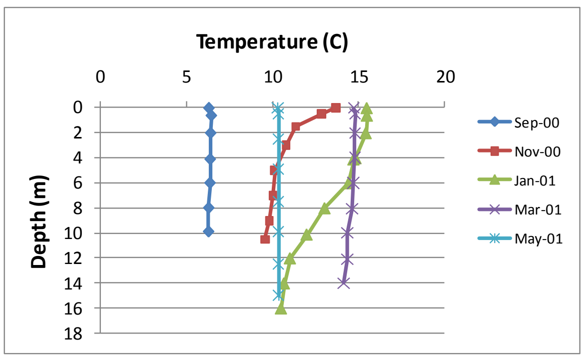


Figure 6. Water temperature (C) at Pumphouse Point monitoring site. Data Hydro Tasmania.

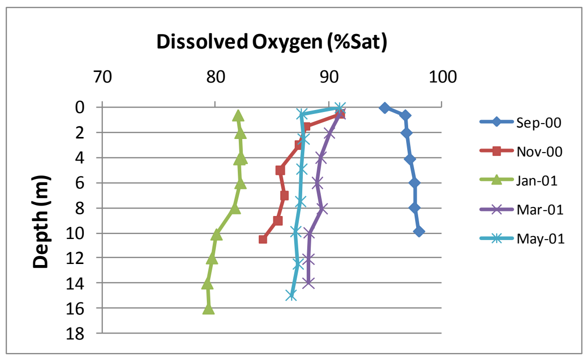


Figure 7. Dissolved oxygen (% Saturation) at Pumphouse monitoring site. Data Hydro Tasmania.

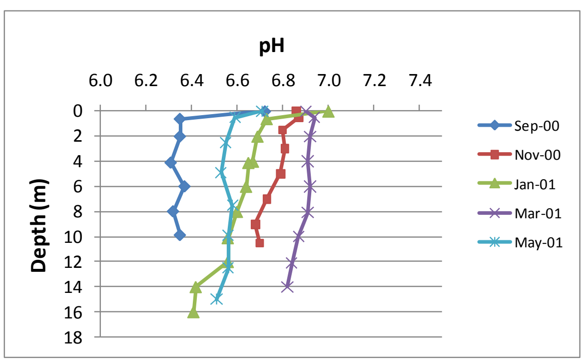


Figure 8. pH profiles at Pumphouse monitoring site. Data Hydro Tasmania.

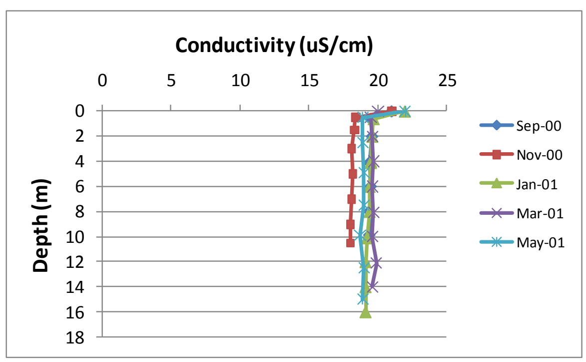


Figure 9. Electrical conductivity (µS/cm) at Pumphouse monitoring site. Data Hydro Tasmania.

Physical chemical parameters from the Narcissus site (Figure 10) show similar ranges to the other sites in Lake St Clair. pH (not shown) was also similar. Surface nutrient concentrations are available for the 'Middle' site (Figure 11), and show consistently low levels. Nitrate shows seasonality, with lower levels in summer, presumably due to uptake by algae. There are no site-specific water quality trigger values for Lake St Clair. Nitrate values exceed the ANZECC (2000) water quality trigger value for lakes and reservoirs which is 10 µg/L for (Nitrate + Nitrite). Chlorophyll-*a* levels at the Middle site are also below the ANZECC (2000) target of 3µg/l for Protection of Aquatic Ecosystems. Chlorophyll-*a* was also measured at the Narcissus (Figure 10) and Pumphouse sites (Figure 12) with both sites having values below 1 µg/L.

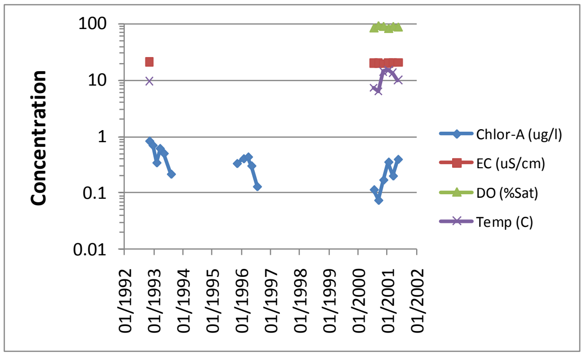


Figure 10. Chlorophyll-A and physical parameters from Narcsissus monitoring site in northern Lake St Clair. Data from Hydro Tasmania.

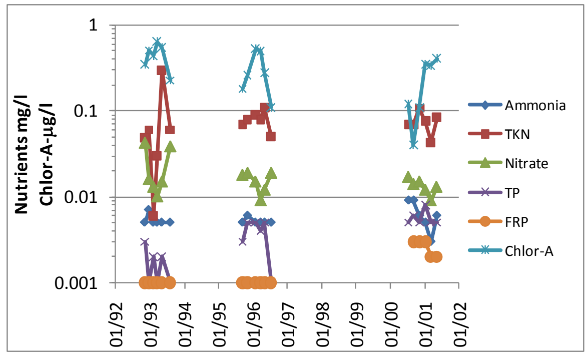


Figure 11. Nutrient concentrations (mg/L) and Chlorophyll-A concentrations (µg/L) at 'Middle' monitoring site in Lake St Clair. Data from Hydro Tasmania

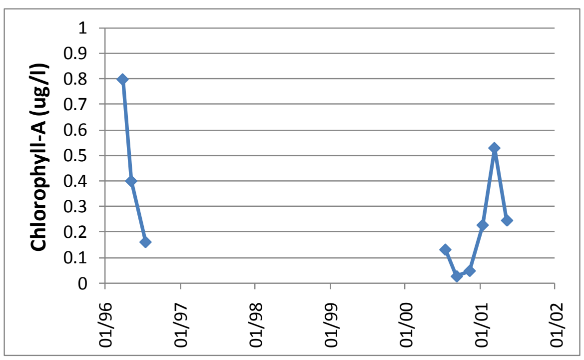


Figure 12. Chlorophyll-a (µg/L) off Pumphouse monitoring site in 1996 - 1997, and 2000-2001. Data collected by Hydro Tasmania

Total metal and sulphate analyses were completed on samples collected from the 'Middle' monitoring site during the July 2000 to May 2001 monitoring period. These results are summarised in Table 1 and show low concentrations of all metals, and sulphate levels <1 mg/L.

Surface water quality sampling was also completed in 1995 by Davies and Driessen (1997) from 11 sites on the Narcissus River and Lake St Clair. Data from the area around Pumphouse Point and Cynthia Bay (Figure 13) are summarised in Table 2. Samples collected elsewhere in the lake broadly agree with Hydro results presented above.

The results show consistently low levels of nutrients, within expected levels for freshwater lakes and reservoirs (ANZECC 2000). Faecal coliform levels in the water were above detection on several occasions, indicating that the drinking water supplied to the Visitor's Centre from the Lake did not meet health standards. The water supply is now treated, and all waste is directed to the waste water treatment plant (B. Batchelor pers comm.).

Point source monitoring is conducted upstream and downstream of the Lake St Clair Waste Water Treatment Plant (WWTP) which is a Level 2 premise managed by PWS. Monitoring data for the 11 year period 1999-2010 is presented in Figure 15a-h.

Table 1. Summary of total metal analyses from Middle monitoring point, July 2000-May 2001. Data collected by Hydro Tasmania.

Jul00-May01	Al_{tot} mg/L	Cd_{tot} mg/L	Cr_{tot} mg/L	Co_{tot} mg/L	Cu_{tot} mg/L
Mean	0.049	0.001	0.001	0.001	0.002
Median	0.052	0.001	0.001	0.001	0.001
Max	0.055	0.001	0.001	0.001	0.004
n=	5	6	5	5	6

Jul00-May01	Fe_{tot} mg/L	Pb_{tot} mg/L	Mn_{tot} mg/L	Ni_{tot} mg/L	Zn_{tot} mg/L	SO_4 mg/L
Mean	0.020	0.005	0.005	0.001	0.001	0.488
Median	0.020	0.005	0.005	0.001	0.001	0.520
Max	0.022	0.005	0.005	0.001	0.002	0.620
n=	6	5	6	5	6	6

Figure 13. Parks and Wildlife Service monitoring sites in Lake St Clair; CB1 is Cynthia Bay visitor Centre, CB2 is off shore, PP1 and PP2 are near Pumphouse Point. (Davies and Driessen, 1997).

Note that analytical detection limits for ammonia + ammonium are high, at 100 µg/L (seeTable 15a) and do not reflect the upstream concentrations monitored within the lake (see Table 2). Nitrate data (not shown) is similarly of questionable value as the detection limit (100 µg/L) is too high to detect either natural background concentrations (around 10 µg/L) or those that may be contributed by the WWTP.

Table 2. Statistical summary of water quality monitoring results from Cynthia Bay and Pumphouse Point, collected by Parks and Wildlife Service in 1995. (Data from PWS, Davies and Driessen, 1997)

Site	Statistic	Nitrate-N µg/L	Ammonia-N µg/L	TN µg/L	DRP µg/L	TP µg/L	Turbidity NTU	EC µS/cm	F. col CFU/100ml
CB1	Mean	9.8	2.3	99.7	1.0	1.8	0.8	23.7	44.3
	Median	10.0	1.0	92.0	1.0	1.0	0.5	23.0	<1
	max	19.0	7.0	151.0	1.0	5.0	2.6	27.0	210
	n	*11*	*9*	*9*	*9*	*9*	*9*	*9*	*5*
CB2	Mean	14.5	2.1	87.5	1.0	1.2	0.4	22.3	<1
	Median	15.0	1.0	81.0	1.0	1.0	0.3	22.0	<1
	max	20.0	6.0	124.0	1.0	2.0	1.1	26.0	2
	n	*11*	*11*	*11*	*11*	*11*	*11*	*11*	*5*
PP1	Mean	13.7	3.2	91.4	1.0	1.6	0.7	22.5	<1
	Median	13.0	3.0	79.0	1.0	1.0	0.3	22.0	<1
	max	22.0	7.0	155.0	1.0	7.0	4.6	26.0	<1
	n	*11*	*10*	*11*	*11*	*11*	*11*	*11*	*5*
PP2	Mean	14.8	5.4	85.9	1.0	1.3	0.3	22.2	<1
	Median	16.0	1.0	80.0	1.0	1.0	0.3	22.0	<1
	max	21.0	35.0	138.0	1.0	3.0	0.5	26.0	<1
	n	*11*	*10*	*11*	*11*	*11*	*11*	*11*	*5*

Total P is occasionally elevated in the downstream samples until 2005. TP is typically <5 µg/L upstream in Lake St Clair. Total Kjehldahl Nitrogen, which represents the combination of organically bound nitrogen and ammonia, is occasionally elevated at the downstream monitoring site. Conductivity, pH, dissolved oxygen and TSS are unchanged in relation to inputs from the WWTP, with pH and DO showing significant seasonality. Low oxygen recorded in summer 2010 corresponds with extremely low flow in the river, and increased water temperatures (data not shown).

Faecal contamination data, monitored as thermotolerant coliforms, suggests that natural or “background” sources of faecal material are detectable at both monitoring sites, and that increased levels of coliforms downstream of the WWTP are only infrequently elevated above the background level. The flux of nutrients into the waterway cannot be calculated as no flow data are available. The impacts of these inputs on Lake King William are discussed in the following section.

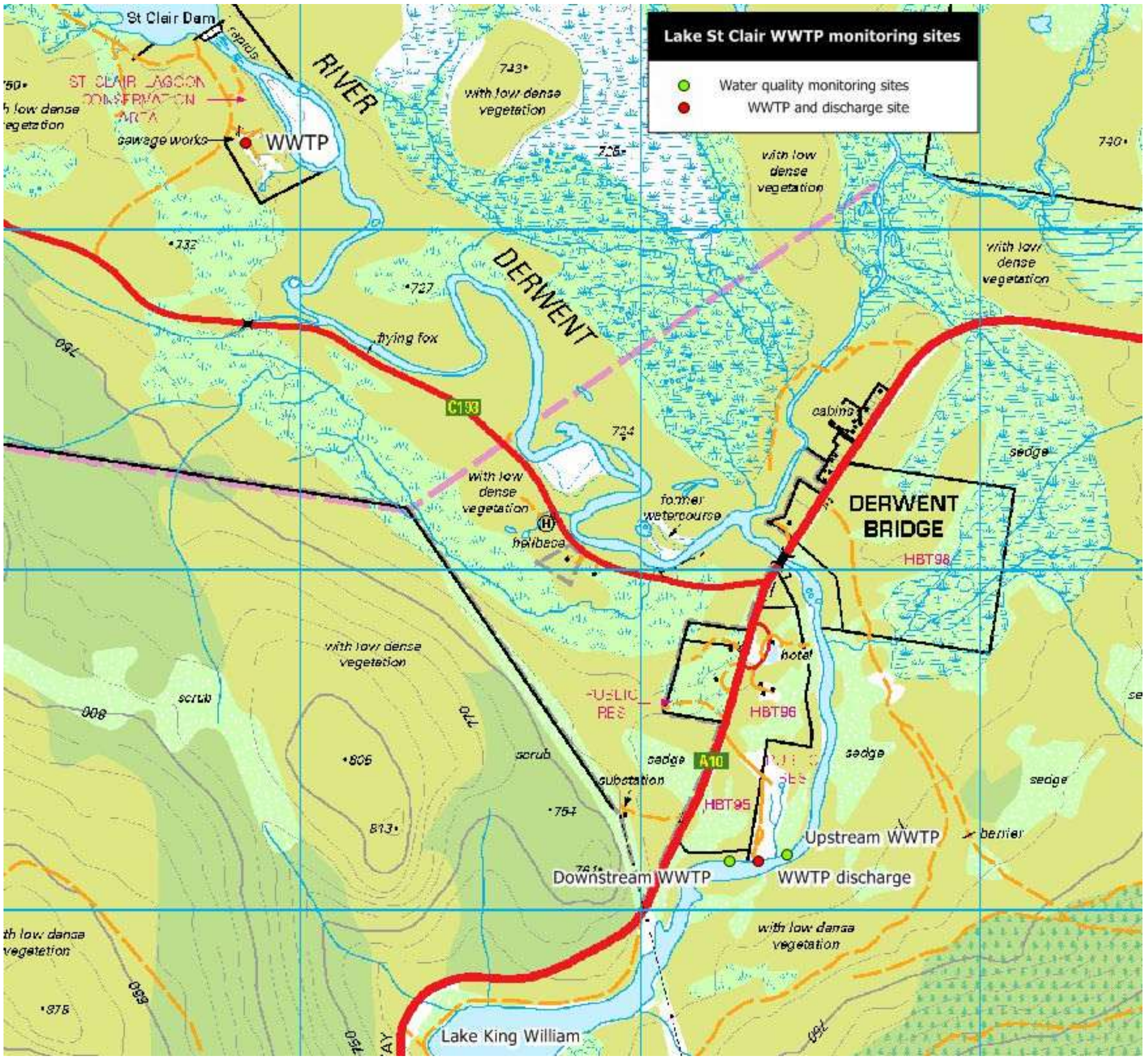
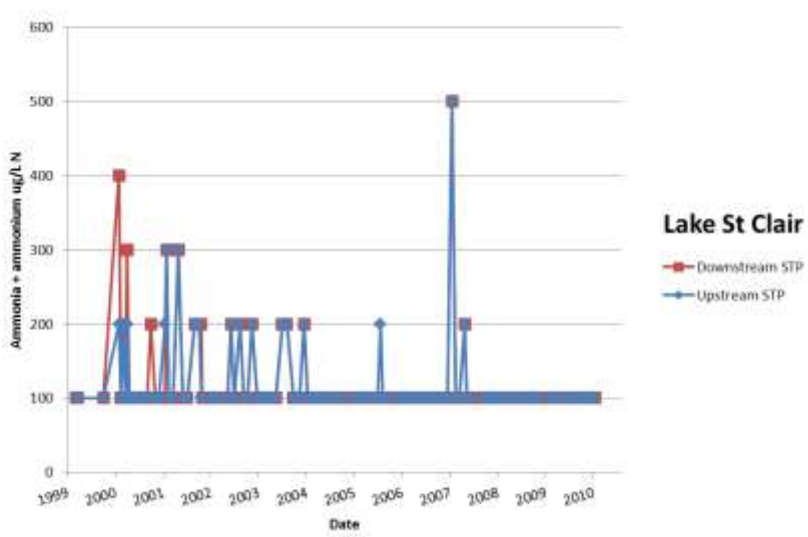
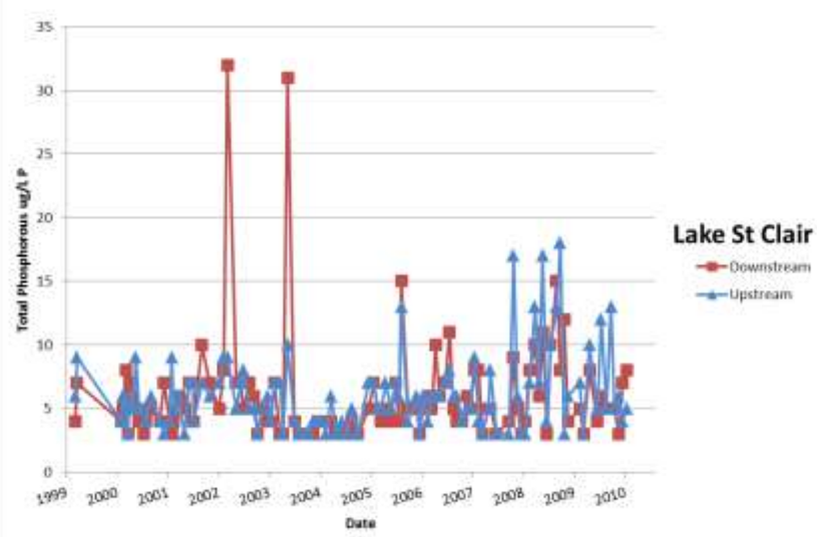


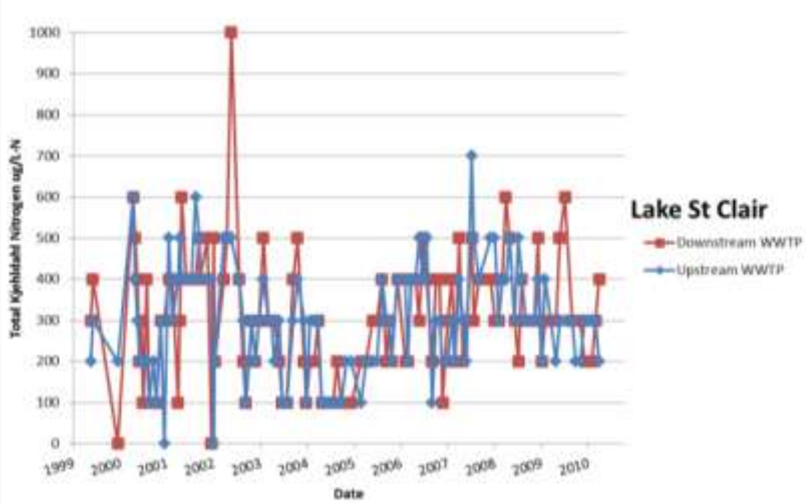
Figure 14 Location of upstream and downstream monitoring locations (green dots), Lake St Clair WWTP.



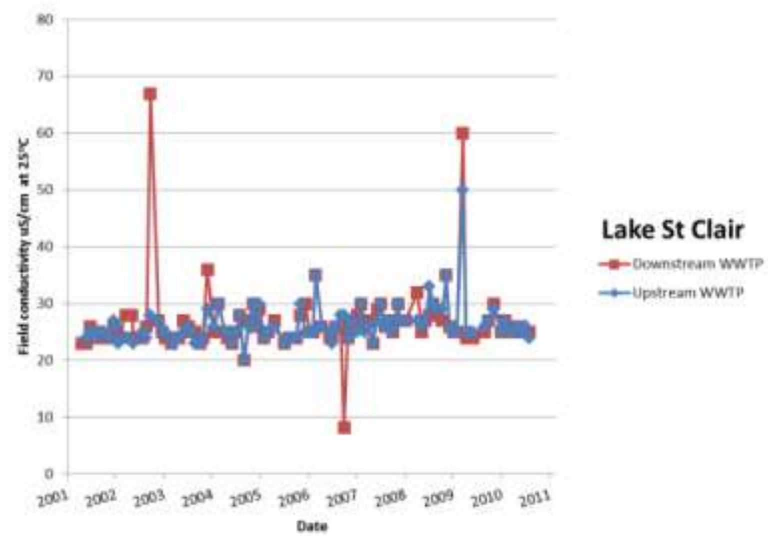
a) Ammonia and ammonium (ug/L-N)



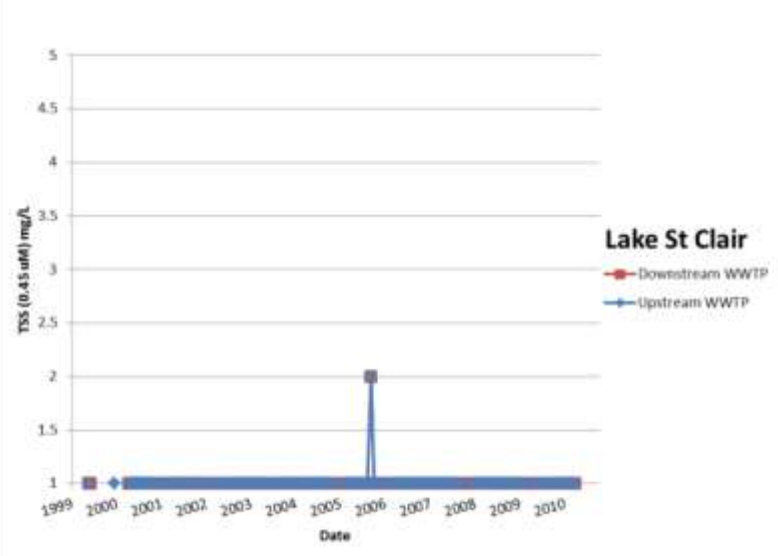
b) Total phosphorous (ug/L-P)



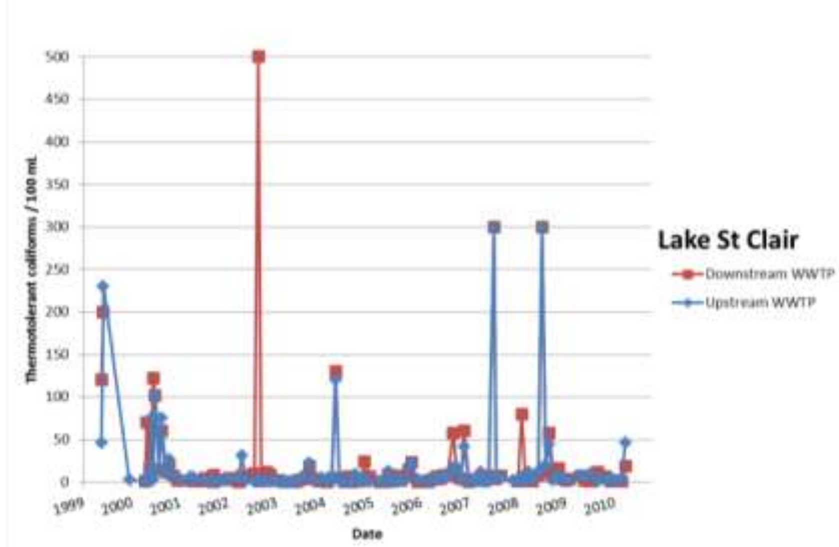
c) Total Kjehdahl nitrogen (ug/L-N)



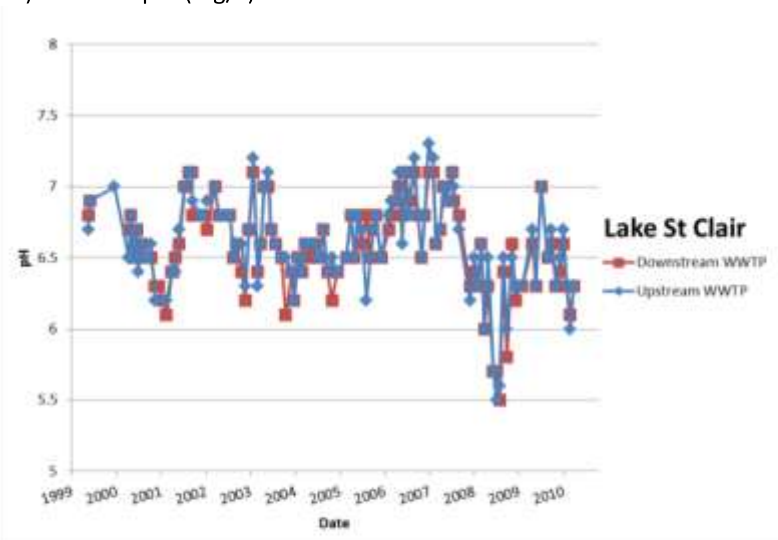
d) Field conductivity (μS/cm at 25^{o}C)



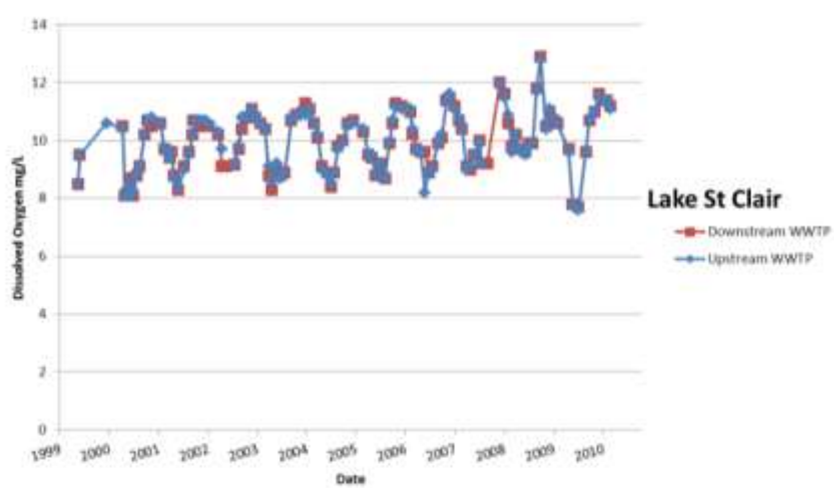
e) TSS 0.45 µm (mg/L)



f) Thermotolerant coliforms presumptive (cells/100 mL)



g) pH



h) Dissolved oxygen (mg/L)

Figure 15 a-h Results of upstream (blue) and downstream (red) monitoring in the River Derwent for the Lake St Clair WWTP, 1999-2010. Data from PWS and EPA.

2.1.2 Lake King William

Lake King William receives inflow from Lake St Clair, the Navarre River and runoff from the King William Ranges. Discharge from the lake enters Butlers Gorge Power Station at a rate of between 20 – 30 cumecs throughout the year.

Hydro Tasmania has monitored water quality in the lake between 1992 and 2008, with monitoring during the 2007 – 2008 period initiated due to low lake levels resulting from drought conditions. Hydro monitoring locations in Lake King William are shown in Figure 16.

Figure 16. Hydro Tasmania monitoring sites in Lake King William.

Physico-chemical profiles collected from the lake near Clark Dam in 2000-2001 (Figure 17 - Figure 20) show seasonal temperature changes with thermal stratification in summer, similar to Lake St Clair. Surface dissolved oxygen values are high, but in January 2001 levels were reduced at depth. During this same monitoring period the pH is elevated in the surface waters, and combined the results suggest surface algal growth with degradation of organic material at depth. Compared to Lake St Clair, EC values are slightly higher, although still below the Hydro operational target of 30 µS/cm.

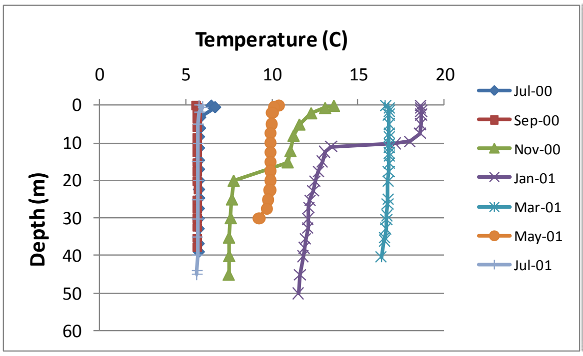


Figure 17. Temperature profiles from Lake King William 2000-2001 from 'Off Clark Dam' monitoring site. Data from Hydro Tasmania.

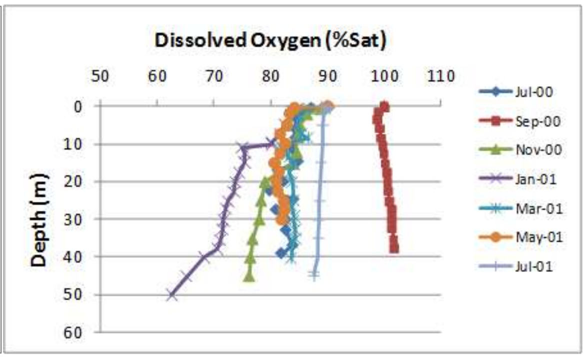


Figure 18. Dissolved oxygen (%Saturation) from Lake King William from 'Off Clark Dam' monitoring site.2000-2001. Data from Hydro Tasmania.

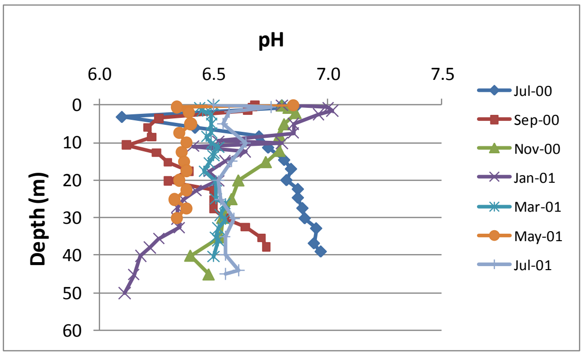


Figure 19. pH profiles from Lake King William from 'Off Clark Dam' monitoring site.2000-2001. Data from Hydro Tasmania.

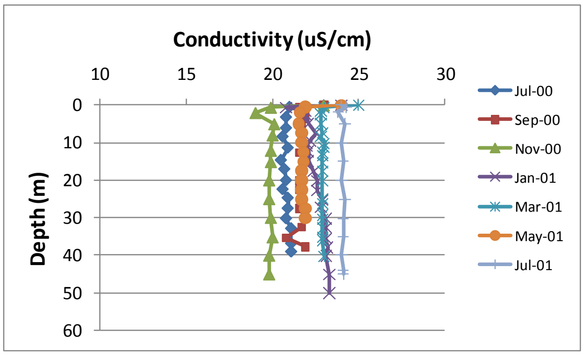


Figure 20. Electrical conductivity profiles from Lake King William from 'Off Clark Dam' monitoring site.2000-2001. Data from Hydro Tasmania.

Comparisons of physico-chemical parameters and nutrients from 1992 – 2002 and 2008 provide an indication of changes to the lake over time (Figure 21 - Figure 27). Temperature, EC and pH show similar ranges in results between the two monitoring periods. Turbidity values in 2008 were higher than those recorded during the earlier monitoring (Figure 25) and may be related to increased turbidity associated with wave action on exposed shore lines, and / or increased algal growth during the low lake period. The turbidity levels remained below Hydro's site specific trigger of 10 NTU.

Unfortunately, water quality results for similar Nitrogen species are not available for the two periods, and TKN is compared with Total Nitrogen in Figure 25. The TN values in 2008 exceed Hydro's site specific target of 0.2 mg/L, but are below the ANZECC (2000) trigger value of 0.35 mg/L. TN and TKN values are lower in summer months, consistent with the uptake of nutrients through algal growth during the summer.

Total phosphorus (Figure 26) shows a seasonal peak in summer of 1992-93, with increasing concentrations 'baseline' levels between 1992 and 2002, with the 2002 levels similar to the 2008 results. This increase corresponds to the period when the waste water treatment plant was implemented downstream of Lake St Clair, and *may* be reflecting this input. The TP concentrations remain below the ANZECC (2000) and Hydro's site-specific targets of 0.01 mg/L.

Chlorophyll-*a* levels are higher in 2008, as compared to the previous monitoring period. This increase is likely related to the drought which reduced the through-flow of water in the lake. Peak concentrations exceeded the ANZECC (2000) trigger value of 3 µg/L, and the Hydro site-specific trigger of 2.5 µg/L(Hydro Tasmania Consulting, 2008a). As there are no results between 2002 and 2008, nor any results since 2008, it is not possible to determine if this increase is solely related to the drought, or associated with a longer-term trend of increased algal growth.

Blue-green algae were found to be present at elevated concentrations throughout the 2008 monitoring period (Figure 28), including during winter. The cell counts exceeded 2,000 cells/mL, which lead to Hydro Tasmania determining the cyanobacteria biovolume in the samples, consistent with NH&MRC guidelines. The biovolumes in Lake King William were found to be within the NH&MRC surveillance level of 0.04 – 0.4 mm^3/L requiring no further action (Hydro Tasmania, Lake King William Status Report, May 2008). Hydro Tasmania also conducted toxicological test work confirming the algae were non-toxic at the concentrations present in the lake (*M^{c}Causland, pers.comm.*).

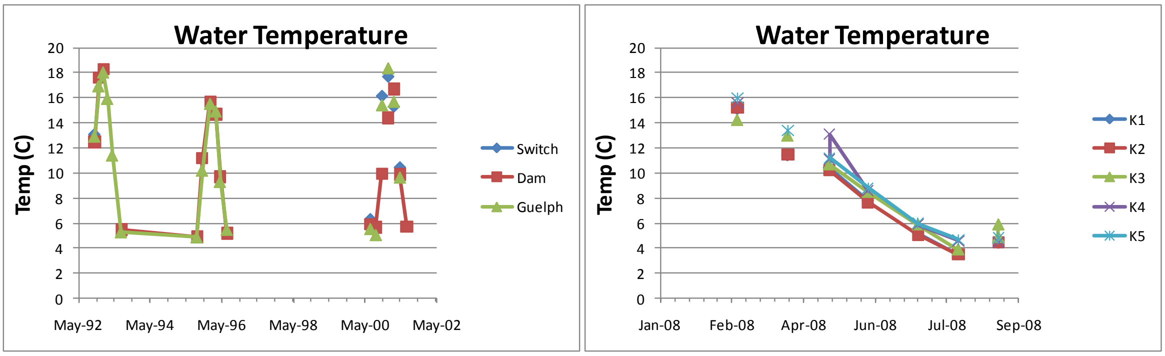


Figure 21. Time-series of water temperature in Lake King William. Left graph shows results from 1992 - 2002, right graph shows results from 2008. Data from Hydro Tasmania.

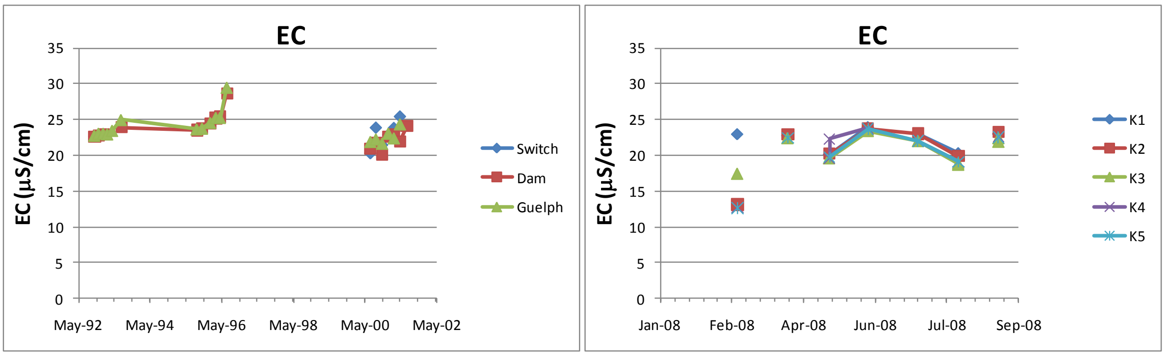


Figure 22. Time-series of electrical conductivity (µS/cm) in Lake King William. Left graph shows results from 1992 - 2002, right graph shows results from 2008. Data from Hydro Tasmania.

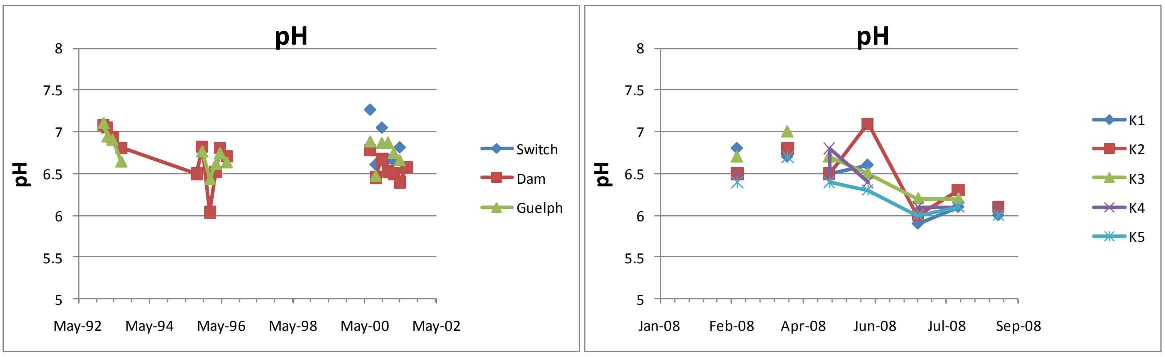


Figure 23. Time-series of pH in Lake King William. Left graph shows results from 1992 - 2002, right graph shows results from 2008. Data from Hydro Tasmania.

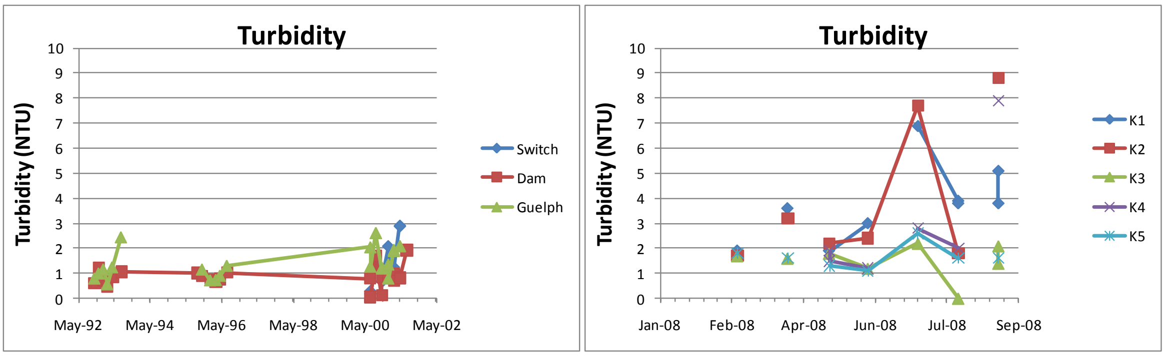


Figure 24. Time-series of turbidity in Lake King William. Left graph shows results from 1992 - 2002, right graph shows results from 2008. Data from Hydro Tasmania.

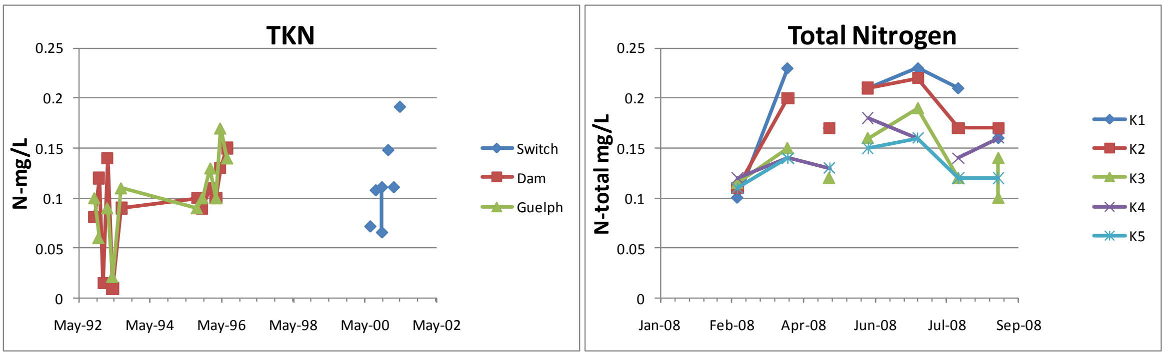


Figure 25. Time-series of TKN and Total Nitrogen in Lake King William. Left graph shows TKN results from 1992 - 2002, right graph shows TN results from 2008. Data from Hydro Tasmania.

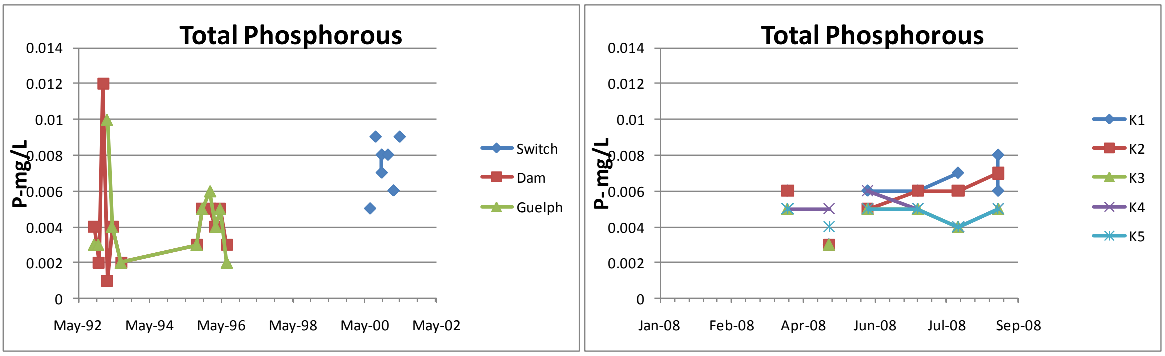


Figure 26. Time-series of Total Phosphorus in Lake King William. Left graph shows results from 1992 - 2002, right graph shows results from 2008. Data from Hydro Tasmania.

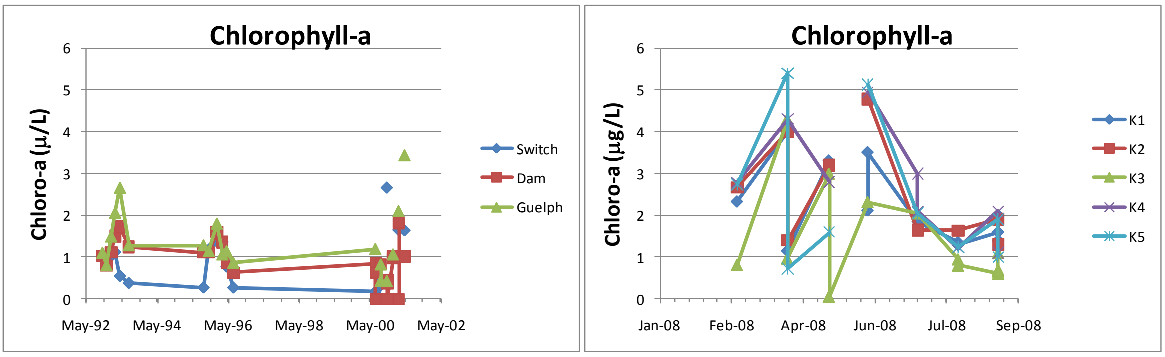


Figure 27. Time-series of Chlorophyll-*a* in Lake King William. Left graph shows results from 1992 - 2002, right graph shows results from 2008. Data from Hydro Tasmania.

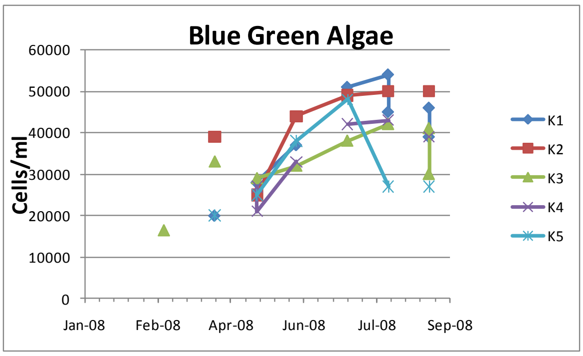


Figure 28. Time-series of blue-green algae in Lake King William from 2008. Data from Hydro Tasmania.

Total metal concentrations were determined between July 2000 and May 2001 in surface samples from Switchyard Bay in Lake King William. A summary of results (Table 3) shows that both metal and sulphate levels are very low. The aluminium and iron concentrations are likely attributable to fine particulates or colloidal material in the water.

Table 3. Summary of total metal concentrations collected from 'Switchyard Bay' July 2000 – May 2001. Data from Hydro Tasmania.

Jul00-May01	Al_{tot} mg/L	Cd_{tot} mg/L	Cr_{tot} mg/L	Co_{tot} mg/L	Cu_{tot} mg/L
Mean	0.045	0.001	0.001	0.001	0.001
Median	0.054	0.001	0.001	0.001	0.001
Max	0.058	0.001	0.001	0.001	0.002
n=	5	6	5	5	6

Jul00-May01	Fe_{tot} mg/L	Pb_{tot} mg/L	Mn_{tot} mg/L	Ni_{tot} mg/L	Zn_{tot} mg/L	SO_4 mg/L
Mean	0.041	0.005	0.005	0.001	0.003	0.660
Median	0.035	0.005	0.005	0.001	0.003	0.610
Max	0.075	0.005	0.005	0.001	0.005	1.000
n=	6	5	6	5	6	5

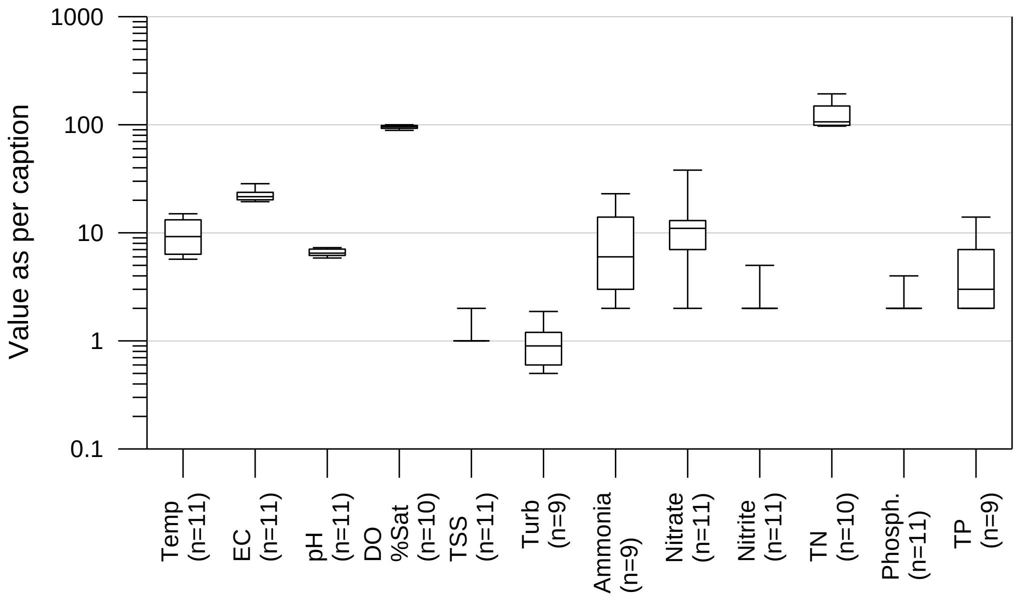


Figure 29. Water quality results from Upper Derwent Nutrient Study 1996-1997 from Tarraleah Canal. Temp (°C), EC (µS/cm), pH, DO (% Saturation), TSS (Total Suspended Solids in mg/l), Turbidity (NTU), Nitrate (µg/l), nitrite (µg/l), Total Nitrogen (µg/l), Phosphate, (µg/l), Total Phosphorus (µg/l). Data from Coughanowr (2001)

2.1.3 Tarraleah Canal

Downstream of the Butlers Gorge Power Station water is transported to the Tarraleah Power Station via the Tarraleah Canals. Water quality in one of the Canals was measured between May 1996 and April 1997 as part of the Upper Derwent Nutrient Study (Coughanowr, 2001). The results (Figure 29) shows ranges of parameters similar to those measured within Lake King William.

2.1.4 Upper Nive River

The Nive River upstream of Pine Tier Lagoon is an unregulated water way with its catchment extending into the Walls of Jerusalem National Park. Hydro Tasmania maintains a continuous recording flow and water quality site at Nive at Gowan Brae. Results from this site are summarised in Figure 30 through Figure 35 .

The flow results provide an indication of what the flow regime of the Upper Derwent was like, prior to modification. Flows show a prolonged period of relatively high base flow, punctuated with episodic high flow events, and a short summer period with very low flow. Water temperature and EC generally show peaks during low-flow periods. pH is also higher during some summer periods, probably associated with increased photosynthetic activity in the river. Dissolved Oxygen is higher in winter when water temperatures are lower. Turbidity values are overall very low, suggesting low sediment yield from the catchment.

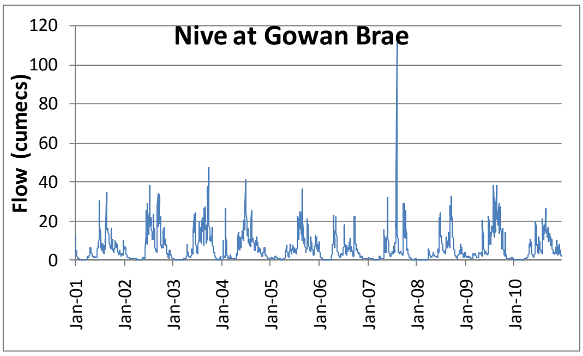


Figure 30. Average daily flow at Nive at Gowan Brae 2001 – 2010. Continuous data Hydro Tasmania.

