DEPARTMENT *of*
PRIMARY INDUSTRIES,
WATER *and* ENVIRONMENT

Tasmania

Water Quality of Rivers in the Coal Catchment

A Report Forming Part of the Requirements for State of Rivers Reporting

PART 5

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The Department of Primary Industries, Water and Environment

The Department of Primary Industries, Water and Environment provides leadership in the sustainable management and development of Tasmania's resources. The Mission of the Department is to advance Tasmania's prosperity through the sustainable development of our natural resources and the conservation of our natural and cultural heritage for the future.

The Water Resources Division provides a focus for water management and water development in Tasmania through a diverse range of functions including the design of policy and regulatory frameworks to ensure sustainable use of the surface water and groundwater resources; monitoring, assessment and reporting on the condition of the State's freshwater resources; facilitation of infrastructure development projects to ensure the efficient and sustainable supply of water; and implementation of the *Water Management Act 1999*, related legislation and the State Water Development Plan.

3 Nutrient Load Estimates

3.1 Background Comment

From a management perspective, there is a need to identify sediment sources in order to develop and target appropriate strategies and measures for reducing sediment mobilisation. It is important to establish the magnitude of the suspended sediment flux from a river basin as well as to obtain information on the primary sources of the sediment mobilised within the catchment and transported to the basin outlet. Fine sediment is a vector for the transport of nutrients and a wide range of contaminants, including heavy metals and microorganics. Sediment–water interactions can also exert an important control on riverine water quality (Neal *et al.,* 1997).

During runoff events manual samples were collected from selected sites in the Coal River catchment. These flood samples were analysed to provide information on the key properties of the suspended sediment transported by rivers in the study area during an event. Figure 3.1 provides a clear example of the how runoff events impact on water quality. The runoff from a quarry site, combined with road runoff and drainage, contributed substantial loads of suspended solids to Burns Creek at Eldon Road. Measurements of turbidity and total suspended solids were taken upstream and downstream of the confluence of Burns Creek and the runoff from the quarry. Upstream turbidity and total suspended solids concentrations were 11.2 NTU and 8 mg/L respectively. Downstream of the confluence turbidity was greater than 1000 NTU and exceeded the levels measurable by the field meter. Total suspended solids were 3,450 mg/L.

Figure 3.1: Burns Creek at Eldon Bridge Road during a runoff event in January 2000.

The water entering Burns Creek as road and quarry runoff also had considerably lower conductivity. Upstream of the confluence, the conductivity was 828 µS/cm whereas the downstream measurement was 99 µS/cm. Conductivity in Burns Creek is generally higher due to slightly saline groundwater, whereas lower concentrations are recorded for the road runoff as this is primarily rainwater from the event. The effects of high rainfall events on sites such as Burns Creek can be quite considerable.

Nutrient load estimates for the Coal River were derived from nutrient; turbidity and flow data collected at the Richmond weir (CR3), approximately 4km upstream from the river mouth at Pitt Water Reserve. Data for load analysis was collected by two principal methods, through regular monthly sampling and opportunistic sampling targeting flood events. Turbidity data was collected manually during monthly and flood sampling in addition to being logged continuously in conjunction with flow data from the site. Unfortunately the continuous loggers only provided an accurate recording of turbidity from January to October 1999 and November to December 2001. The site was also sandbagged in October 1999 and this affected the low end of the level-flow rating until November 2001, resulting in the inability to accurately determine low and moderate flows over the weir for this period.

A total of 35 monthly nutrient samples were collected from this site between February 1999 and December 2001, along with 13 general ions samples from which suspended solids data was available. Historical records provided additional data on the relationship between nutrient concentrations and flows. Automatic, flow-triggered water sampling equipment was not installed at this site because of the very low expected frequency of moderate to high flow events. Because of this, flood flow nutrient samples were collected manually when the opportunity arose.

3.2 Monthly sampling

Table 3.1 shows a summary of turbidity, total suspended solids and nutrient concentrations collected on a monthly basis from the Coal River at the Richmond weir. It should be noted that total suspended solids concentrations fell below laboratory detection limits on all sampling occasions. As such, total suspended solids were assigned a default value of 10 mg/L, which is equivalent to the laboratory detection limits.

Table 3.1: Summary statistics for nutrients and suspended solids collected from the Coal River at Richmond during **monthly** sampling conducted between February 1999 and December 2001.