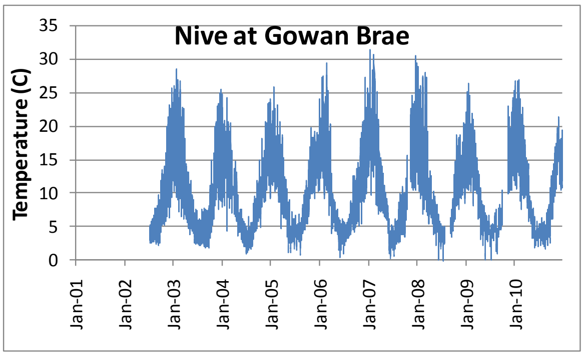


Figure 31. Hourly temperature at Nive at Gowan Brae 2001 – 2010. Continuous data Hydro Tasmania.

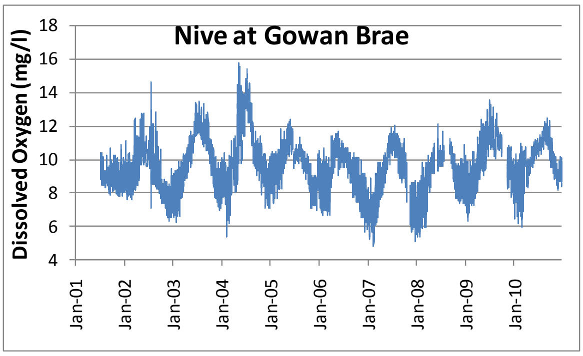


Figure 32. Hourly dissolved oxygen at Nive at Gowan Brae 2001 – 2010. Continuous data Hydro Tasmania.

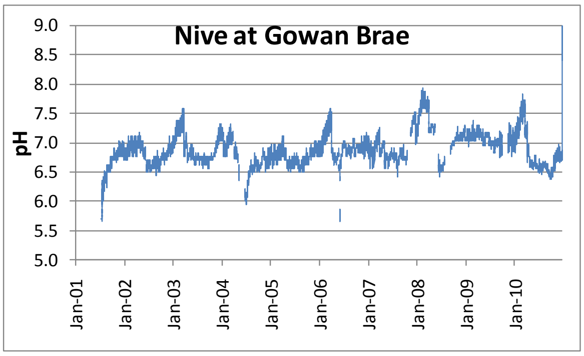


Figure 33. Hourly pH readings at Nive at Gowan Brae 2001-2010. Continuous data Hydro Tasmania.

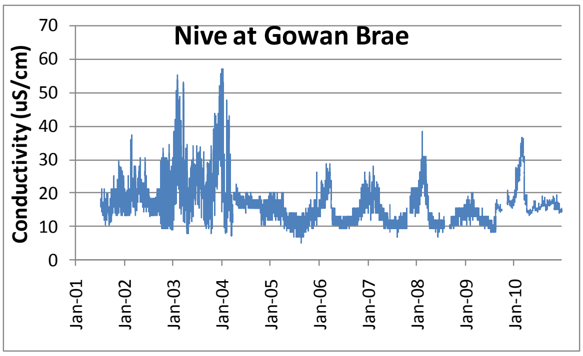


Figure 34. Hourly EC at Nive at Gowan Brae 2001-2010. Continuous data collected by Hydro Tasmania.

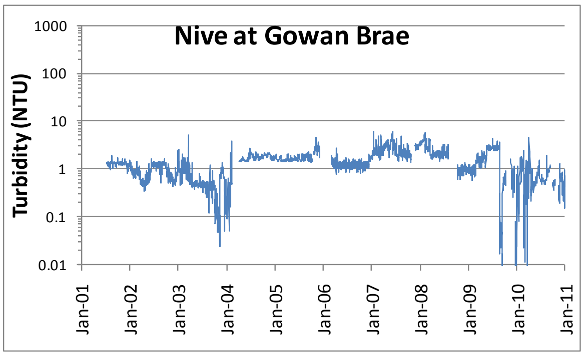


Figure 35. Average daily turbidity readings at Nive at Gowan Brae 2001 – 2010. Continuous data Hydro Tasmania.

2.1.5 Nive River at Lyell Highway and above Tungatinah

Most of the water from the Upper Nive River is diverted into Bronte Lagoon via Pine Tier Lagoon and the Bronte Canal. Any spill from Pine Tier Lagoon continues to flow down the Nive River which continues to pick up catchment inflows until it discharges into Lake Liapootah. There is a continuous recording water quality monitoring site on the Nive River approximately 8 river km downstream of Pine Tier Lagoon where it crosses the Lyell Highway for the first time (Figure 2). Flow in the Nive River is measured upstream of Tungatinah, which is approximately 20 river km farther downstream.

A time-series of flow at the Nive River above Tungatinah site is shown in Figure 36, and shows winter base flows of 1 – 10 cumecs, with short duration higher flow events common in winter. These peaks are attributable to both catchment inflows and spills from Pine Tier Lagoon. In the summer, when virtually all water in the Nive can be captured in the lagoon, flows decrease to <0.1 cumecs. Water quality results from the Nive at Lyell Highway (Figure 37 - Figure 41) show seasonal temperature fluctuation with high daily variability in summer. EC, for the short duration available, shows an inverse pattern to flows, with higher EC during periods of low flow. Increased algal activity in summer is indicated by higher pH values and highly variable dissolved oxygen levels. Turbidity shows peaks in winter, likely associated with high flow events.

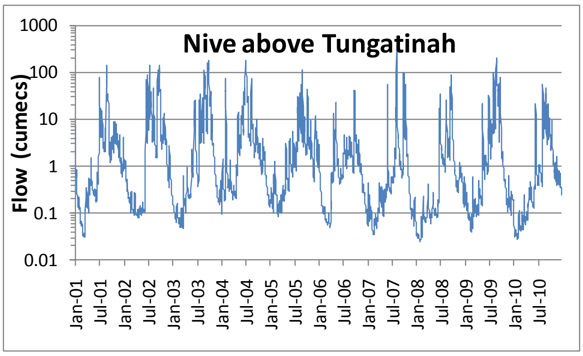


Figure 36. Continuous recording flow results from Nive River upstream of Tungatinah 2 001 -2010. Note this site is about 20 km downstream of water quality site. Data Hydro Tasmania.

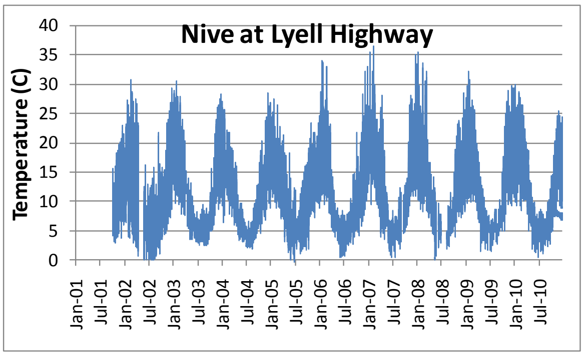


Figure 37. Continuous recording temperature (°C) results 2001 - 2010 from Nive River at Lyell Highway. Data Hydro Tasmania.

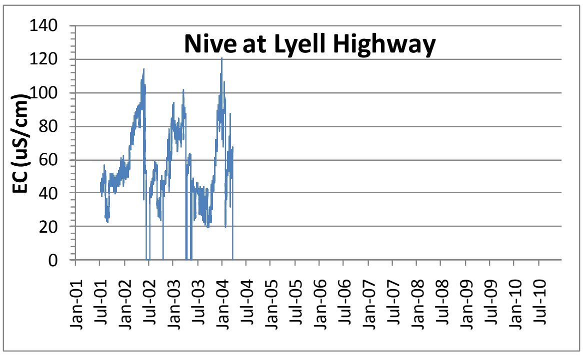


Figure 38. Continuous recording EC (µS/cm) results 2001 - 2010 from Nive River at Lyell Highway. Data Hydro Tasmania.

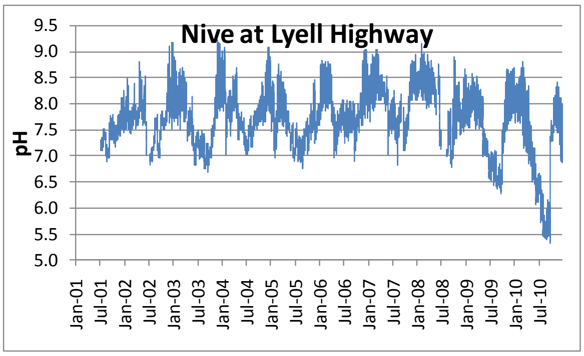


Figure 39. Continuous recording pH results 2001 - 2010 from Nive River at Lyell Highway. Data Hydro Tasmania.

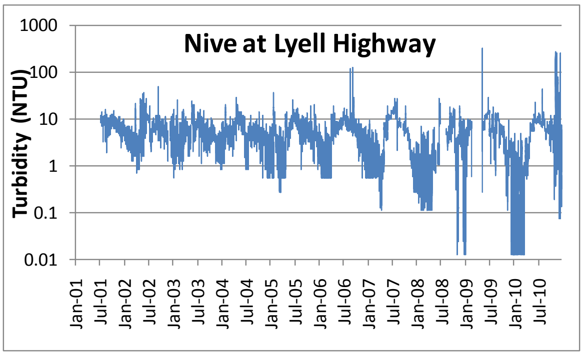


Figure 40. Continuous recording turbidity (NTU) results 2001 - 2010 from Nive River at Lyell Highway. Data Hydro Tasmania.

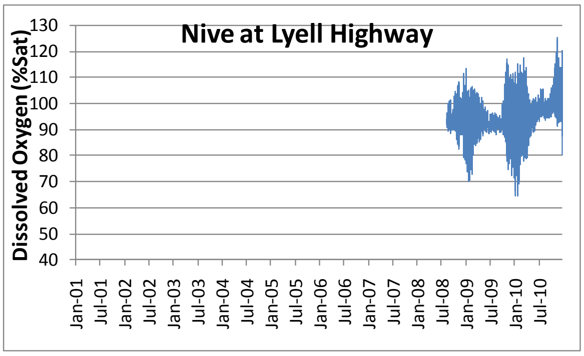


Figure 41. Continuous recording dissolved oxygen (% saturation) results 2001 - 2010 from Nive River at Lyell Highway. Data Hydro Tasmania.

The Nive River upstream of Tungatinah was included in the Upper Derwent Nutrient Study (Coughanowr, 2001). These results are overall very similar to those from the Tarraleah Canal, except Total Nitrogen and ammonia are higher at Tarraleah (Figure 42).

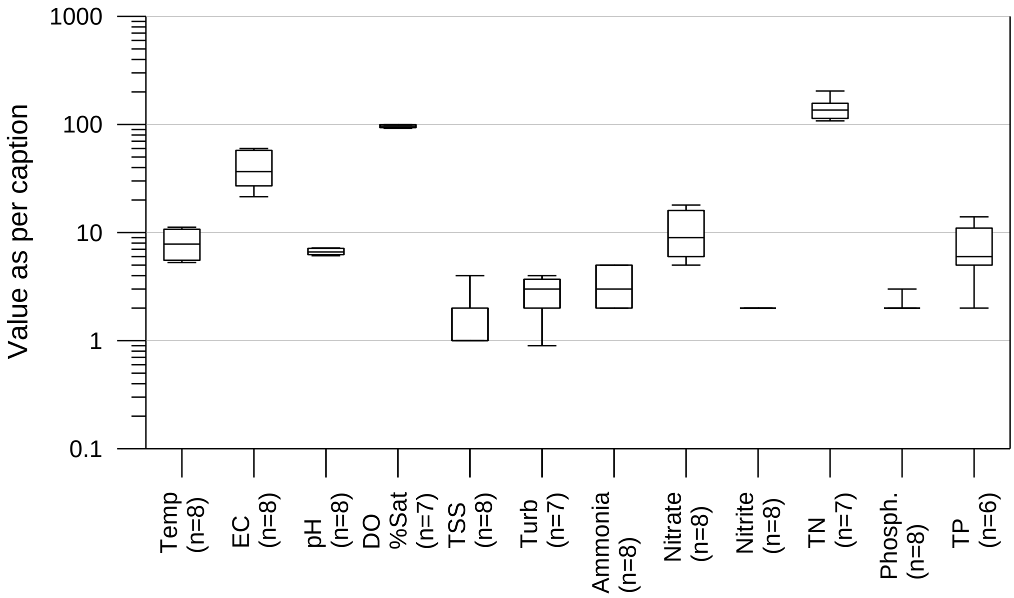


Figure 42. Summary of water quality results from the Nive River above Tungatinah between 1996 and 1997. Data from the Upper Derwent Nutrient Study (Coughanowr, 2001). Units for parameters are: Temperature (°C), EC (µS/cm), pH units, DO (Percent saturation), Total Suspended Solids (mg/L), Turbidity (NTU, Nitrate (µg/L), Nitrite (µg/L), Total Nitrogen (µg/L), Phosphate (µg/L), Total Phosphorus (µg/L).

2.1.6 Bronte Lagoon

Bronte Lagoon receives inflow from the Upper Nive River via Pine Tier Lagoon, and the Upper Clarence River via Laughing Jack Lagoon, so it is a good indicator of input from these headwater areas into the Derwent.

Water quality results from the canal exiting Bronte Lagoon are summarised in Figure 43 and show similar summer peaks in chlorophyll-a, temperature and turbidity. Conductivity values are low, at about 20 – 30 µS/cm.

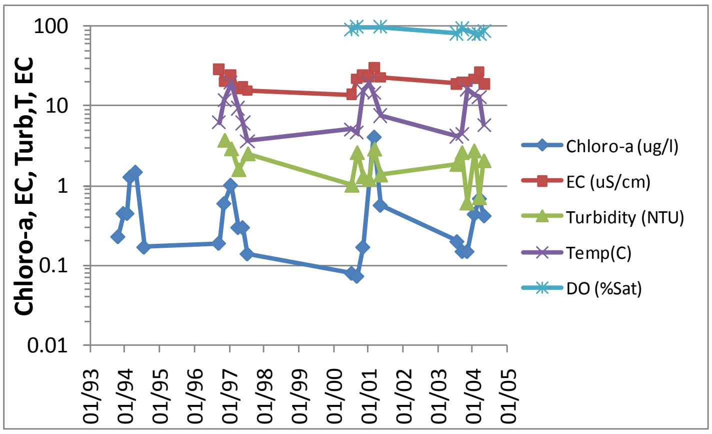


Figure 43. Time-series of chlorophyll-a (1993-2004) and physico-chemical water quality parameters (1996 -2004) from surface waters in Bronte Lagoon canal. Data from Hydro Tasmania

2.1.7 Lake Echo

Lake Echo is a medium sized storage in the Derwent headwaters. The major inflow to the lake is from Little Pine Lagoon, which captures water from the Little Pine River in the Upper Ouse catchment. Water leaves Lake Echo via the Echo Power Station and flows into the Dee Lagoon. Monitoring locations used by Hydro Tasmania are presented in Figure 44.

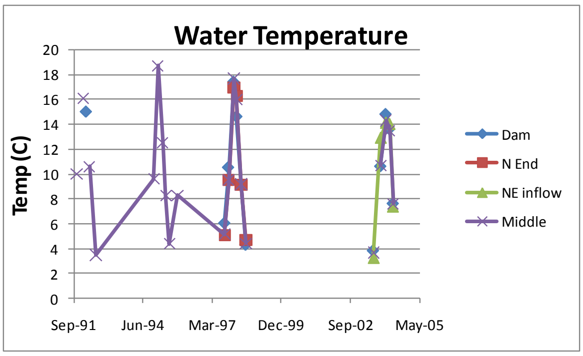
Low lake levels in Lake Echo have been linked to elevated turbidity, and algal blooms have been documented in the lake (Hydro Tasmania 2007, 2009a), including the presence of blue-green algae at elevated levels. Figure 45 through Figure 52 show water quality results from the lake from multiple sampling periods between 1991 and 2009 from different monitoring points in the lake.

Results for temperature and pH are similar to other lakes in the Derwent headwaters, but EC is slightly higher, ranging from about 25 – 30 µS/cm. This may be due to more dolerite in the catchment as compared to the lakes further west.

Turbidity, total Nitrogen, total Phosphorus and chlorophyll-*a* all show peaks in the 2008- 2009 data set which may be attributable to the drought causing low lake levels. Peak nutrient and turbidity values in 2008 exceed the Hydro site specific targets and ANZECC (2000) trigger values for the Protection of Aquatic Ecosystems.

Similar to Lake King William, blue-green algae were consistently present in the lake. On two occasions (Aug 07, Sep 07) the calculated biovolumes of the algae exceeded the NH&MRC cyanobacteria biovolume surveillance level (0.04 mm^3/L) and on one occasion (Nov 07) exceeded the NH&MRC cyanobacteria biovolume alert level (0.4 mm^3/L) (Hydro Tasmania, 2008). By January 2008, the biovolume had decreased to below the surveillance level.

Figure 44. Google Earth image of Lake Echo showing Hydro Tasmania monitoring sites.



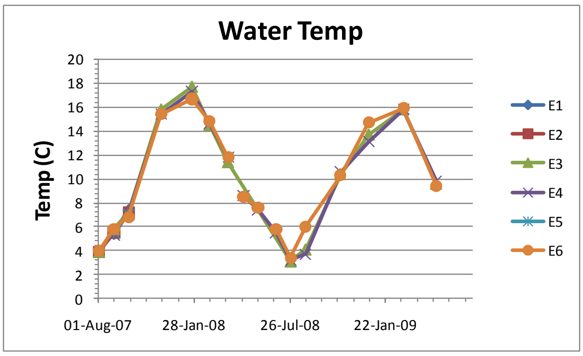
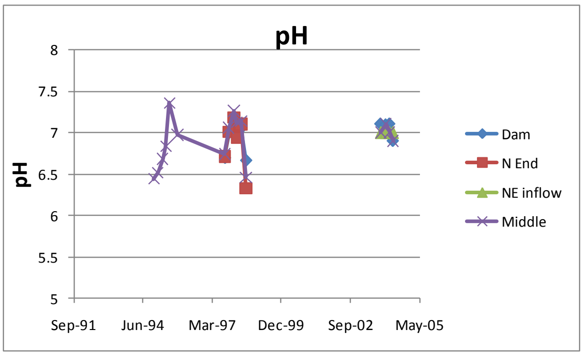


Figure 45. Water temperature in Lake Echo between 1991 - 2005 (left) and in 2007 - 2009 (right). Data from Hydro Tasmania.



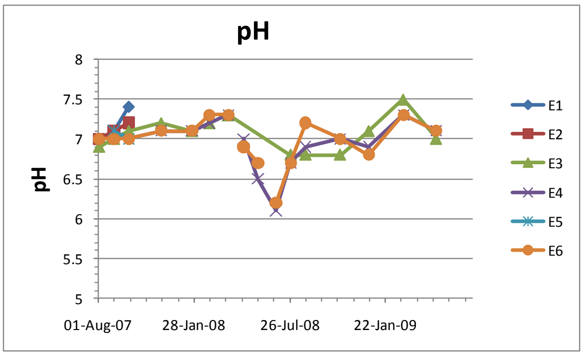


Figure 46. pH in Lake Echo between 1991 - 2005 (left) and in 2007 - 2009 (right). Data from Hydro Tasmania

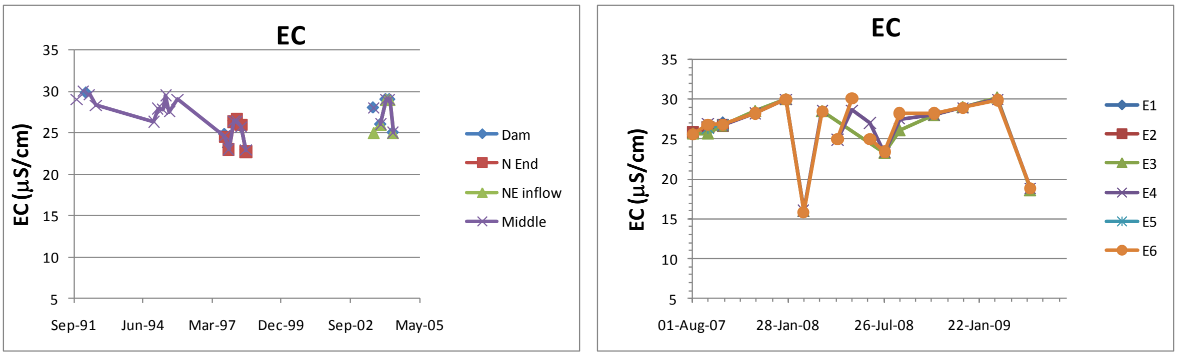


Figure 47. EC in Lake Echo between 1991 - 2005 (left) and in 2007 - 2009 (right). Data from Hydro Tasmania.

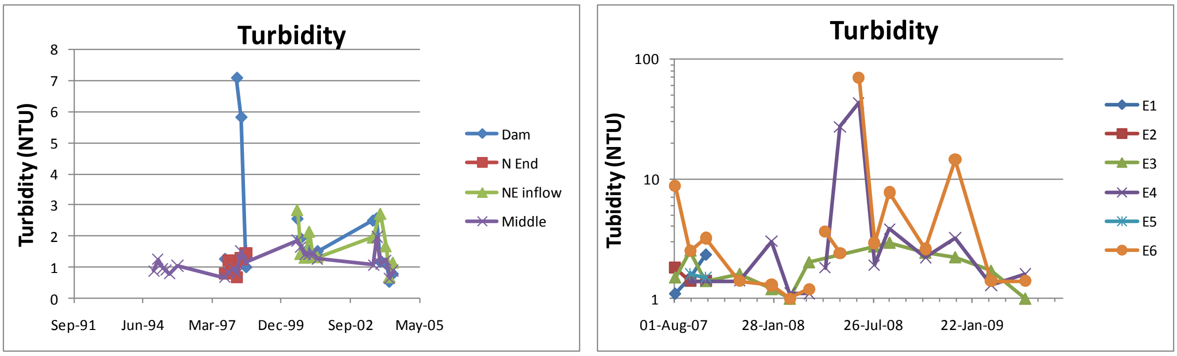


Figure 48. Turbidity in Lake Echo between 1991 - 2005 (left) and in 2007 - 2009 (right). Data from Hydro Tasmania.

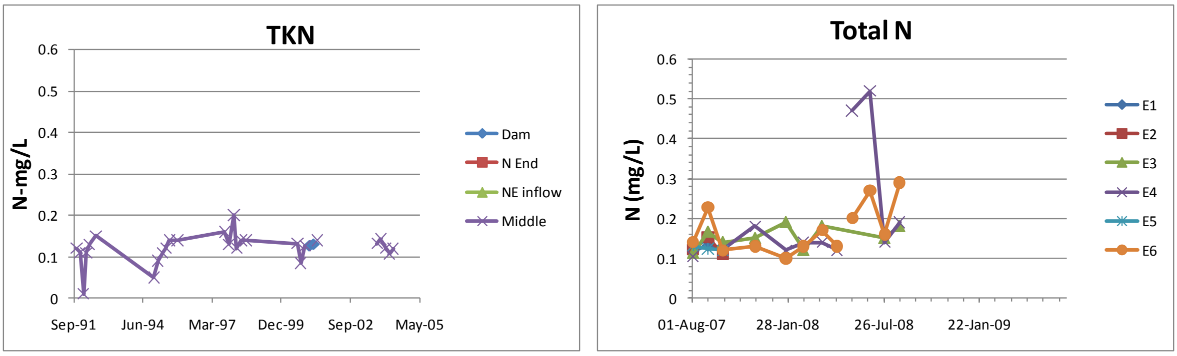


Figure 49. TKN and Total Nitrogen in Lake Echo between 1991 - 2005 (left) and in 2007 - 2009 (right). Data from Hydro Tasmania.

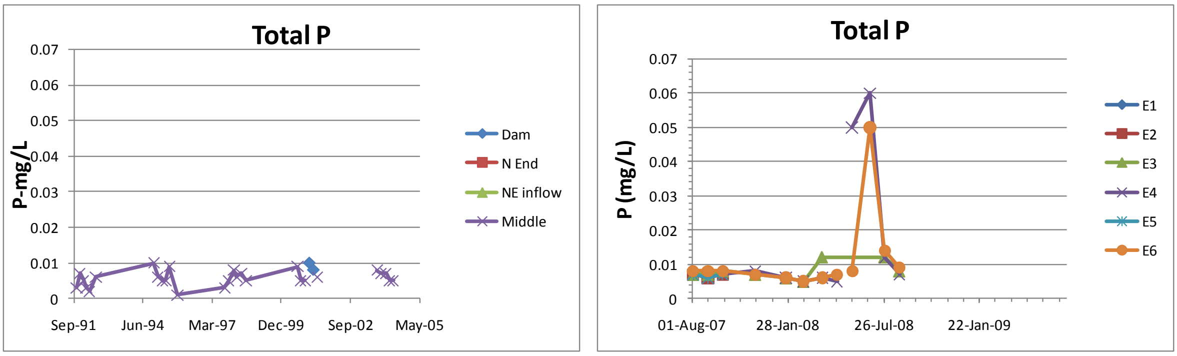
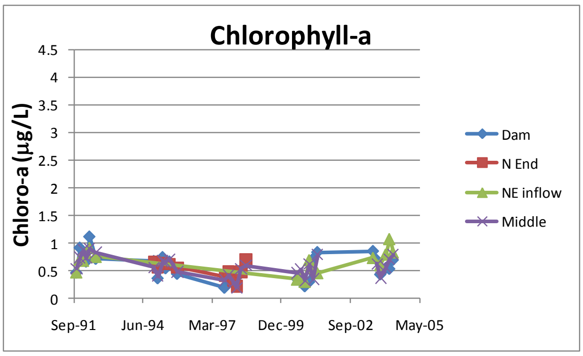


Figure 50. Total Phosphorus Lake Echo between 1991 - 2005 (left) and in 2007 - 2009 (right). Data from Hydro Tasmania.



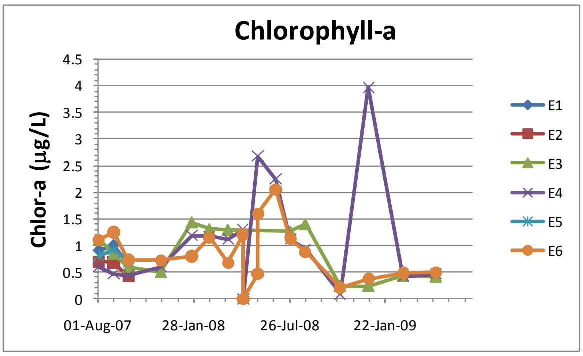


Figure 51. Chlorophyll-a in Lake Echo between 1991 - 2005 (left) and in 2007 - 2009 (right). Data from Hydro Tasmania.

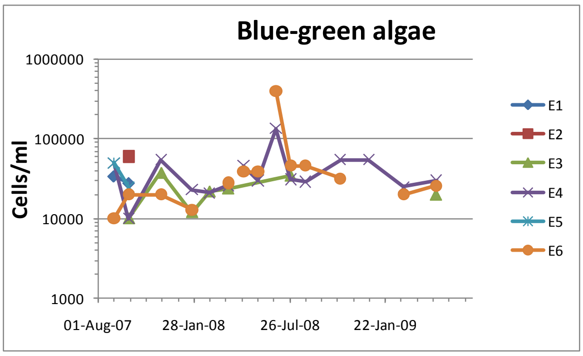


Figure 52. Blue-green algae in Lake Echo 2007 – 2009. Data from Hydro Tasmania.

2.1.8 Dee Lagoon

The water in Dee lagoon is predominantly derived from Lake Echo and from catchment inflows into Mentmore Bay. Monitoring in Dee Lagoon includes a continuous recording water quality site situated near the 'Inlet' of the Dee Tunnel which transfers water into Bradys Lake (Figure 53). The site measures temperature, EC, pH, dissolved oxygen and turbidity. Periodically, water quality samples are collected from the lake, with the most recent monitoring occurring in 2007-2008 corresponding to a drought period when lake levels were low.

Figure 53. Google Earth image of Dee Lagoon showing Hydro Tasmania monitoring locations.

Results from the continuous recording site (Figure 54 to Figure 56) show seasonal changes in temperature, ranging from 5°C to 25°C. pH shows summer peaks and high variability during summer, with both trends most likely associated with algal growth in the surface waters. Dissolved oxygen also reflects primary production, with large fluctuations in the summer months. EC does not show any clear seasonal trend, with this parameter likely affected by unregulated inflows and lake level fluctuations. Turbidity shows elevated levels over the past two winters which have been attributed to increased sediment inflow from Lake Echo due to erosion in the channel connecting the two water bodies (Hydro Tasmania Consulting, 2008b), and re-suspension due to low lake levels (*M. Egerrup, pers. comm*).

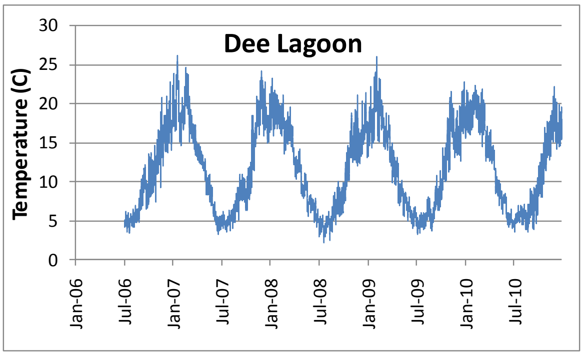


Figure 54. Continuous temperature results from the Inlet to the Dee Tunnel 2006 - 2010. Data from Hydro Tasmania.

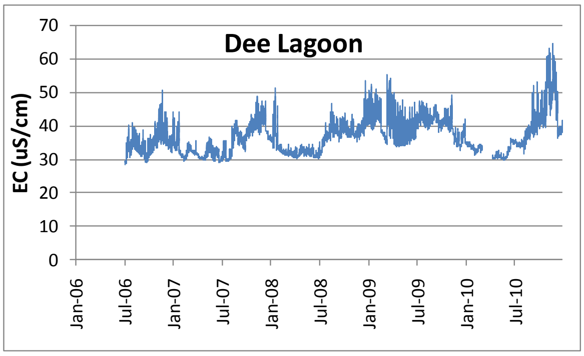


Figure 55. Continuous EC (µS/cm) results from the Inlet to the Dee Tunnel 2006 - 2010. Data from Hydro Tasmania.

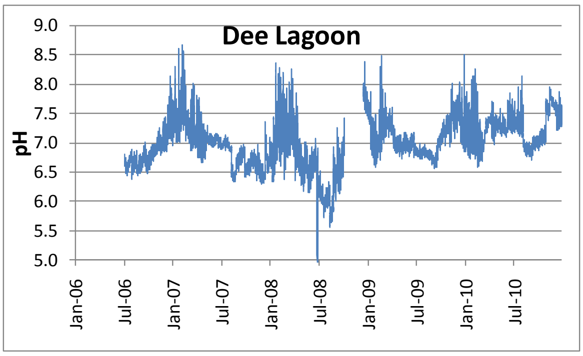


Figure 56. Continuous pH results from the Inlet to the Dee Tunnel 2006 - 2010. Data from Hydro Tasmania.

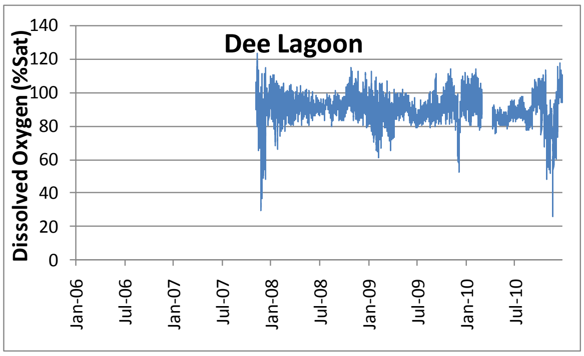


Figure 57.Continuous dissolved oxygen (% Saturation) results from the Inlet to the Dee Tunnel 2007 - 2010. Data from Hydro Tasmania.

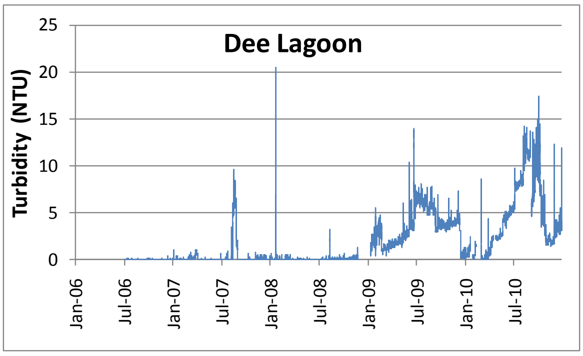


Figure 58. Continuous turbidity (NTU) results from the Inlet to the Dee Tunnel 2006 - 2010. Data from Hydro Tasmania.

Water quality samples from the lake are collected periodically from the lake, and results between 1989 and the 2008 are summarised in Figure 59 to Figure 65. The connectivity with Lake Echo is evident in the EC monitoring results which shows a similar decrease in EC in Lake Echo and Dee Lagoon in February 2008. The other physico-chemical parameters show seasonal patterns similar to other water ways in the region and the continuous recording results. Turbidity levels in Dee Lagoon (Figure 62) show two peaks in the 1990 – 2005 results, with the earliest of these peaks corresponding to a peak in Lake Echo. Maximum nutrient levels in Dee Lagoon are lower than in Lake Echo, as is turbidity, consistent with localised processes causing the increases in Lake Echo (Figure 67).

The 2007 – 2008 monitoring was completed during a drought period resulting in low lake levels. Similar to Lake Echo, there were three periods (Aug 07– Nov 07) in which the cyanobacteria biovolumes exceeded the NH&MRC surveillance trigger of 0.04 mm^3/L (Hydro Tasmania, 2008c). Chlorophyll-*a*, TN and TP exceeded ANZECC (2000) and internal Hydro triggers on at least one occasion in the lagoon.

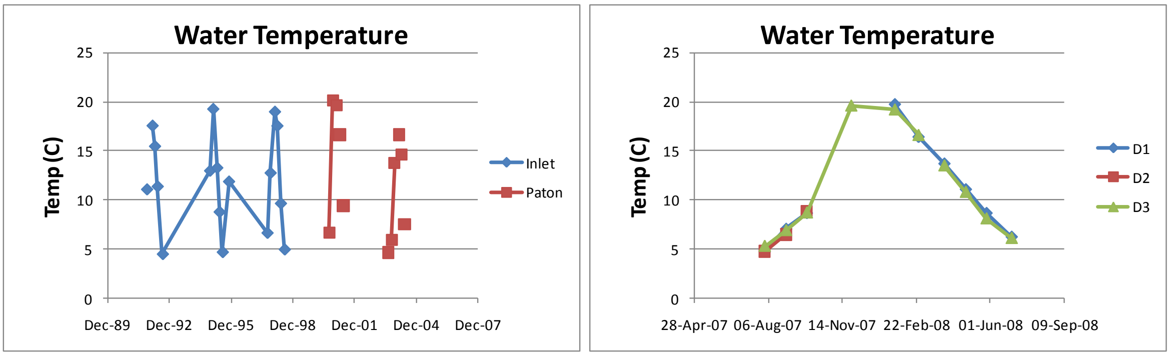


Figure 59. Water temperature in Dee Lagoon 1990 - 2005 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

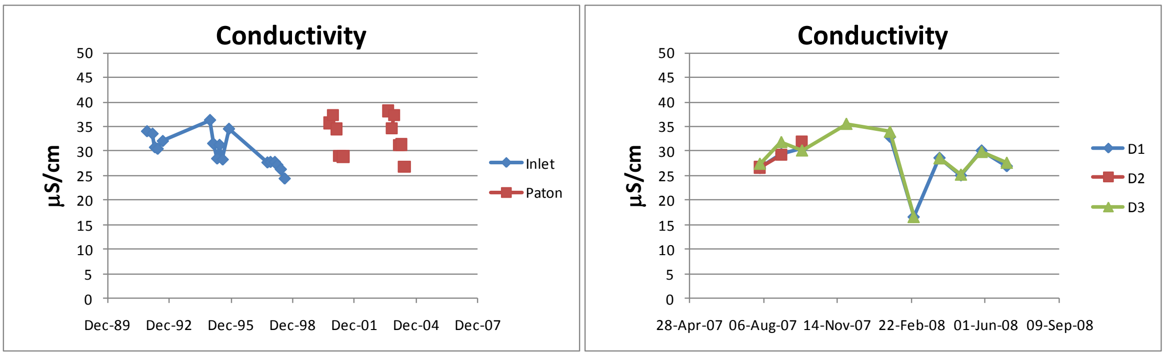


Figure 60. Electrical conductivity results from Dee Lagoon 1990-2005 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

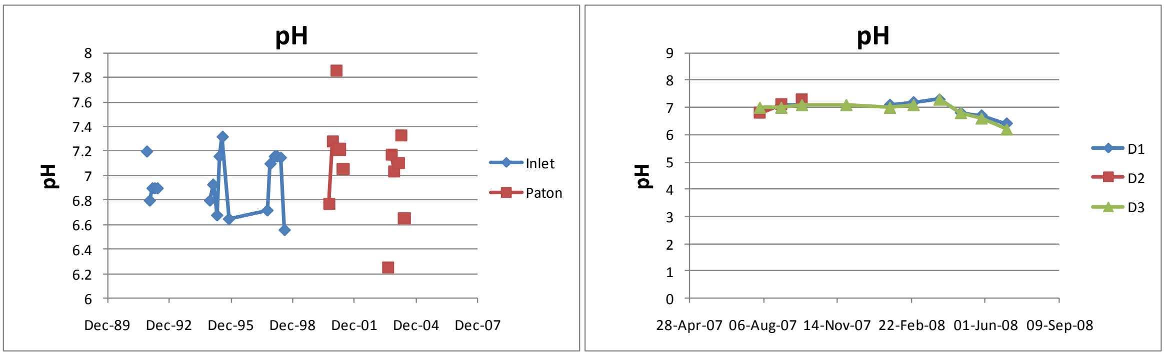


Figure 61. pH results from Dee Lagoon 1990 - 2005 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

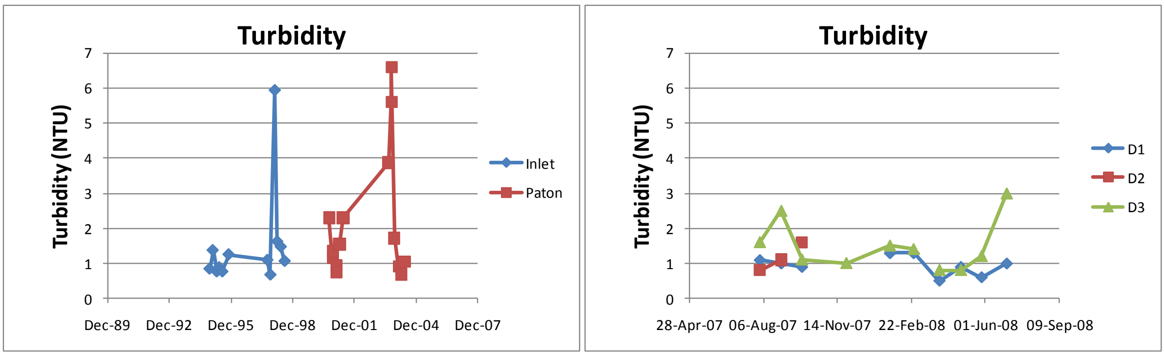


Figure 62. Turbidity results from Dee Lagoon 1990 - 2005 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

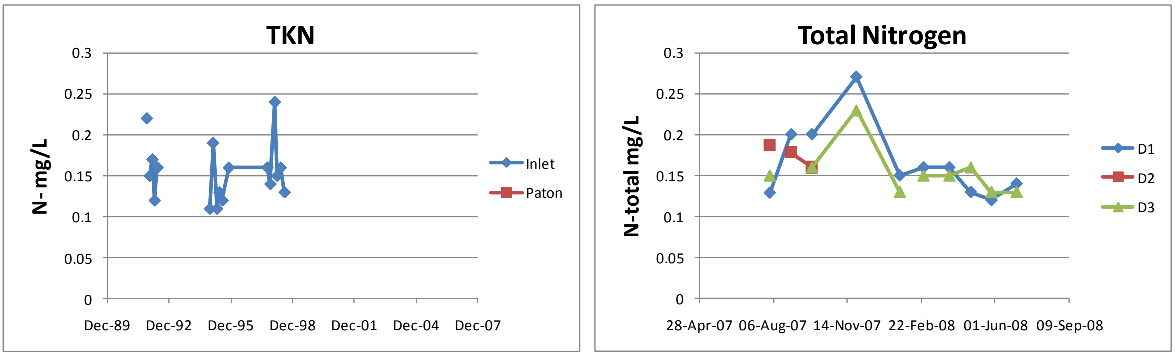


Figure 63. TKN and Total Nitrogen results from Dee Lagoon 1990 - 2005 (left) and 2007 - 2008 (right). Data Hydro Tasmania.

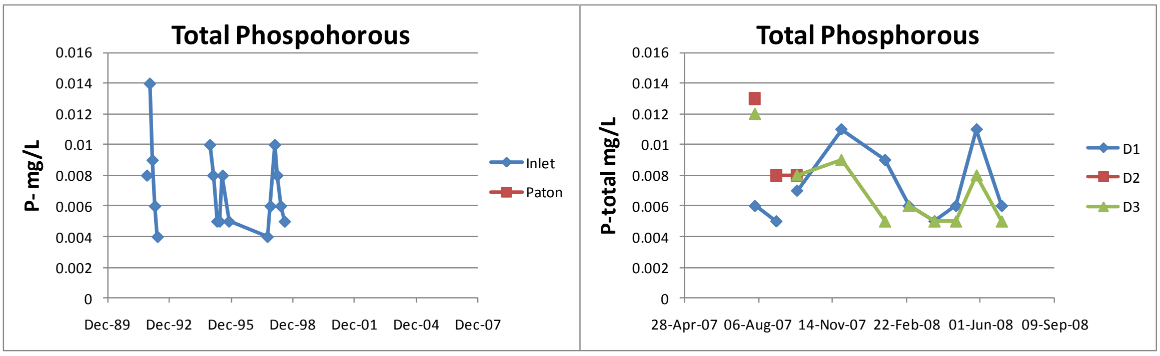


Figure 64. Total Phosphorus results, Dee Lagoon 1990 - 2005 (left) and 2007 - 2008 (right). Data Hydro Tasmania.

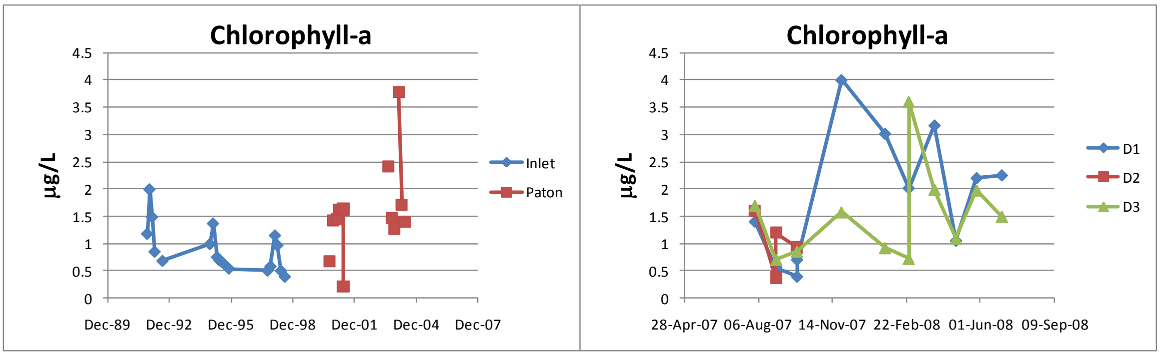


Figure 65. Chlorophyll-a results from Dee Lagoon 1990 - 2005 (left) and 2007 - 2008 (right). Data Hydro Tasmania.

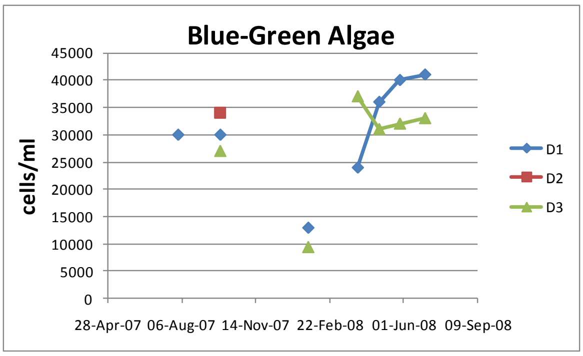


Figure 66. Blue-green algae results, Dee Lagoon 1990 - 2005 (left) and 2007 - 2008 (right). Data Hydro Tasmania.

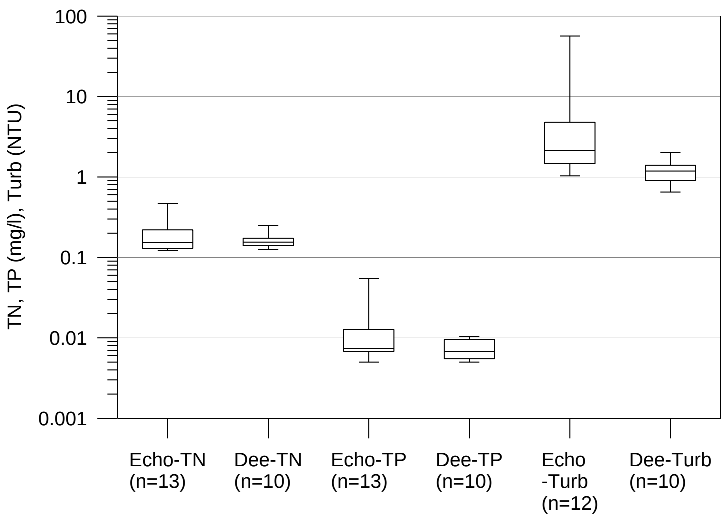


Figure 67. Comparison of TN, TP and turbidity in Lake Echo and Dee Lagoon in 2007 - 2008. Data Hydro Tasmania.

Nutrient and turbidity data from Mentmore Bay 2000-2001 (not presented) showed higher concentrations as compared to Batchlers Shore, suggesting Mentmore Creek is a source of nutrients and turbidity to the lagoon, and/or, wave induced turbidity is an issue in the isolated bay. An example of this is shown in Figure 68 which compares TKN results from Dee Lagoon with Bronte Lagoon, Lake Echo and Tungatinah Lagoon. The elevated levels in Mentmore Creek appear isolated within the system.

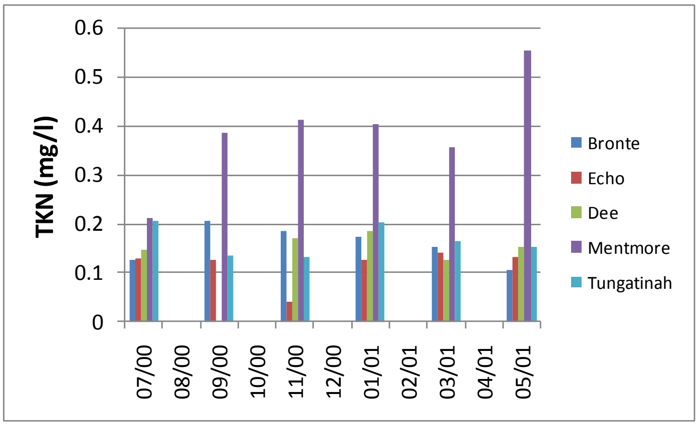


Figure 68. Comparison of TKN in Bronte Lagoon, Lake Echo, Dee Lagoon at Batchlers, Dee Lagoon at Mentmore and Tungatinah Lagoon.

Metal and sulphate concentrations were determined on water samples collected from Dee Lagoon off Batchlers Shore between July 2000 and May 2004 (Table 4). Concentrations are low, below ANZECC (2000) trigger values for protection of aquatic ecosystems, and similar to those present in Lake King William.

Table 4. Summary of total metal concentrations from off Batchlers Shore monitoring point, between July 2000 and May 2004. Data from Hydro Tasmania.

Jul 00-May04	Al_{tot} mg/L	Cd_{tot} mg/L	Cr_{tot} mg/L	Co_{tot} mg/L	Cu_{tot} mg/L
Mean	0.048	0.001	0.001	0.001	0.001
Median	0.032	0.001	0.001	0.001	0.001
Max	0.101	0.001	0.001	0.001	0.003
n=	11	12	11	11	12

Jul 00-May01	Fe_{tot} mg/L	Pb_{tot} mg/L	Mn_{tot} mg/L	Ni_{tot} mg/L	Zn_{tot} mg/L	SO_4 mg/L
Mean	0.062	0.005	0.007	0.001	0.002	0.390
Median	0.067	0.005	0.005	0.001	0.001	0.430
Max	0.094	0.005	0.019	0.001	0.005	0.610
n=	6	11	12	11	12	12

2.1.9 Tungatinah Lagoon

Tungatinah Lagoon is the final impoundment before water enters the Tungatinah Power Station, with the lagoon receiving the combined inflows from Bronte and Dee Lagoons via Bradys Lake and Lake Binney. Tungatinah Lagoon is relatively small, and because the power station operates much of the time, residence time of water within the impoundment is low.

Temperature profiles from Tungatinah Lagoon show a well-mixed water column with seasonal temperature changes (Figure 69). The profiles may also reflect seasonal changes to water level in the lagoon, with maximum water depths occurring in September (the different water depths may also reflect slight differences in sampling location). Water quality parameters in the lake reflect the relative inflow of the sources, with higher EC in summer probably reflecting inflows from the larger storage, Lake Echo, and lower EC reflecting inflows from the 'Bronte' arm during the winter (Figure 70 to Figure 73). For the period of record available (2000-2001), nutrient and chlorophyll-*a* levels are generally low, except for TP which is slightly above the trigger ANZECC (2000) and site-specific Hydro trigger value of 0.01 mg/L

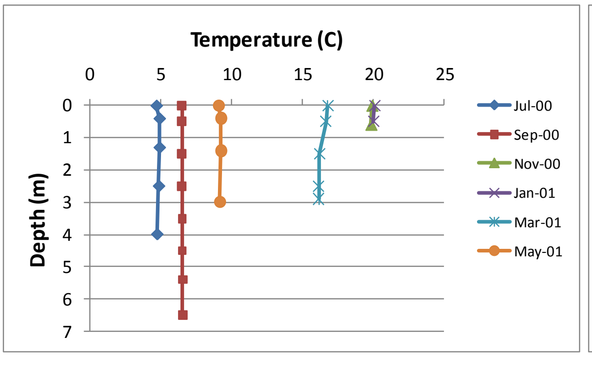


Figure 69. Temperature profiles from Tungatinah Lagoon, September 2000-May 2001. Data from Hydro Tasmania.

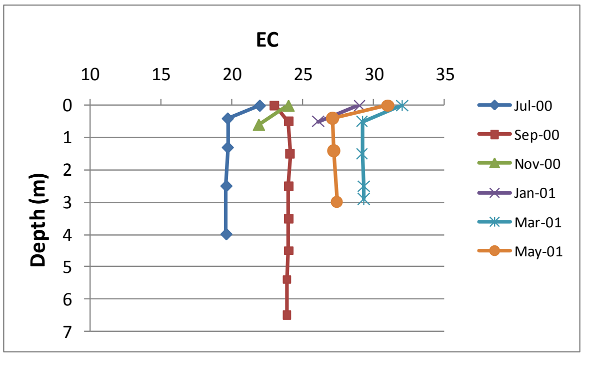


Figure 70. EC profiles from Tungatinah Lagoon, September 2000-May 2001. Data from Hydro Tasmania.

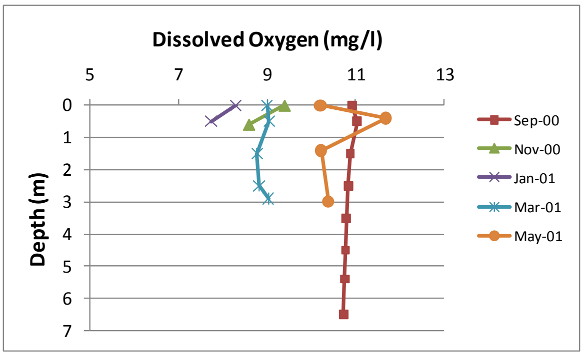


Figure 71. Dissolved oxygen profiles from Tungatinah Lagoon, September 2000-May 2001. Data from Hydro Tasmania.

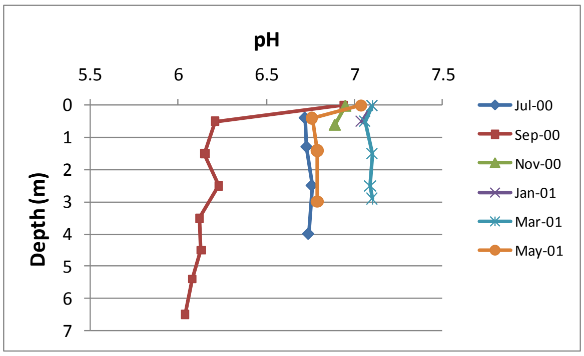


Figure 72. pH profiles from Tungatinah Lagoon, September 2000-May 2001. Data from Hydro Tasmania.

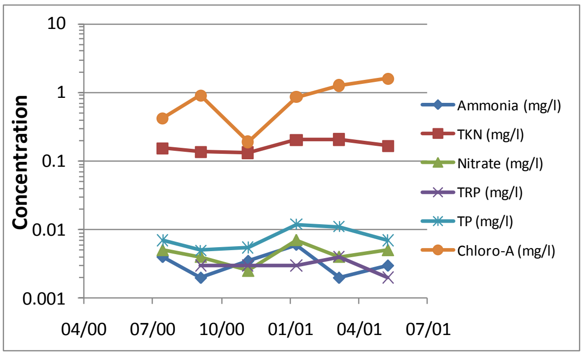


Figure 73. Nutrient and chlorophyll-a concentrations in Tungatinah Lagoon September 2000-May 2001. Data from Hydro Tasmania.

The Upper Derwent Nutrient Study included a monitoring site at the outflow of the Tungatinah Power Station (Figure 74). Water is generally similar to that flowing into the Tarraleah Power Station, indicating the entire headwaters of the Derwent have similar characteristics. Minor differences include Tarraleah having slightly higher nitrate values, but Tungatinah having higher total nitrogen values.

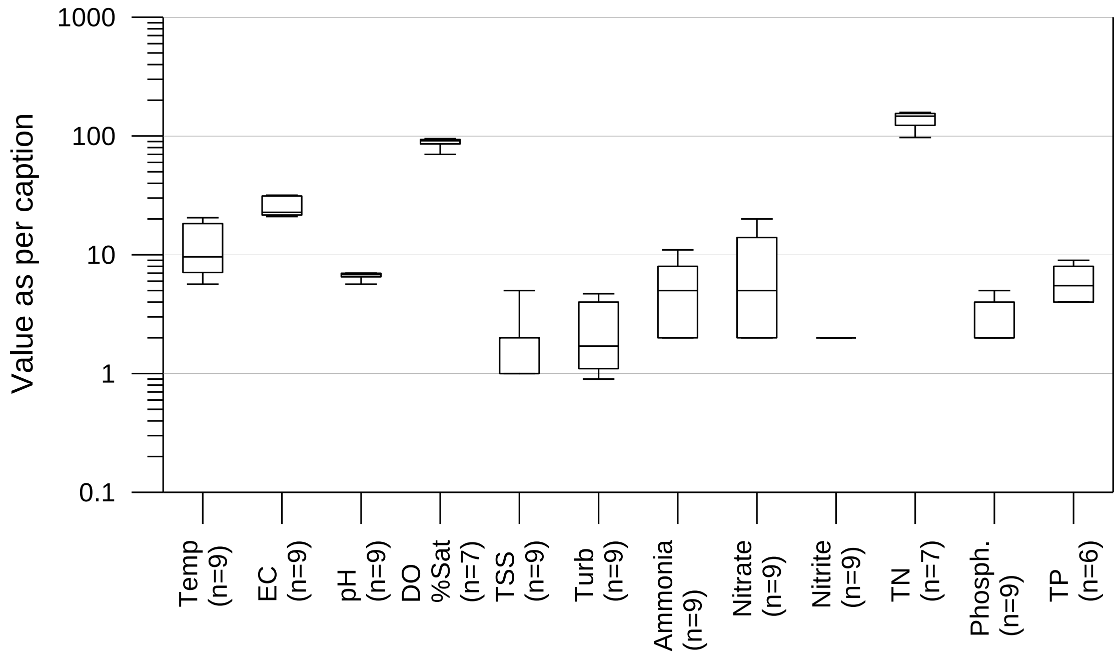


Figure 74. Summary of water quality results 1996 - 1997 from the outflow of Tungatinah Power Station. Data from Upper Derwent Nutrient Study (Coughanowr, 2001).

2.1.10 Liapootah Lagoon

The outflow of the Tarraleah and Tungatinah Power Stations, (along with flow in the Nive River downstream of Pine Tier Lagoon), enter the Liapootah Lagoon which forms the feed for the Lower Derwent Power Scheme. Water quality in Liapootah Lagoon was measured in 2000 – 2001, with the results summarised in Figure 75 through Figure 78. Seasonal temperature changes are evident in the lagoon, but only minor surface warming occurs in summer, presumably due to the short-residence time of water in the impoundment. The other parameters show that the final quality of water from the headwaters of the Derwent is characterised by low EC, turbidity, nutrient and Chlorophyll-a levels.

Metal levels collected from Liapootah (Table 5) show overall low levels, although total iron is slightly higher than in the upstream lakes, probably due to inflows from the Nive River.

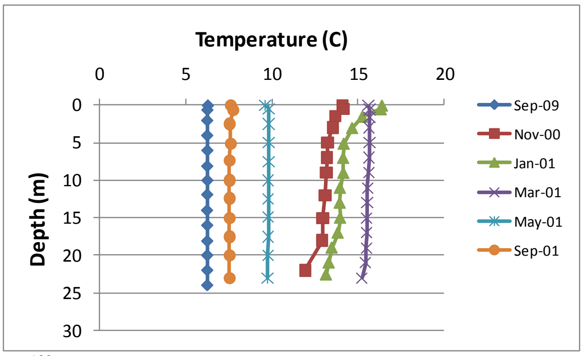


Figure 75. Temperature profiles from Liapootah Lagoon, 2000-2001. Data from Hydro Tasmania.

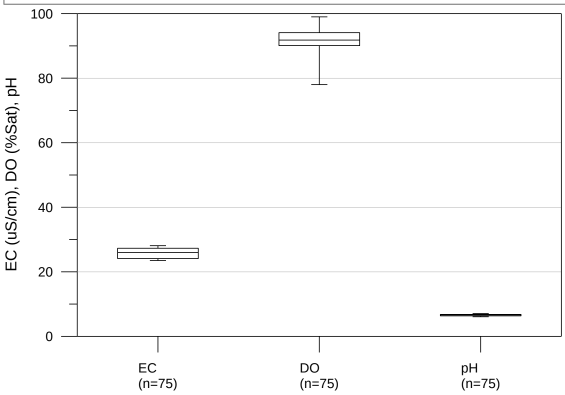


Figure 76. Summary of EC, DO and pH values from Liapootah Lagoon, 2000 - 2001. (Data Hydro Tasmania).

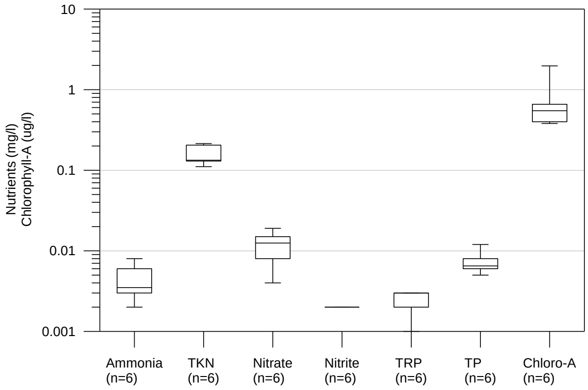


Figure 77. Summary of nutrient values & chlorophyll-a in Liapootah Lagoon 2000-2001. (Data Hydro Tasmania).

Jul 00-May 01	Al_{tot} mg/L	Cd_{tot} mg/L	Cr_{tot} mg/L	Co_{tot} mg/L	Cu_{tot} mg/L
Mean	0.082	0.001	0.001	0.001	0.002
Median	0.072	0.001	0.001	0.001	0.001
Max	0.196	0.001	0.001	0.001	0.007
n=	5	6	5	5	6

Jul 00-May 01	Fe_{tot} mg/L	Pb_{tot} mg/L	Mn_{tot} mg/L	Ni_{tot} mg/L	Zn_{tot} mg/L	SO_4 mg/L
Mean	0.103	0.005	0.008	0.001	0.002	0.408
Median	0.101	0.005	0.007	0.001	0.002	0.430
Max	0.169	0.005	0.013	0.001	0.004	0.540
n=	6	5	6	5	6	6

Table 5. Summary of metal and sulphate results from Liapootah Lagoon between July 2000 and May 2001. (Data from Hydro Tasmania).

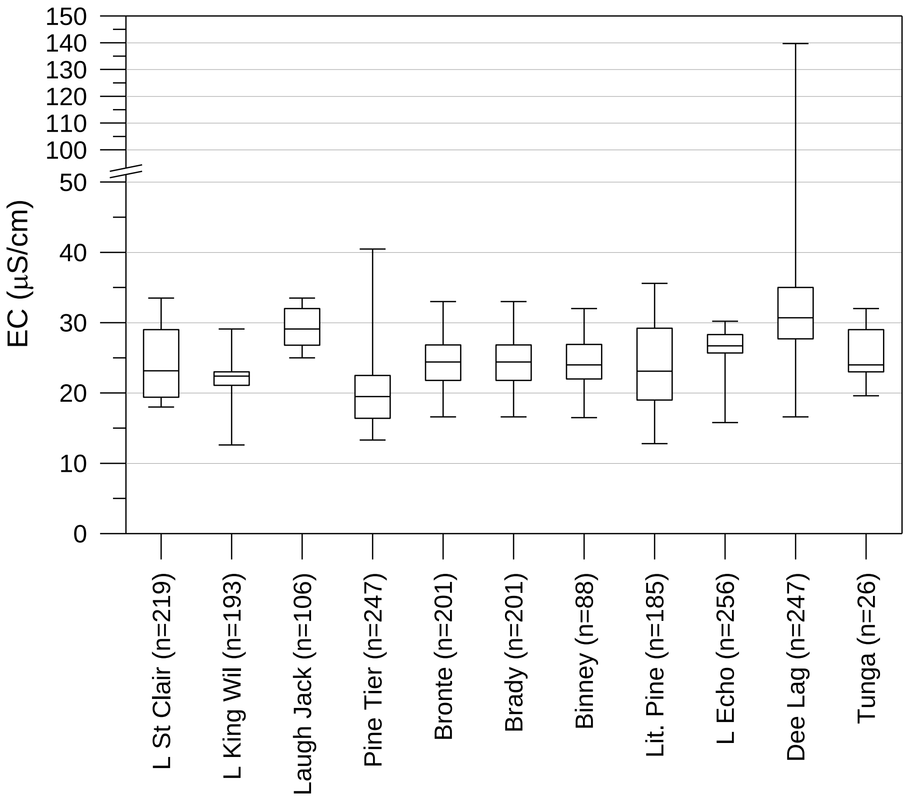


Figure 78. Summary of EC values in the headwaters of the Derwent River. (Data from Hydro Tasmania.)

Summary of Derwent Headwaters-Central Plateau

Water quality in the headwaters of the Derwent River has the following characteristics:

- The waters are very dilute, with Lake St Clair and Lake King William in the west of the catchment having slightly lower EC than the eastern headwaters. This is likely attributable to higher rainfall, and the waterways being underlain by sedimentary rather than doleritic bedrock. A summary of EC values for the headwater lakes is shown in Figure 78;
- The highly modified flow regime affects water quality in the catchment through the storage of water in impoundments, and the diversion of water out of rivers;
- Large lakes within the Derwent headwaters undergo seasonal thermal stratification, whilst smaller water bodies, due to low residence time, show seasonal temperature changes but no depth stratification;
- Increased algal productivity in the lakes during the summer drives seasonal increases in pH and large fluctuations in dissolved oxygen (associated with photosynthesis and respiration). The seasonal response of pH is attributable to the very soft nature of the waters which have little buffering capacity;
- Turbidity values tend to be low, and are likely associated with algal growth in summer and more turbid inflows in winter. Dee Lagoon appears susceptible to elevated turbidity which Hydro Tasmania has linked to erosion in the channel from Lake Echo;
- Nutrient levels in the lakes are generally low, although monitoring by Hydro Tasmania during periods of low lake levels in 2007 – 2008 found slightly to moderately elevated levels of nitrogen, phosphorus and Chlorophyll-*a*

compared to ANZECC (2000) trigger values and site specific Hydro trigger levels. Maximum nutrient and Chlorophyll-*a* levels in 2007 – 2008 were generally higher than values collected between 1991 – 2004. There is no data available to evaluate nutrient behavior post-2008 so it is unknown if these levels have decreased as lake levels increased;

- There has been a small increase in Total Phosphorus in Lake King William since the early 1990s. This is likely attributable to the installation of a waste water treatment plant in the late 1990s on the waterway which connects Lake St Clair and Lake King William. It is likely that this small increase has been accompanied by a decrease in parameters associated with waste water in Lake St Clair near Pumphouse, but there is no data to confirm this;
- Blue-green algae were present in all lakes monitored in 2007 – 2008, with levels in Lakes Echo and Dee exceeding the NH&MRC 'surveillance' trigger between August and November 2007. Levels decreased in subsequent monitoring periods. It is unknown if this is the first occurrence of these algae, or how levels compared to previous years in the water-bodies as there are no historical results for comparison;
- The passage of water through the Tarraleah and Tungatinah power station results in well mixed water entering the lakes of the Lower Derwent Power Scheme.

2.2 Lower Derwent Lakes

Summary of hydrology and regulation

Downstream of Lake Liapootah, the Derwent flows through a cascade of impoundments created by a series of dams and power stations in the Derwent valley. The chain consists of Wayatinah Lagoon, Lake Catagunya, Lake Repulse, Cluny Lagoon and Lake Meadowbank. Major riverine inflows to the Derwent in this region occur at the upstream end of Lake Catagunya, where the Florentine River enters, and in Lake Meadowbank, where the Dee, Ouse and Clyde Rivers enter. The Lower Derwent Power Scheme is a 'run-of-river' scheme with inflows to the top of the system passing through the lakes and being discharged to the Derwent Estuary with little temporal storage.

Summary of data sources presented

Water quality monitoring of Lakes Catagunya and Lake Meadowbank has been completed by Hydro Tasmania at various times since 1991, and this information is summarised in the following sections. These lakes are located at the upstream and downstream end of the power scheme so provide information about what is entering, and exiting the system.

2.2.1 Lake Catagunya

Hydro Tasmania monitoring sites in Lake Catagunya are shown in Figure 79. Water column profiles were collected from the lower lake (off Dunns Hill) between July 2001 and May 2002 and provide an indication of seasonal changes in the lake. This monitoring site was adopted as the 'downstream' site in the lake, instead of a site closer to the dam wall, for safety reasons *(P. Harding, pers. comm.*, Figure 80).

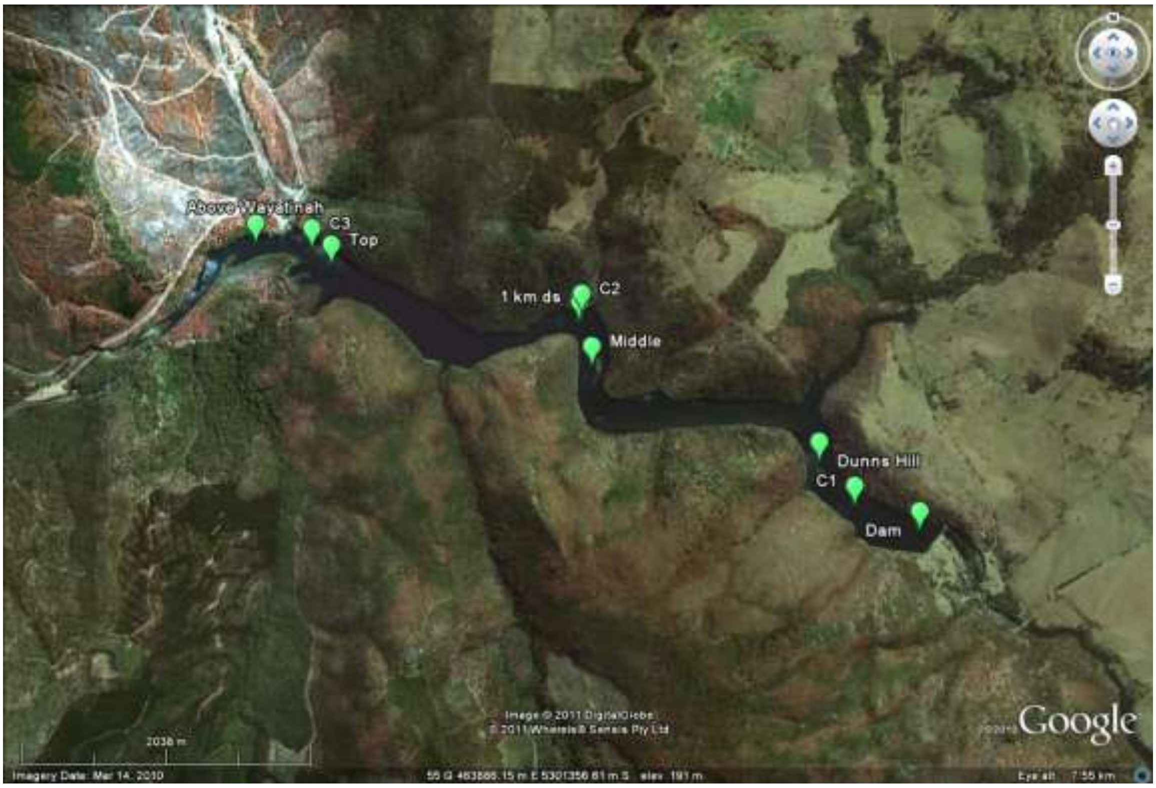


Figure 79. Google Earth image of Lake Catagunya showing Hydro Tasmania monitoring sites.

Temperature changes over the year are similar to the lakes in the headwaters, with warmer surface waters occupying the top 20 m of the water column by the end of summer (Figure 80). During periods of thermal stratification, oxygen levels in the deeper waters are reduced, with <5% saturation (<0.5 mg/L dissolved oxygen) near the bottom in March 2002. It is unknown how far upstream the low dissolved oxygen levels persisted, but it is likely they persisted downstream to the dam wall. Overturning and mixing of the lake between March and May is evident by the uniform and elevated levels of dissolved oxygen in the May profile.

pH profiles recorded values generally between 6.8 and 7.2, except for the low oxygen bottom waters where pH is reduced (Figure 80). EC profiles show that values are generally higher than the headwater lakes, ranging from about 30- 60 µS/cm. This is likely due to inflows from the Florentine River, with distinct catchment geology (Figure 14, PART1) and other runoff from the catchment. The changes in EC values over the year is likely attributable to the varying source of water in the lake; if primarily derived from the headwaters, then low EC would be expected.

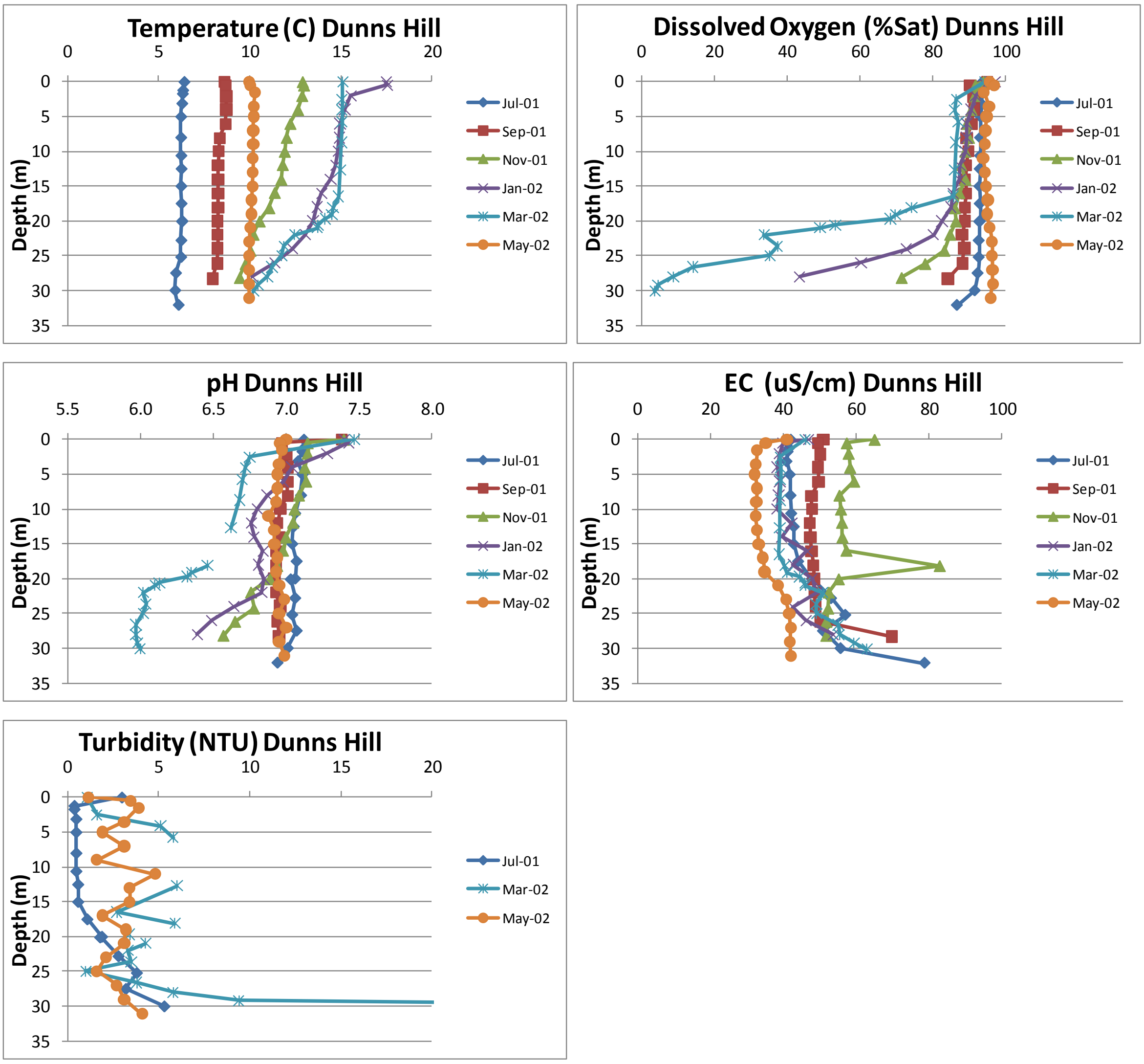


Figure 80. Water column profiles for Dunns Hill, Lake Catagunya 2001 –May 02. (Data from Hydro Tasmania.)

July turbidity values are low, except for bottom water, and consistent with the through-flow of low turbidity water from the headwaters. In March and May, turbidity is variable through the water column, and increases in the zone of low dissolved oxygen.

Time-series of water quality parameters in Lake Catagunya have been constructed using information between 1992 and 2008 (Figure 81 and Figure 88). Surface temperature results show seasonal temperature changes similar to the lake profiles. The EC (Figure 82) results highlight the higher EC water at the upstream end of the lake above the Wayatinah Power Station discharge, which are attributable to the inflow from the Florentine and possibly discharge from the fish hatchery located in Wayatinah. The very low EC in March 2006 is likely associated with water derived from the headwaters. pH values are in a similar range as other lakes in the system, with the 2007 – 2008 values showing a seasonal increase in summer, consistent with an increase in primary production (Figure 83).

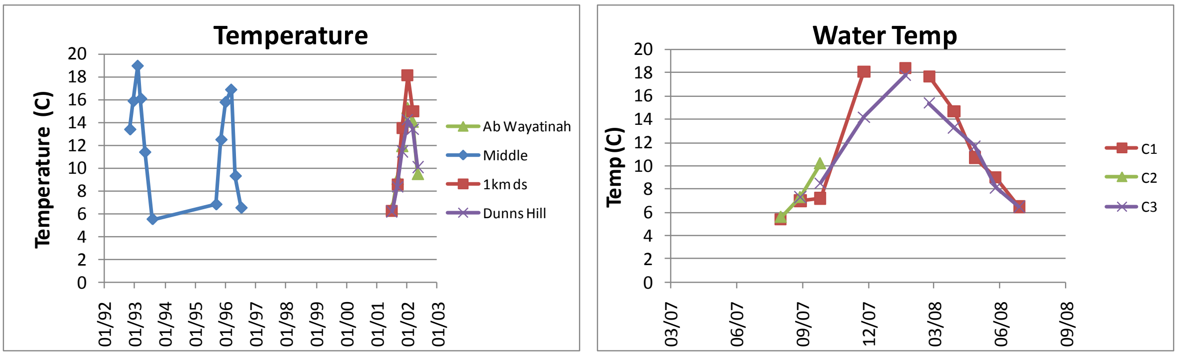


Figure 81. Surface temperature (°C) results from Lake Catagunya, 1992 - 2002 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

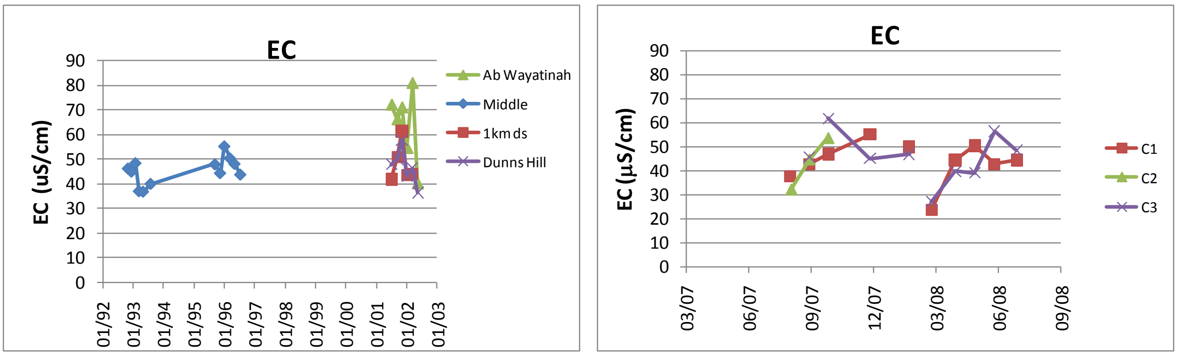


Figure 82. Surface EC (µS/cm) results from Lake Catagunya, 1992 - 2002 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

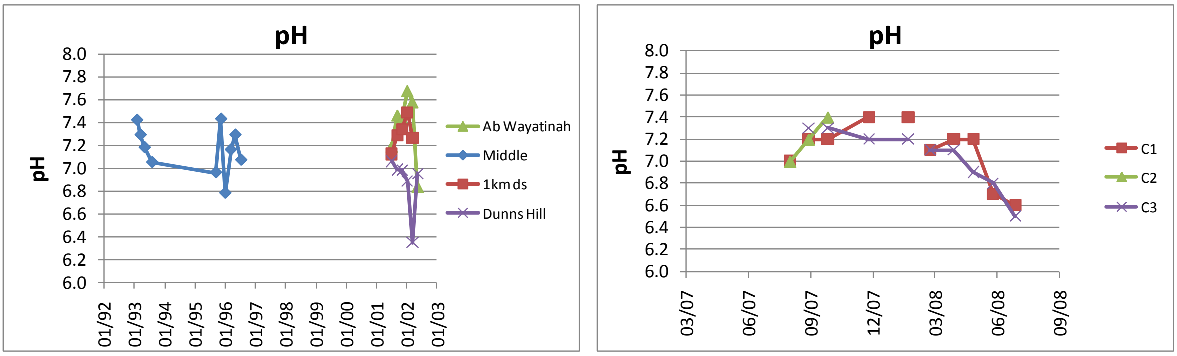


Figure 83. pH results from Lake Catagunya, 1992 - 2002 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

Turbidity values in the 2001-2002 and 2007-2008 data sets show turbidity peaks during winter months, except for one peak in March 2002 (Figure 84). These peaks are higher than those present in headwaters lakes, and are likely attributable to local catchment inflows. Nutrient values (Figure 85 and Figure 86) also show winter peaks, with the 2007-2008 values exceeding the earlier monitoring results.

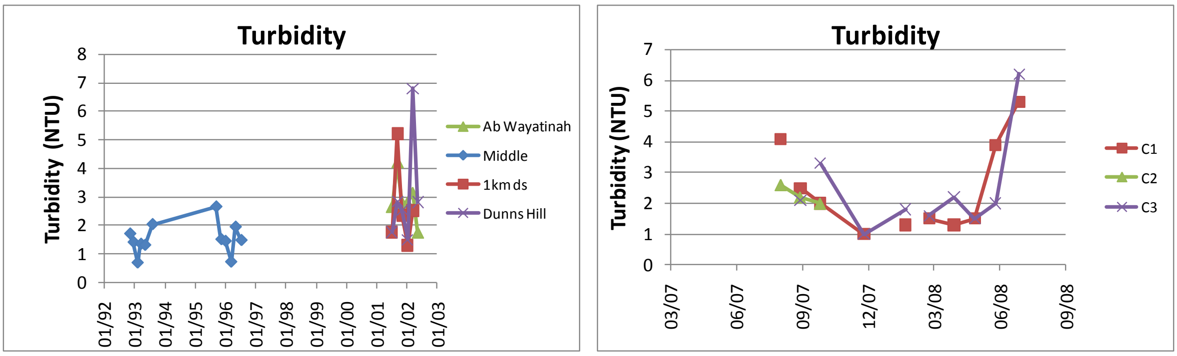


Figure 84. Turbidity (NTU) results from Lake Catagunya, 1992 - 2002 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

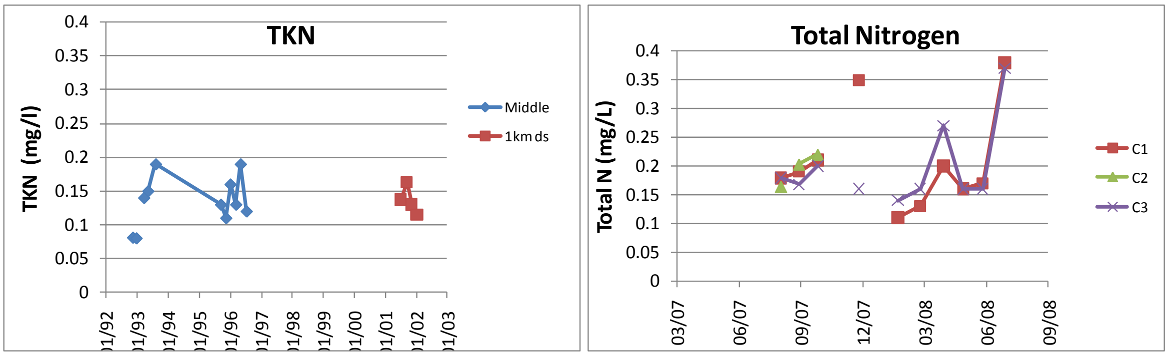


Figure 85. Nitrogen species in Lake Catagunya. TKN (mg/l) from 1992 - 2002 (left) and Total Nitrogen (mg/l) from 2007 - 2008. Data from Hydro Tasmania.

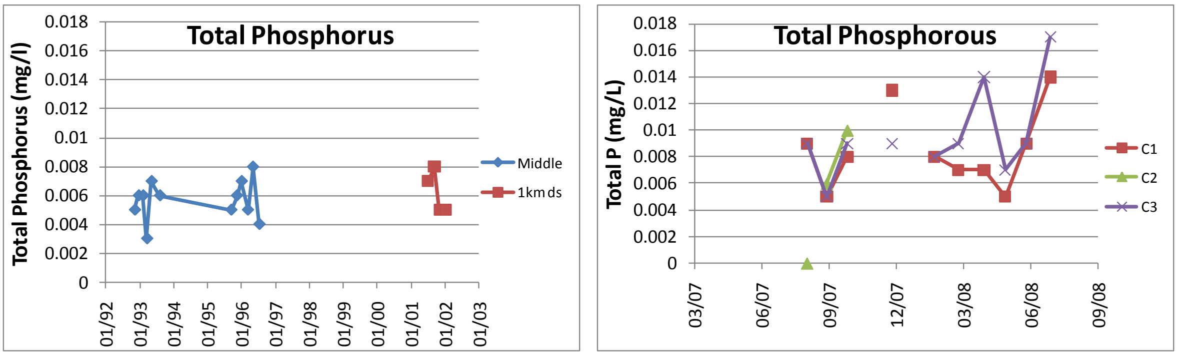


Figure 86. Total phosphorus (mg/l) results from Lake Catagunya, 1992 - 2002 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

Chlorophyll-*a* values show summer peaks, coinciding with warmer water temperatures, and much higher values as compared to the headwater impoundments, with most 2007 – 2008 values exceeding the ANZECC (2000) trigger of 5 µg/l for freshwater lakes and reservoirs. The maximum 2007-2008 chlorophyll-a results, which correspond to drought conditions (Figure 87) are higher than previously recorded values in the lake. Blue-green algae were present in the lake during the 2007 – 2008 monitoring period (Figure 88), but did not pose a risk based on biovolume calculations (*M.M[c]Causland, pers comm.*).

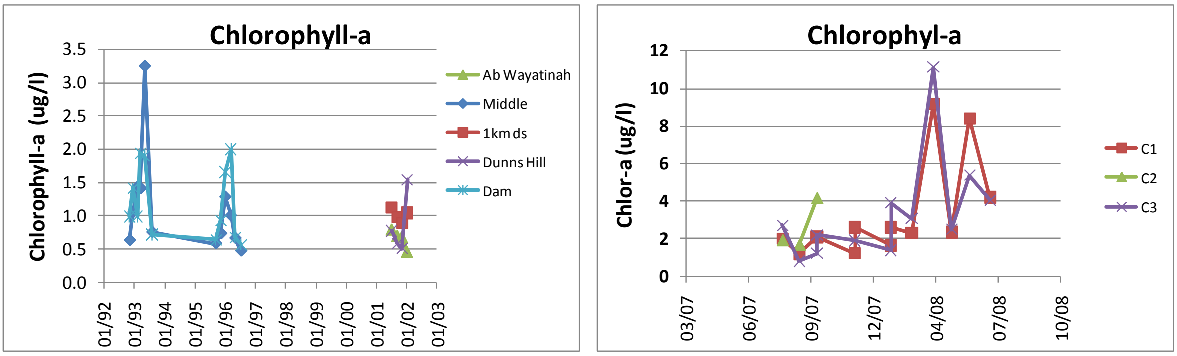


Figure 87. Chlorophyll-a results from Lake Catagunya, 1992 - 2003 (left) and 2007 - 2008 (right). Noted different scale on 2007 – 2008 results. Data from Hydro Tasmania.

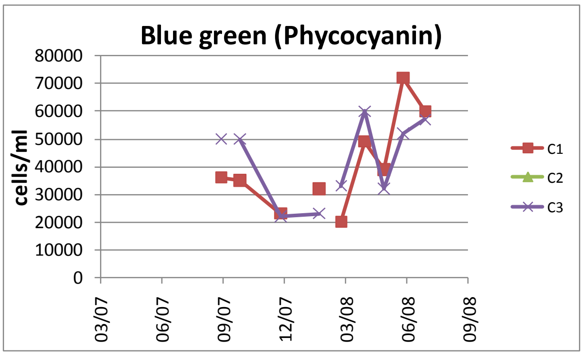


Figure 88. Blue-green algae results from Lake Catagunya, 1992 - 2003 (left) and 2007 - 2008 (right). Data from Hydro Tasmania.

Metal concentrations (Table 6) show generally low concentrations. Iron and aluminium levels are higher than recorded in Lake Liapootah and are likely due to the inflow of unregulated rivers and creeks into the impoundment.

Table 6. Summary of total metal concentrations from '1 km ds' site in Lake Catagunya, July 2000 - Jan 2001.

Jul00-Jan 01	**Al_{tot} mg/L**	**Cd_{tot} mg/L**	**Cr_{tot} mg/L**	**Co_{tot} mg/L**	**Cu_{tot} mg/L**
Mean	0.162	0.001	0.00125	0.001	0.001
Median	0.172	0.001	0.001	0.001	0.001
Max	0.21	0.001	0.002	0.001	0.001
n=	4	4	4	4	4

Jul00-Jan 01	**Fe_{tot} mg/L**	**Pb_{tot} mg/L**	**Mn_{tot} mg/L**	**Ni_{tot} mg/L**	**Zn_{tot} mg/L**	**SO_4 mg/L**
Mean	0.186	0.005	0.010	0.001	0.003	0.655
Median	0.178	0.005	0.010	0.001	0.002	0.605
Max	0.229	0.005	0.012	0.001	0.005	0.880
n=	4	4	4	4	4	4

2.2.2 Lake Meadowbank

Lake Meadowbank is the final impoundment in the Lower Derwent Power Scheme, and as shown in Figure 89 differs from other lakes in the catchment in that it is largely surrounded by cleared agricultural land. The Dee and Ouse Rivers enter the Derwent upstream of Lake Meadowbank, and the Clyde River enters near the lower end of the lake.

Figure 89. Google Earth image of Lake Meadowbank showing Hydro Tasmania monitoring sites.

Water quality profiles have been collected from four locations in Lake Meadowbank between 2004 –2005 and in 2010 (Figure 90 - Figure 93). Temperature profiles show that the lake is generally well mixed, with thermal stratification only occurring in the downstream sites of Clyde Arm (minor) and Ski Club in summer. In the summer months, there is also an increase in surface water temperatures downstream, reflecting additional warming during storage in the lake (Figure 90).

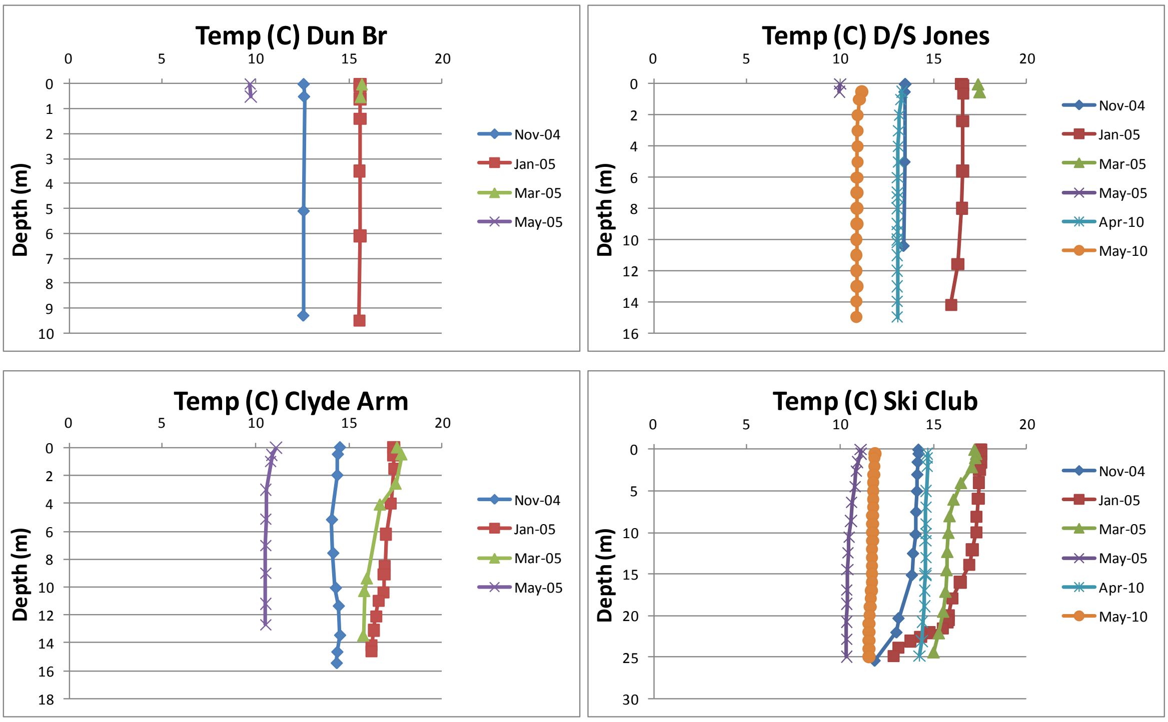


Figure 90. Temperature profiles from Lake Meadowbank 2004 - 2005 and 2010. Data from Hydro Tasmania.

The two upstream sites in the lake, Dunrobin Bridge and Downstream Jones show uniform dissolved oxygen profiles for all sampling runs, suggesting mixing occurs over the entire depth of the water column year round, probably due to inflows from the upstream power station (Figure 91). At the Clyde Arm there are reductions in dissolved oxygen with depth year round, suggesting a lower flushing rate and/or the increased presence of organic matter in the water column. The most downstream site near the Ski Club shows reductions in dissolved oxygen during the summer months at depths of greater than 20 m. This is similar to the depth in Lake Catagunya at which dissolved oxygen decreases, and probably represents the limit of wave induced mixing in the lakes.

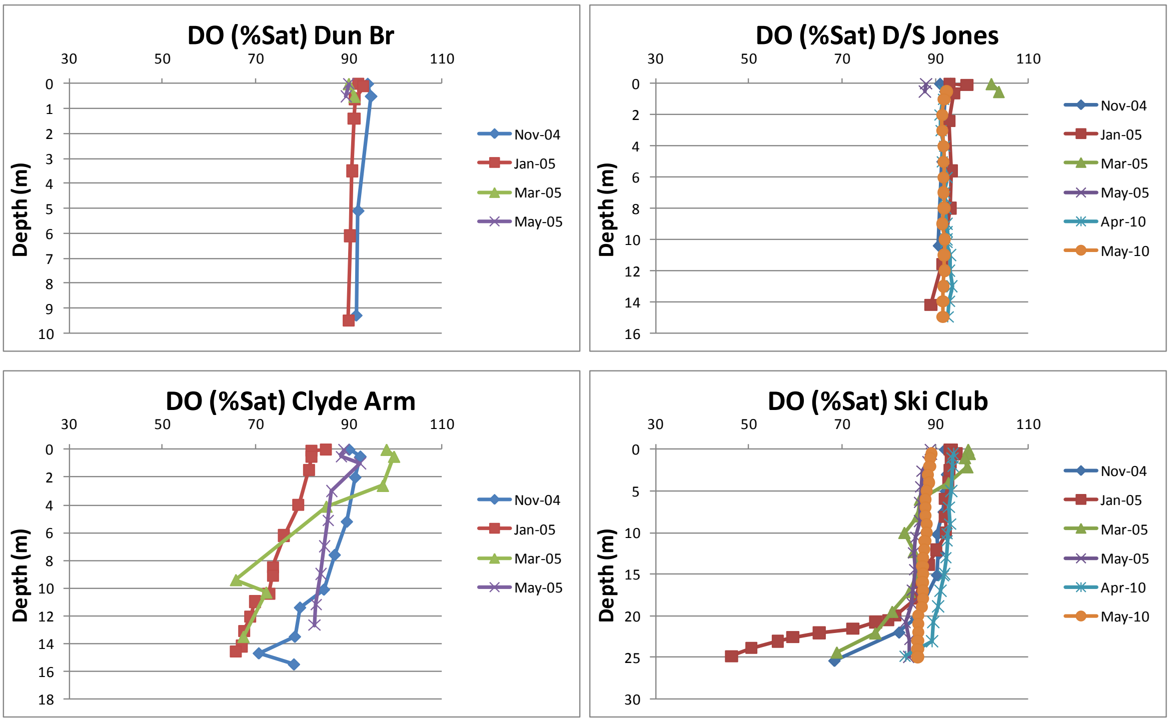


Figure 91. Dissolved oxygen profiles from Lake Meadowbank2004 - 2005 and 2010. Data from Hydro Tasmania.

Electrical conductivity values (Figure 92) are typically in the range of 45 – 60 µS/cm, which is slightly higher than Lake Catagunya and probably reflects the inflow of rivers from the lower catchment. EC is notably higher in the Clyde Arm, with values of up to 600 µS/cm measured in November 2004. This higher EC water accounts for the slightly higher temperature recorded at depth at the site in November, and appears to be occupying the base of the water column at the Ski Club site during the same month, most likely due to inputs from the Clyde. In January 2005 there was also higher EC water at the base of the water column at Ski Club, but this water is likely associated with the low dissolved oxygen conditions at the site during this time, rather than the inflow of high EC water from the Clyde or other tributary.

pH profiles from Lake Meadowbank show that slightly higher pH water is present in the Clyde Arm during most seasons as compared to the other sites, reflecting the inputs of the Clyde River (Figure 93). At the end of summer there is notable decrease in pH between about 10-12 m depth at the Downstream Jones and Ski Club sites. This chemocline is not present in the temperature or dissolved oxygen profiles, and may be associated with primary production in the lake.

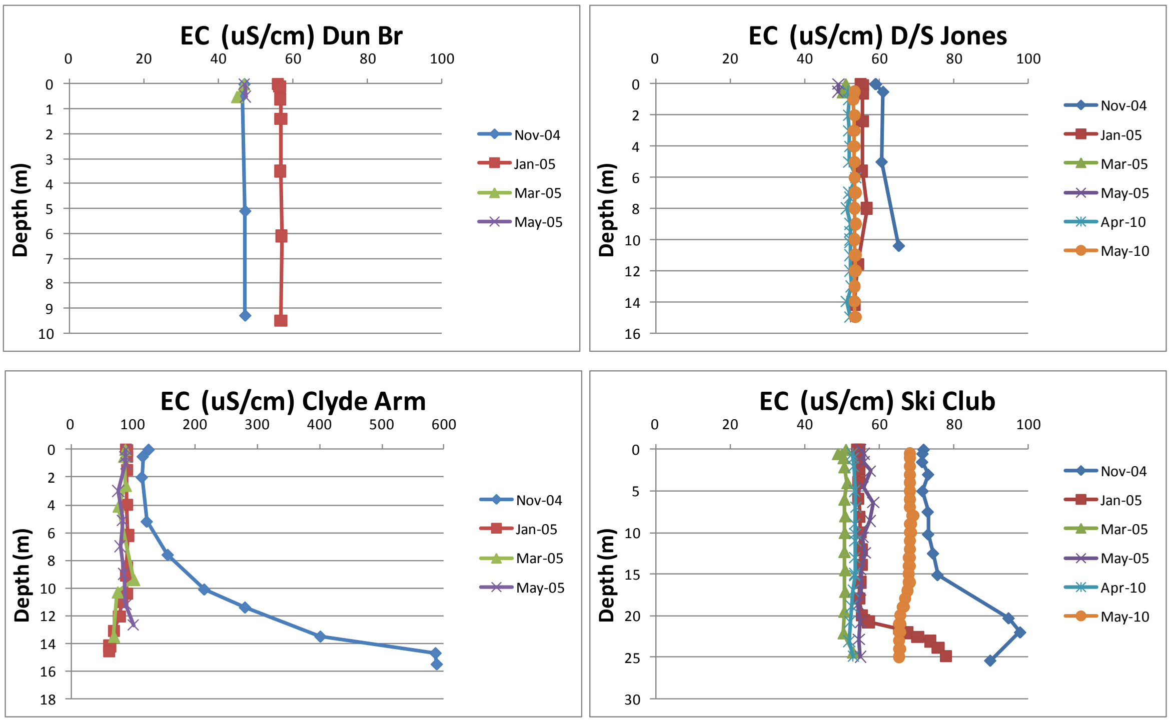


Figure 92. EC (µS/cm) profiles from Lake Meadowbank2004-2005 & 2010. Data Hydro Tasmania.

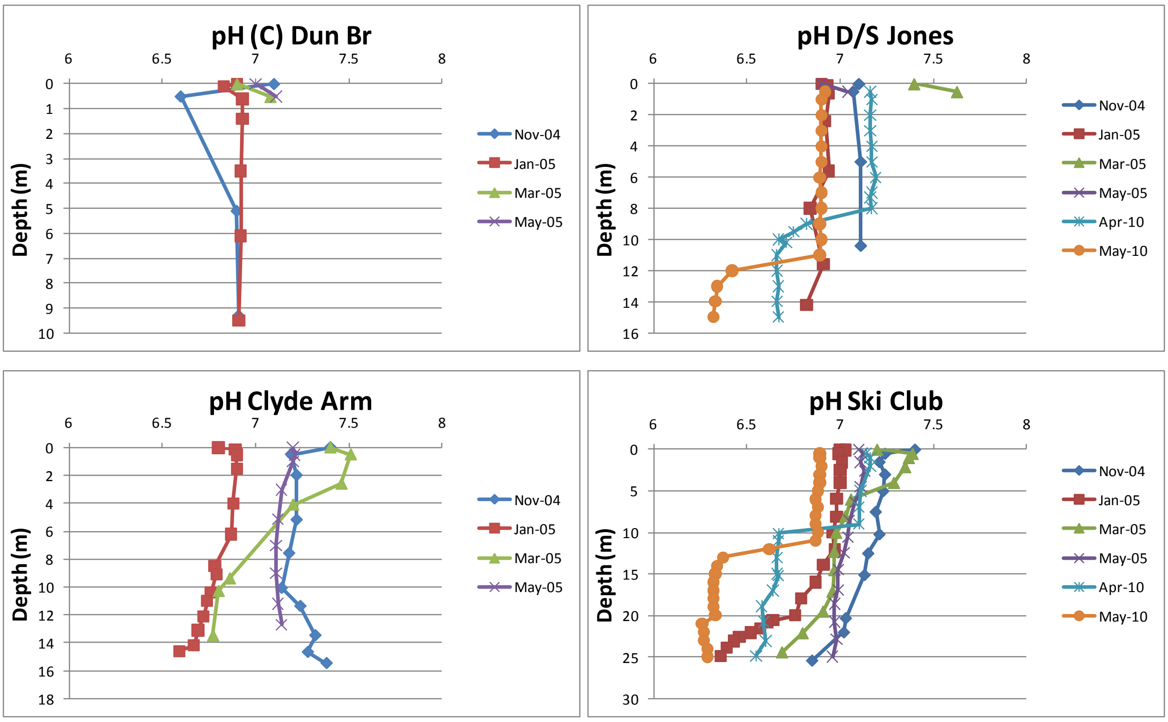


Figure 93. pH profiles from Lake Meadowbank2004 - 2005 and 2010. Data from Hydro Tasmania.

Turbidity profiles from the downstream Ski Club site for the period July 2004 – May 2005 (Figure 94) show highest turbidity levels occurred in July, with decreasing values through the spring and summer. This is consistent with winter inflows from tributaries being the main source of turbidity. Nutrient levels were measured in surface waters in Lake Meadowbank over several periods between 1992 - 2008; unfortunately, the parameters have varied over time so trends over the entire period cannot be constructed for all nutrient species.

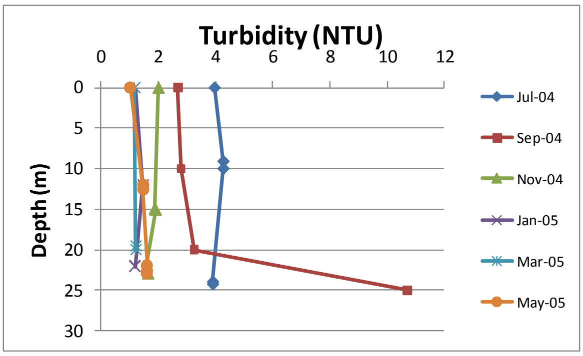
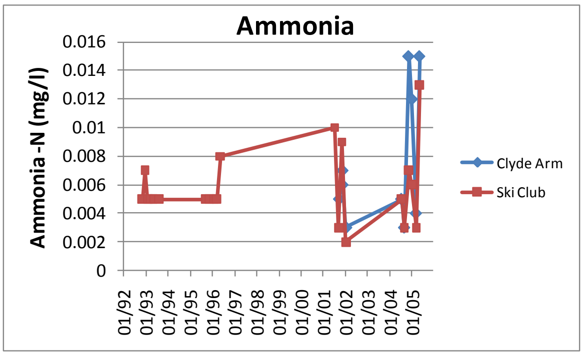


Figure 94. Turbidity profiles from Ski Club site July 2004 - May 2005. Data from Hydro Tasmania.



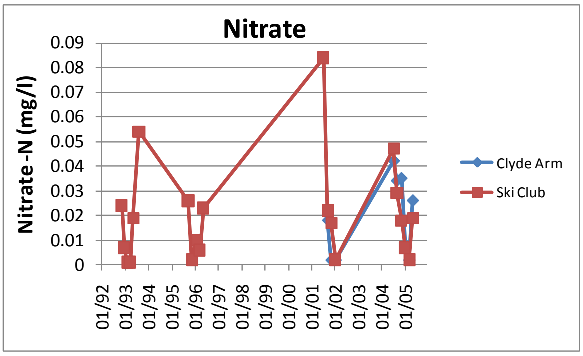


Figure 95. Nitrogen species measured in Lake Meadowbank between 1992 and 2005. Ammonia (left) and nitrate (right). Data from Hydro Tasmania.

Ammonia and nitrate (Figure 95) were measured at the downstream Ski Club and Clyde Arm sites between 1992 and 2005. These results show higher ammonia levels in the Clyde Arm on some occasions, but overall similar values between the two sites. Total Nitrogen, measured in 2007 – 2008 (Figure 96) varies between 0.01 and 0.25 mg/L throughout the lake, below the ANZECC (2000) trigger value of 0.35. The higher concentration of TN at the downstream M1 monitoring site suggests that concentrations in the lake can increase downstream due to inflows from the Clyde or other tributaries.

Total phosphorus levels (Figure 97) are also higher in the Clyde Arm during the 2001-2005 monitoring runs as compared with the sites in the main lake. TP values exceeded the ANZECC (2000) trigger of 0.01 mg/L during numerous monitoring runs prior to 2002. In the 2007 – 2008 results, TP results are near or below the trigger level, with the highest value recorded at the most upstream monitoring site. Total reactive phosphorus results are available for the 1992 – 2005 monitoring periods and show that in general, about half of the TP results are attributable to TRP (Figure 98). Chlorophyll-*a* results (Figure 99) indicate summer blooms, with the highest levels recorded in 2008. Similar to Lake Catagunya, many values during 2007 – 2008 exceeded the ANZECC (2000) chlorophyll-a trigger of 5 µg/L. Turbidity peaks (Figure 100) occur in winter, consistent with the turbidity profiles from the lakes, indicating that the main source of turbidity in the lake is from inflows rather than algal blooms. Similar to other lakes in the Derwent system, elevated numbers of blue-green algae have been present in the lake, although based on biovolume calculations and toxicological investigations, these algae have not been found to present a risk (*M.M^{c}Causland, pers com*).

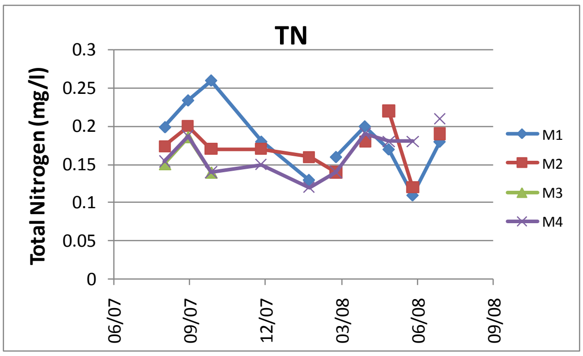


Figure 96. Total Nitrogen in Lake Meadowbank 2007 - 2008. Data from Hydro Tasmania.

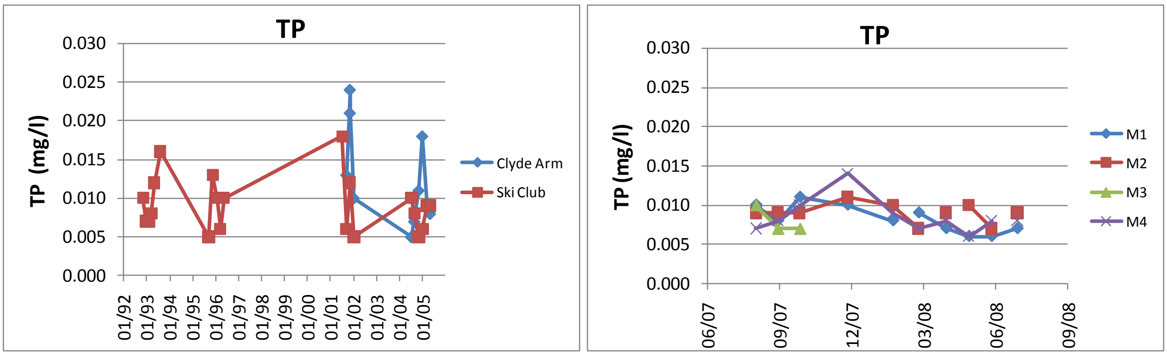


Figure 97. Total phosphorus in Lake Meadowbank 1992 - 2005 (left) and 2007 - 2008 (left). Data from Hydro Tasmania.

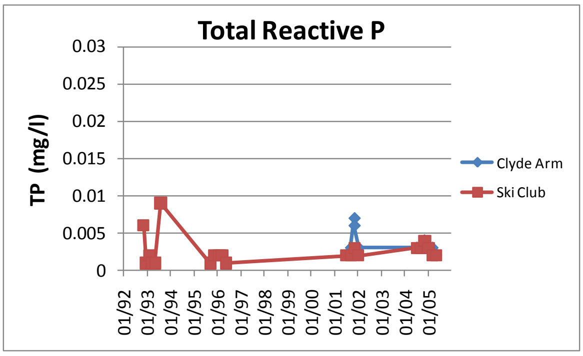


Figure 98. Total reactive phosphorus in Lake Meadowbank 1992 - 2005. Data from Hydro Tasmania.

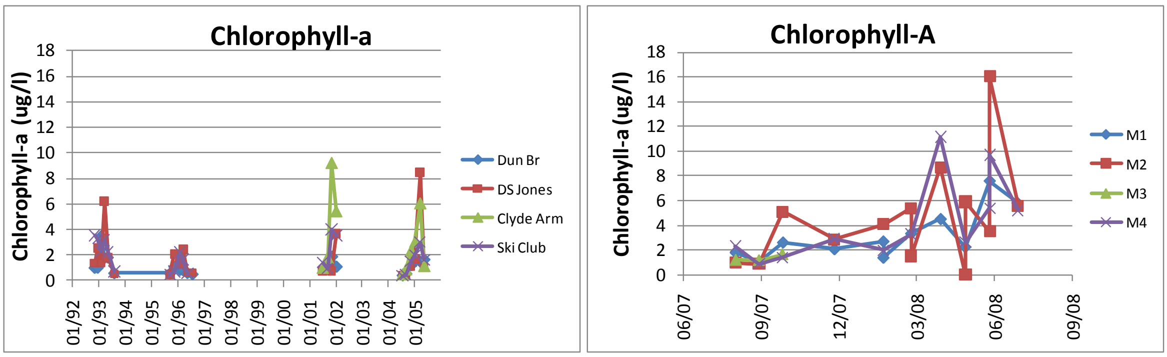


Figure 99. Chlorophyll-a in Lake Meadowbank 1992 - 2005 (left) and 2007 - 2008 (right). Data Hydro Tasmania.

Total metal concentrations were determined on surface samples at the Clyde Arm site and at the downstream Ski Club site. The results are summarised in Table 7 and

Table 8 and show overall low levels. Aluminium and iron results are indicative of very fine suspended sediments or colloidal material in the water. The iron and aluminium values are similar to Lake Catagunya suggesting that suspended solids are not increasing between the lakes.

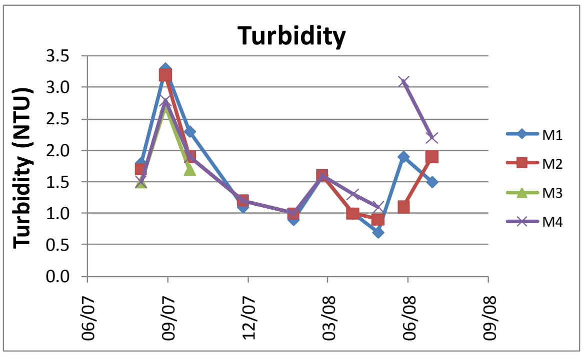


Figure 100. Turbidity in Lake Meadowbank 2007 - 2008. Data Hydro Tasmania.

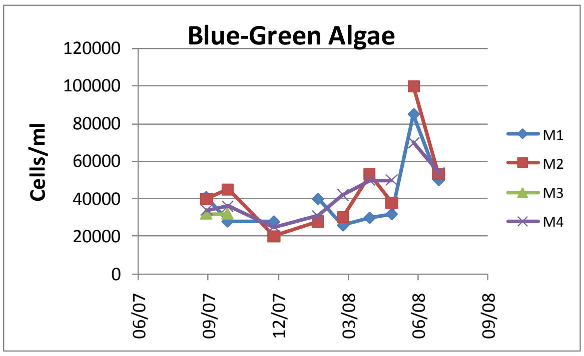


Figure 101. Blue-green algae cell counts in Lake Meadowbank 2007 - 2008. Data Hydro Tasmania.

Table 7. Summary of total metal concentrations in Lake Meadowbank in 'Clyde Arm' between July 2001 and May 2005. Data from Hydro Tasmania.

Jul00-May05	Al_{tot} mgl/L	Cd_{tot} mgl/L	Cr_{tot} mgl/L	Co_{tot} mgl/L	Cu_{tot} mgl/L
Mean	0.132	0.001	0.001	0.001	0.001
Median	0.107	0.001	0.001	0.001	0.001
Max	0.255	0.001	0.001	0.001	0.002
n=	9	9	9	9	9

Jul00-May05	Fe_{tot} mgl/L	Pb_{tot} mgl/L	Mn_{tot} mgl/L	Ni_{tot} mgl/L	Zn_{tot} mgl/L	SO_4 mgl/L
Mean	0.190	0.005	0.009	0.001	0.002	1.831
Median	0.197	0.005	0.007	0.001	0.001	1.500
Max	0.247	0.005	0.016	0.001	0.005	3.600
n=	9	9	9	9	9	9

Table 8. Summary of total metal concentrations in Lake Meadowbank Off Ski Club between July 2001 and May 2005. Data from Hydro Tasmania.

Jul00-May05	Al_{tot} mg/L	Cd_{tot} mg/L	Cr_{tot} mg/L	Co_{tot} mg/L	Cu_{tot} mg/L
Mean	**0.173**	**0.001**	**0.001**	**0.001**	**0.001**
Median	**0.136**	**0.001**	**0.001**	**0.001**	**0.001**
Max	**0.494**	**0.001**	**0.002**	**0.001**	**0.002**
n=	**10**	**10**	**10**	**10**	**10**

Jul00-May05	Fe_{tot} mg/L	Pb_{tot} mg/L	Mn_{tot} mg/L	Ni_{tot} mg/L	Zn_{tot} mg/L	SO_4 mg/L
Mean	0.186	0.005	0.008	0.001	0.002	0.929
Median	0.164	0.005	0.009	0.001	0.002	0.885
Max	0.410	0.005	0.011	0.001	0.004	1.400
n=	10	10	10	10	10	10

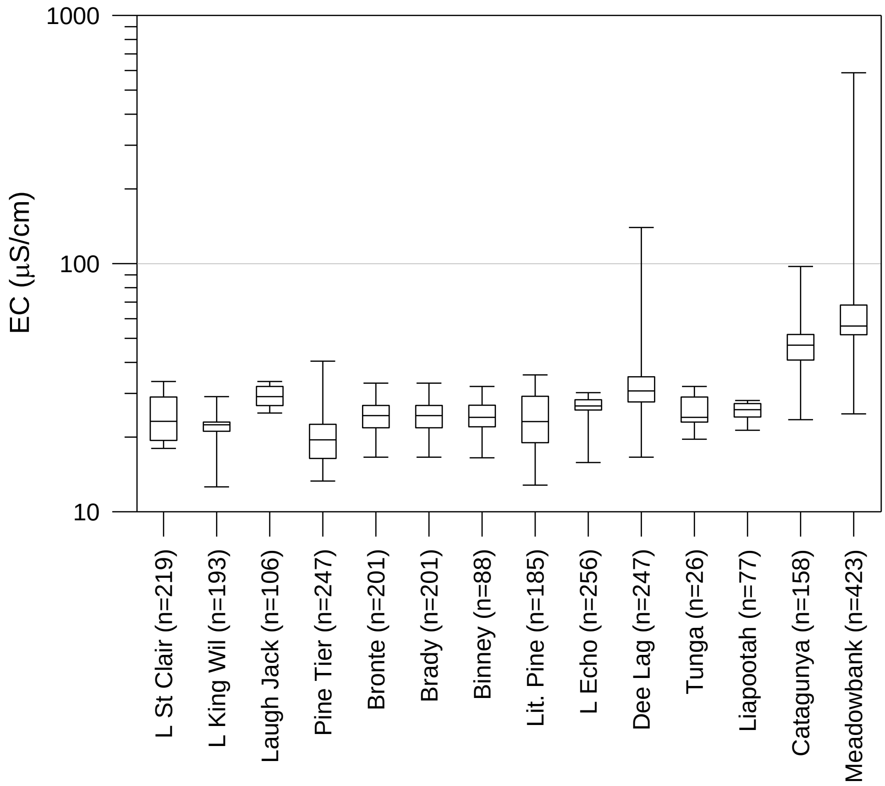


Figure 102. Summary of EC results from storages in the Derwent system.

Summary of Lower Derwent Lakes

Water quality in the Derwent Lakes downstream of the Central Plateau has the following characteristics:

- Seasonal temperature changes occur, although thermal stratification is less common as compared to the large, upstream storages due to the shallow nature of the lakes, and the low residence time of water in the system. An exception occurs in the downstream end of Lake Catagunya where thermal stratification can lead to the development of anoxic bottom waters, and in the deeper downstream end of Lake Meadowbank where thermal stratification and reduced dissolved oxygen levels are present in summer;
- During summer and dry periods, water quality in the lakes is dictated by the large volume of high quality water entering the system via the Tarraleah and Tungatinah power stations. During high rainfall periods, inflow from the unregulated (or less regulated) tributaries can affect water quality. There is evidence that inflows from the Florentine increase EC, and inflows from the Clyde can increase EC, turbidity and nutrients. An example of how these inflows affect the lakes is shown in Figure 102, where EC values in Lake Catagunya and Lake Meadowbank are considerably higher than in the headwater lakes;
- Increases in turbidity are more common in winter, suggesting high turbidity winter inflows as the source. Inputs are likely associated with land use practices in these tributary catchments;
- During drought conditions in 2007 and 2008, chlorophyll-*a* levels in both lakes exceeded the ANZECC (2000) trigger level of 3 µg/L;
- Overall, water quality is determined by very high quality water derived from the headwaters overprinted with inputs from tributaries entering the lakes.

2.3 Western inflows to Derwent River

Summary of hydrology and regulation

The Lower Derwent Power Scheme has two main western inflows, the Florentine and the Broad Rivers (Figure 10 PART 1); smaller tributaries include the Repulse and Jones Rivers. The Florentine enters the Derwent at Lake Catagunya, upstream of the discharge from the Wayatinah Power Station, while the Broad River enters further south at Lake Cluny. Both tributaries are unregulated, with the principle water allocation being aquaculture on the Florentine (annual allocation 25,550 ML or 70 ML/day). Aquaculture is considered a "non-abstractive" take as water returns to the river downstream of operations, although diversion may still impact flow conditions and water quality, especially under summer base flows. Unlike other allocations, non-abstractive takes are year-round and have no seasonal restrictions.

The western tributaries of the Lower Derwent catchment, downstream of Meadowbank, include the Tyenna, Plenty, Styx and Lachlan Rivers, with numerous smaller rivers, creeks and rivulets. The rivers in this part of the Derwent catchment are characterised by small catchment areas, and moderate river length. There are no Hydro developments in these rivers, and their unregulated flow sets them apart from most of the rest of the Derwent catchment. Many of the rivers are relatively undeveloped in the upper catchments, although forestry activity is a significant land-use. Flows are seasonally high in winter.

Summary of data sources presented

The Tyenna is the most studied western inflow, with a permanent flow monitoring station mid-way down the catchment. This site has been monitored monthly for basic physico-chemical parameters, nutrients (monthly) and pesticides (quarterly) by DPIPWE, from 2003 to 2009. The DEP Upper Derwent Nutrient Study (1996-1998) is the most comprehensive spatial dataset for physico-chemical parameters and nutrients for this part of the catchment. This study included the Broad, Florentine, Tyenna, Plenty, and Styx Rivers, and some tributaries of those river systems. Hydro Tasmania maintain a flow station on the Florentine at Florentine Rd, however the associated water quality monitoring (turbidity, EC, pH, DO; twice yearly) has not been included in this review. Monthly monitoring associated with the operation of two fish farms is reported to Council as a Level 1 activity, but was not available for this study.

Water quality data is presented along with ANZECC guidelines for the Protection of Aquatic Ecosystems, and it should be noted that only a sub-set of parameters are specifically based on Tasmanian conditions. (TP, TN, Nitrate + nitrite for upland rivers; chlorophyll-*a* for freshwater lakes and reservoirs).

Spatial & temporal trends

2.3.1 Florentine River

Figure 14 (PART 1) shows flow patterns in the Florentine for the period 2009- 2011. Flows are seasonally variable, with summer base flows of ~5 cumecs, and high flow events (>10 cumecs) associated with winter and spring. Winter flows may exceed 100 cumecs for short periods (Figure 103). Data from the Upper Derwent Nutrient Study (1996-1998) shows water quality differs from the Derwent headwaters on the Central Plateau, with EC between 150 and

250 µS/cm, and pH between 7.6 and 7.8. The EC signal from the Florentine River is picked up in Lake Catagunya, with conductivity greater than that measured in the Derwent headwaters. Turbidity was similar to the Central Plateau sites 'Nive above Gowan Brae', however no summer data was available to investigate seasonal cycles of oxygen and temperature.

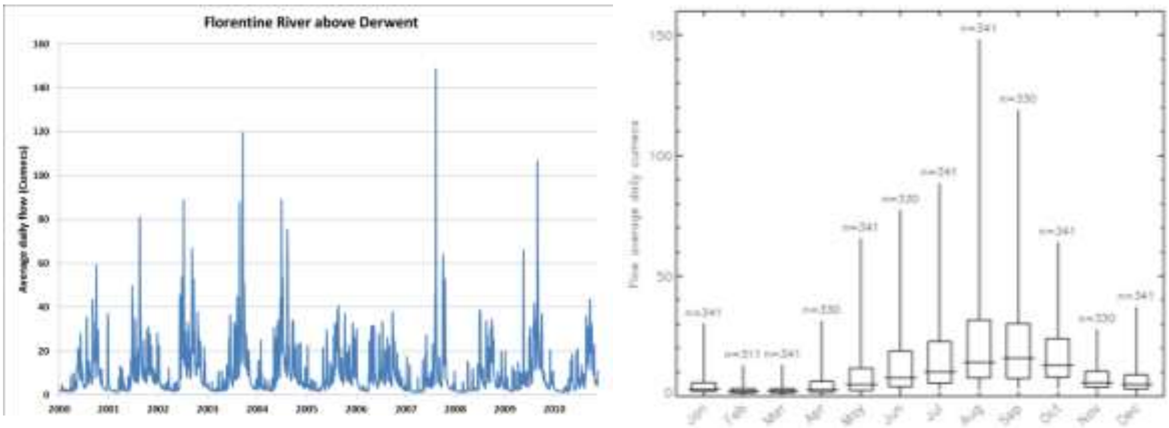
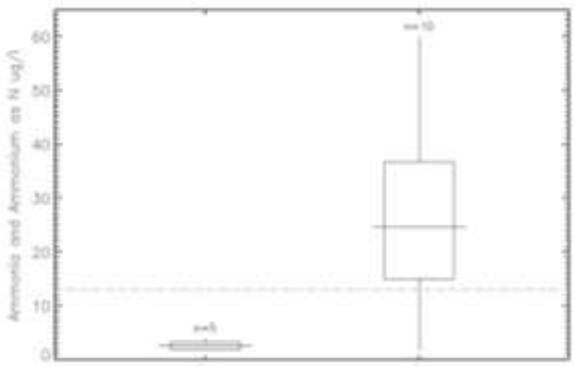
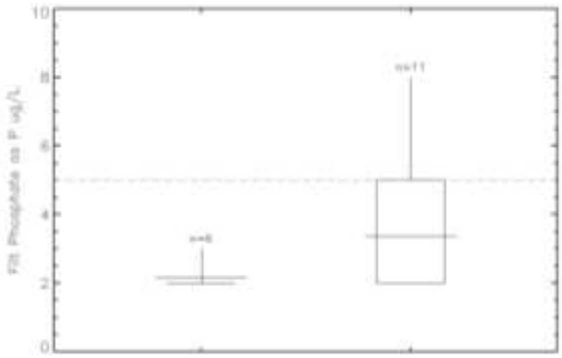


Figure 103 Average daily flow (left, cumecs) Florentine River above Derwent for the period 2000-2010, and summarized by month (right). "Boxes" (80th, 50th, and 20th percentile; "whiskers" maximum and minimum, n= no of sample events. (Data from Hydro Tasmania).

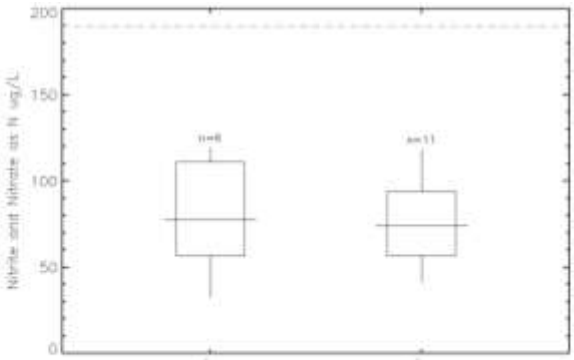
An Atlantic salmon hatchery is located on the Florentine River, just above its confluence with the Derwent and Lake Catagunya. Water quality monitoring data upstream and downstream of the fish farm is presented in Figure 104 a-h).



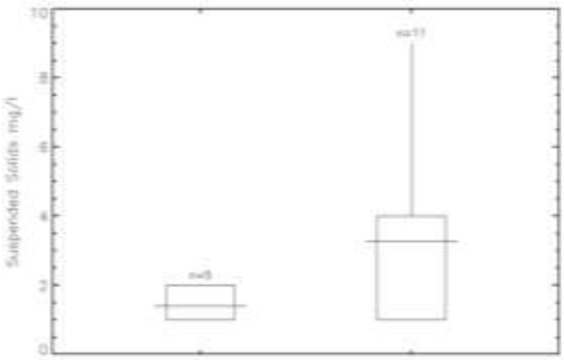
a) Ammonia + ammonium as N (µg/L)



b) Dissolved phosphate as P (µg/L)



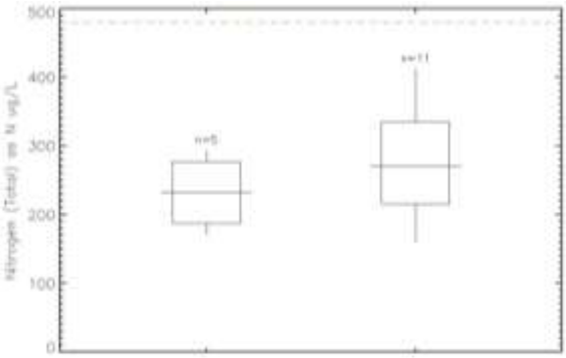
c) Nitrate + nitrite as N (µg/L)



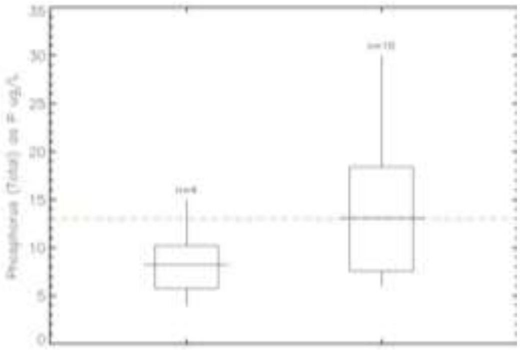
d) TSS (mg/L)

Figure 104 a-h) Water quality data (1996 – 1998) from the Upper Derwent Nutrient Study comparing parameters upstream (left box and whiskers), and downstream (right box and whiskers) of the Florentine River fish farm. "Boxes" (80th, average, and 20th percentile; "whiskers" maximum and minimum, n= no of sample events. Dotted line = ANZECC WQ guideline, where appropriate (Data from DEP).

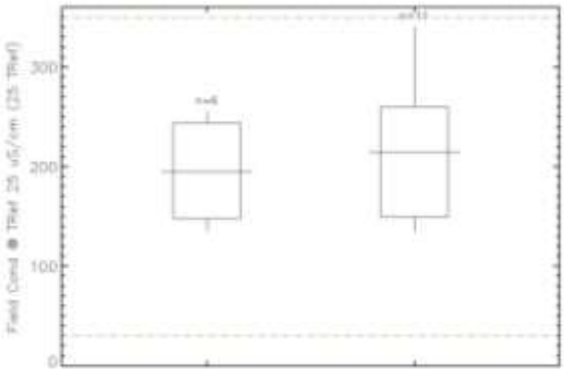
Data from the 1996-1998 survey shows water quality deteriorated downstream, with significant inputs of ammonia, dissolved phosphate, TSS, and to a lesser degree TN and TP. It is likely that the higher EC and pH at both sites is due to catchment geology (limestone), with Figure 104 g-h) showing only a slight increase in these parameters downstream of the fish farm. The river typology described in the CFEV dataset for the Florentine is distinct from the surrounding rivers (Figure 4, PART 1) with the area forming part of the south-east karst basin (DPIW, 2008). Industry were approached to contribute more contemporary data for this study, but declined. In the absence of current data, it is assumed that water quality impacts persist.



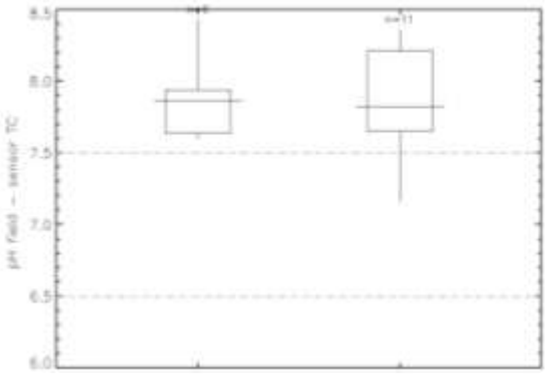
e) Total Nitrogen (µg/L)



f) Total Phosphorous (µg/L)



g) Field conductivity (µS/cm)



h) Field pH

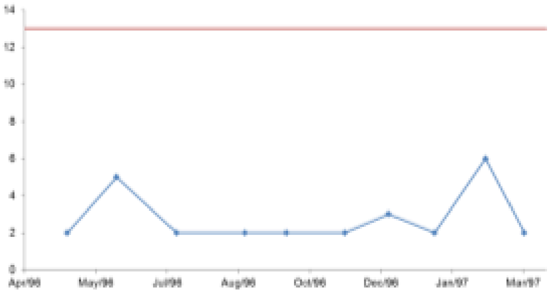
Figure 104 a-h (cont) Water quality data from the Upper Derwent Nutrient Study comparing parameters upstream (left box and whiskers), and downstream (right box and whiskers) of the Florentine River fish farm. "Boxes" (80th, average, and 20th percentile; "whiskers" maximum and minimum, n= no of sample events. Dotted line = ANZECC WQ guideline, where appropriate. (Data from DEP).

Inputs from the Wayatinah fish hatchery were not specifically studied in the UDNS. Water intake for the hatchery is primarily from the Derwent River, however in summer months when water temperature may be an issue for fish health, water may be drawn from the cooler, deeper waters of the Wayatinah Lagoon. Fish are cultured on-site for 12 months, then transferred at the smolt stage to marine farms in southern Tasmania. Approximately 50% of the smolt supplied to Tasmanian farms is sourced from the Wayatinah and Florentine hatcheries, and was scheduled to reach 3.7 million smolt in 2007 (CSIRO, 2011). Andrew (2002) noted that recirculation technology had been introduced at the Wayatinah hatchery, to improve effluent quality.

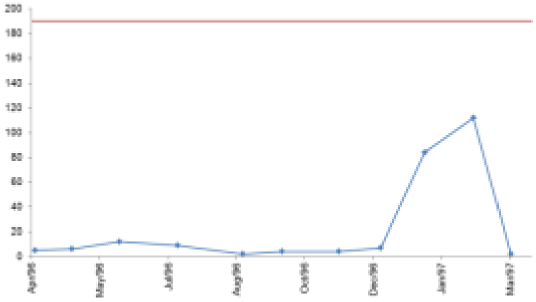
2.3.2 Broad River and Lake Fenton

There is no continuous flow monitoring data for the Broad River, although total contribution to flows in the Derwent are assumed to be small due to the small catchment size

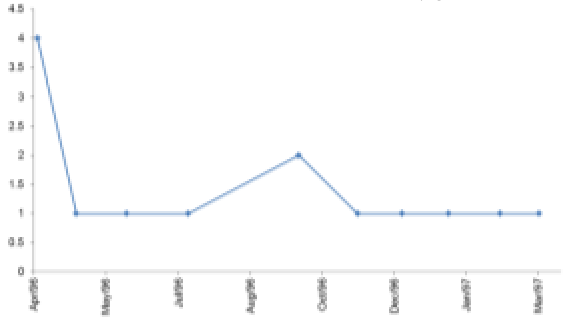
(140 km^2) and short river length. Mean historical flows were recorded as 4.2 cumecs by Coughanowr (2001). Water quality data is limited to that collected in the Upper Derwent Nutrient Study, summarized in Figure 105. A water allocation exists for the Broad (aquaculture, 183 ML/yr) although no facility has been constructed at this time. Water quality was found to be extremely good, characterised by clear waters with low EC of 20-30 µS/cm, similar to the Derwent headwaters above Butlers Gorge, Tungatinah and Lake Echo power stations. pH was slightly lower than the Nive and Florentine Rivers.



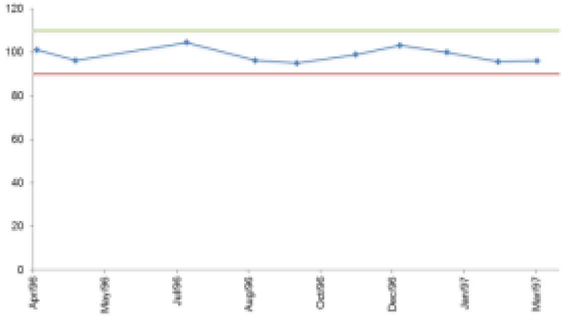
a) Ammonia + ammonium as N (µg/L)



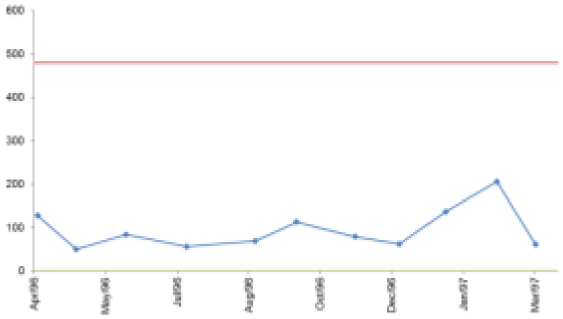
b) Nitrate + nitrite as N (µg/L)



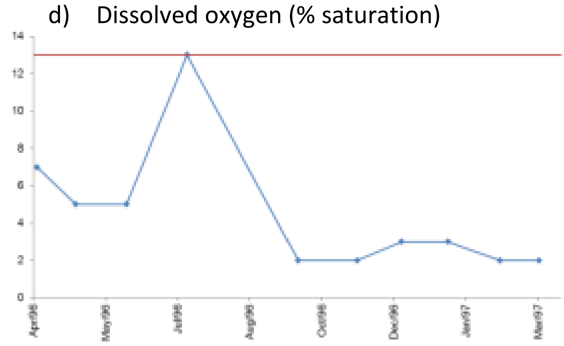
c) TSS (mg/L)



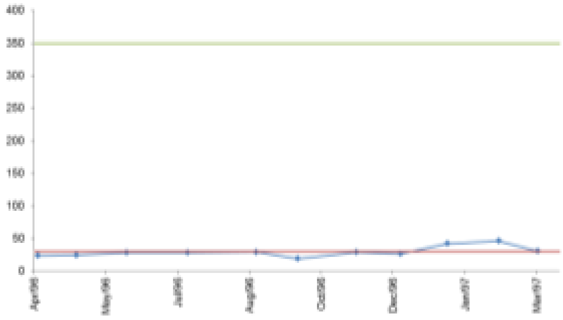
d) Dissolved oxygen (% saturation)



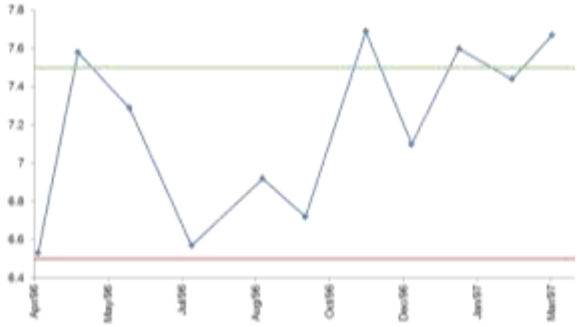
e) Total Nitrogen (µg/L)



f) Total Phosphorous (µg/L)



g) Field conductivity (µS/cm)



h) Field pH

Figure 105 a- h) Water quality data from the Upper Derwent Nutrient Study for the Broad River. Solid line= ANZECC WQ guideline or range, where appropriate. (Data from DEP).

Filtered phosphate and nitrite were below detection on all occasions, while turbidity was < 1 NTU, and TSS frequently below detection. Elevated nitrate + nitrite and TN were associated with low flows and warmer water temperatures in summer, while TP was seasonally high in winter (Figure 105).

Lake Fenton is located in the Mt Field National Park, and contributes water to Hobart's domestic water supply via Lady Barron Creek. A small portion of the Broad River catchment is diverted into Lake Fenton via a drain across the Wombat Moor (Hobart Water, 2000). Water quality is generally excellent, and reflects an alpine catchment contained within a conservation area. Water quality from Lake Fenton is summarized in Figure 106. Data from 2002-2010 shows waters are clear (Colour < 10 Hazen units, < 1 NTU), neutral pH (20th percentile 6.6; 80th percentile 7.3) with infrequent faecal contamination. Temperature profiles are similar to other alpine lakes (Figure 17; Figure 45), while conductivity appears to have undergone a stepwise change post winter 2003. The reason for the increase is unknown, but there is a coinciding slight increase in turbidity

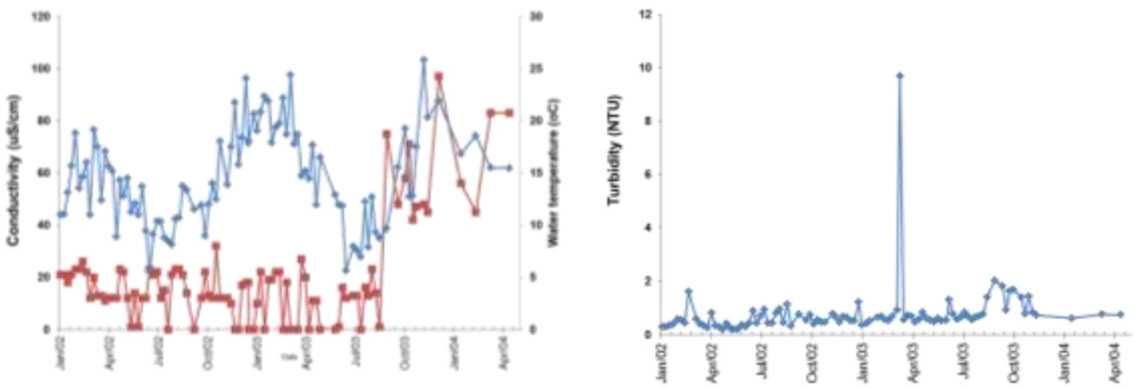


Figure 106 Conductivity (red squares), temperature (blue diamonds) (Left) and turbidity data (right) from Lake Fenton, 2002- 2004. (Data from Southern Water).

2.3.3 Tyenna River

The Tyenna River was studied in detail as part of the Upper Derwent Nutrient Study, and sites were located to reflect major tributaries and/or point sources from the headwaters through to the area of intense agricultural land-use downstream of Westerway (Figure 107). Dams and off-takes are concentrated around the towns of Gretna, Plenty, Bushy Park and Westerway (see Figure 22 and 23, PART1). Flows are presented in Figures 11 and 14 (PART1).

A summary of data collected by Coughanowr (2001) is presented here with more recent data from the DPIPWE flow monitoring site '*Tyenna at Newbury Rd*' monitored between 2003 and 2009. Figure 108 shows the combined results of the spatial (1996-1997) and longitudinal (1997-1998) studies, with upper catchment sites (left) through to lower catchment (right). Ammonia is low in the upper catchment and tributaries (tributary data not shown), and increases immediately downstream of National Park and Karanja, attributed to the presence of aquaculture facilities. Dissolved phosphate and TP also increases notably downstream of Karanja, but to a lesser degree downstream of Russell Falls. Nitrate+ nitrite shows a significant spike below Maydena, most likely associated with the Junee karst system, and a possible

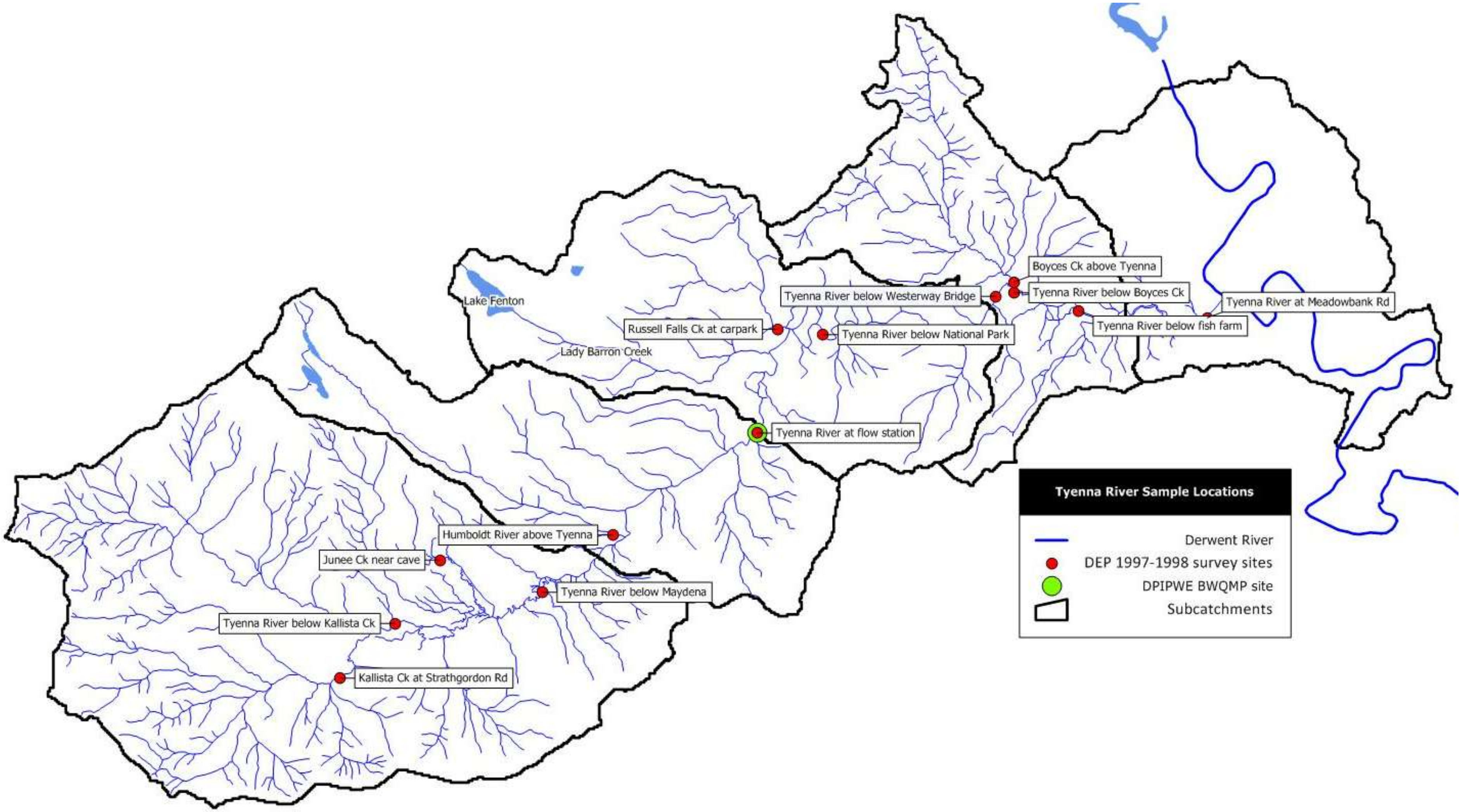
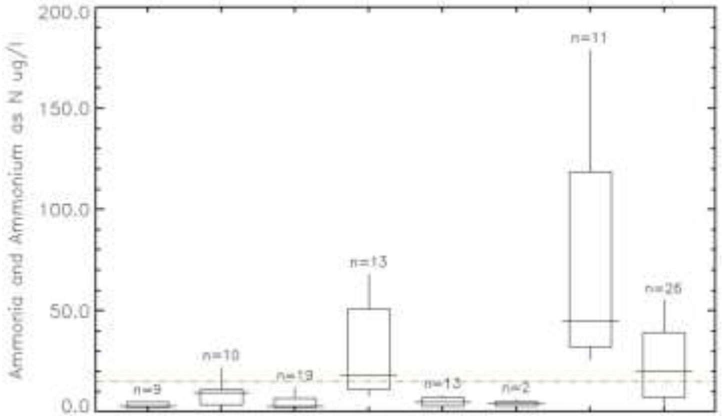
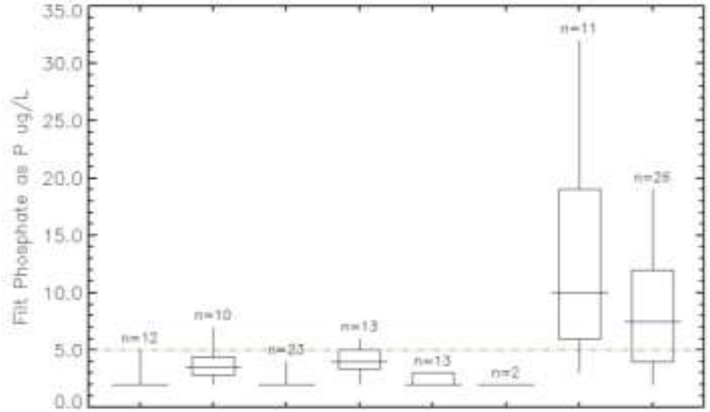


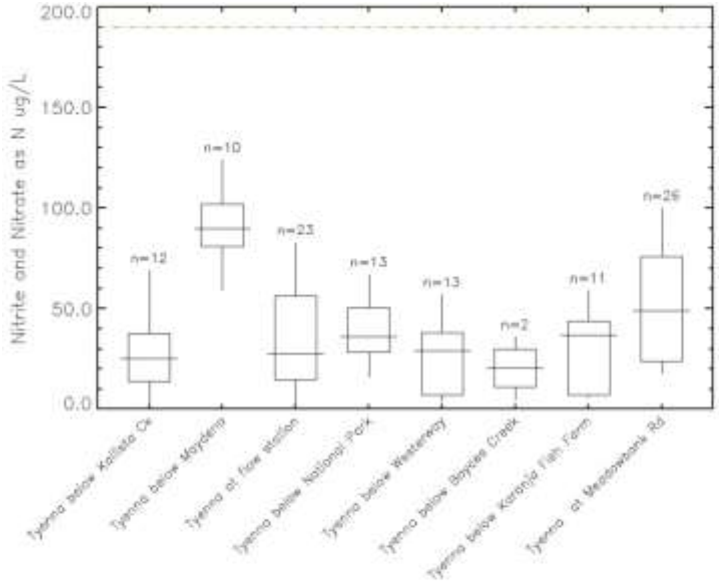
Figure 107 Location of monitoring sites in the Tyenna catchment. Base layer by CFEV, the LIST © State of Tasmania.



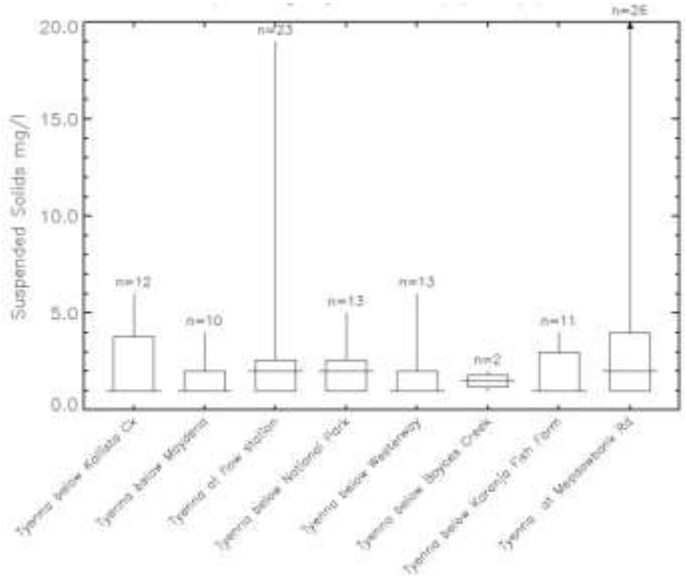
a) Ammonia + ammonium as N (µg/L)



b) Dissolved phosphate as P (µg/L)

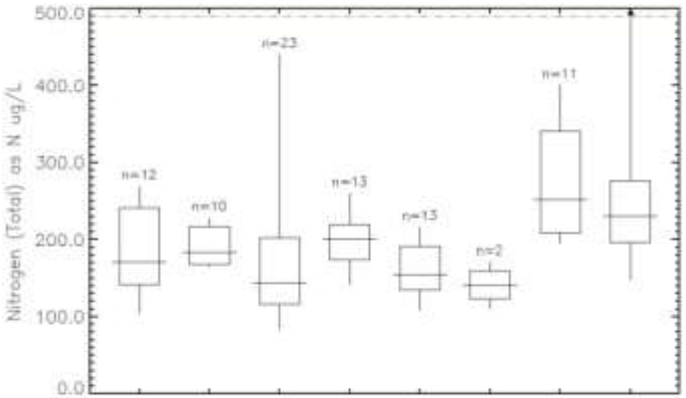


c) Nitrate + nitrite as N (µg/L).

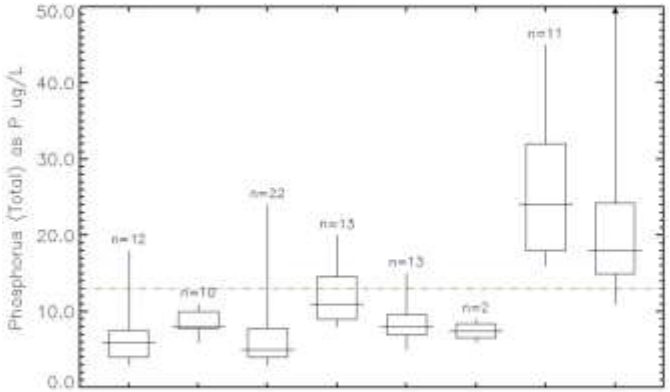


d) TSS (mg/L)

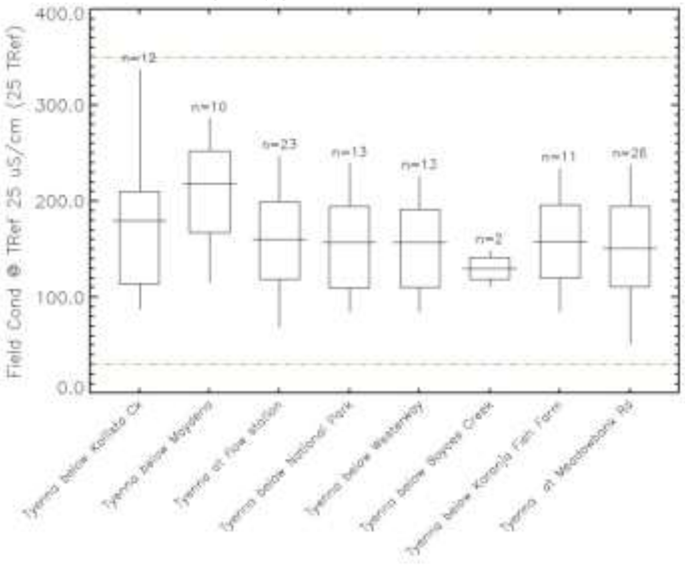
Figure 108 a-h) Water quality data, longitudinal study of the Tyenna River catchment Upper Derwent Nutrient Study (Data from DEP).



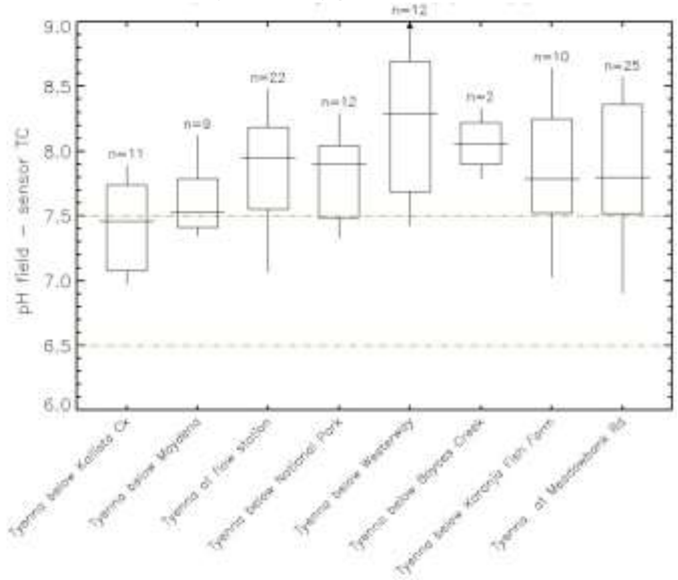
e) Total Nitrogen (µg/L)



f) Total Phosphorous (µg/L)



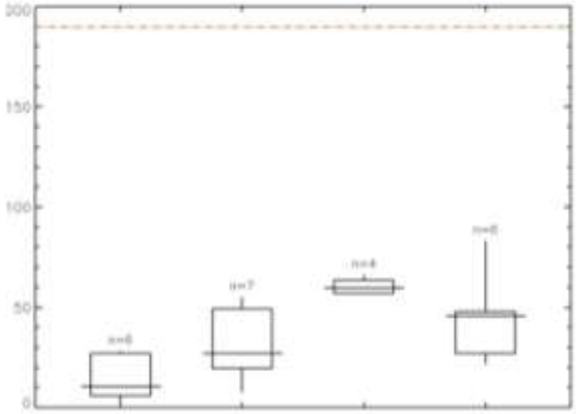
g) Field conductivity (µS/cm)

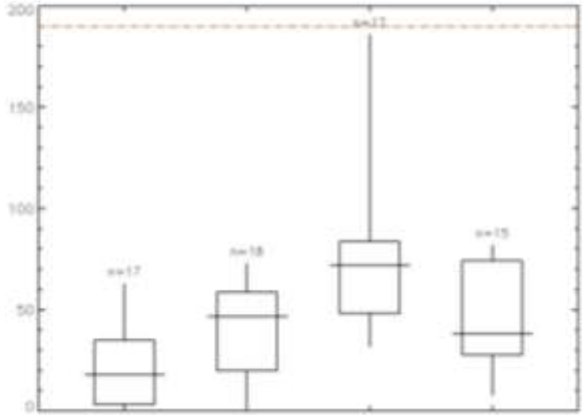


h) Field pH

Figure 108 a-h continued) Water quality data, Upper Derwent Nutrient Study. "Boxes" (80th, average, 20th percentile; "whiskers" maximum/minimum, n= number of samples. ANZECC default trigger value for upland river shown, where appropriate. (Data from DEP.*)*

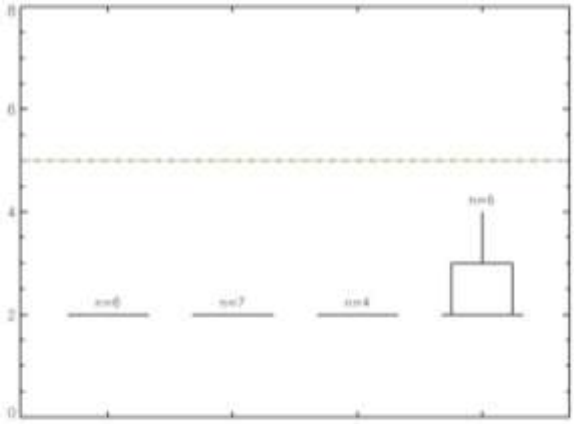
contribution from the STP. Nitrate drops gradually downstream, until the junction of the Tyenna with the Derwent at Meadowbank Dam. TSS is seasonally variable with occasional spikes at the bottom of the river system (133 mg/L), occurring during a flood event and probably associated with intensive land-use at the bottom of the catchment. Conductivity is higher than the adjacent Broad River (~150 µS/cm), although Tyenna tributaries are much lower (Humboldt River, Rufus Ck) at around 50 µS/cm.

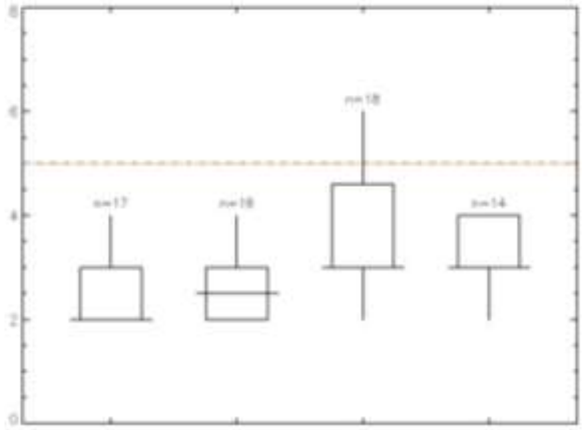




a) Nitrate + Nitrite as N (µg/L) 1996-1998

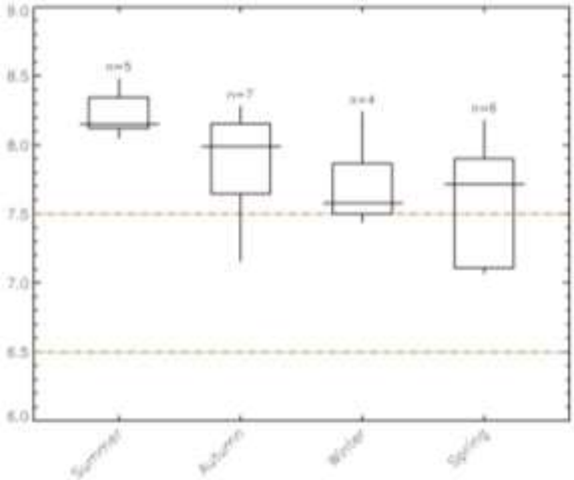
Nitrate + Nitrite as N (µg/L) 2003-2009

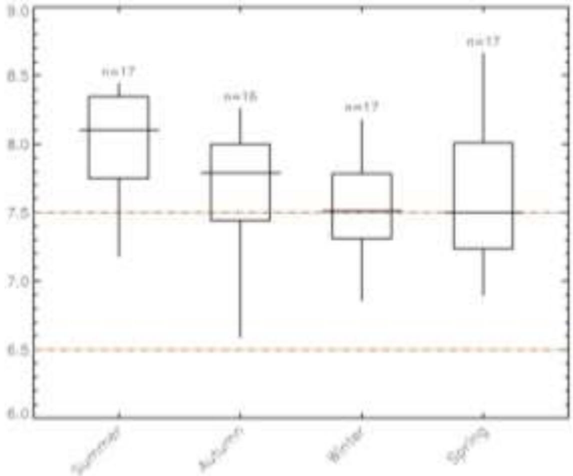




b) Dissolved phosphate as P (µg/L) 1996-1998

Dissolved phosphate as P (µg/L) 2003-2009

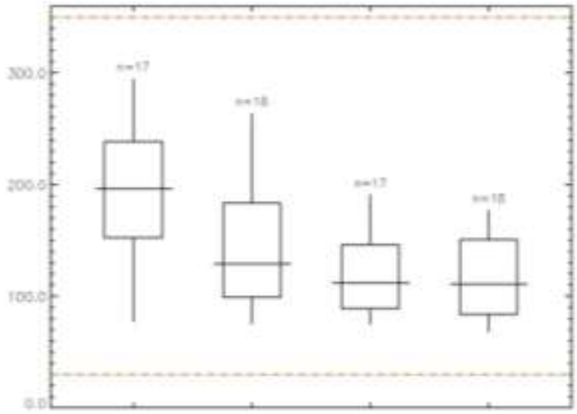




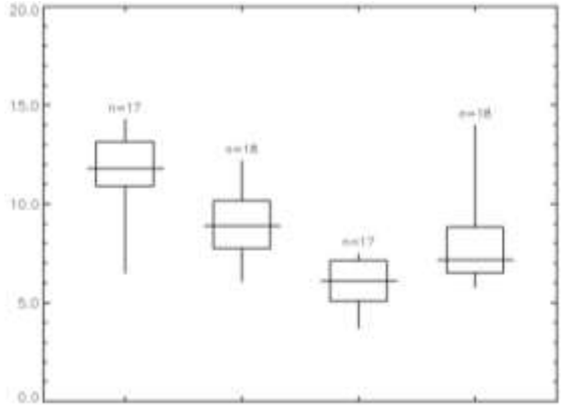
c) pH 1996-1998

pH 2003-2009

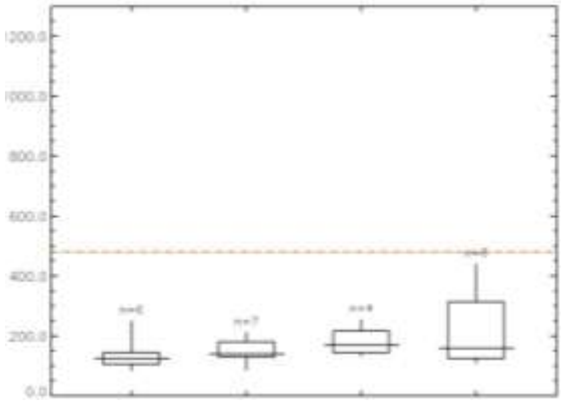
Figure 109 Seasonal variation in water quality parameters for the site 'Tyenna at Newbury Rd' (Left UDNS for period1996-1998, right DPIPWE BWQMP 2003-2009). "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= no samples.



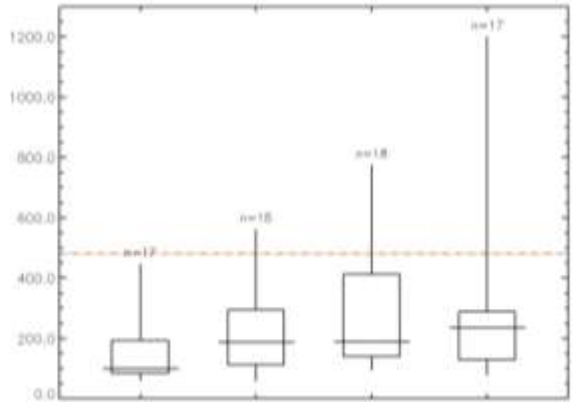
d) Conductivity µS/cm 2003-2009



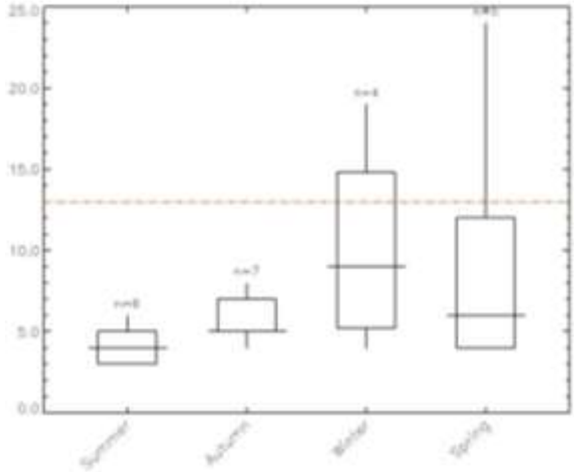
e) Temperature (°C) 2003-2009



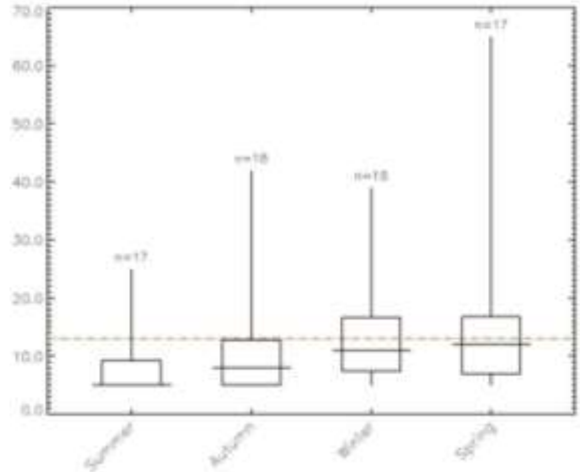
f) Total Nitrogen (µg/L 1996-1998)



Total Nitrogen (µg/L) 2003-2009



g) Total Phosphorous (µg/L) 1996-1998



Total Phosphorous (µg/L) 2003-2009

Figure 109 cont. Seasonal variation in water quality parameters for the site 'Tyenna at Newbury Rd' (Left UDNS for period 1996-1998, right DPIPWE BWQMP 2003-2009). "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= number of samples. Conductivity and temperature were not significantly different in the two studies, only 03-09 presented.

Forestry Tasmanian studied water quality before, during and after roading and infrastructure works (culverts etc) in two headwater streams of the Tyenna River. Turbidity was monitored at high frequency (15 minute intervals) for over 4 years in a control creek and in the creek impacted by construction of stream crossings, and eventually harvest. Reports prepared by FT showed that prior to any road works, turbidity fell below the Australian Drinking Water guideline of 5NTU ~ 80% of the time, with increased turbidity often but not always associated with increased rainfall. EC varied between 65 and 120 µS/cm, while dissolved oxygen fluctuated seasonally. During and post-construction, increases in turbidity were observed, with background values roughly doubled for a short-period (3 weeks) (Roberts, 2008; 2010).

Water quality responds to seasonal changes in flow, with 1996-1998 nitrate+ nitrite data showing a distinct winter maximum (Figure 109), possibly due to karstic features located in the upper catchment, and other catchment sources of nitrate. Phosphate was often below detection, whilst conductivity declined following winter and spring rains, peaking in summer. Water temperature showed distinct seasonal effects, as did dissolved oxygen (not shown). Data from the DPIPWE Baseline Water Quality Monitoring Program for the period 2003-2009 is presented alongside (Figure 109, right side), and shows that whilst similar seasonal trends are maintained over this period, the range of concentrations recorded is often significantly increased for nutrients. This may be attributable to changes in catchment land-use, or reflect the fact that these parameters are influenced by seasonal rainfall. In very dry years (1997, 2006) TN is low, whilst wet years (2009), or dry years with extreme winter events (2007), TN inputs can be significant (Figure 110). Both TN and TP are typically seasonally low in summer during base flows.

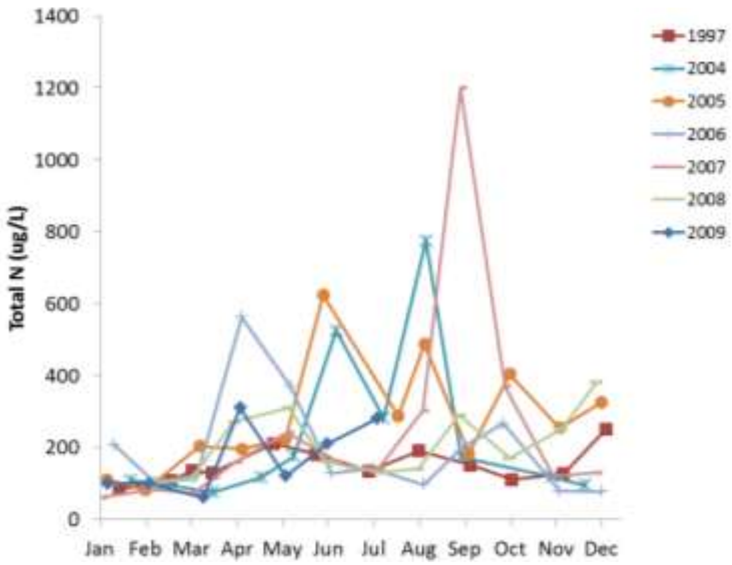


Figure 110 Annual variability in Total Nitrogen at Tyenna at Newbury Rd, monthly monitoring. 1997 data DEP, 2004-2009 DPIPWE.

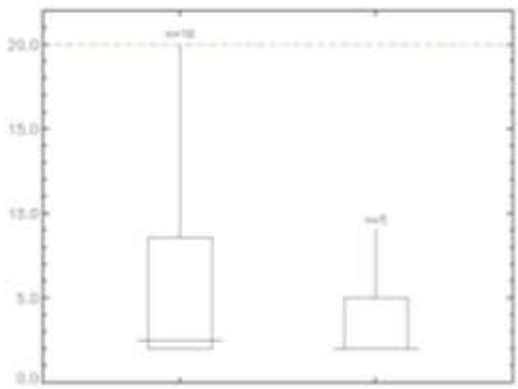
Pesticides were monitored quarterly by DPIPWE at "*Tyenna at Newbury Rd*" as part of the Baseline Water Quality Monitoring Program, with none of the standard suite of pesticides detected at any time between 2003-2009, however monitoring did not extend to event based (high-flow) sampling. The BWQMP pesticide monitoring program at this site has ceased, and monitoring within the catchment is under review. It is likely that future monitoring will focus on the Styx and Plenty Rivers.

2.3.4 Styx, Plenty and Lachlan River catchments

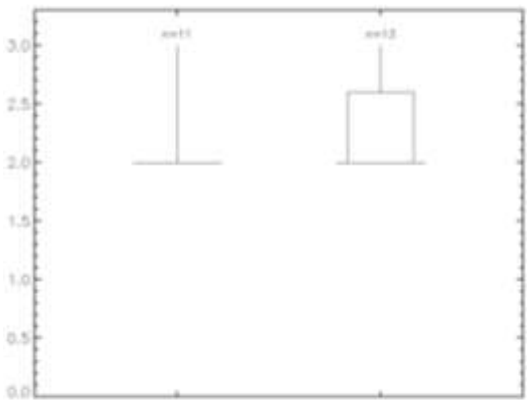
Long-term monitoring with good spatial and temporal coverage is lacking for these catchments, and current data for these rivers is mostly limited to issue based investigations (pesticides, turbidity etc). Data from the lower Plenty and lower Styx (1996) showed water quality intermediate between that of the Broad River and the Tyenna River for basic physico-chemical parameters (Coughanowr, 2001).

Nutrients measured at the base of these rivers showed TN, TP and ammonia and nitrate were periodically high (Figure 111). Conductivity and pH are presented in Figure 112.

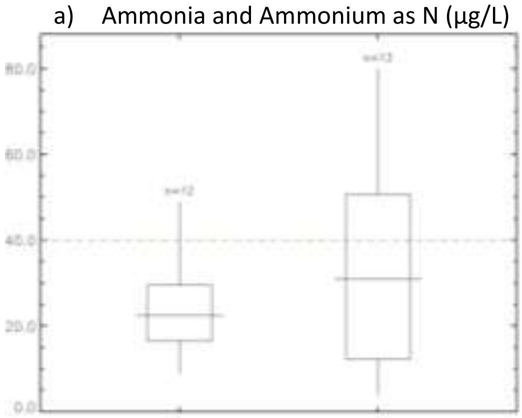
A small monitoring program conducted as part of the Plenty Rivercare Plan (Greening Australia, 2010) showed generally good water quality in the upper and mid-catchment, with episodic late summer low dissolved oxygen in the river downstream of Salmon Ponds. AUSRIVAS monitoring near Stony Creek in the upper Plenty catchment shows good macro-invertebrate health for combined season scores. Riparian vegetation is generally in good condition, and the pristine condition of the Snowy Ranges contributes to good water quality. The presence of gorges in the catchment has limited development and access to the river in some parts, and hence contributes to protecting water quality.



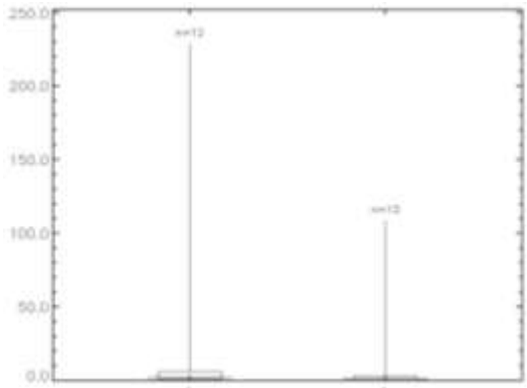
a) Ammonia and Ammonium as N (µg/L)



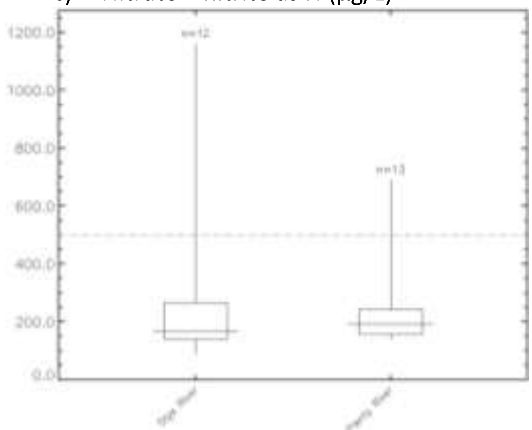
b) Dissolved phosphate as P (ug/L)



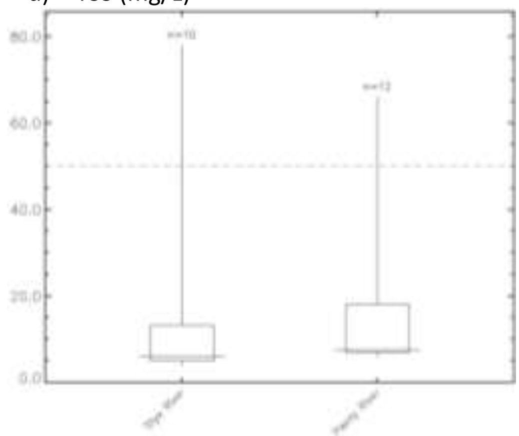
c) Nitrate + nitrite as N (µg/L)



d) TSS (mg/L)

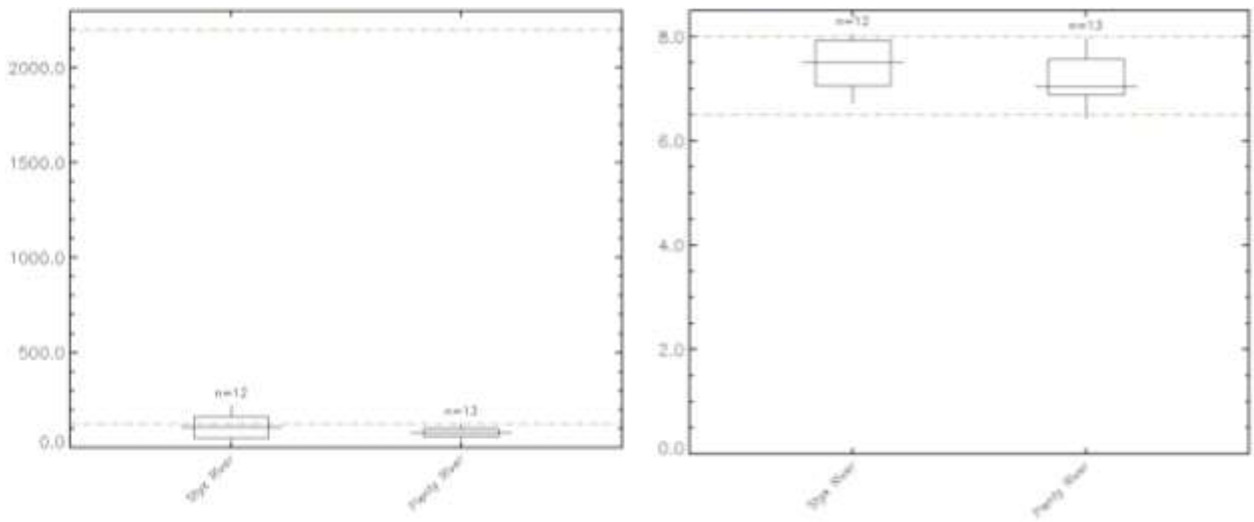


e) Total Nitrogen (µg/L)



f) Total Phosphorous (µg/L)

Figure 111 a-f) Water quality data, for the Styx (left box and whiskers) and Plenty (right) from the Upper Derwent Nutrient Study, 1996-1997. "Boxes" (80th, average, 20th percentile; "whiskers" maximum/minimum, n= number of samples. ANZECC default trigger value for lowland river shown, where appropriate.. (Data from DEP).



a) Field conductivity (µS/cm) b) Field pH

Figure 112) Water quality data, for the Styx (left box and whiskers) and Plenty (right) from the Upper Derwent Nutrient Study, 1996-1997. "Boxes" (80th, average, 20th percentile; "whiskers" maximum/minimum, n= number of samples. ANZECC default trigger value for lowland river shown where appropriate. (Data from DEP). "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= number of samples.

In the lower Plenty, a number of weirs constructed in the late 1800's affect river flow and sediment transport (Greening Australia, 2010). Previously 8 sites around these smaller rivers were studied on a quarterly bases from 1995-1998 by Waterwatch, in partnership with Australian Newsprint Mills (Norske Skog) to establish baseline water quality and monitor trends and changes over time. Data showed generally good water quality, with episodic increases in faecal coliforms and turbidity.

Summary of western inflows

Water quality in the western inflows to the Derwent has the following characteristics:

- Rivers are unregulated, and contribute a "natural" flow signal to the Derwent River, particularly in winter;
- Nutrients are seasonally variable, and loads are influenced by drought, with lower contributions of TN and TP in dry years;
- Conductivity in the Florentine and Tyenna Rivers are elevated compared to the Derwent headwaters, while the Broad, Styx and Plenty have much more dilute waters. These differences are likely attributable to both differences in underlying geology, and catchment inputs, with headwaters of the Tyenna around Junee Cave having distinctive nitrate profiles. Inputs from western inflows are detectable in the lower Derwent lakes;
- Tributaries of the Tyenna (Lady Barron Ck, Humboldt River, Rufus Creek) are very dilute, having very low EC values, and waters originating in Mt Field National Park (Broad River, Lake Fenton) are of very high quality;
- Water quality reflects an increase in down-catchment intensity of land-use, with several point sources (WWTP, aquaculture facilities) influencing nutrient loads; contemporary data is not available to assess on-going impact of aquaculture.

Access to Level 1 data is important to understand impacts in this catchment, particularly with respect to fish farm operations and STPs.

2.4 Eastern inflows to Derwent River

Summary of hydrology and regulation

Flows in all major eastern inflows to the Derwent are regulated, either by diversions and storages constructed as part of the Upper Derwent Power Scheme (Dee River), irrigation (Clyde River) or both (Ouse River). Lake Echo is an in stream storage on the Dee River, receiving water from Little Pine Lagoon, and the Ouse via Monpeelyata Canal. The Lake Echo power station discharges directly into Dee Lagoon, as does spills from Lake Echo. Water may continue down the natural waterway to the lower Derwent below Cluny Lagoon, however the majority of the water is transferred to Bradys Lake via the Dee Tunnel (Hydro Tasmania, 2001). Flows in the Dee upstream of the Derwent are presented in Figure 11 (PART1), and show uniform low flows during summer, with a slight increase in winter months.

Flows in the upper Ouse are diverted to Great Lake via the Liawenee Canal (and out of catchment), and to Lake Echo via the Monpeelyata Canal. Tributaries of the Ouse (Shannon River, Little Pine River) are dammed or diverted, but are no longer part of the power generation network following the closure of the Waddamana and Shannon Power Stations in 1965. Storages in this part of the power scheme (Shannon Lagoon, Penstock Lagoon) now provide irrigation and riparian water to the Shannon and Ouse catchments, with water excess to irrigation demand directed out of the catchment via Great Lake. Lagoon of Islands is managed for both riparian/irrigation demands and as a recreational fishery.

The headwaters of the Clyde River are regulated through the impoundments of Lakes Crescent and Sorell to provide water through one of the oldest irrigation schemes in the state. Water level is regulated in both lakes, with flows in the Clyde controlled by releases from Lake Crescent for irrigation, carp control and domestic supply to Bothwell. Hamilton no longer draws its water supply from the Clyde due to water quality issues. Water demand is regulated by Water Management Plans for the Clyde, and for the lakes, and managed by the Clyde River Trust.

Summary of data sources presented

Water quality in storages on the Dee River (Lake Echo, Dee Lagoon) is previously described in Section 2.1. Water quality in the Dee River itself is limited to a Hydro monitoring site above the confluence of the Dee with the Derwent. This site was also monitored during the Upper Derwent Nutrient Study spatial survey in 1996-1997 (Coughanowr, 2001). The Dee enters a “natural” section of the Derwent between Cluny Lagoon and Lake Meadowbank.

Monitoring sites in the Ouse catchment are numerous, particularly in the upper catchment where diversions and transfers to Great Lake occur. Water quality monitoring in Penstock Lagoon and Lagoon of Islands is extensively documented in Hydro reports: water quality data from locations below these storages is presented here. Hydro monitoring sites in the upper Ouse (Staffhouse Creek, above the confluence of the Shannon), in the lower Ouse at Ashton, and the Shannon River at Hermitage, and the Upper Derwent Nutrient Study site located immediately above the confluence of the Ouse with the Derwent between Cluny Lagoon and Lake Meadowbank are presented (Figure 113).

Clyde data is drawn from the DPIPWE Baseline Water Quality Monitoring Program Site immediately downstream of Lake Crescent, and the spatial and longitudinal datasets collected by DEP as part of the Upper Derwent Nutrient Study. Monitoring data from the STP at Bothwell was provided by Central Highlands Council, Southern Water and the EPA.

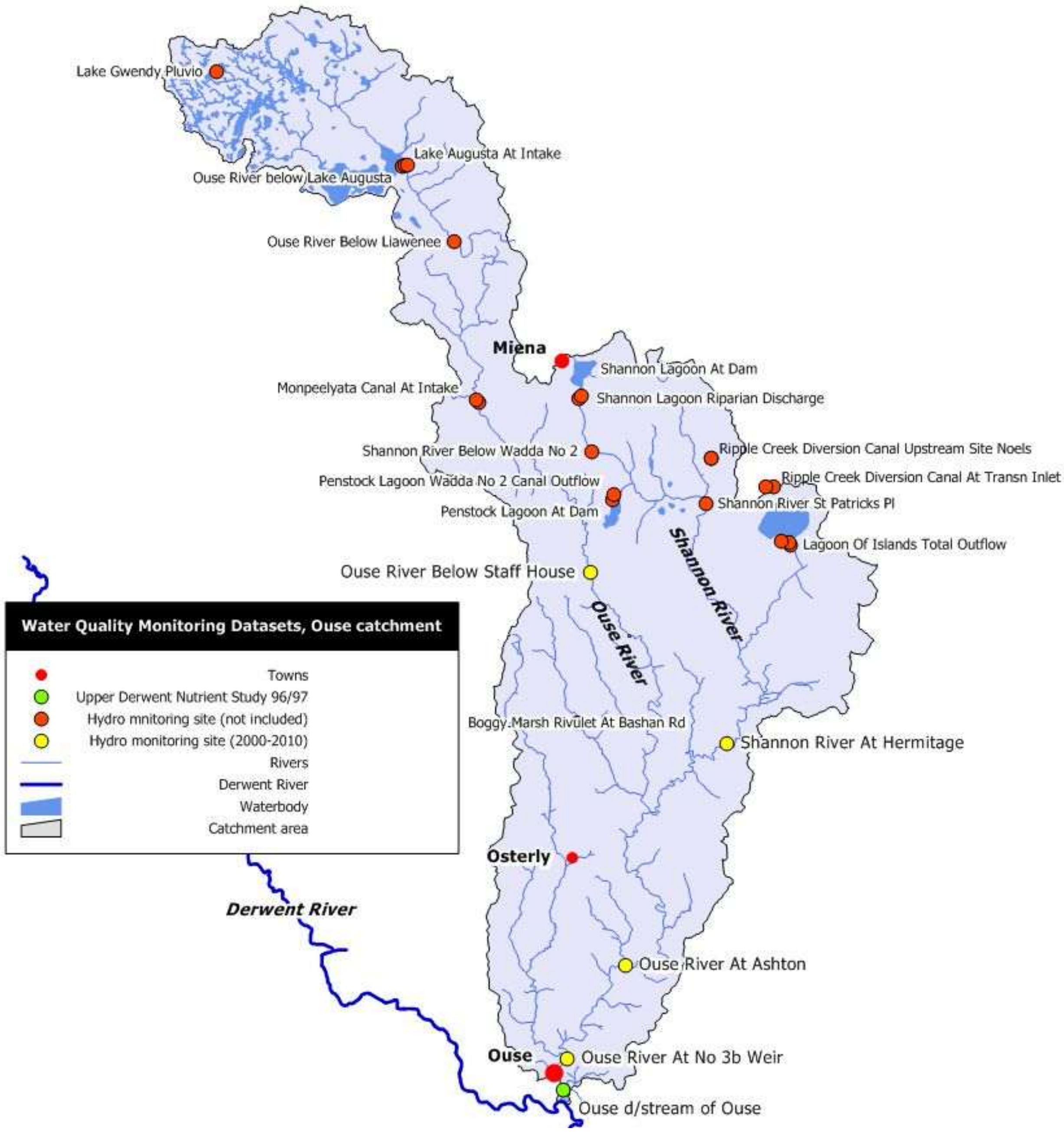


Figure 113 Location of water quality, quantity and weather monitoring sites for the Ouse and Shannon Rivers. Data from selected sites presented in this report. Base layer by CFEV, the LIST © State of Tasmania.

Spatial & temporal trends

2.4.1 Dee River

Nutrients monitored in the lower Dee as part of the Upper Derwent Nutrient Study are presented in Figure 114. Ammonia and dissolved phosphate were frequently below detection, while nitrate + nitrite peaked in both winter and summer. Total N and P showed summer maximum in 1996, but not 1997; reflecting a flood peak in April 96, and low river flows in 1997 during drought conditions. TN levels recorded in the Dee River during drought conditions (~300 µg/L) were not as low as those recorded in Dee Lagoon during the more recent drought in 2007-2008, at around 150 µg/L, whilst TP results were similar for both periods (~ 10 µg/L). This may be a result of the majority of water from Dee Lagoon being transferred to Bradys Lake, and the lower Dee results being influenced by pickup from lands utilised for grazing in the lower Dee before entering the Derwent below Cluny. Suspended solids and turbidity were extremely low during the dry summer of 96/97 (Figure 115), but conductivity increased to around 700 µS/cm (Figure 116). This inverse relationship between turbidity and conductivity during dry periods is observed a number of times in the last 10 years, and suggests high conductivity periods reflect ground water dominated inputs, whereas high turbidity periods result from surface runoff.

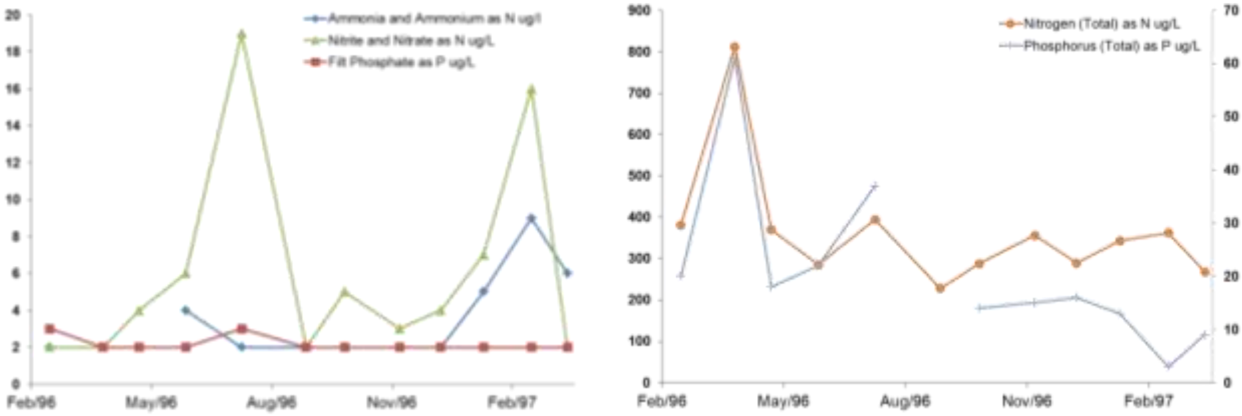


Figure 114 Dissolved nutrients (left) and total nutrients (right) in µg/L, Dee above Derwent monitored as part of Upper Derwent Nutrient Study, 1996-1997. TN scaled on left axis, TP on right. (Data from DEP).

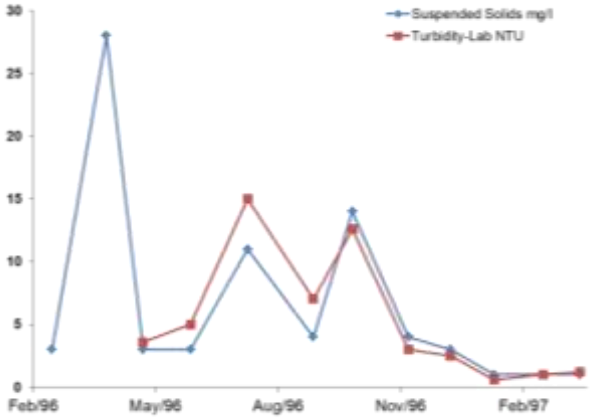


Figure 115 Suspended solids (mg/L) and turbidity (NTU) monitored at Dee above Derwent as part of Upper Derwent Nutrient Study, 1996-1997. (Data from DEP).

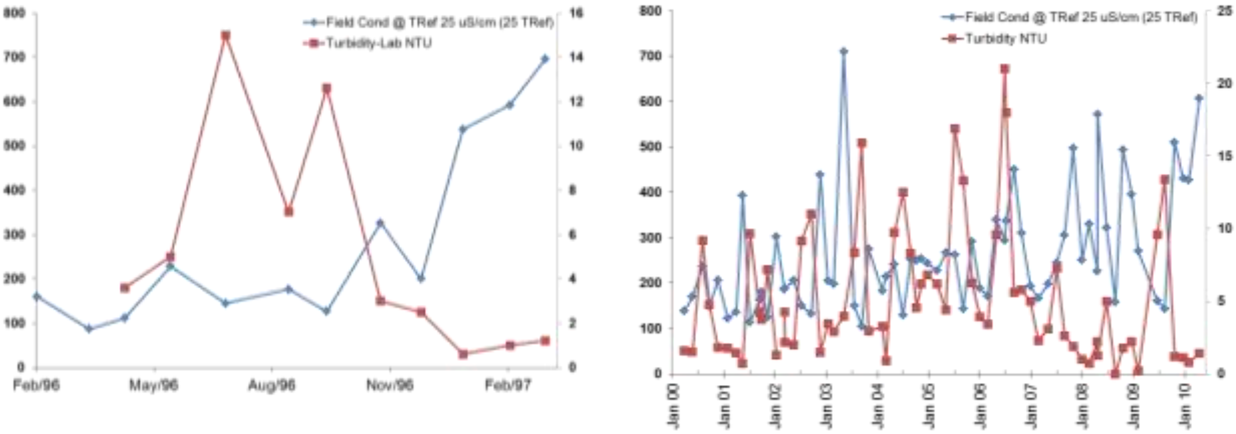


Figure 116 Field parameters monitored as part of the Upper Derwent Nutrient Study (1996-1997, left) and Hydro Tasmania (2000-2010) at Dee River above Derwent. Conductivity (µS/cm) scaled on left axis, turbidity (NTU) scaled on right axis. (Data from DEP and Hydro Tasmania).

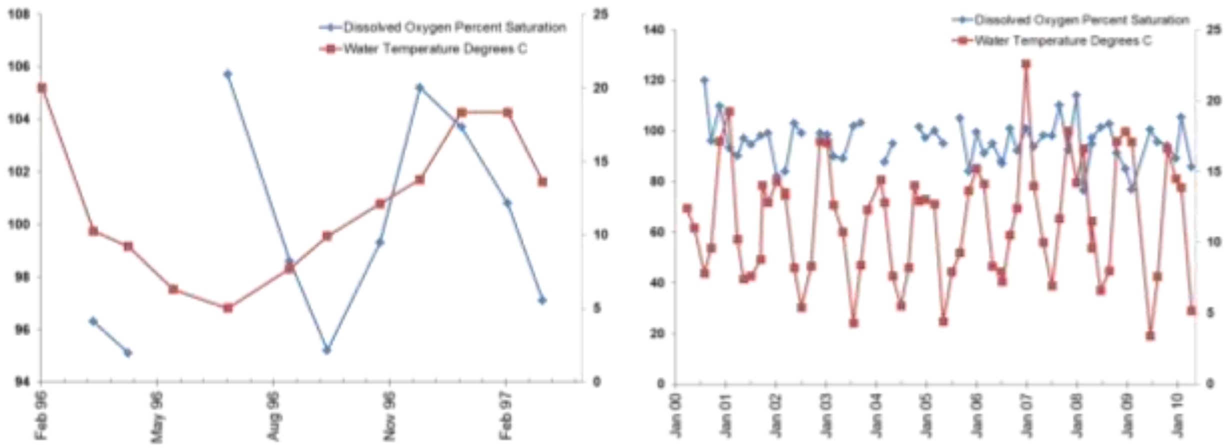


Figure 117 Field parameters monitored as part of the Upper Derwent Nutrient Study (1996-1997, left) and Hydro Tasmania (2000-2010) at Dee River above Derwent. Dissolved oxygen (%) scaled on left axis, water temperature (°C) scaled on right axis. (Data from DEP and Hydro Tasmania).

Water temperature trends are similar to most waterways and waterbodies in this part of the catchment, with seasonal warming to around 18 °C in summer, and cooling to ~5°C in winter (Figure 117). Dissolved oxygen also shows some seasonal variation. pH is often lowest at the end of summer.

2.4.2 Ouse River

Flows in the lower Ouse River above 3B weir are presented in Figure 11 (PART 1), and show uniform and low base flows in summer, with a seasonal maximum in winter between July and October. Winter rains are variable and may not always be sufficient to produce prolonged events in the river Figure 15(PART 1).

Ouse River at Staffhouse Creek

Conductivity and turbidity profiles in the Ouse at Staffhouse Creek are presented in Figure 118, and show distinct seasonal profiles, with often inverse relationship between these parameters, similar to the Dee River (Figure 116). Conductivity is higher than that recorded for Derwent headwaters, peaking in summer with significant dilution in winter, consistent with groundwater being the source of the high conductivity, and high rainfall events leading to increased turbidity. Dissolved oxygen is generally high, and water temperature shows a strong seasonal pattern, with ranges similar to those recorded for other upland rivers (Figure 119). pH follows water temperature, possibly due to increased primary productivity, although pH is very sensitive to diurnal fluctuations, and there will be finer scale cycling over these monthly observations. Chlorophyll-*a* and phytoplankton data are limited, with sampling over the summer of 2006 showing chlorophyll was typically low (~ 2 µg/L) with occasional spike to 12 µg/L. Metals were sampled on four occasions over the summer of 1999/200, with copper, cadmium, manganese and zinc at or below detection limits. Iron varied between 60 and 170 µg/L, slightly elevated compared to Derwent headwaters (data not shown).

Ouse River at Ashton

Further down the Ouse River, monitoring at Ashton shows an increase in conductivity and turbidity (Figure 121) and some loss of the clear seasonal patterns observed in these parameters upstream (Figure 118). Land use in the lower part of the Ouse catchment is largely grazing, with irrigated agriculture and plantations adjacent to the main river course (Figure 39 PART 1). Monitoring intensity increased from monthly or bi-monthly to weekly during the period of very dry conditions in 2006-2008.

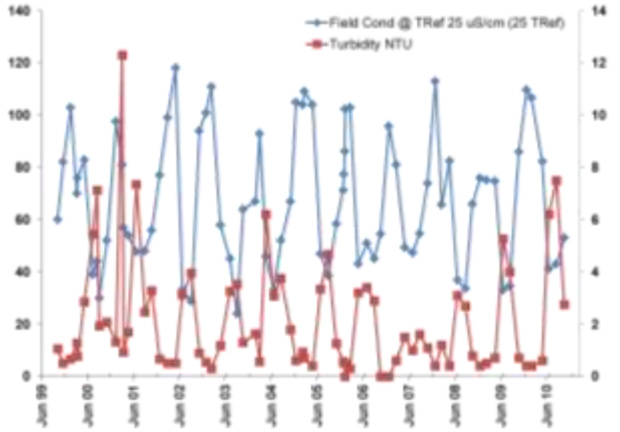


Figure 118 Field parameters monitored at Ouse River at Staffhouse Creek by Hydro (2000-2010). Conductivity (µS/cm) scaled on left axis, turbidity (NTU) scaled on right axis. (Data from Hydro Tasmania).

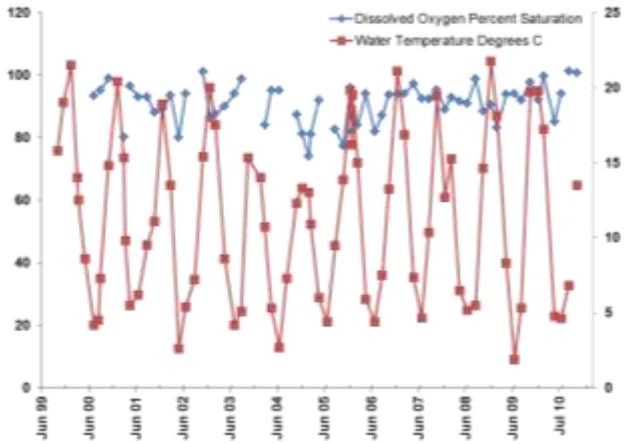


Figure 119 Field parameters monitored at Ouse River at Staffhouse Creek by Hydro (2000-2010). Dissolved oxygen (%) scaled on left axis, temperature (°C) scaled on right axis. (Data from Hydro Tasmania).

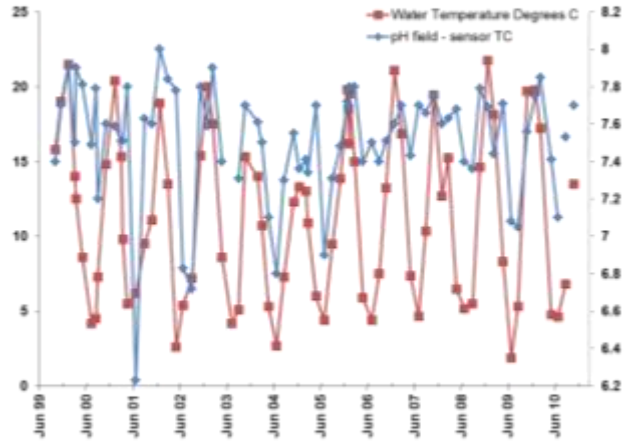


Figure 120 Field parameters monitored at Ouse River at Staffhouse Creek by Hydro (2000-2010). Temperature (°C) scaled on left axis, pH scaled on right axis. (Data from Hydro Tasmania).

Water temperature and dissolved oxygen ranges are slightly increased from Ouse at Staffhouse Creek (Figure 122), as is pH (Figure 123). Monitoring for blue-green algae during this time show seasonally high levels of the pigment phycocyanin in the summer of 2005-2007, with a decline in 2008 (Figure 124). Intracellular[1] and extracellular[2] microcystins (toxins produced by certain cyanobacterial species) were monitored in the summer of 2006 and 2008, with extracellular microcystin-LR detected in all 2008 samples, periodically exceeding the Australia Drinking Water guideline of 1.3 µg/L (EPA, 2011). Intracellular microcystin-LR concentrations were much lower.

Nutrients were monitored on a monthly or fortnightly basis between summer 2006 and spring 2008, with dissolved and total nutrients presented in Figure 125. Total phosphorous remained low during 06-07, but increased substantially throughout most of 2008, however monitoring data did not

[1] inside the cyanobacterial cells
[2] outside the cyanobacterial cells

include TN for this period. The cause of elevated TP is not clear from the available data, as there is insufficient monitoring at Ouse at Staffhouse Creek to determine if inputs are from higher in the catchment. High TP may be correlated with flow in Blackburn Ck or from the Shannon at St Patricks, which are known to have high TP *(M. Egerrup, pers. comm)*. Limited metals data from summer 2006 shows copper, cadmium, zinc and aluminium below detection with low levels of manganese (~140 µg/L) and moderate levels of iron (~300 µg/L).

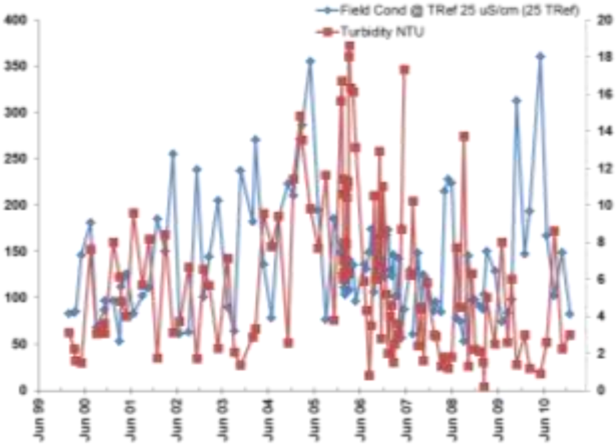


Figure 121 Field parameters monitored at Ouse River at Ashton by Hydro (2000-2010). Conductivity (µS/cm) scaled on left axis, turbidity (NTU) scaled on right axis. (Data from Hydro Tasmania).

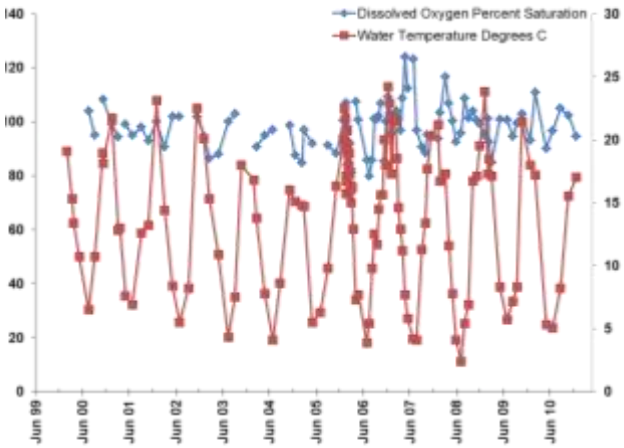


Figure 122 Field parameters monitored at Ouse River at Ashton by Hydro (2000-2010). Dissolved oxygen (%) scaled on left axis, temperature (^{o}C) scaled on right axis. (Data from Hydro Tasmania).

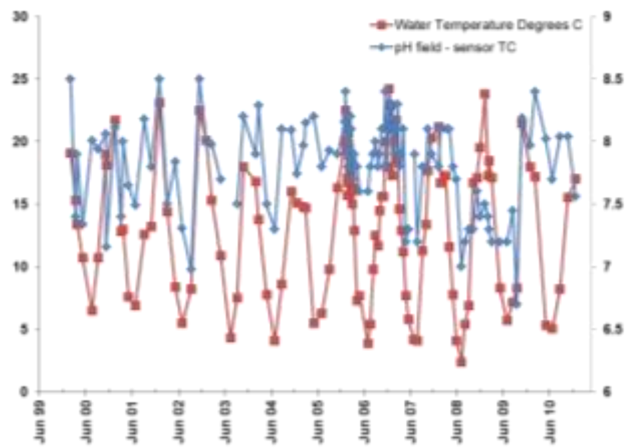


Figure 123 Field parameters monitored at Ouse River at Ashton by Hydro (2000-2010). Temperature (^{o}C) scaled on left axis, pH scaled on right axis. (Data from Hydro Tasmania).

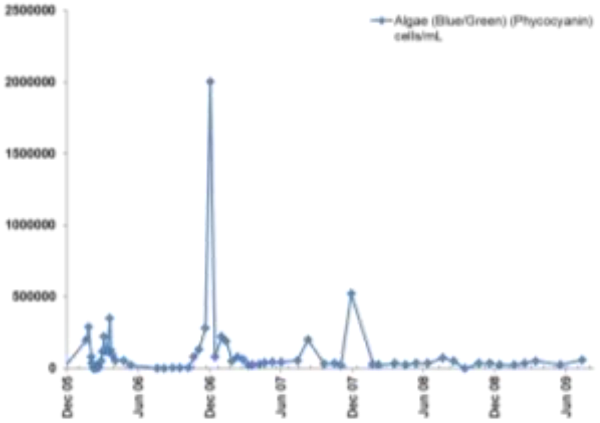


Figure 124 Blue-green algae (monitored as phycocyanin) at Ouse River at Ashton (2005-2009). Data from Hydro Tasmania.

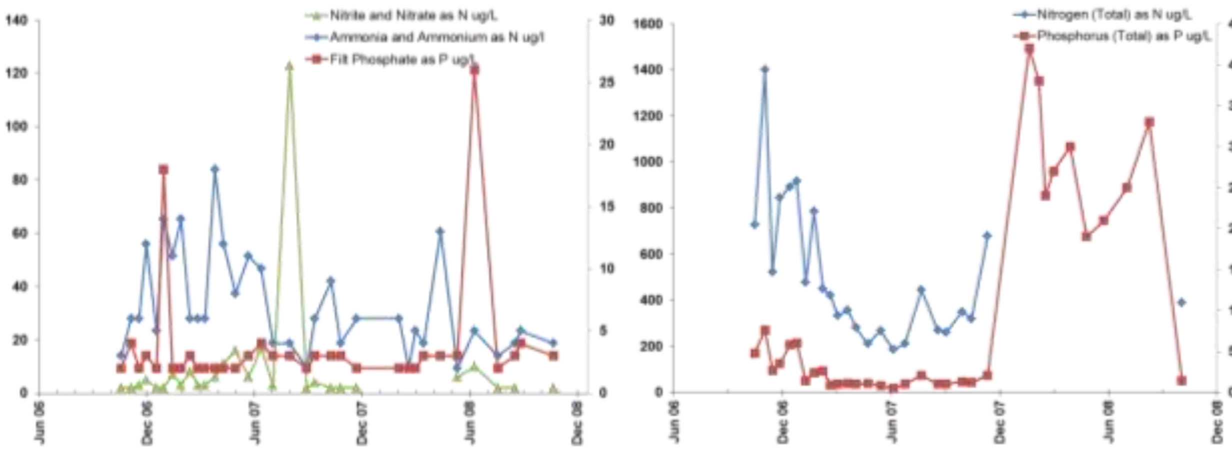


Figure 125Dissolved nutrients (left) and total nutrients (right) in µg/L, monitored at Ouse River at Ashton 2006-2008. Nitrogen, nitrate + nitrite scaled on left axis, Phosphorous species and ammonia on right. (Data from Hydro).

Ouse River below Ouse

Monitoring data at this site below the township of Ouse is only available for the period 1996-1997, with all nutrients (Figure 126) and conductivity (Figure 128) having a fairly similar pattern of spring minimum in 1996, and summer maximum in 1997. Suspended solids and turbidity (Figure 127) followed a reverse pattern with maximum in spring, declining in summer 1997, consistent with surface runoff patterns.

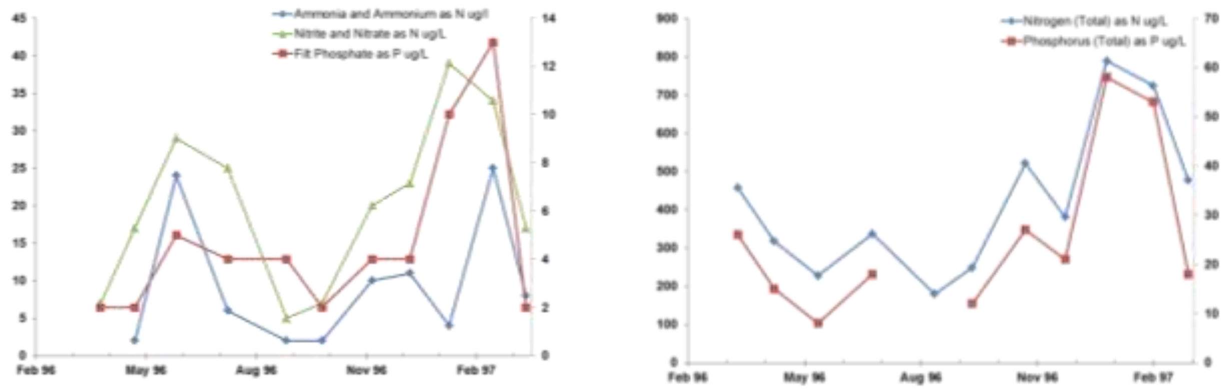


Figure 126 Dissolved nutrients (left) and total nutrients (right) in µg/L, monitored at Ouse River below Ouse as part of Upper Derwent Nutrient Study, 1996-1997. Nitrogen scaled on left axis, Phosphorous on right. (Data from DEP).

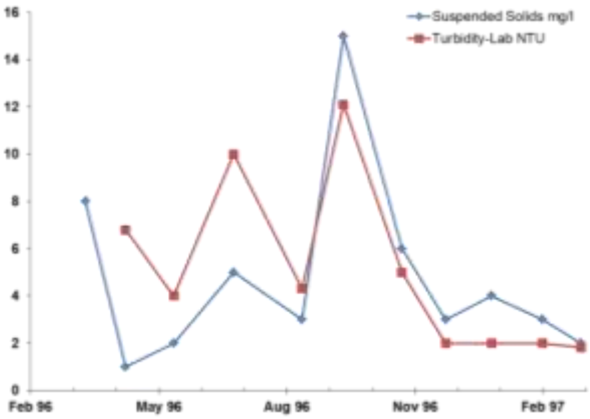


Figure 127 Suspended solids and turbidity monitored at Ouse River below Ouse as part of Upper Derwent Nutrient Study, 1996-1997. (Data from DEP).

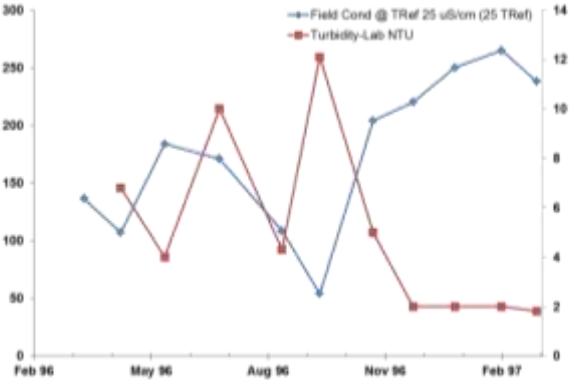


Figure 128 Field parameters monitored as part of the Upper Derwent Nutrient Study (1996-1997, left) at Ouse River below Ouse. Conductivity (µS/cm) scaled on left axis, turbidity (NTU) scaled on right axis. (Data from DEP).

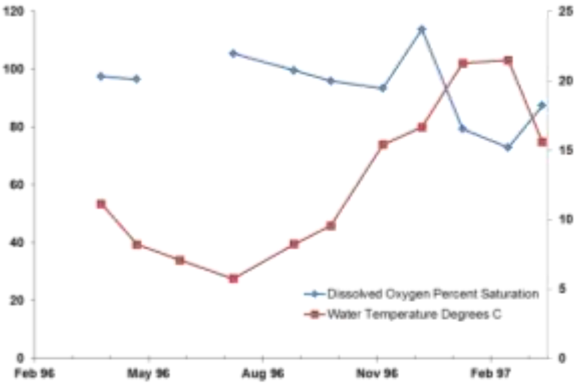


Figure 129 Field parameters monitored as part of the Upper Derwent Nutrient Study (1996-1997, left) at Ouse River below Ouse. Dissolved oxygen (%) scaled on left axis, water temperature (^{o}C) scaled on right axis. (Data from DEP).

Shannon at Hermitage

Monitoring data collected from the site 'Shannon at Hermitage' reflects inputs from the eastern part of the Ouse catchment, downstream of Shannon Lagoon and Lagoon of Islands (Figure 113). Flows from Lagoon of Islands have varied in recent years, with water level management strategies in 2008/2009 resulting in reduced inflows, and no outflows into the Shannon (Hydro Tasmania Consulting, 2009b). Time series data for this site show similar patterns to 'Ouse at Staffhouse Creek' with respect to dissolved oxygen, temperature, and pH while the influence of groundwater on seasonal turbidity and conductivity levels during drought is not as pronounced (Figure 130-Figure 132). Water in the Shannon is more turbid and has higher conductivity than the upper Ouse, potentially due to salinity (Hydro Tasmania Consulting, 2009b). There was a marked reduction in the range of pH values recorded in the period January 2006 to June 2008 (Figure 132).

Algal monitoring showed periodically high concentrations on phycocyanin, (Figure 133), with chlorophyll-*a* following a similar trend. Chlorophyll-*a* was elevated through each summer period, declining to background levels in winter, with a seasonal maximum of 81 µg/L in January 2006.

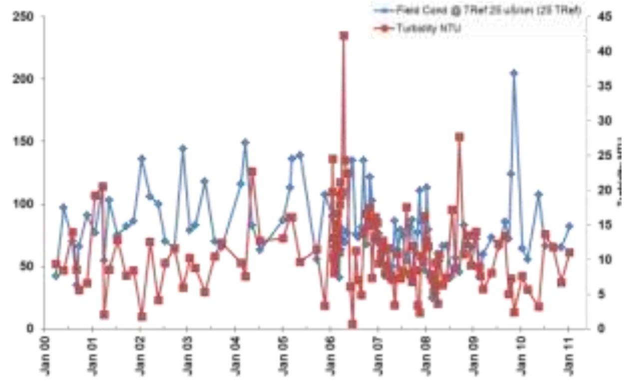


Figure 130 Field parameters monitored at Shannon River at Hermitage by Hydro (2000-2010). Conductivity (µS/cm) scaled on left axis, turbidity (NTU) scaled on right axis. (Data from Hydro Tasmania).

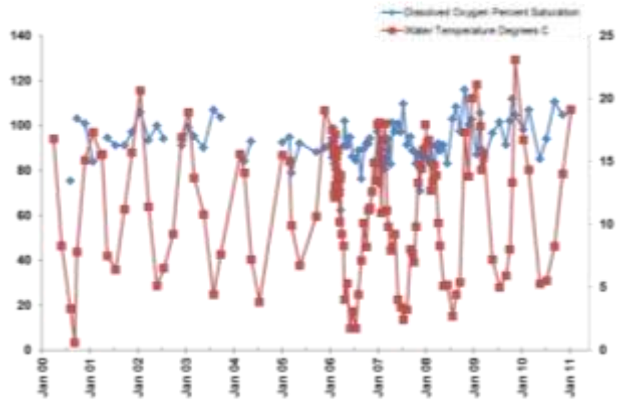


Figure 131 Field parameters monitored at Shannon River at Hermitage by Hydro (2000-2010). Dissolved oxygen (%) scaled on left axis, temperature (^{o}C) scaled on right axis. (Data from Hydro Tasmania).

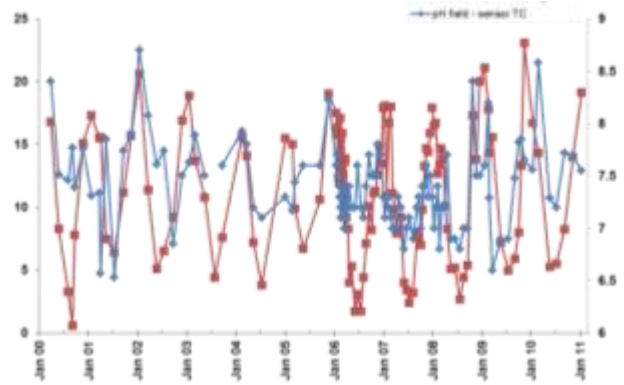


Figure 132 Field parameters monitored at Shannon River at Hermitage by Hydro (2000-2010). Temperature (^{o}C) scaled on left axis, pH scaled on right axis. (Data from Hydro Tasmania).

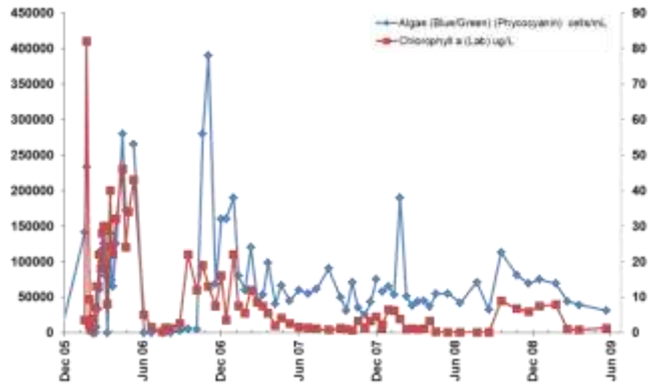


Figure 133 Algal counts (measured as phycocyanin, (left axis) and chlorophyll a (µg/L, right axis)at Shannon River at Hermitage by Hydro (2005-2009). (Data from Hydro Tasmania).

Dissolved nutrients are plotted in Figure 134, and show ammonia + ammonium levels were extremely high in late summer of 2006, while dissolved phosphate showed a cycle of both winter and summer maxima, probably associated with internal cycling of P. Nitrate + nitrite follows the TN signal from December 2005 to mid-2007, after which periodically high concentrations > 30 µg/L are observed. Monitoring for TN appears to have ceased in December 2007, immediately prior to a significant and sustained rise in TP concentrations (Figure 134).

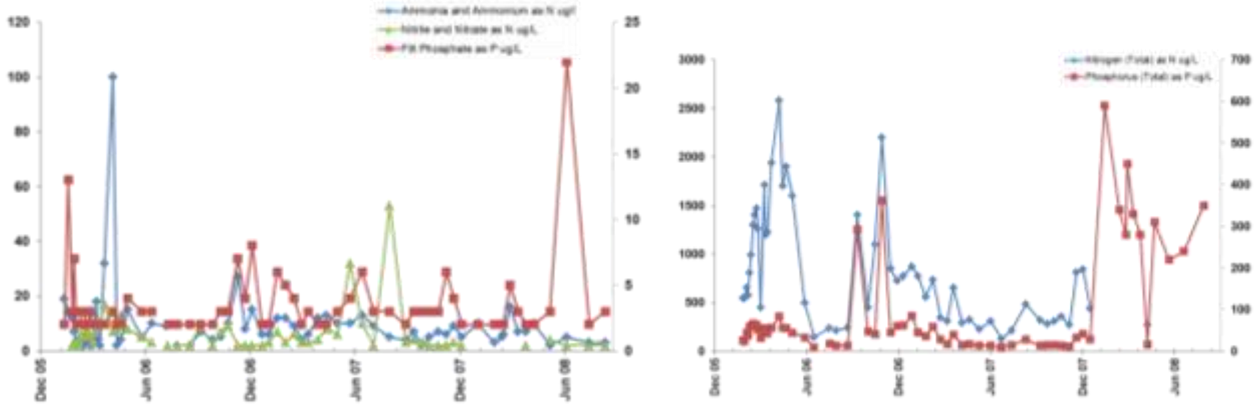


Figure 134 Dissolved nutrients (left) and total nutrients (right) in µg/L, monitored at Shannon River at Hermitage 2006-2008. Nitrogen species scaled on left axis, Phosphorous species scaled on right. (Data from Hydro Tasmania).

2.4.3 Clyde River

Lakes Crescent and Sorell lie on the eastern margin of the Central Plateau, and are the headwaters of the Clyde River. Both lakes are shallow, polymictic[3] and have similar morphometry, climate, soils, geology and vegetation in their catchments, and both originated from natural lakes that have been altered, primarily for the supply of irrigation water since the 1830s (Uytendaal, 2003). There are however significant differences in water chemistry and ecology of the lakes, with Cheng and Tyler (1973) describing the contrast in the adjacent lakes as a “limnological paradox”. Lake Sorell is mesotrophic and described as resembling a clear-water, macrophyte dominated system, with Lake Crescent moderately eutrophic, showing characteristics of a turbid phytoplankton dominated system (Uytendaal, 2003). There was a strong correlation between suspended solids and phytoplankton abundance, however phytoplankton only contributed a small portion of the turbidity in Lake Crescent. Lake level coupled with wind-driven re-suspension of sediments was identified as a causative factor in increased levels of turbidity (suspended solids), nutrients and phytoplankton. Phosphorous was identified as the main limiting nutrient in both lakes by Cheng and Tyler (1973), with Uytendaal (2006) proposing that colloidally bound phosphorous was a major component of suspended solids.

Water level management in the lakes is complex due to the potentially conflicting requirements of irrigators, town water demands along the Clyde, the trout fishery in Lake Sorell, and the presence of both pest species (European carp, *Cyprinus carpio*) and the endangered Golden galaxid (*Galaxias auratus*) a non-migratory native galaxid. High irrigation demand, a series of dry years and a need to minimise spawning opportunities for carp resulted in record low water levels and resultant changes in water quality in the lakes (and ultimately the Clyde) in the mid 90’s. During recent drought in 2007-2008, releases from Lake Crescent were ceased under EPBC Act requirements to preserve water for the Golden galaxid. Emergency pipelines supplied water from the Shannon River into the Clyde catchment for residents and farmers around Bothwell

The Clyde River catchment is considered highly modified, and is impacted by head water flow regulation, diversion and abstraction, resulting in significant changes to seasonal flow patterns. Flow in the Clyde River monitored immediately downstream of the release point from Lake Crescent is presented in Figure 16 (PART 1). Discharge from the Lake is minimal during winter months, with summer

[3] De-stratifies and mixes frequently due to wind action

releases to supply water for irrigation, storage and town water needs at Bothwell. Flows increase down catchment as a result of local rainfall, which imposes a more seasonal flow pattern with highest flows in winter, with down catchment extractions and low rainfall in summer resulting in low flows at Hamilton and Bothwell (PART 1 Figure 17 to 19). Water quality monitoring data from the Clyde River downstream of Lake Crescent was collected during the Upper Derwent Nutrient Study (1997-1998) and as part of the DPIPWE Baseline Water Quality Monitoring Program (2003-2009, Figure 135).

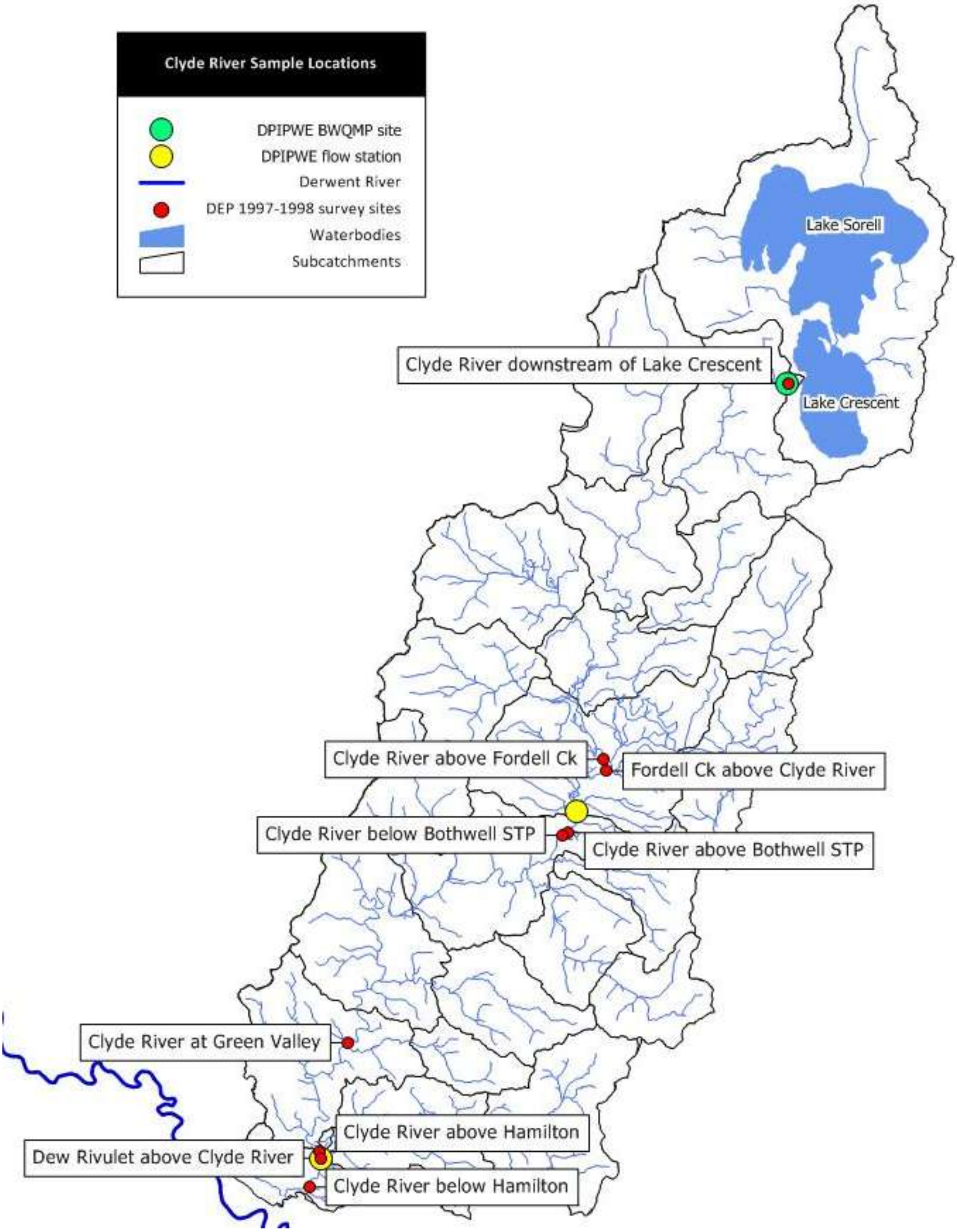
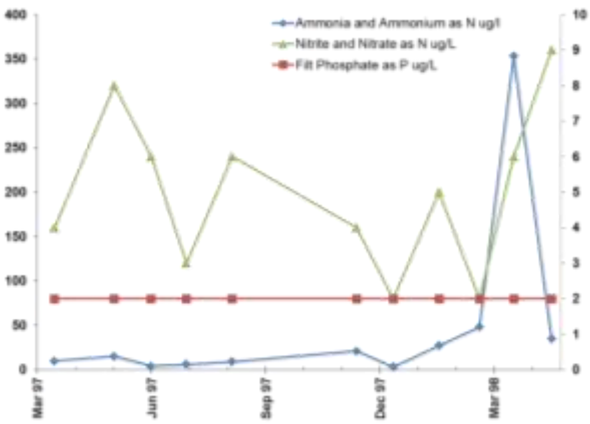
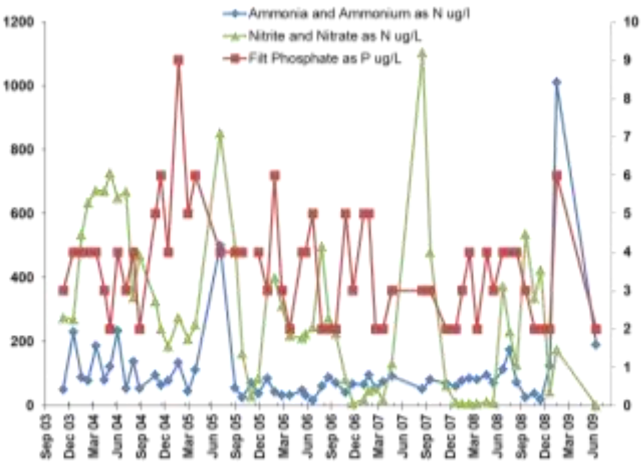


Figure 135 Location of monitoring sites in the Clyde catchment. Base layer by CFEV, the LIST © State of Tasmania.

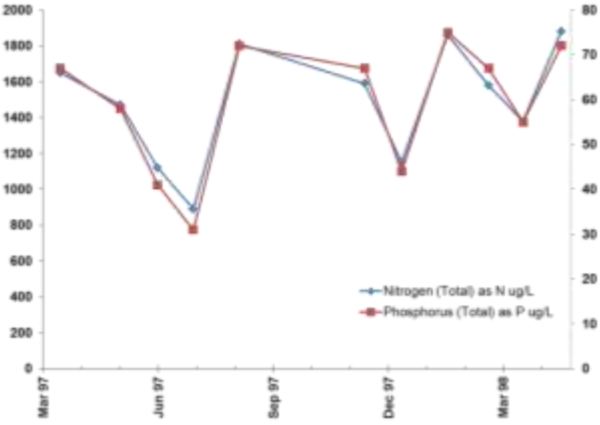
Results from both programs are presented in Figure 136. Phosphate was consistently below detection in 97/98, but present in detectable concentrations on most occasions in the period 2003-2009.



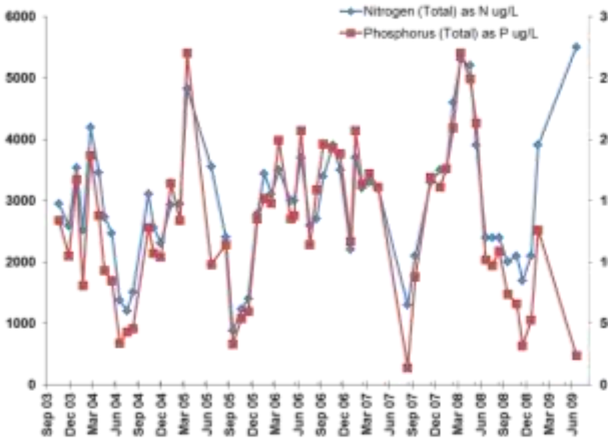
a) UDNS: ammonia scaled on left axis, phosphate and nitrate/nitrite on right axis. All data µg/L.



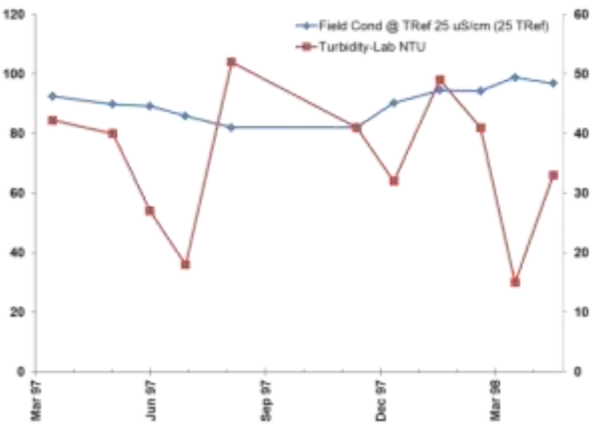
b) BWQMP: ammonia and nitrate/nitrite scaled on left axis, phosphate on right axis. All data µg/L.



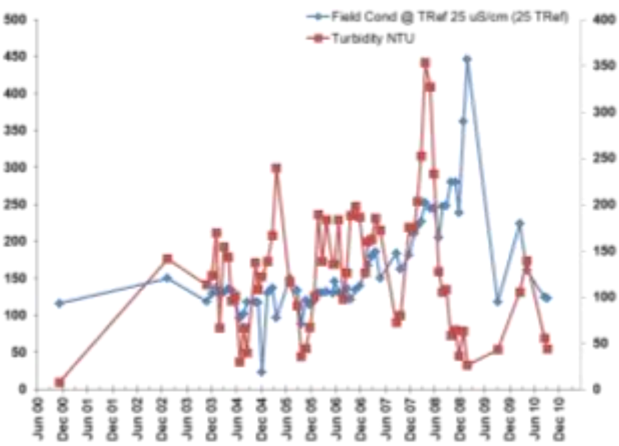
c) UDNS: TN scaled on left (µg/L), TP on right (µg/L).



d) BWQMP: TN scaled on left (µg/L), TP on right (µg/L).



e) UDNS: Conductivity scaled on left (µS/cm), turbidity on right (NTU).



f) BWQMP: Conductivity scaled on left (µS/cm), turbidity on right (NTU).

Figure 136 a-f) Surface nutrients monitored at Clyde River downstream of Lake Crescent by DEP (left, 1997-1998) and DPIPWE (right, 2003-2009). Note different x-axis scales for DEP and DPIPWE data.

Ammonia and nitrate + nitrite concentrations measured in 1997/1998 during drought conditions were high compared to the headwaters of other eastern inflows (Dee, Ouse) but were low compared to 2003-2009 data. The increase in ammonia in 1998 corresponds to increased ammonia in Lake Crescent, however a corresponding increase in phosphate in Lake Crescent is not observed in the Clyde (note that monitoring only conducted until May 1998).

TN and TP follow similar patterns for both time periods, with the exception of the final sampling event in 2009. TN and TP are highly correlated, as is turbidity (Figure 137). This strong relationship indicates total nutrients are transported into the Clyde as particulate matter from Lake Crescent, a large shallow lake with high organic sediments, subject to wind driven re-suspension. TN and TP loads in the upper Clyde may potentially be modeled using turbidity and the relationship in Figure 137, and high frequency turbidity loggers, similar to those deployed at other DPIPWE continuous monitoring sites.

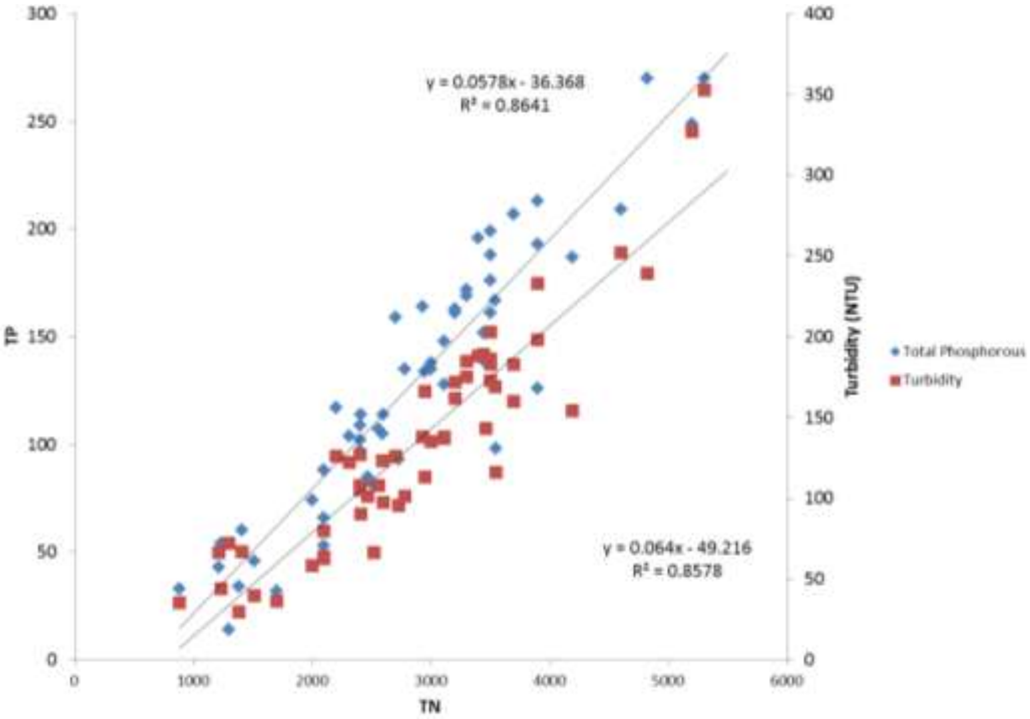


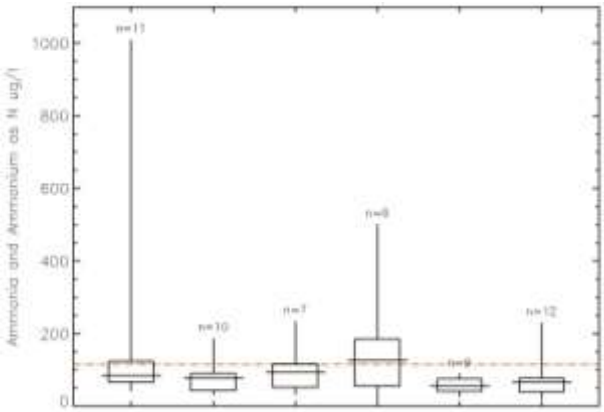
Figure 137 Relationship between TN and TP (blue, µg/L) and TN and turbidity (red, NTU) for the period 2003-2009 at Clyde River downstream of Lake Crescent. (Data from DPIPWE).

Conductivity varies considerably, from around 100 µS/cm to a peak of 450 µS/cm in early 2009 (Figure), and is not correlated with flow in the river, but as with nutrients, driven by conditions (lake level, wind) in Lake Crescent.

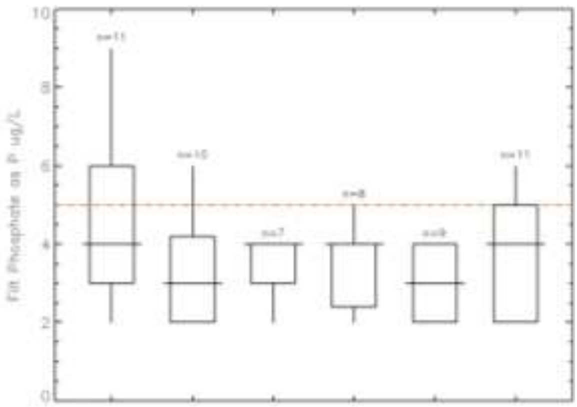
Bi-monthly variation in nutrients over time for the DPIPWE dataset are presented in Figure 138 a-g), along with the site-specific trigger values derived for the Clyde downstream of Lake Crescent. These triggers allow assessment of potential change at the site since the derivation of the triggers based on data from 2003-2006, and indicate the expected range during base flow conditions (DPIW, 2008).

Ammonia, nitrate + nitrite and dissolved phosphate show weak seasonality with slight increase in ammonia in winter following the reduction in flows from Lake Crescent. Turbidity, TN, TP, pH, conductivity, dissolved oxygen and temperature show strong seasonal cycling. TN, TP and turbidity tend to decline following reduced flows (around April/May of each year), while conductivity appears largely independent of flow and season.

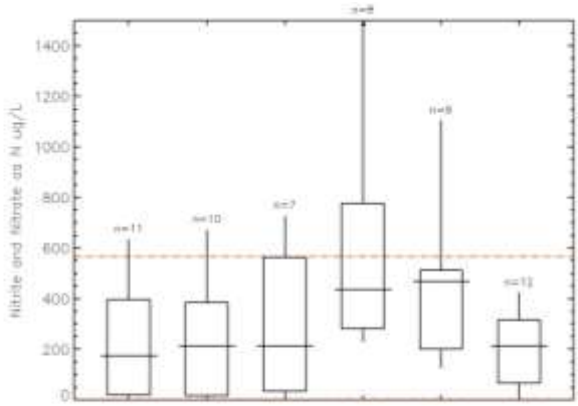
Down catchment stresses on water quality include land clearing, stock access, irrigation, waste water discharges and private forestry, with less than 5% of the catchment land use classified as conservation. Impacts of the waste water treatment plants at Bothwell and Hamilton were monitored as part of the Upper Derwent Nutrient Study in 1997/98, a subset of results are presented in Figure 139. Ammonia, dissolved and total phosphorous increased downstream of the Bothwell STP, however this facility is now on a re-use scheme with almost 100% uptake of recycled water (*S. Gallagher pers. comm., EPA*). Turbidity values generally decline with distance from Lake Crescent.



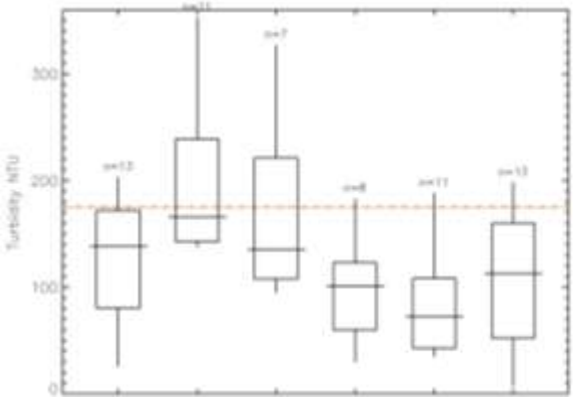
a) Ammonia + ammonium as N, µg/L



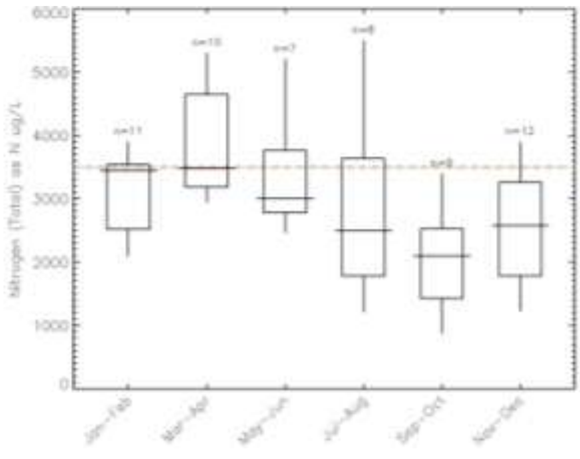
b) Dissolved phosphate as P, µg/L



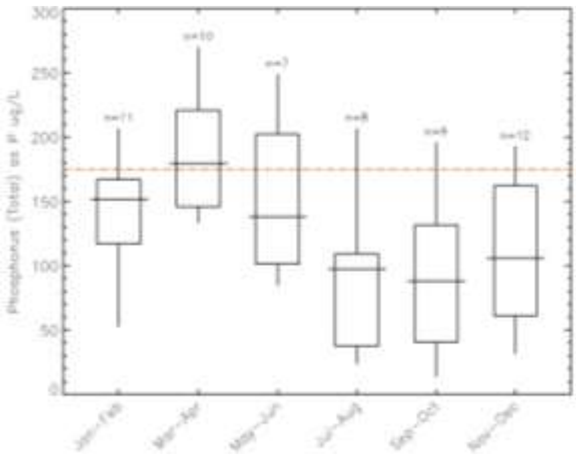
c) Nitrate+nitrite as N, µg/L (Max 4500 µg/L Jul)



d) Turbidity, NTU

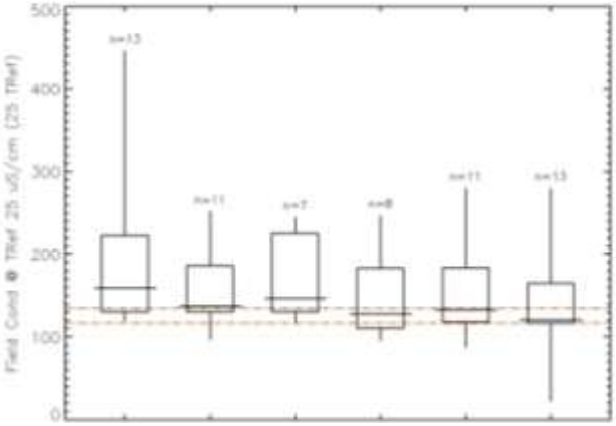


b) Total Nitrogen, µg/L

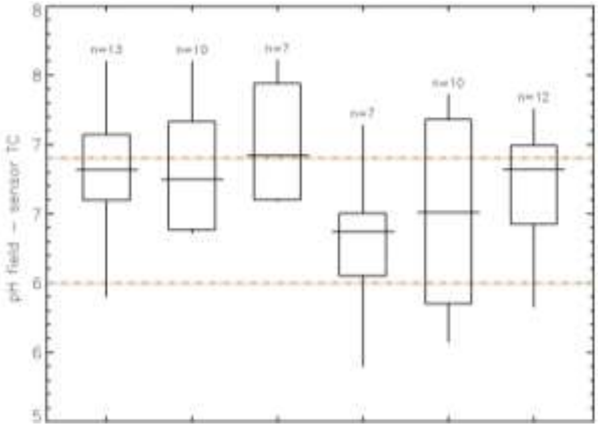


c) Total Phosphorous, µg/L

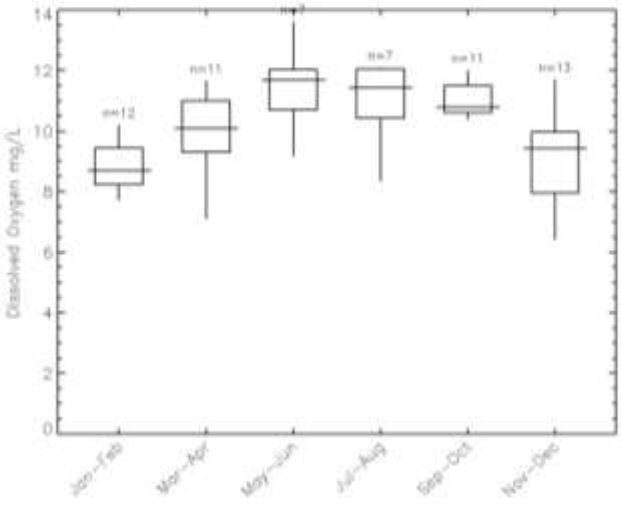
Figure 138 a-g) Water quality data, for the Clyde downstream of Lake Crescent from 2003-2006. "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= number of samples. DPIPWE site-specific trigger values shown where appropriate.. (Data from DPIPWE).



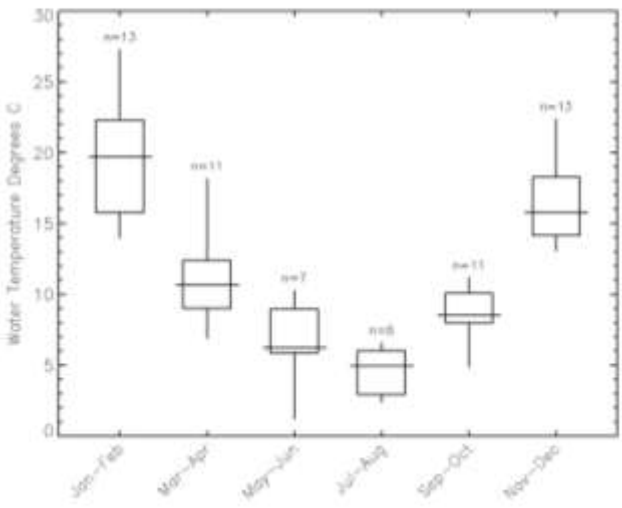
d) Conductivity, µS/cm



e) pH



f) Dissolved Oxygen, note mg/L



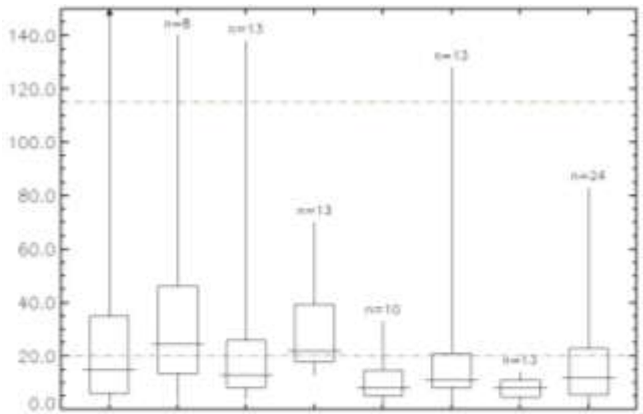
g) Water temperature, °C

Figure 138 continued. Water quality data for the Clyde downstream of Lake Crescent from 2003-2006. "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= number of samples. DPIPWE site-specific trigger values shown where appropriate.. (Data from DPIPWE).

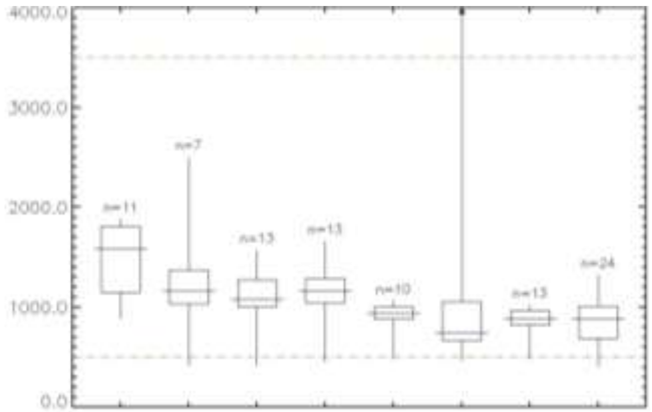
Moderate to severe erosion in the central plateau region of the eastern inflows contributes to poor water quality, and some parts of the catchments are severely affected by dryland salinity, particularly around Bothwell and Hamilton (Andrew, 2002).

Dew Rivulet, a small creek with largely ephemeral inflows, was identified as a significant source of nitrates, TN, dissolved and total phosphorous, and conductivity, but not turbidity. A Rivercare Plan for the Dew was developed by Greening Australia and local landholders, which identified potential for sediment generation from grazing, overstocking and erosion of north facing slopes, as well as the presence of numerous in-stream dams as factors in periodically poor water quality (Greening Australia, 2008). Water quality monitoring in 2008 showed conductivities in excess of those previously reported by Coughanowr (2001), with values around 2000 µS/cm recorded.

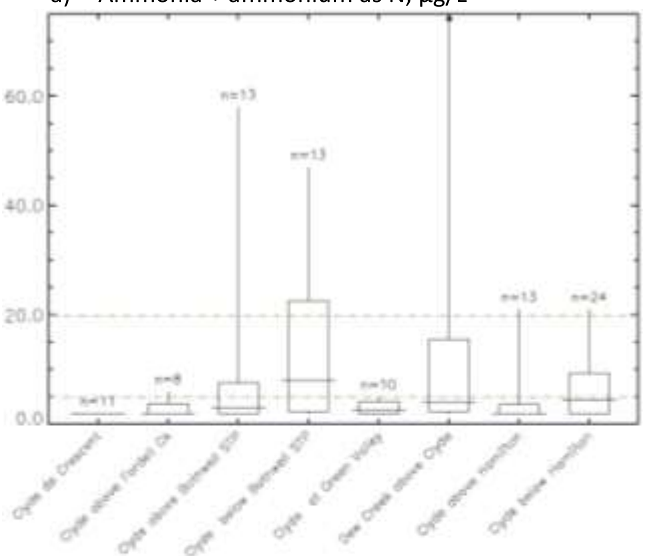
Water allocation in the Clyde catchment is high, and a proposal to increase water availability for irrigation through the Shannon-Clyde Irrigation scheme is currently on hold. Under this scheme, water from the River Clyde, Shannon River and Great Lake would deliver an additional 8,700ML of water per year to the region, at high reliability. Currently, most water allocations are used for irrigation of grass and pasture, and poppies (Figure 140).



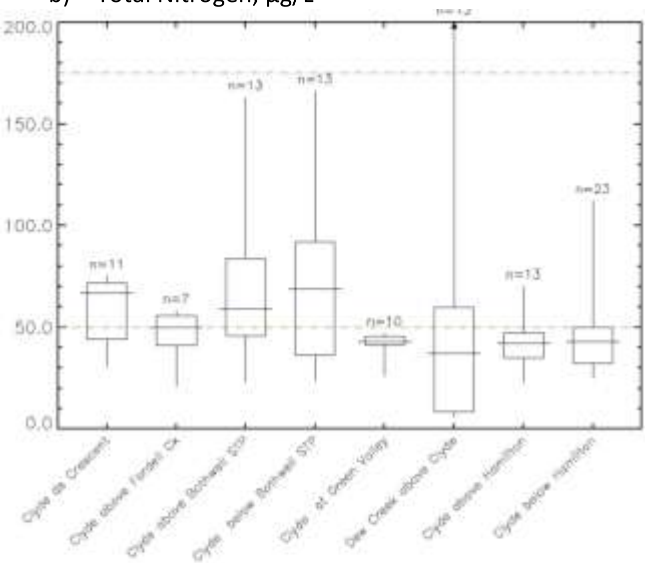
a) Ammonia + ammonium as N, µg/L



b) Total Nitrogen, µg/L



c) Dissolved phosphate as P, ug/L



d) Total Phosphorous, µg/L

Figure 139 Water quality data, longitudinal study of the Clyde River catchment Upper Derwent Nutrient Study. "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= number of samples. DPIWE site specific or ANZECC default trigger value for lowland river shown, where appropriate. (Data from DEP.)

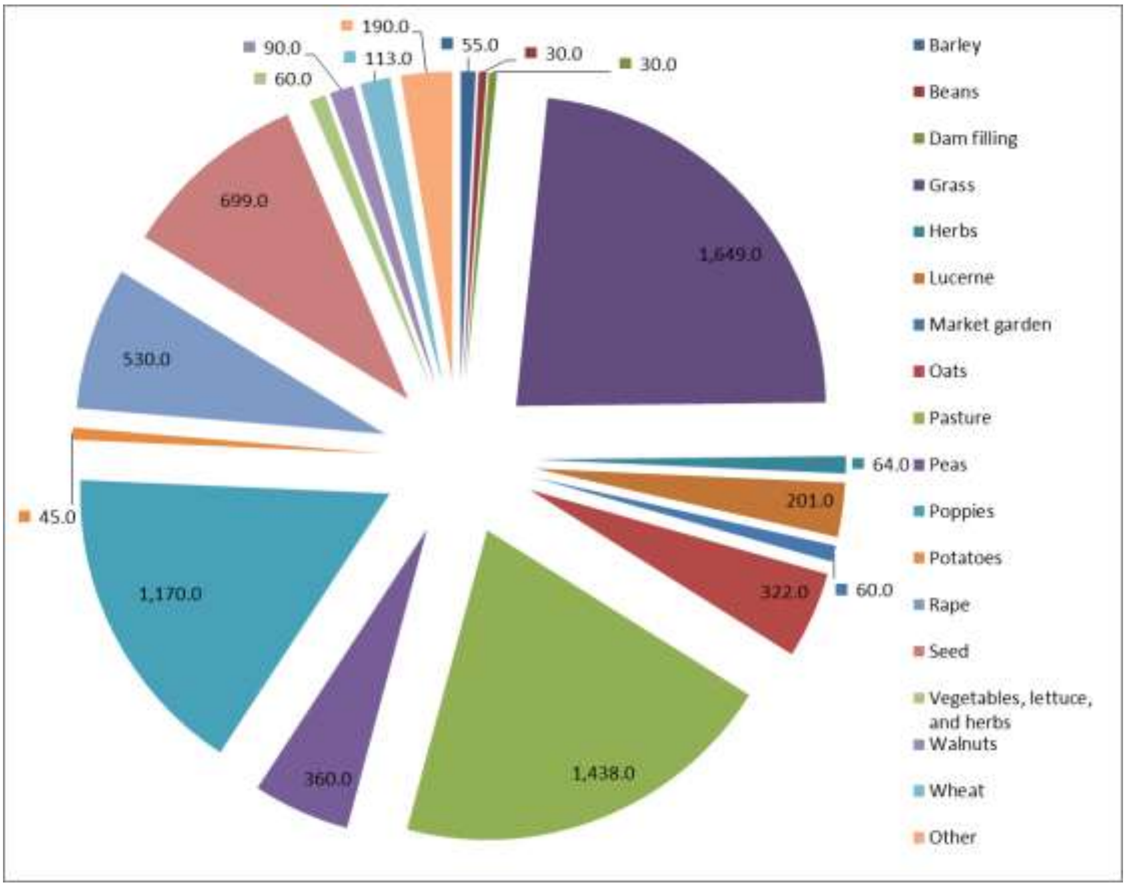


Figure 140 Water use in the Clyde catchment by crop 2005-2006 (ML).

Summary of Eastern Inflows

Water quality in the eastern inflows to the Derwent River has the following characteristics:

- Diversion of water out of rivers (and the catchment) and the storage of water in impoundments results in a highly modified flow regime, affecting water quality. The management of water for irrigation releases results in a seasonal reversal of flows downstream of impoundments;
- Moderate to severe erosion in the central plateau region of these catchments contributes to poor water quality, and some parts of the catchments are severely affected by dryland salinity, particularly around Bothwell and Hamilton;
- Groundwater and surface water both influence riverine water quality.

<u>Dee and Ouse Rivers</u>

- Rivers maintain a distinctly seasonal cycle for temperature, dissolved oxygen, turbidity, conductivity and suspended solids. Turbidity is often seasonally high in winter, accompanied by low EC waters associated with winter rains.
- Conductivity tends to increase down catchment, however annual rainfall patterns, drought cycles and land-use can all affect these seasonal cycles;
- The cycle of drought and wet years has an impact on water quality, with total Nitrogen loads in the Dee low under very dry conditions observed in 1996;

- Levels of blue-green algae (measured as phycocyanin) are periodically high;
- Total P concentrations in the Ouse underwent a significant increase through 2008, with insufficient data post 2008 to determine if concentrations have stabilized;

Clyde River

- Flows are significantly altered from natural regime of high winter flows by controlled releases in the upper Clyde for irrigation , however rainfall throughout the catchment contributes to a more natural flow pattern in the mid and lower catchment;
- Water quality is impacted by lake level management in Lake Crescent, a large shallow lake with high organic sediments, subject to wind driven re-suspension, and frequently turbid. Management objectives include eradication of carp, protection of a threatened native galaxid and minimisation of turbidity;
- Water quality is generally very poor, with elevated nutrients, turbidity and conductivity immediately downstream of Lake Crescent. Nutrients are believed to be elevated due to internal cycling of sediments with the lakes, rather than catchment sources to the lakes themselves;
- Nutrients measured during drought conditions in 1997/98 were significantly lower than those recorded in later monitoring programs, however TN and P loads are strongly associated with turbidity lost from Lake Crescent;
- Poor water quality at the end of the catchment has resulted in Hamilton drawing its water supply from Lake Meadowbank.

2.5 Derwent below Meadowbank

Summary of hydrology and regulation

Meadowbank Dam is the last major dam on the Derwent before the river becomes estuarine around New Norfolk. Flows at Meadowbank are controlled by power station activity, with year round discharges of up to 160 cumecs. Higher winter flows are superimposed over this discharge with minor contributions from the Tyenna, Plenty and Styx Rivers (Figure 38 PART 1). The location of the salt wedge is important with respect to the freshwater intakes at both Bryn Estyn and Lawitta (Norske Skog), and Hydro Tasmania are committed to maintaining a 20 cumec discharge from the Meadowbank Dam to prevent upstream migration of the tidally driven tongue of salt water. Water quality monitoring data collected by Norske Skog as part of the Derwent Estuary Program shows bottom water at the New Norfolk Bridge is frequently saline and may persist for extended periods, but is rapidly replaced with freshwater through the entire water column during high river flows. During large floods, freshwater may push the salt wedge south of Elwick Bay.

Summary of data sources presented

Data for this section of the Derwent catchment is primarily drawn from monitoring conducted by Southern Water at and around the intake to the Bryn Estyn water treatment plant, and Norske Skog upstream of the paper mill and effluent discharge site. Norske Skog monitoring forms part of the DEP Ambient Water Quality monitoring program, and is the uppermost site in the estuarine program.

Spatial & temporal trends

Movement of the salt wedge in bottom waters of the Derwent is presented in Figure 141, which shows surface water salinity never exceeds 0.5 psu, while bottom waters range between 0 psu and 30 psu, depending on tidal stage and river flows. Saline bottom waters tend to be slightly warmer, higher in ammonia, dissolved phosphate, total Phosphorous, and total and dissolved zinc; but seasonally lower in dissolved oxygen, colour and total organic carbon (Figure 142). Nitrate + nitrite and TN are higher in bottom waters, while pH and TSS tend to have similar ranges in fresh and saline waters.

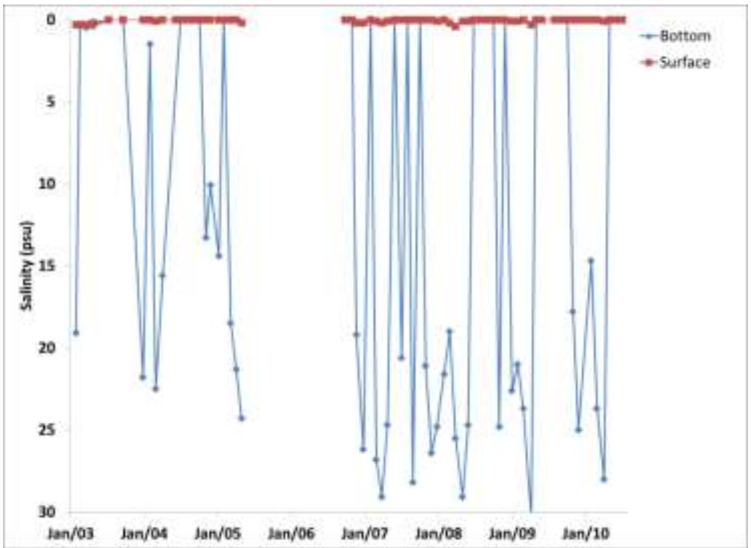
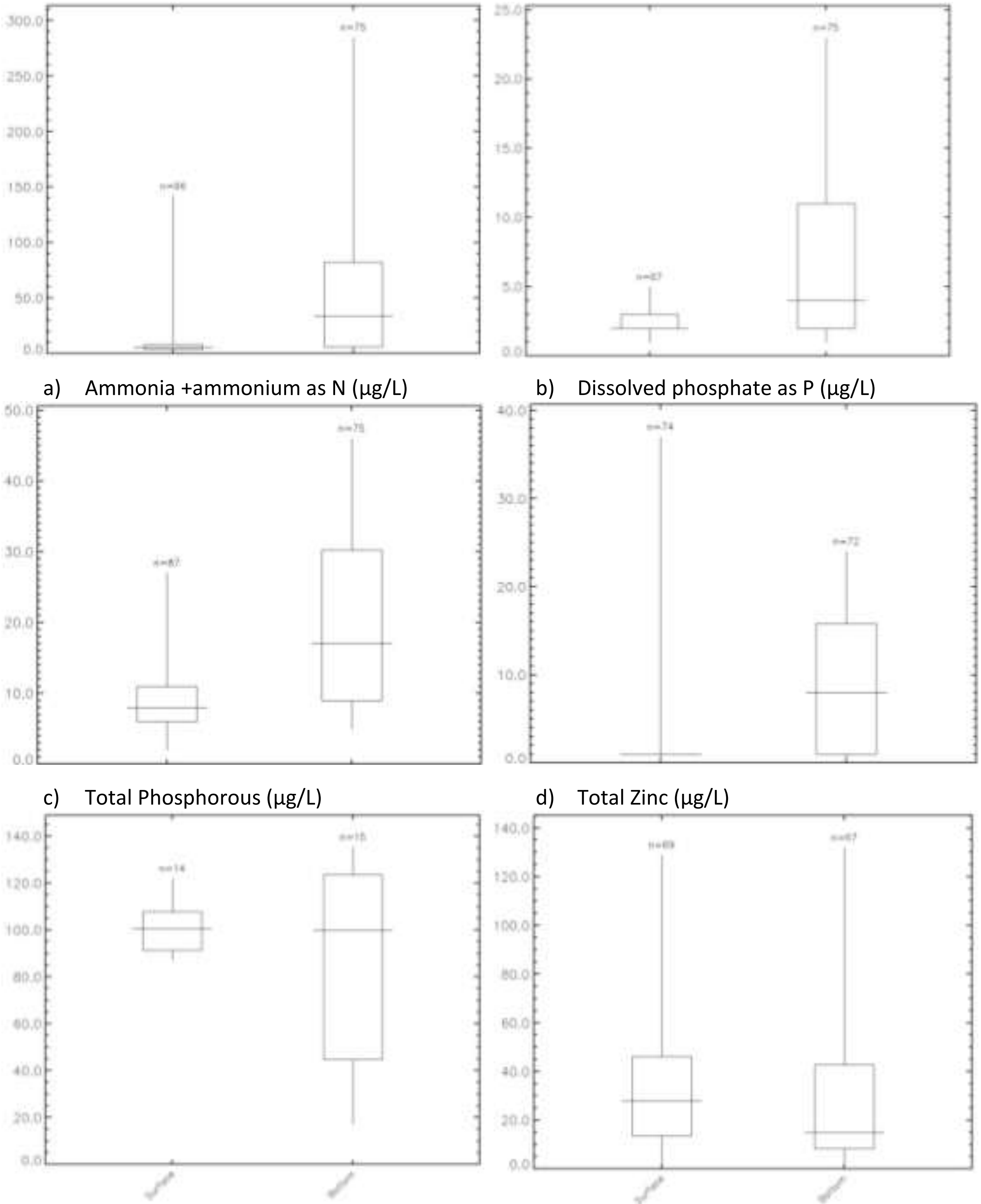


Figure 141 Salinity of surface (red) and bottom (blue) waters at New Norfolk Bridge, 2003-2010. Note no data between June 2005 and October 2006. (Data Norske Skog and DEP).

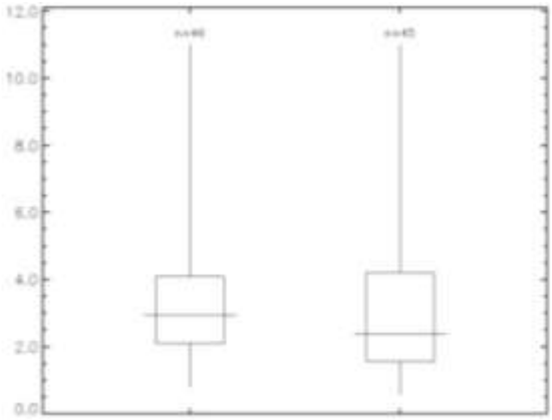


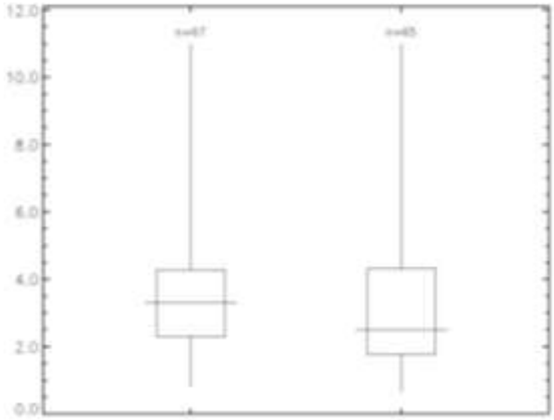
a) Ammonia +ammonium as N (µg/L) b) Dissolved phosphate as P (µg/L)

c) Total Phosphorous (µg/L) d) Total Zinc (µg/L)

e) Dissolved oxygen (% saturation) f) True Colour (Hazen units)

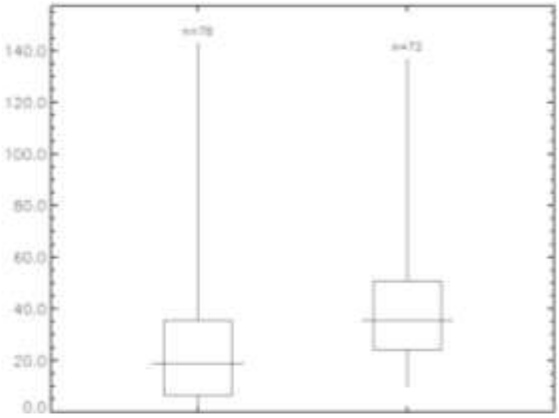
Figure 142a-l) Water quality in surface (left) and bottom (right) for parameters monitored at New Norfolk Bridge, 2000-2010. (Data from Norske Skog and DEP). “Boxes” (80th, 50th, 20th percentile; “whiskers” maximum/minimum, n= number of samples.

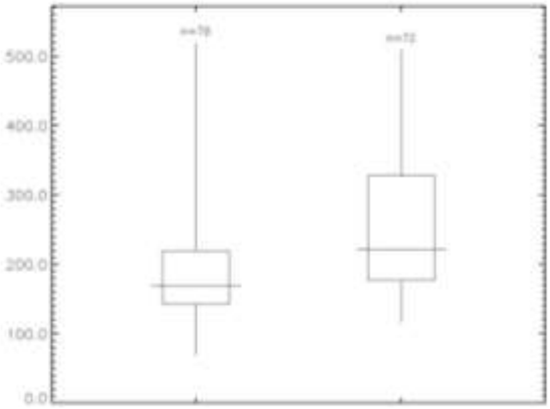




g) Dissolved Organic Carbon (mg/L)

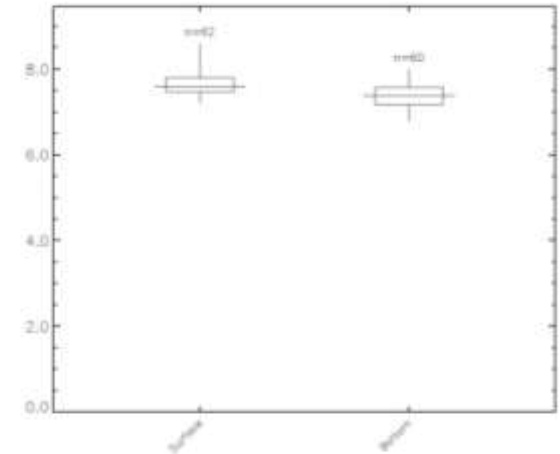
h) Total Organic Carbon (mg/L)

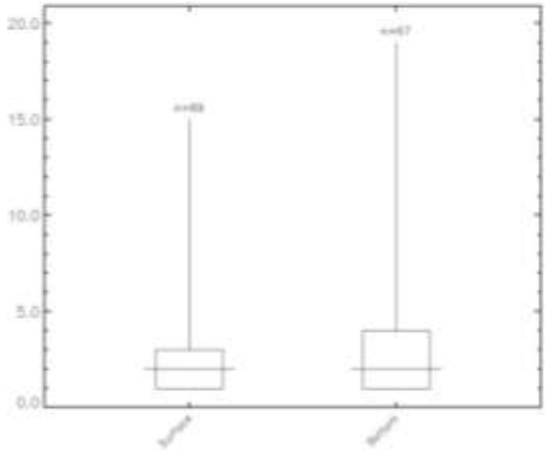




i) Nitrate + nitrite as N (µg/L)

j) Total Nitrogen (µg/L)





k) pH

l) Total Suspended Solids (0.45 µm, mg/L)

Figure 142 a-l cont Water quality in surface (left) and bottom (right) for parameters monitored at New Norfolk Bridge, 2000-2010. (Data from Morske Skog and DEP). "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= number of samples.

Surface concentrations of TN and TP at New Norfolk Bridge reflect catchment water quality upstream of the influence of the Norske Skog paper mill, the township of New Norfolk and the New Norfolk WWTP. Both TN and TP tend to peak during high winter flows (Figure 145) although concentrations are within the default trigger values for lowland rivers developed by ANZECC (Table 23, PART1). TN is mostly in the dissolved form with total filtered nitrogen contributing about 80% of the TN value in surface waters. In this respect, nitrogen behaves similarly to carbon, with almost all the organic carbon in the dissolved form (Figure 144). There is no clear trend for phosphorous, with phosphate forming a variable proportion of the TP concentration. Nitrate and nitrite, and to a lesser degree phosphate peaked during winter, with phosphate often below detection in summer. Ammonia is typically below 20 µg/L (ANZECC trigger for lowland rivers) in surface waters, however has previously been very high during 1999-2000 (Figure 145). TN was not elevated during this period (Figure 143), and there is insufficient upstream ammonia data for the corresponding period to identify the source.

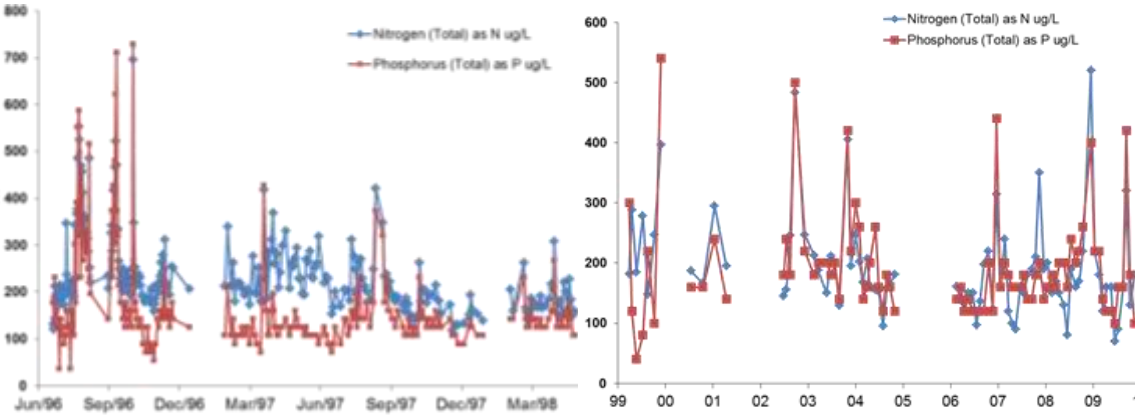


Figure 143 Surface nutrients monitored at Bryn Estyn intake 1996-1998 (left) and New Norfolk Bridge, 2002-2010 (right). Nitrogen scaled on left axis, phosphorous on right axis. (Data from Norske Skog and DEP).

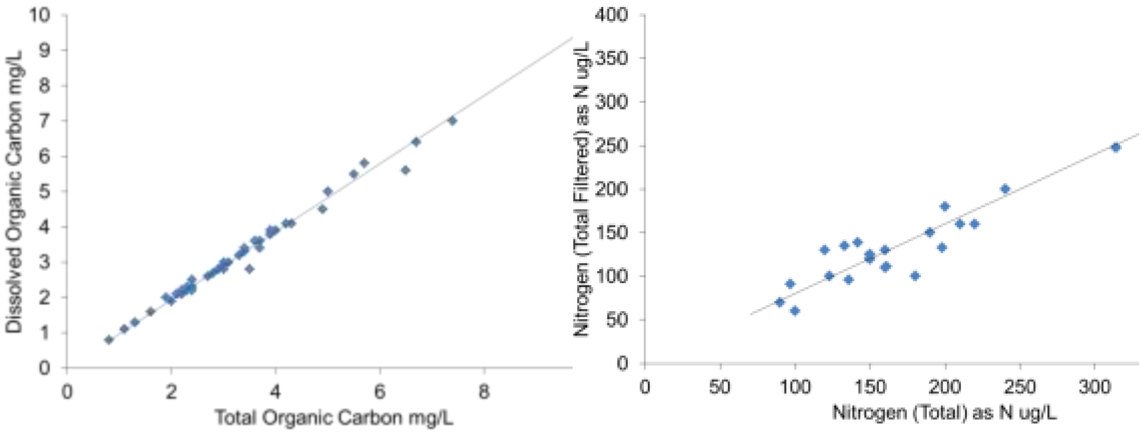


Figure 144 Relationship between Total and Dissolved Organic Carbon (left, 2003-2010) and Nitrogen (right, 2006-2010) in surface samples, New Norfolk Bridge. (Data from Norske Skog and DEP).

Derwent at New Norfolk

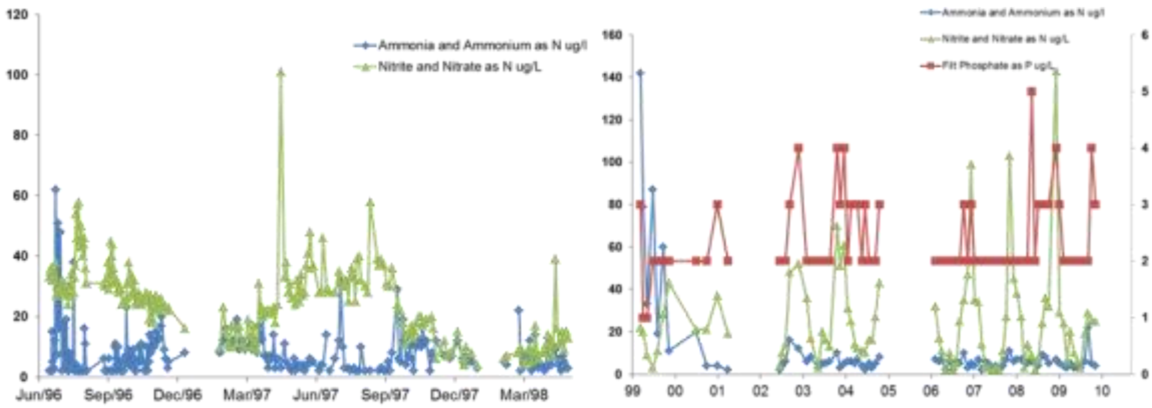


Figure 145 Surface dissolved nutrients monitored at Bryn Estyn Intake 1996-1998 (left) and New Norfolk Bridge, 1999-2010 (right). Nitrogen species scaled on left axis, phosphorous on right axis. (Data from Norske Skog and DEP).

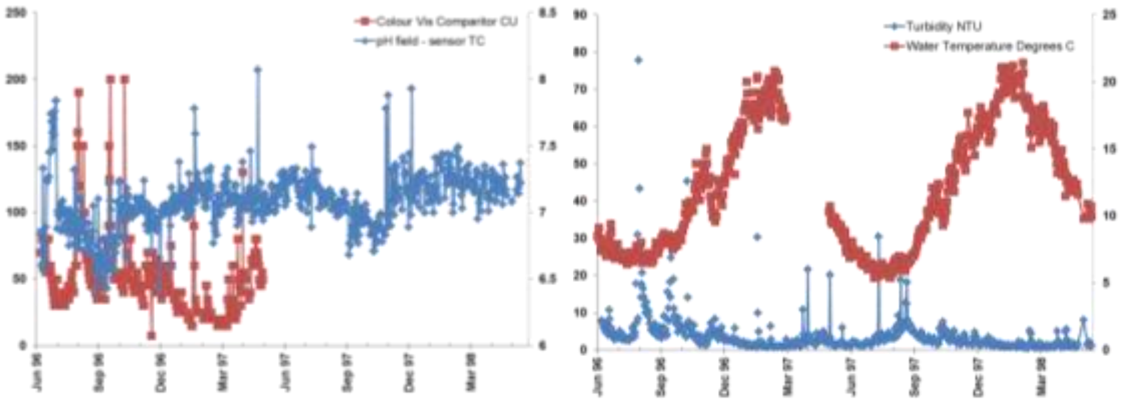


Figure 146 Surface colour (CU) and pH monitored daily at Bryn Estyn intake. Colour scaled on left axis, pH on right; Daily turbidity (NTU) and water temperature (^{o}C). Turbidity scaled on left and temperature on right. (Data from DEP).

Earlier data collected during the Upper Derwent Nutrient Study shows daily, then twice-weekly nutrients for the period July 1996 to April 1998 at the Bryn Estyn intake. Ammonia is occasionally elevated, but not to the same level as 1999 (Figure 145). Colour, pH, water temp and turbidity for this same period are presented in Figure 146.

Faecal contamination in the lower end of the river affects both recreational and drinking water quality. Sources may be associated with both urban and rural land-use, and due to the presence of waste water treatment facilities. Derwent Valley Council monitors recreational water quality using the faecal indicator *Enterococci* at the New Norfolk Bridge, with water quality generally within guidelines for primary contact (Figure 147). This site has a long-term grade of “Good” based on 5 years previous monitoring data during the recreational season (December through March, DEP website).

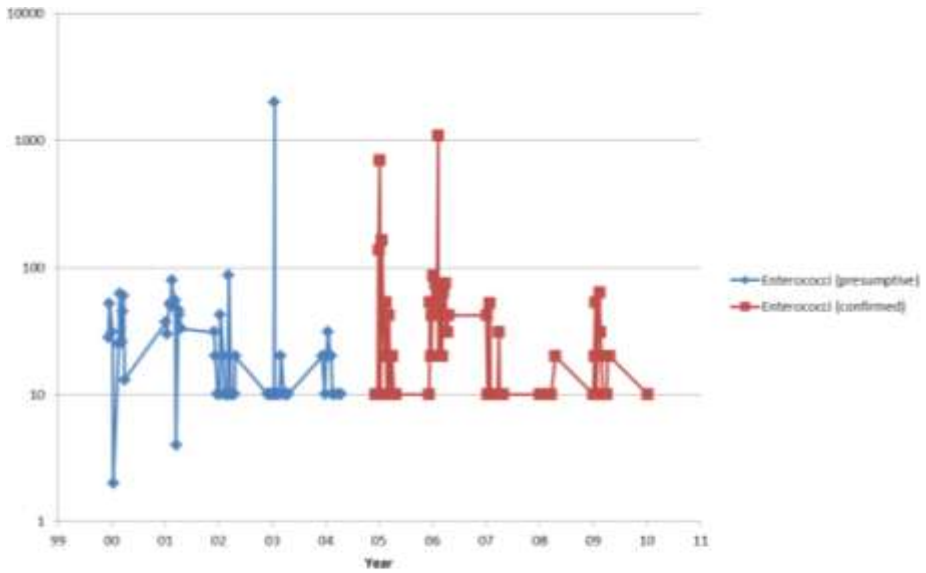


Figure 147 Recreational water quality monitoring data, Derwent River at New Norfolk Bridge 2000-2010 (Data Derwent Valley Council and DEP).

Southern Water have monitored smaller creeks immediately upstream of the Bryn Estyn intake (Glenfern Creek, Mikes Creek, "Hayes Creek" near Hayes Prison Farm) due to the impact of poor water quality during storm and flood events on intake water quality. Figure 148 shows weekly monitoring data for "Hayes Creek", showing a substantial decline in turbidity following a series of actions around in-stream works, and up-grading of the dairy and effluent treatment facilities at the prison farm. Data for faecal contamination (*E. coli* and *Enterococci*) is presented in Figure 149 and also shows an improvement following implementation of these works.

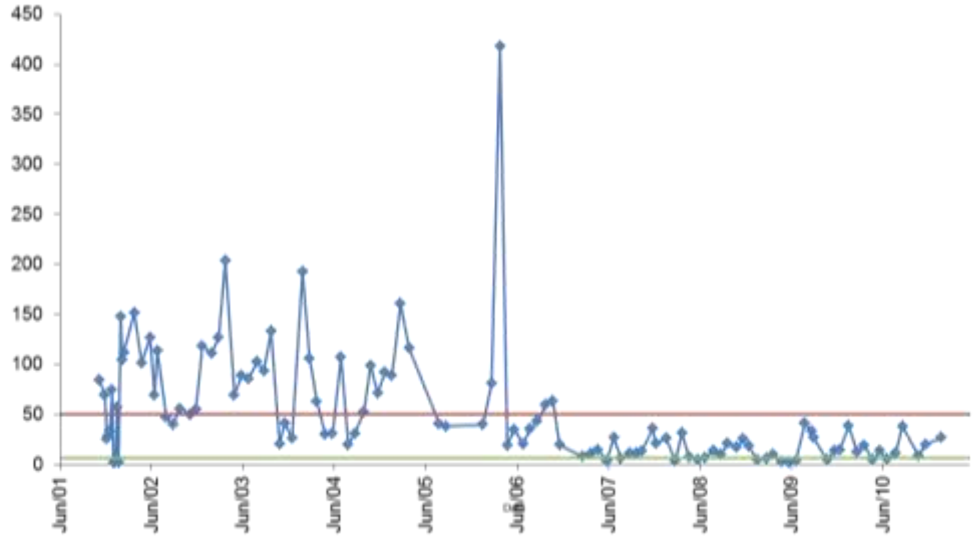


Figure 148 Turbidity (NTU) at "Hayes Creek", downstream of Prison farm. ANZECC default trigger values (upper and lower) for lowland rivers (Data from Southern Water).

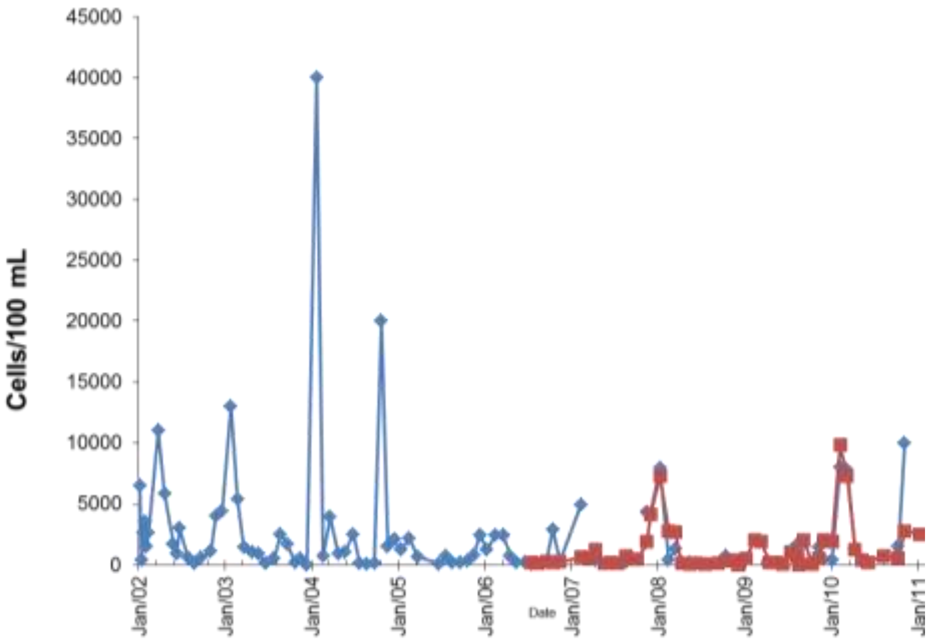


Figure 149 ***E. coli*** **(blue) and** ***Enterococci*** **(red) for "Hayes Creek", downstream of prison farm (Data from Southern Water).**

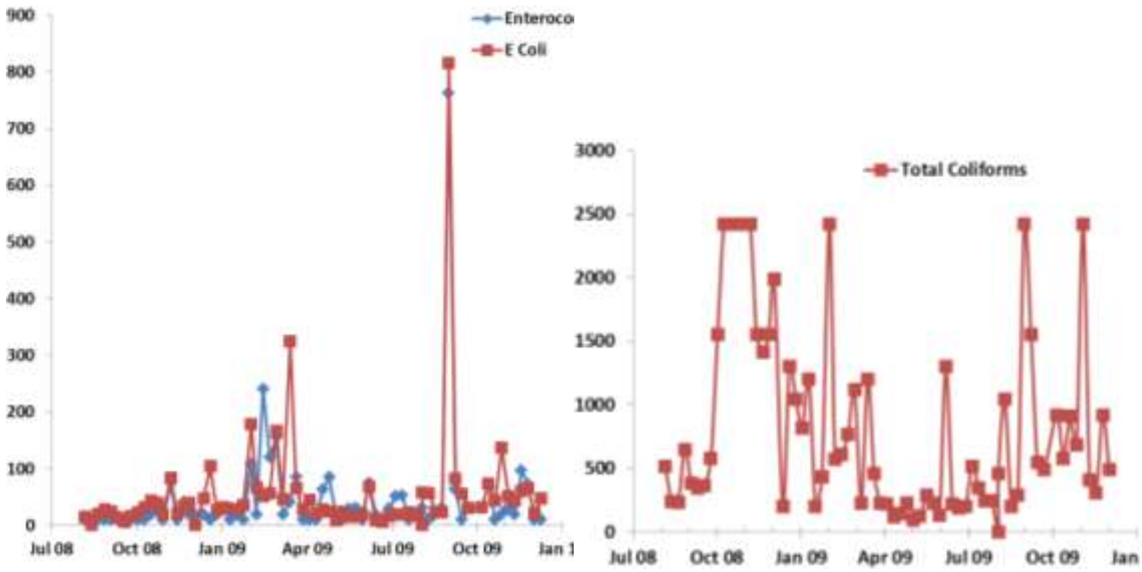


Figure 150 Left: Weekly monitoring data for ***Enterococci*** **(blue) and** ***E. coli*** **(red) as cells/100 mL; and total coliforms (right) at Bryn Estyn intake July 2008-January 2010 (Data from Southern Water).**

Southern Water monitors for a broad range of parameters relating to both catchment health and drinking water criteria at the Bryn Estyn plant. The Drinking Water Treatment Plant supplies a significant part of the drinking water supply for greater Hobart. The plant is located at the bottom of the Derwent catchment and as such is vulnerable to land-use practices and natural processes that can negatively impact on both the quantity and quality of water. Contaminants resulting from chemical use, effluent discharge or as a result of natural processes (biotoxins production) may pose a significant threat to human health. Pesticides have been monitored at a range of intensities (monthly, weekly) with occasional detection of atrazine and hexazinone. Both chemicals are highly water soluble and relatively resistant to degradation, and both have been occasionally detected elsewhere in the catchment by the Spray Information and Referral Unit (SIRU) within DPIPWE. A summary of pesticide use in the Derwent catchments, based on landholder interviews and cropping information is summarised in Part 1 (Bendor et al, 2008). Pesticides are often associated with flood or storm events, and tend to occur as pulses following use, overspray or spillage, and as such will not always be detected in routine grab samples. Southern Water are currently investigating methods for the on-line detection of 2 target pesticides, hexazinone and atrazine, at the intake to Bryn Estyn. This will allow real-time detection of these chemicals and significantly increase understanding of the use of pesticides in the catchment, as well as conditions resulting in an increase risk to drinking water quality.

In addition to the monitoring of contaminants, Bryn Estyn has operational targets for a number of parameters that affect the treatment process (turbidity, pH) or the aesthetic value of the water (colour; see Table 26 PART 1). Data for these parameters are presented in Figure 151 and Figure 152 below. Colour typically exceeds the operational target of 70 Hazen units in winter, when organic carbon is highest (Figure 153). pH only occasionally falls below the lower target of 6.5, whilst turbidity is frequently > 8 NTU. Colour and TOC show similar seasonal trends, with winter flows characterised by dissolved organic carbon-enriched water (see Figure 144).

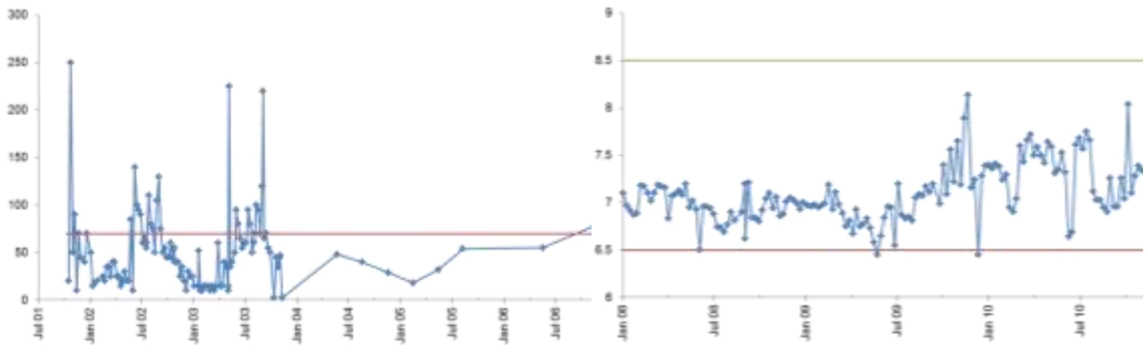


Figure 151 Colour (left, Hazen units) and pH (right) at Bryn Estyn Intake 2001-2006. Also shown are the operational targets of 70 Hazen units and pH 6.5-8.5 for treatment and process control. (Data from Southern Water).

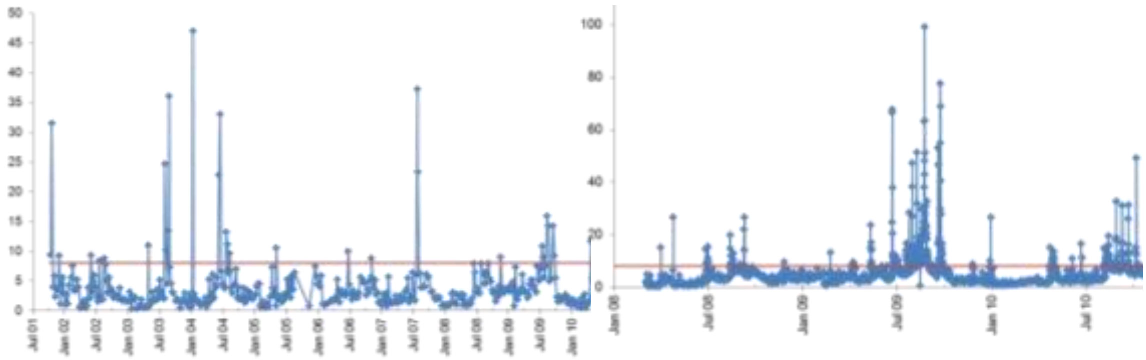


Figure 152 Turbidity data at weekly (left, 2001-2010) and 6 hourly (right, 2008-2011) sampling frequency at Bryn Estyn intake. (Data from Southern Water). Note difference in scales.

A number of sampling frequencies are presented in these figures, which show how trends may be masked as sampling frequency decreases. Colour sampled on a weekly basis (Figure 151, 2001-2003) shows quite a different range of values to twice-monthly sampling (2004-2006), however seasonal cycles are still discernible. Turbidity sampled on a weekly basis (Figure 152) shows winter peaks in July 2009 with a maximum of 15 NTU, however 6-

hourly sampling over the same period shows the turbidity maximum as 100 NTU. Hourly or 15-minute on-line data will likely show a different range of values again.

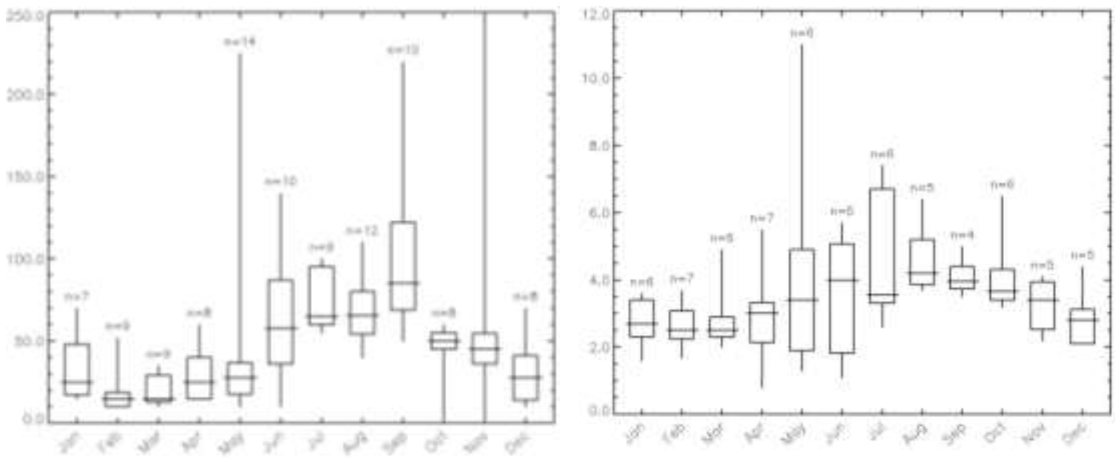


Figure 153 Colour (left, Hazen units) Bryn Estyn at intake 2002-2006, & TOC (right, mg/L) New Norfolk at Bridge, 2000-2010. (Data from Southern Water).

Summary of Derwent below Meadowbank

Water quality in the Derwent below Meadowbank has the following characteristics:

- Below the dam, the river returns to a sinuous form with meander bends and flood plains, with more natural river form and processes (e.g. sediment transport);
- Flows in the lower section of the Derwent below Meadowbank Dam are largely controlled by power generation, with the position of the salt wedge in the upper estuary controlled through minimum flow requirements;
- Saline bottom water significantly alters the water chemistry and stratifies the water column, with the salt wedge frequently present at New Norfolk Bridge, but not known to migrate past the Lawitta rapids;
- Waters reflect the combined impact of generally good water quality from upland headwaters and tributaries, and the gradual decline in water quality of tributaries towards the lower end of the catchment. Signals from local inputs may override the broader catchment loads;
- Some evidence that Hydro lakes provide a degree of buffering with respect to water quality in the lower catchment;
- TN and TP are seasonally high in winter and correlated with flow, while dissolved nutrients show less flow dependence;
- Chlorophyll-*a* maximums tend to occur later than in the headwaters of the Derwent, with maxima in autumn rather than summer. Information on species composition of the algal community and therefore relationship with blooms in the upper catchment were not available;
- Turbidity and TSS influenced by both summer storms and winter floods.

2.6 Catchment fluxes in the Derwent

The following section of the document is a discussion of catchment fluxes for the Derwent catchment. The terms mass load and flux are often used interchangeably and are a measure of the mass of substance being transported over a set time period.

Calculation of fluxes allows comparison of nutrient sources and sinks across the catchment, normalized for flow. Any parameter that can be measured as a concentration can be expressed as a flux, if locally relevant flow data is available. Nutrient fluxes are calculated at a given point in time by multiplying nutrient concentration at a given point in the river (i.e. from monitoring programs) by the river flow, measured at the same location (Coughanowr, 2001). Results are typically expressed as mass per unit time for example kg/day, or tonnes /year. Discharge (flow) data are often measured continuously; however nutrient data is more commonly measured as a discrete sample, typically on a weekly or monthly basis. In general, low or base flows tend to minimise transport of nutrients from diffuse sources, which can result in reduced impact of upstream sources, and low variability. During storm or flood events, the quality and quantity of stream waters can fluctuate widely, and high nutrient loads will be transported as a result of rainfall events. The wide range of flow conditions, changes in concentrations of parameters of interest, and the duration of the flow event result in uncertainties in calculated fluxes as discrete samples taken only represent one point in time. Other factors that can have an effect on the mass loads is the drying and saturation of soils which varies between different seasons and climate cycles, such as drought periods. In order to determine a reliable total mass load from a catchment, the effect of pollutant or chemical mobilisation over a wide range of conditions needs to be ascertained. Few of the datasets collected within the Derwent Catchment were specifically designed with this in mind.

The purpose of this discussion is to provide typical ranges of mass loads in certain areas of the catchment and make comparisons of different time periods. This enables catchment managers and stakeholders to more fully assess the impact of an activity or range of conditions on water quality This information may be used to guide investment and further studies within the catchment.

2.6.1 Estimating fluxes in the Derwent

Calculating fluxes in the catchment is difficult as there are few sites where water quality and water flow information are available on a regular basis. Two time periods have been identified for which estimated flux calculations can be completed. One corresponds to the period of the Upper Derwent Nutrient Study (UDNS), April 1996–March 1997, and the other to a period of monthly lake monitoring by Hydro Tasmania in 2007–2008.

2.6.2 Method for calculating fluxes

The 1996-1997 UDNS monitoring consisted of monthly water quality monitoring over a 2-day period, with all sites located in flowing water (canals or rivers), for which flow data is available. Sites included the major ‘arms’ of the Derwent headwaters (Tarraleah, Tungatinah, Upper Nive) major tributary inputs (Florentine, Dee, Ouse, Clyde, Tyenna) and the Derwent downstream of Lake Meadowbank. When flow data was available, fluxes for this data set were calculated using the average daily flow for the sampling day at the monitoring site and the water quality results for that date. See Coughanowr (2001) for more details on flow and concentration measurements in the UDNS.

The 2007–2008 fluxes were less straightforward to calculate, as this Hydro monitoring program was not intended to establish fluxes through the system but rather monitor water quality in lakes during a drought period. Monitoring sites included Lake King William, Dee Lagoon, Lake Catagunya and Lake Meadowbank. Surface water quality results from these sites were combined with average weekly discharge from the associated power station to derive an estimated flux from the lakes. This information was combined with DPIPWE monitoring results from the Clyde River and Tyenna River, for which both water quality and flow results were available on days close to the Hydro monitoring dates.

These fluxes should be considered rough estimates only, as water quality variability within the lakes, and flow variability through the system are all potential sources of uncertainty. The magnitude of the uncertainties have not been calculated as part of this report, however the estimates are used as the best available data for this period.

2.6.3 Comparison of flow regimes 1996-1997 and 2007–2008

Mean annual flow for the Derwent at Meadowbank is 90 cumecs (1985-2011 data). The discharge in the Derwent River downstream of Lake Meadowbank for the periods investigated is shown in Figure 154. The 1996–1997 period shows several autumn, winter and spring high flow events (> 200 cumecs) and a prolonged low flow period from December 1996 to May 1997. In contrast, the 2007-2008 period had only a few high flow events, with most of the period having flows well below 100 cumecs, reflecting drought conditions in the catchment.

A comparison of flow at the Derwent below Meadowbank site to the average daily flows of sites used to determine the fluxes is contained in Figure 154 and Figure 155. In these, and subsequent flux graphs, the headwater sources (sites upstream of Lake Catagunya), and downstream tributaries (Dee, Ouse, and Clyde) are presented as stacked bars, as these sources all report to the lower lakes. Flows for Lakes Catagunya, the Derwent below Meadowbank and Derwent at Bryn Estyn/ Norske Skog are presented as points on the graph. Using a mass balance approach, flows should be equivalent to the sum of all sources above. For fluxes, calculated loads at the most downstream point should be equivalent to the sum of sources above, minus losses such as deposition or processing within the lakes. Information for the Tyenna River, which enters the Derwent downstream of Lake Meadowbank is also presented as a point on the graph for comparison. The flow balances for both periods show that during periods of low flow, there is a reasonable balance between the sources and the lower monitoring sites, but during periods of high flow, the balance is poor. This 'gap' is attributable to the variability of flow through the system, known inflows that are not included in the balances (e.g., Upper Nive, Ouse, Florentine in 2007 – 2008), additional catchment inflows during high flow periods, and the crude nature of the flow estimates used to derive the fluxes.

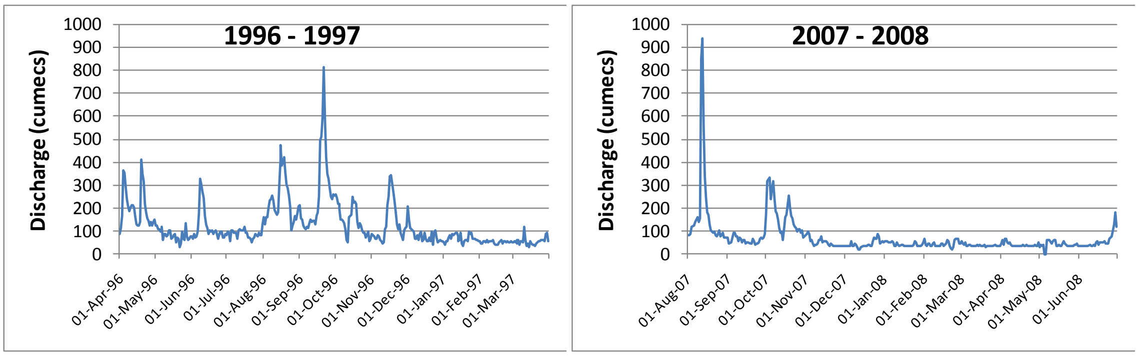


Figure 154. Average daily flow at Derwent below Meadowbank site for April 1996 – May 1997, and August 2007 – June 2008. Data from Hydro Tasmania.

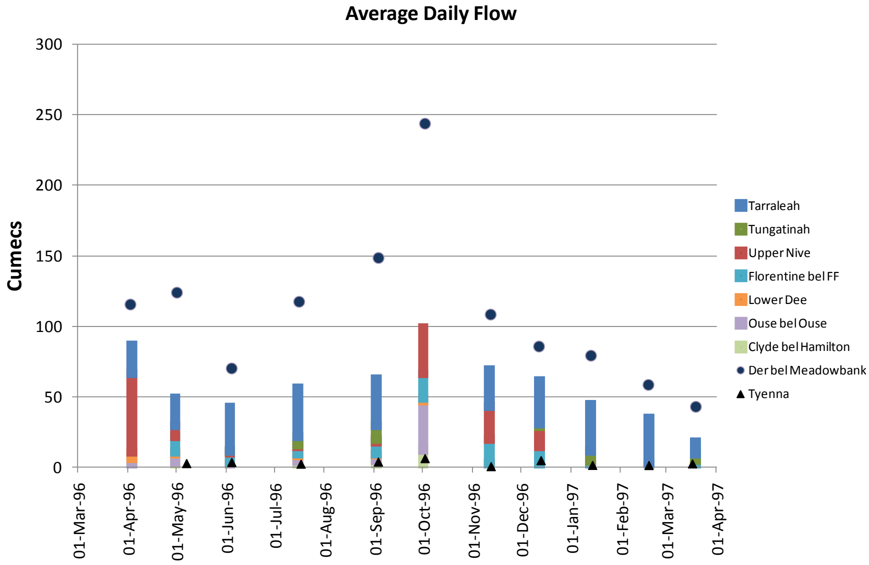


Figure 155. Average daily flow in the Derwent system on UDNS monitoring days. Data from Hydro Tasmania and DPIPWE.

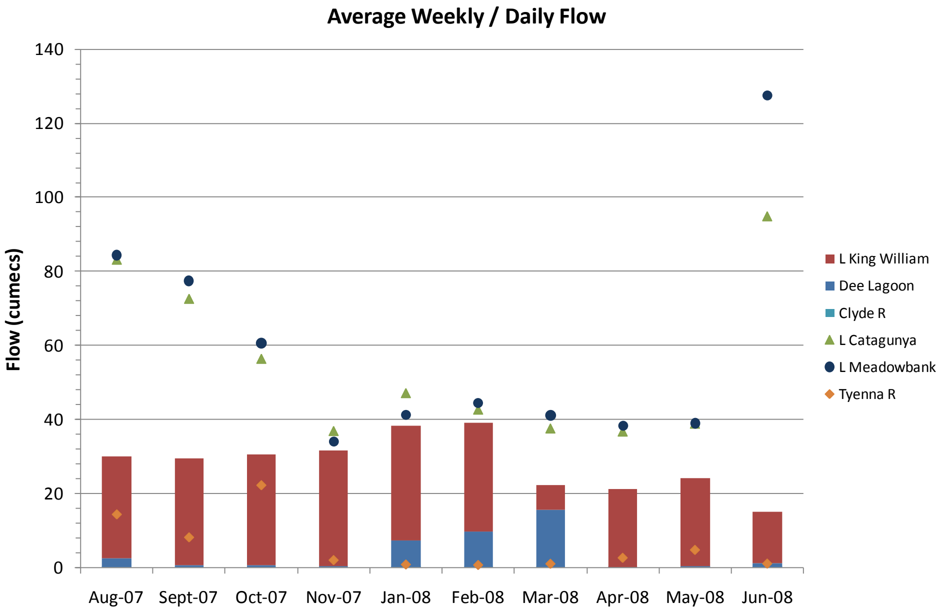


Figure 156. Average weekly flow below Lake King William, Dee Lagoon, Lake Catagunya and Lake Meadowbank during period of Hydro monitoring, and average daily flow in the Clyde River and Tyenna River. Lake flow data from Hydro Tasmania, Clyde and Tyenna data from DPIPWE.

In spite of these short-comings, the comparison of flows shows the following features:

- The Lake King William / Tarraleah ‘arm’ of the system provides a fairly uniform input of water into the system over most of the year;
- During the dry summer months, the majority of flow in the Derwent is derived from the headwater lakes;
- Inputs from Lake Echo / Dee Lagoon are more pronounced during the summer months;
- The flow from the tributaries (Ouse, Clyde, Tyenna) is generally low, but contributes a significant portion of the flow during high flow events (e.g. October 1996, October 2007)

2.6.4 Nutrient fluxes

Total Nitrogen fluxes for the 1996-1997 and 2007–2008 data sets are presented in Figure 157 and Figure 158 respectively. Similar to flow, TN results for 2007–2008 are lower than the earlier monitoring period and the best balances are obtained during periods of low flow. In the 1996-1997 data set, it is evident that during periods of high flow, the Ouse and Clyde contribute a large proportion of the TN flux in the catchment. The Florentine River also contributed a significant and fairly uniform proportion of the TN load to the system.

Similar graphs for Total Phosphorus fluxes are shown in Figure 159 and Figure 160. Peak TP fluxes do not occur at the same time as the peak TN fluxes in the catchment, with high fluxes derived from the Upper Nive and Lower Dee sites in April 1996. The source of this is TP is unknown. High TP fluxes are also present in the lower Derwent sites (Catagunya, Meadowbank and New Norfolk) in June 2008, with the source potentially associated with high TP observed in the Ouse in 2007-2008.

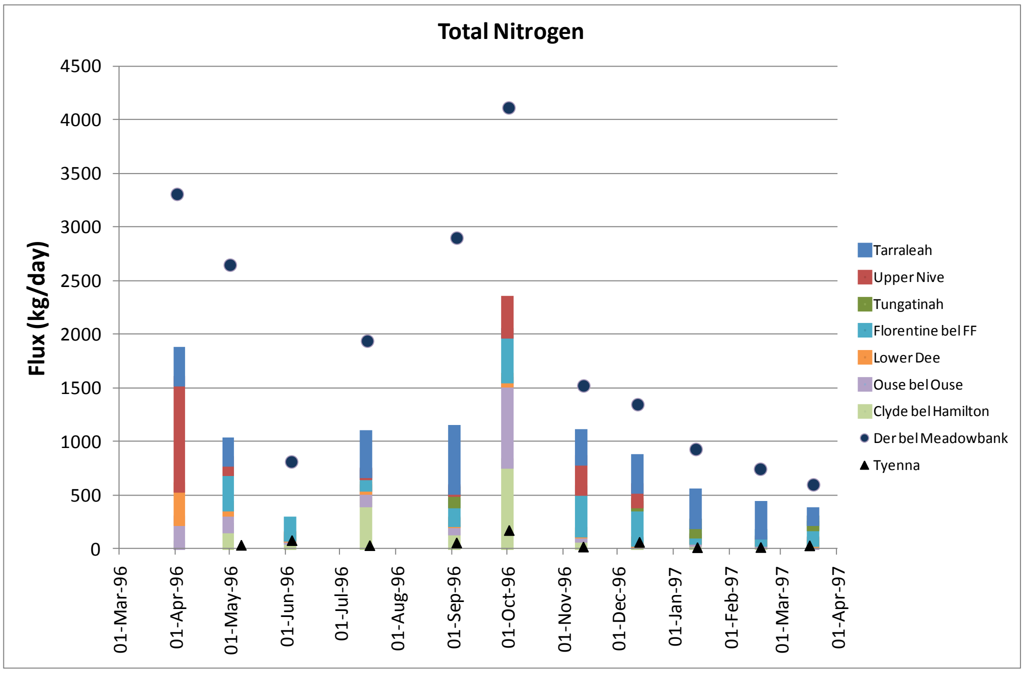


Figure 157. Total nitrogen fluxes for the Derwent catchment, 1996 – 1997 UDNS. Data from DEP, Hydro Tasmania and DPIPWE.

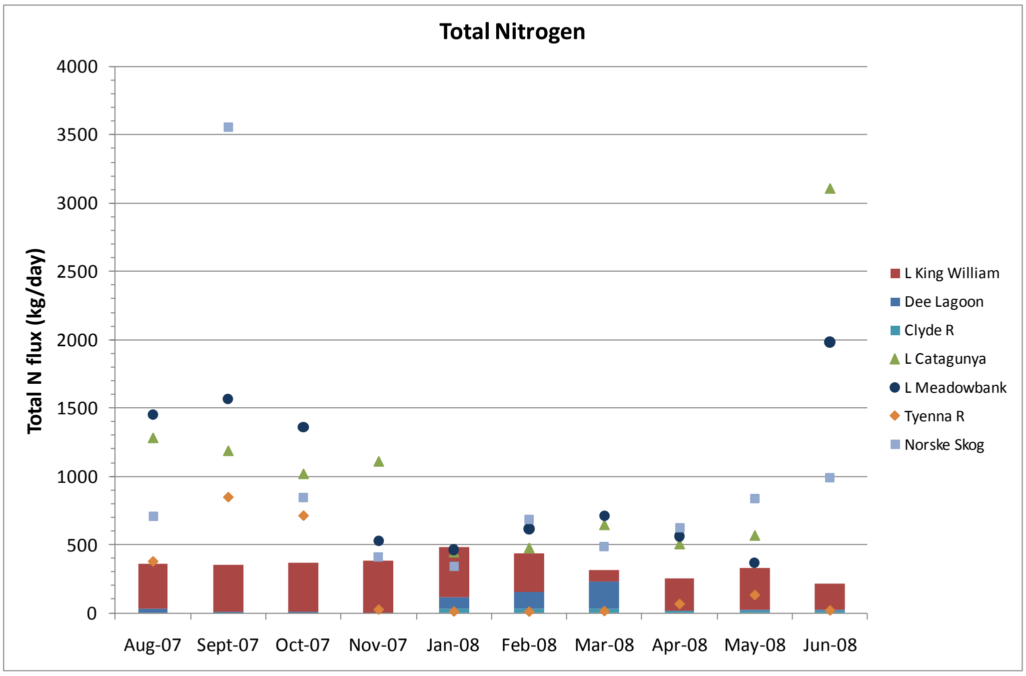


Figure 158. Total Nitrogen fluxes for the Derwent catchment, 2007 - 2008. Data from DEP, Hydro Tasmania and DPIPWE.

Total Dissolved Solids (Figure 161, Figure 162) were calculated using conductivity values and the generic conversion factor of 1µS/cm = 0.64 mg/L TDS (in the absence of a specific conversion factor for the Derwent River and its tributaries). The 1996 - 1997 calculations show that the Florentine River contributes a large proportion of TDS, which is consistent with the presence of limestone in the catchment. The Lake King William/Tarraleah derived water contributes little TDS to the system. Similar to nutrient results, the Clyde and Ouse are major contributors during high flow periods.

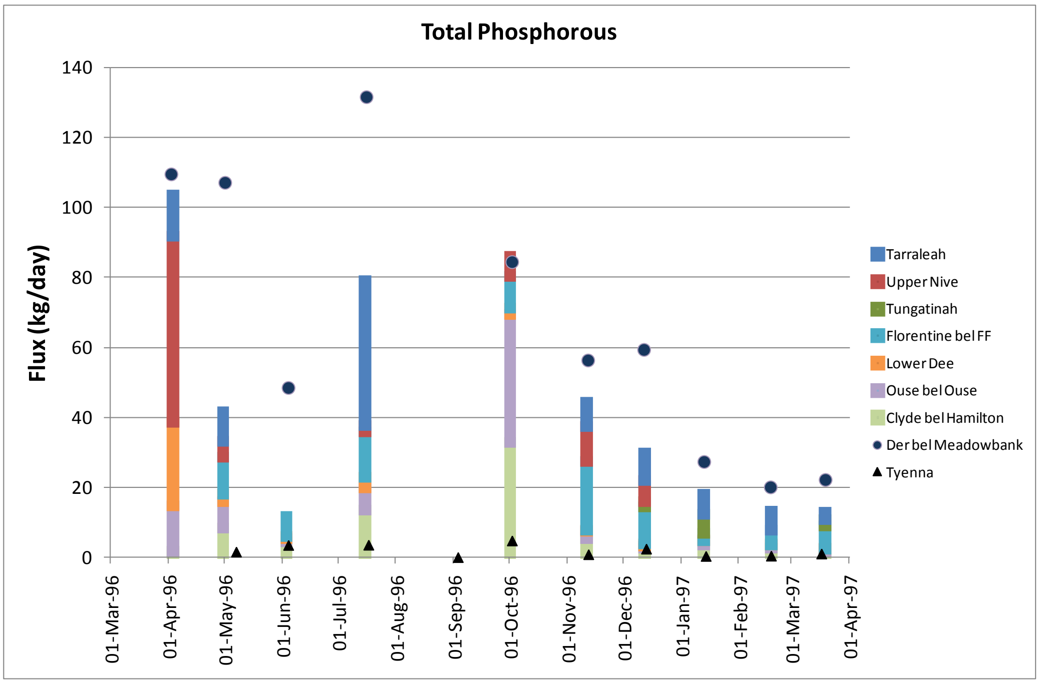


Figure 159. Total phosphorus fluxes in the Derwent catchment 1996 - 1997. Data from Coughanowr (2001), Hydro Tasmania and DPIPWE.

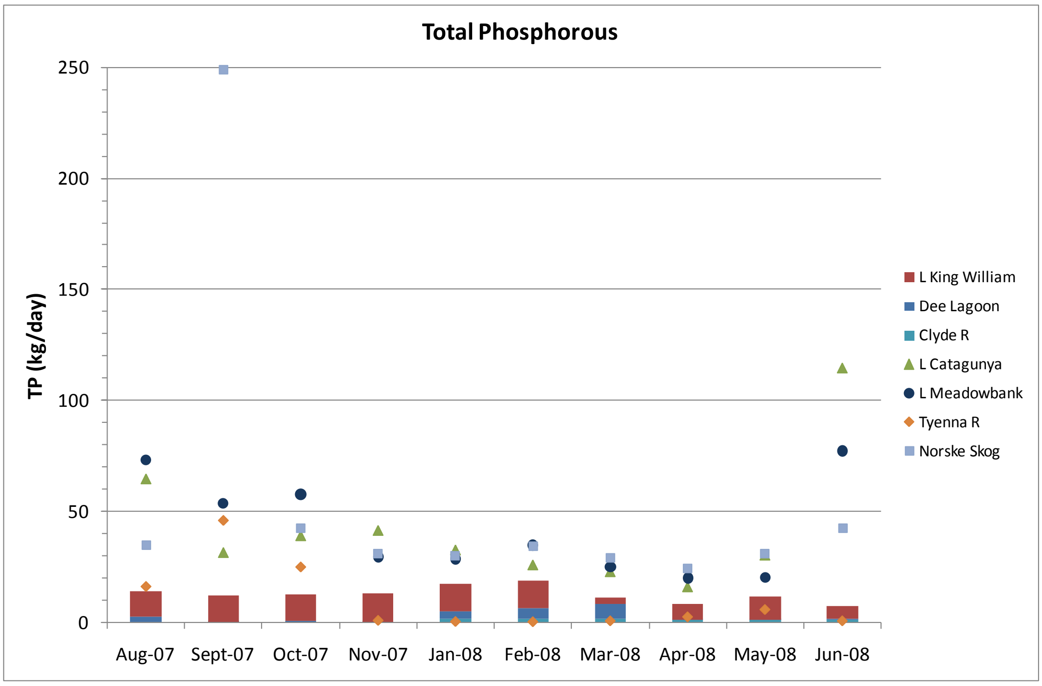


Figure 160. Total phosphorus fluxes in the Derwent catchment 2007 - 2008. Data from Hydro Tasmania and DPIPWE.

Ammonia + ammonium results are only available for the 1996 – 1997 monitoring period, but are interesting in that they show large inputs from Tarraleah, and from the Florentine River, with the sum of the sources sometimes exceeding the downstream Meadowbank results (Figure 163). The source of the ammonia in the Tarraleah canal is presumably Lake King William but the reason for the elevated values is unknown. The inputs from the Florentine are likely associated with the fish hatchery in the lower catchment.

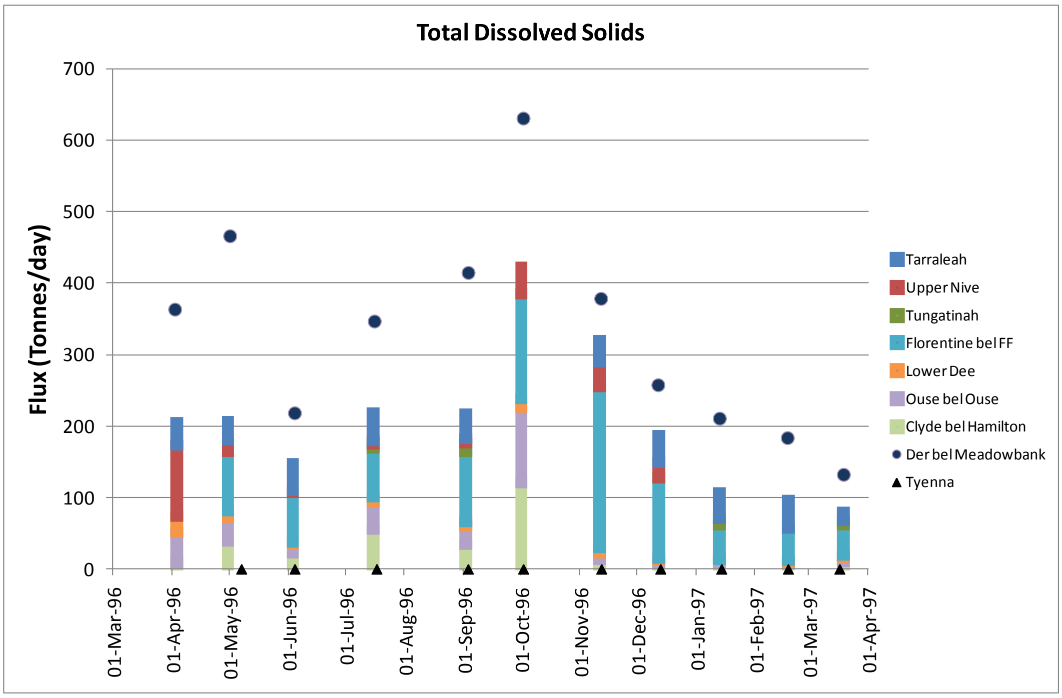


Figure 161. Total Dissolved Solids flux (tonnes/day) in Derwent 1996 – 1997. Data from DEP, Hydro Tasmania and DPIPWE.

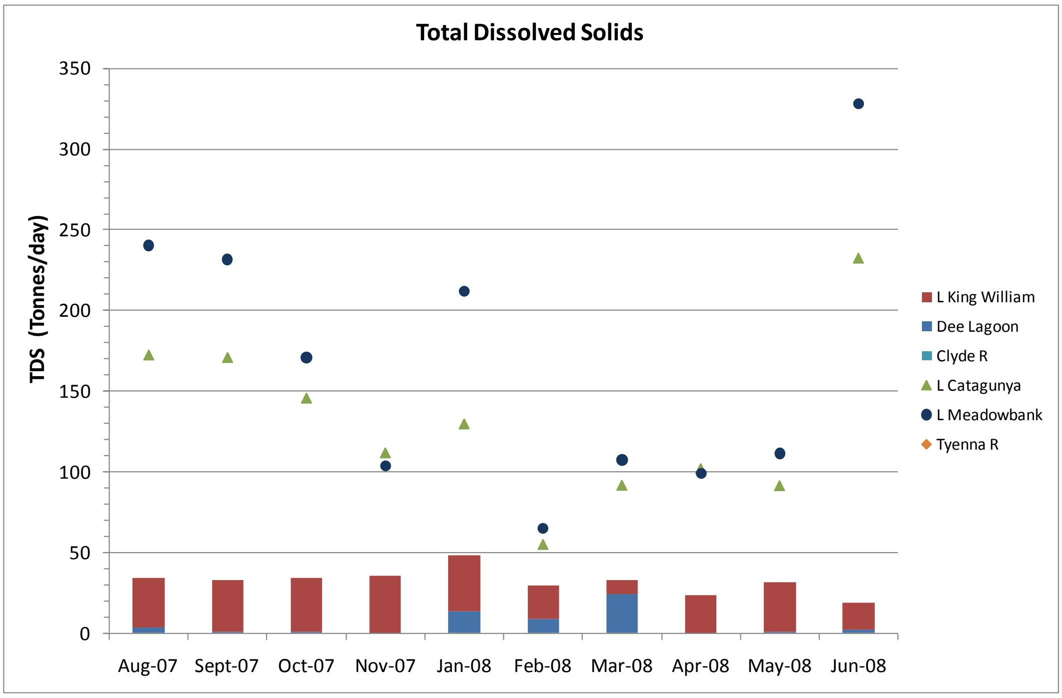


Figure 162. Total dissolved solids in Derwent 2007-2008. Data from Hydro Tasmania and DPIPWE.

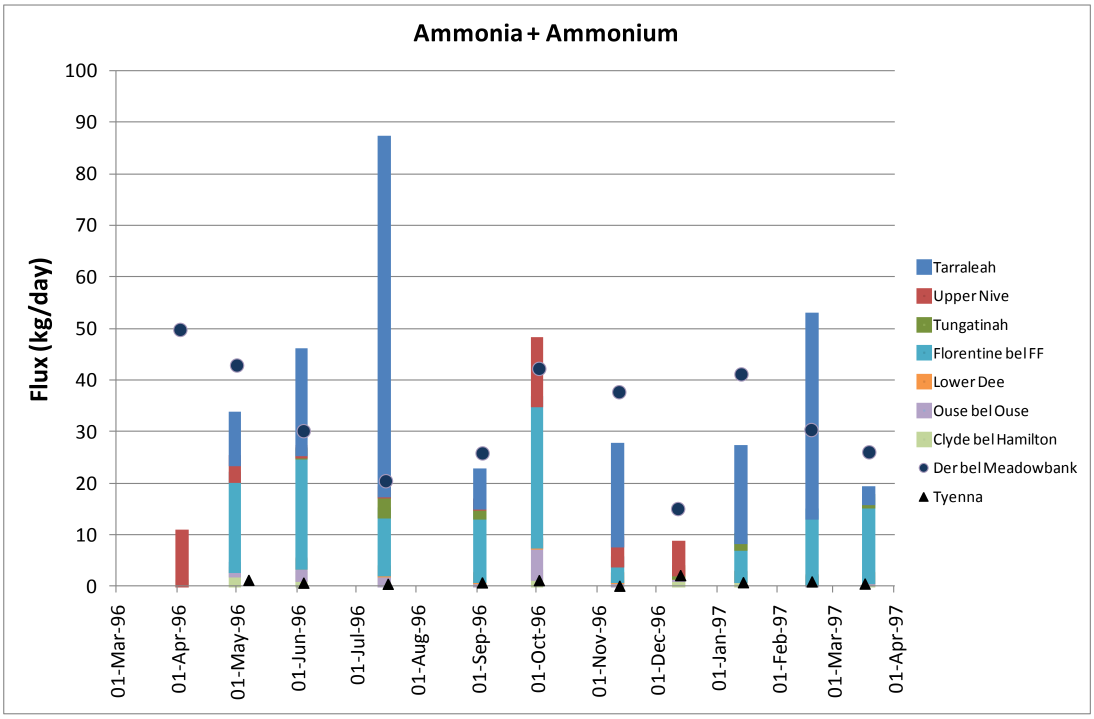


Figure 163. Ammonia + ammonium results for Derwent 1996 - 1997. Data from DEP , Hydro Tasmania and DPIPWE.

2.6.5 Comparison of concentrations and fluxes at Derwent below Lake Meadowbank

Comparing concentrations and fluxes of water quality parameters at the Derwent site below Meadowbank Dam provides a rough indicator of changes in the Derwent catchment between 1996 - 1997 and 2007-2008. Median concentrations (Figure 164) of water quality parameters are similar between the two time periods. The 2007-2008 data set shows lower variability for TP and turbidity, and these differences may be attributable to the drought conditions in 2007-2008. During the drought, tributary inflows, which provide a higher proportion of TP and turbidity as compared to the headwater lakes, were reduced.

The comparison of fluxes (Figure 165) shows substantially lower fluxes during the 2007 - 2008 period. This reduction is attributable to the much lower flows during 2007 - 2008 rather than a major change in water quality in the catchment.

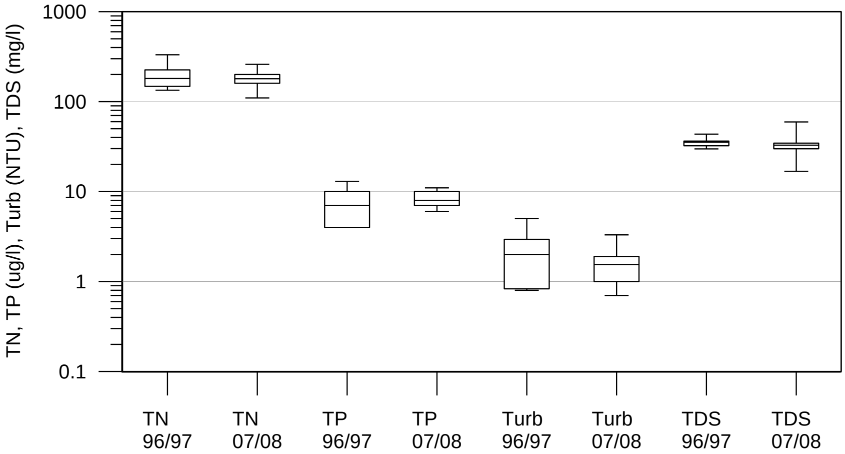


Figure 164. Summary of water quality results for Derwent River below Meadowbank for 1996 – 1997 and 2007 – 2008. Data from DEP, Hydro Tasmania and DPIPWE.

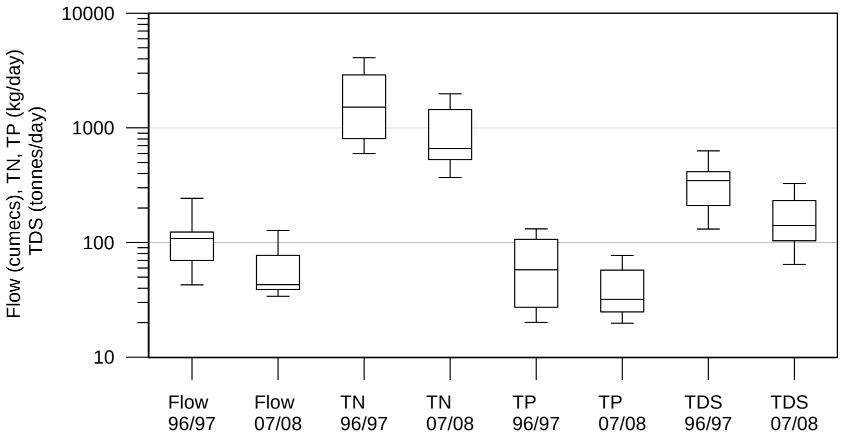


Figure 165. Comparison of flow, TN, TP and TDS fluxes at the Derwent downstream of Lake Meadowbank site. Data from DEP, Hydro Tasmania and DPIPWE.

2.6.6 "Bottom of the catchment" concentration and fluxes, Bryn Estyn & New Norfolk

Bryn Estyn

Data for this analysis was drawn from high frequency monitoring at Bryn Estyn, conducted as part of the Upper Derwent Nutrient Study in 1996-1998. Total and dissolved nutrients were monitored daily initially, then twice weekly during the study. This results in a reasonably robust estimate of fluxes for this period, due to the high frequency of both concentration and flow data. This site represents the downriver extent of the freshwater dominated system, with only a few kilometres of river length before water chemistry and flow is potentially affected by tidal movement of the salt wedge. It thus represents the best net estimate of nutrients from all sources in the catchment. A summary of flow conditions at Bryn Estyn is presented in Figure 38 (PART 1). The western inflows have only a minor effect on total flow except during high winter flow events. Concentration data for high frequency monitoring during 1996-1998 is presented in Figure 143, and Figure 145 -146. Corresponding flux data is presented below in Figure 166.

Fluxes presented in Figure 157 (monthly data) show similar seasonal trends to those presented in Figure 166 (daily or weekly data) with greatest loads associated with high winter rains (Figure 167, however median values calculated with high frequency data are up to a factor of 2 greater. Based on average daily flow, the range of loads calculated under high flows conditions may vary by almost an order of magnitude. High intensity sampling is required to provide a contemporary comparison value at this site, and e vent-based monitoring is essential to understanding the rate and intensity of changes in nutrient concentrations on both a local and catchment scale.

Differences in fluxes estimated above for Derwent below Meadowbank and at the Bryn Estyn intake may be for a number of reasons:

- Derwent below Meadowbank calculations are based on monthly sample intervals (i.e. coarser resolution) that may miss short-duration high flow events;
- There may be significant catchment inputs on N and P between Meadowbank Dam and Bryn Estyn;
- The Bryn Estyn sample point (the intake) may have been adversely affected by local tributaries. These tributaries would increase contaminants during the higher flows in the earlier data set. Recent remediation/improvements of the local tributaries reported by Southern Water may have also reduced the load estimates in the later data set.

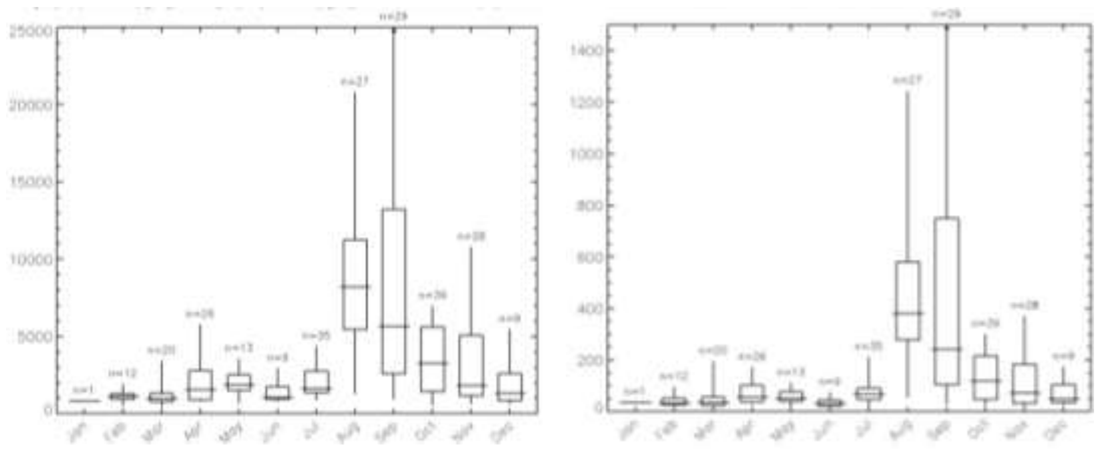


Figure 166 Monthly fluxes for TN (kg/day left) calculated from high frequency sampling at Bryn Estyn, 1996-1998. Maximum TN in September = 39,850 kg/day; and TP (kg/day, right). Maximum TP in September 3380 kg/day). Data from DEP.

New Norfolk

Monitoring post 1998 is largely based on monthly or quarterly monitoring data collected by Norske Skog Hobart. Due to the smaller number of sampling events, and varying frequency of analyses, results have been grouped as bi-monthly. Data is from surface samples only, to remove the effect of saline bottom water on calculations of catchment load (Figure 141).

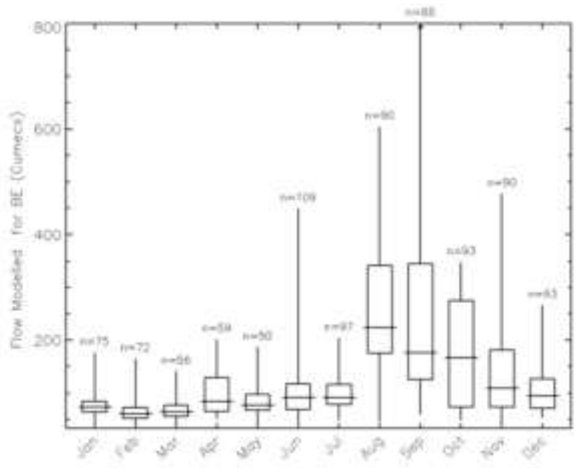
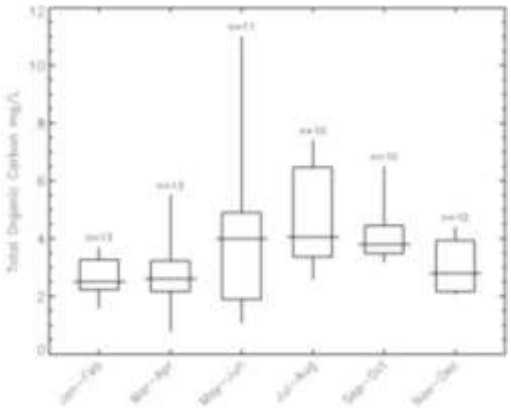
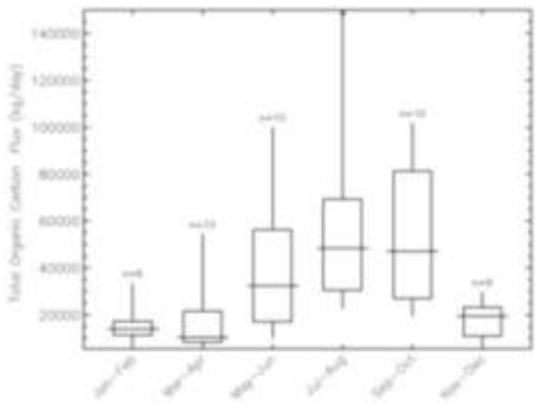


Figure 167 Monthly flow (cumecs) modelled for Bryn Estyn, 1996-1998. Maximum flow in September 977.4 cumecs.

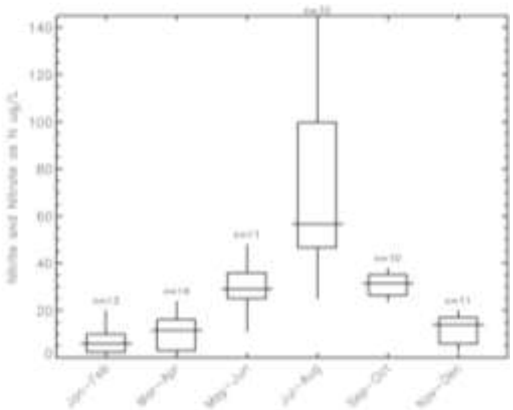
Parameters have been presented as two groupings, based on a study of catchment loads by CSIRO as part of an assessment of river flow on environmental effects in the upper Derwent estuary (Parslow et al, 2002). Concentration and fluxes for TOC, nitrate + nitrite, TN, and TP, show broadly similar seasonal trends with annual peaks associated with higher winter flows (Figure 168 a-e) .



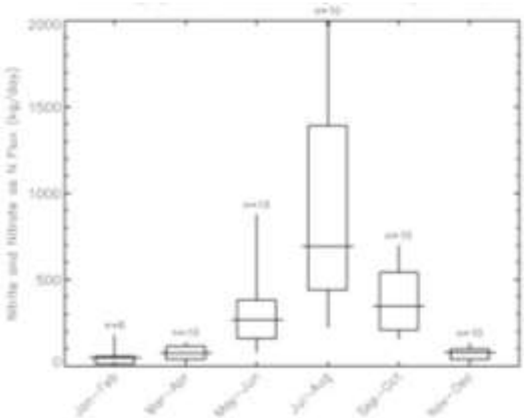
a) Concentration TOC mg/L 2003-2010.



Flux TOC kg/day (max Jul-Aug = 400,000 kg/day) 2003-2010.

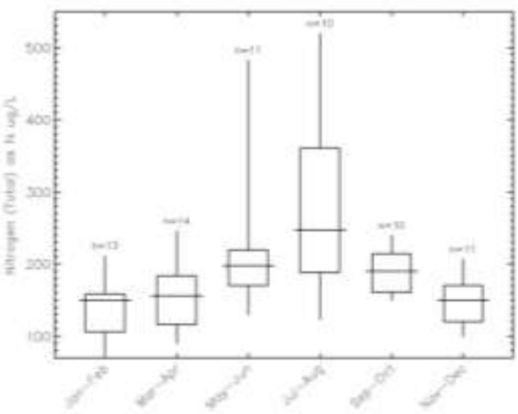


b) Concentration nitrate+ nitrite (µg/L) 2003-2010

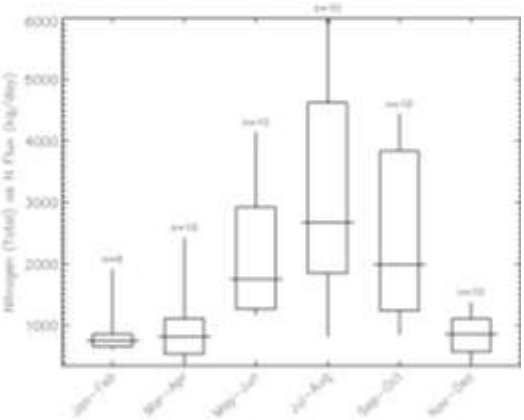


Flux nitrate+ nitrite kg/day (max Jul-Aug = 400,000 kg/day) 2003-2010.

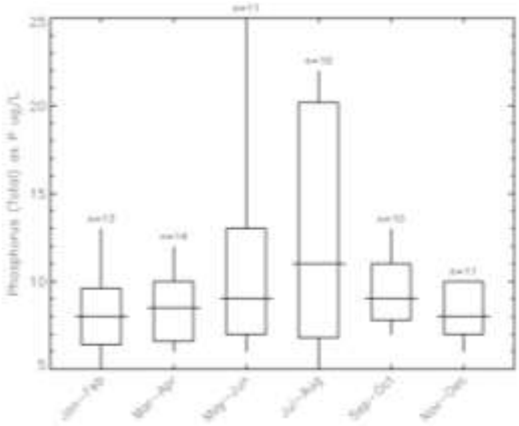
Figure 168 . Concentration (left plot) and calculated flux (right plot) for parameters monitored monthly at New Norfolk, 2003-2010. (Data from Norske Skog and DEP).



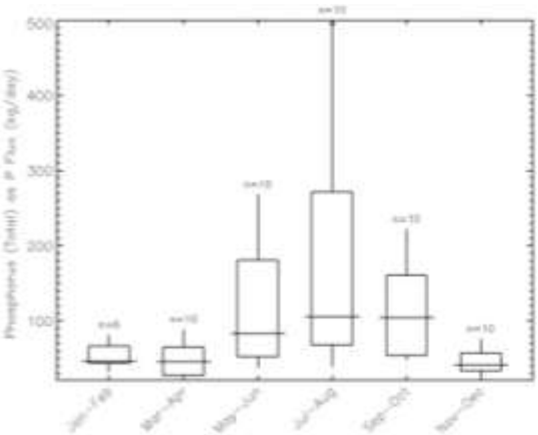
c) Total N (µg/L) 2003-2010



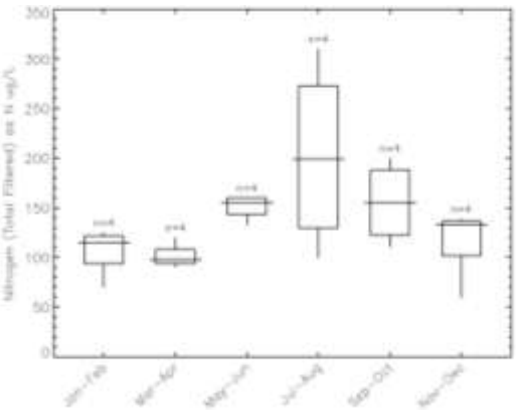
Flux Total N (max Jul-Aug = 22,000 kg/day) 2003-2010.



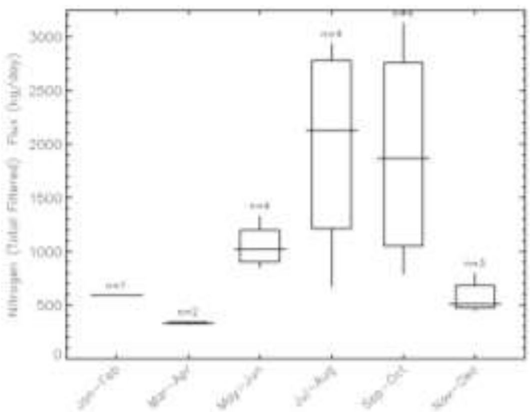
d) Total P (µg/L) 2003-2010



Flux Total P (max Jul-Aug=1100 kg/day) 2003-2010.

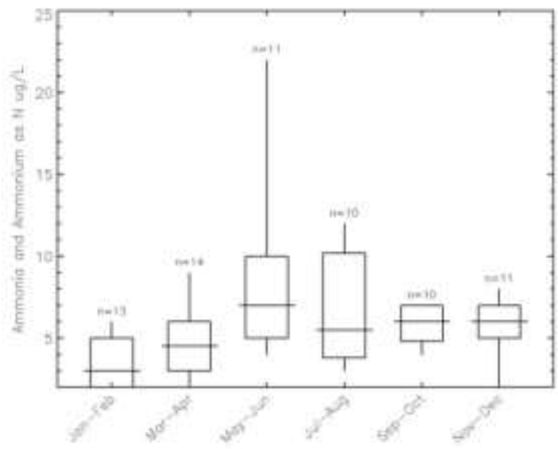


e) Total filtered N (µg/L) 2003-2010

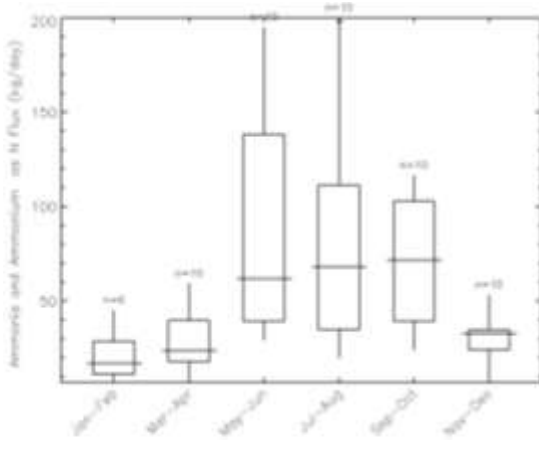


Flux Total filtered N (kg/day) 2003-2010

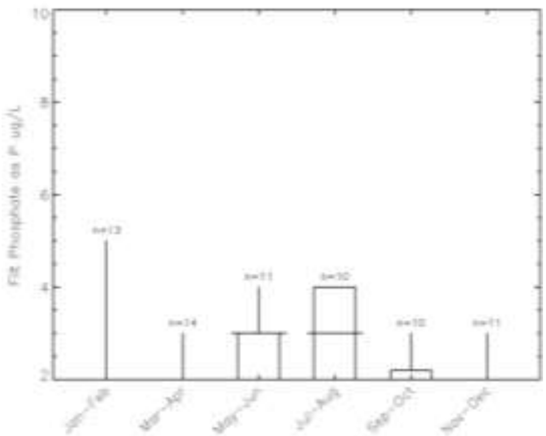
Figure 168 cont. Concentration (left plot) and calculated flux (right plot) for parameters monitored monthly at New Norfolk, 2003-2010. (Data from Norske Skog and DEP).



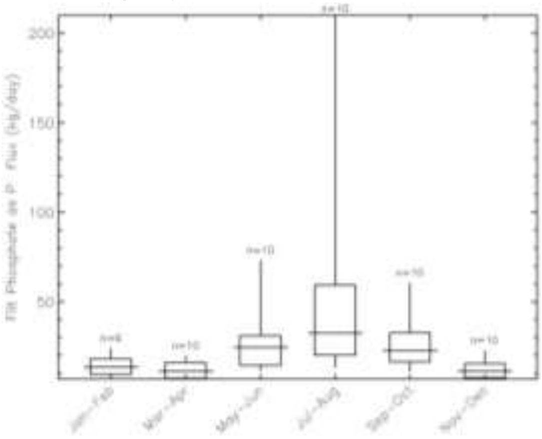
f) Ammonia +ammonium (µg/L) 2003-2010



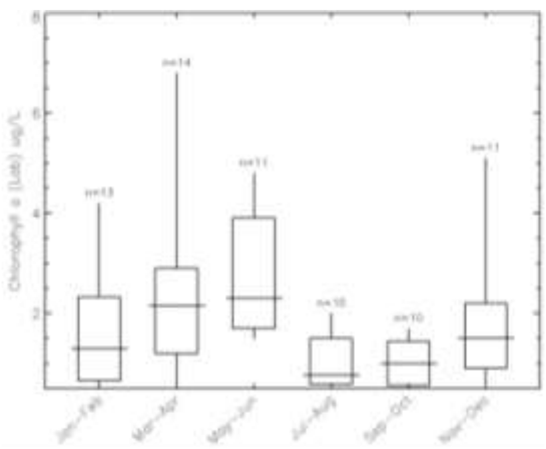
Flux ammonia + ammonium (max Jul-Aug =519 kg/day) 2003-2010.



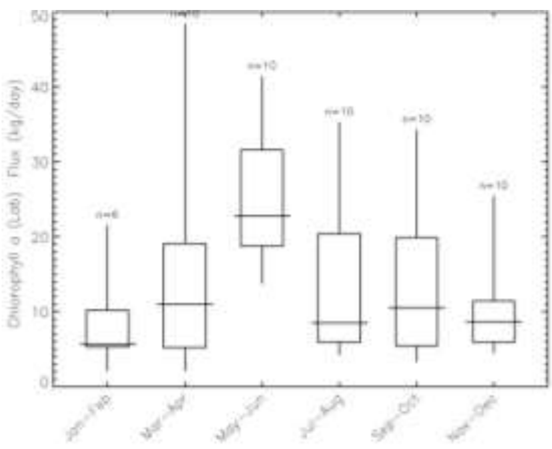
g) Dissolved phosphate (µg/L) 2003-2010.



Flux dissolved phosphate (kg/day) 2003-2010.

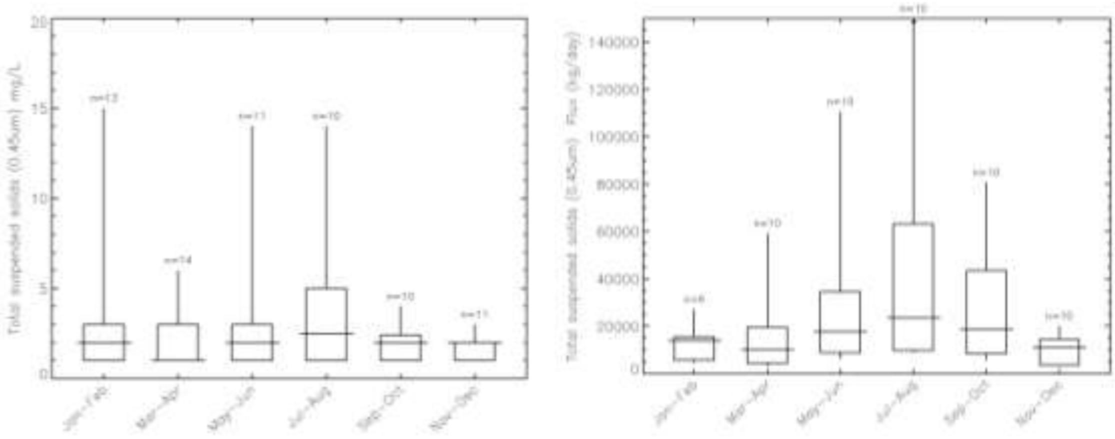


h) Chlorophyll-*a* (µg/L) 2003-2010.



Flux chlorophyll-*a* (kg/day) 2003-2010

Figure 168 cont. Concentration (left plot) and calculated loads (right plot) for parameters monitored monthly at New Norfolk, 2003-2010. (Data from Norske Skog and DEP). "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= number of samples.



i) TSS (mg/L) 2003-2010 Flux TSS (kg/day) 2003-2010

Figure 168 cont. Concentration (left plot) and calculated loads (right plot) for parameters monitored monthly at New Norfolk, 2003-2010. (Data from Norske Skog and DEP). "Boxes" (80th, 50th, 20th percentile; "whiskers" maximum/minimum, n= number of samples.

Parslow et al (2002) observed that these parameters showed a statistically significant increase with flow, however dissolved organic nitrogen was not so strongly linked. The filterable phosphate seasonal loading is very similar to that of TP, however many results were below detection in months with low flow, leading to increased uncertainty around flux calculations. Ammonia and filterable phosphate showed no statistically significant relationship with flow in the CSIRO study (Parslow et al, 2002).

Chlorophyll-*a* data shows both concentrations and flux peak in late autumn, in contrast to chlorophyll-*a* data further up the catchment which tends to show peaks in mid-summer. TSS median values are uniformly low across the year, however events may occur as a result of local summer storms or from high winter rain and associated flows. From a catchment perspective, summer loads are negligible compared to winter, however at a local level, elevated TSS and turbidity may cause problems for water quality, for example at the Bryn Estyn inlet, with impacts on water treatment processes (*A. Crawford, pers. comm*).

Whilst catchment fluxes for most parameters vary seasonally in response to flow, there is also a strong, overriding inter-annual variability attributed to climatic conditions resulting in 'wet' or 'dry' years. In wet years, the net export of TN and TP, TSS, nitrate + nitrite and TOC are much greater than in dry years (*J. Whitehead, unpublished figures*). Two major factors may influence this pattern in the future; significant changes to land-use within the catchment and shifts in catchment rainfall due to predicted climate change impacts.

Summary of flux calculations

The flux calculations presented here should be considered within the constraints of the data available for this project, and reflect only limited time periods and locations within the catchment. Despite the obvious limitations of some of the data, the following conclusions have been drawn:

- Based on available flow data, there is a seasonality to the source of headwater flows and associated fluxes in the Derwent, largely due to retention and release of water;

- Tributary inflows are generally low, but may be significant during flood events, with significant increases in fluxes of measured parameters including nutrients (e.g. Ouse and Clyde catchments);
- Flux/load data provides useful information for ascertaining sources within the catchment, although more refined studies are required to better quantify and further define point and diffuse sources.