	Total suspended solids (mg/l)	**Turbidity (NTU)**	**Total N (ug/l)**	**Nitrate (ug/l)**	**Nitrite (ug/l)**	**Ammonia (ug/l)**	**Total P (ug/l)**	**DRP (ug/l)**
N =	14	38	36	36	36	36	36	36
Mean	10	4.27	654.8	27.25	2.528	26.22	16.11	5.028
95% conf. Int.	0.0	0.05	2.071	0.456	0.016	0.244	0.101	0.033
Median	10	2.55	617	14.00	2.000	20.00	14.5	4.000
Minimum	10	1.12	399	1.000	2.000	4.000	2.000	2.000
Maximum	10	28.9	1380	244.0	9.000	117.0	56.00	17.00

An overview of the monthly data is given here to provide a baseline against which flood data can be compared. A more detailed discussion on the monthly data is provided in previous sections.

Mean and median turbidity levels showed little variation during monthly sampling for the period of study. Peak turbidity (28 NTU) occurred in November 2001 after a rain event. Mean and median total nitrogen concentration exceeded 500 μg/L, and high total nitrogen concentrations coincided with elevated total phosphorous and turbidity. The correlation between high turbidity and elevated concentrations of both nitrogen and phosphorous suggests that these nutrients were largely associated with particulate matter.

3.3 Flood sampling

The lower half of the Coal River is a regulated system, with highly modified flows due to the presence of Craigbourne Dam, which is operated to provide water for irrigation in the lower catchment. Because of this, the normal pattern of seasonal change in discharge is not found. Figure 3.1 shows the near continuous hydrographic record of flows at Richmond weir (CR3), between January 1999 until December 2001. As pointed out above, this site was sandbagged between October 1999 and November 2001 and this has made flow estimates for this period less dependable. Because of the lower confidence in the accuracy of flow records for this site, all discharge volume and nutrient load estimates discussed in the following paragraphs should be viewed as general estimates only, and are likely to have a reasonably high level of inaccuracy.

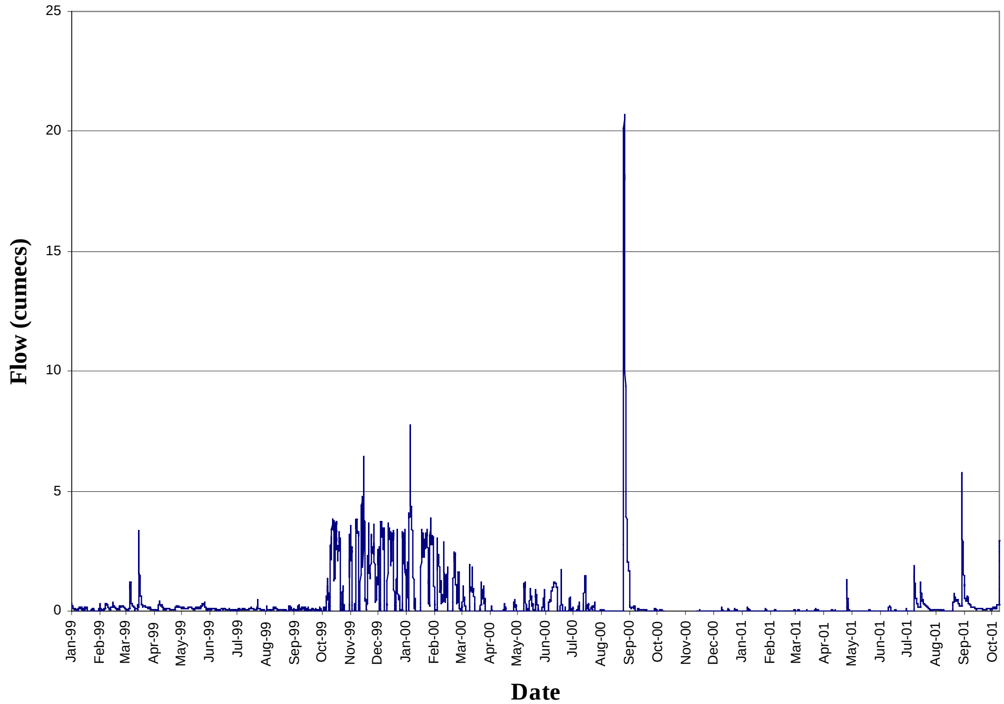

Figure 3.2: Continuous flow records at CR3 (Coal River at Richmond) from January 1999 until December 2001.

At CR3, any flow above about 1 m^3s^{-1} can be regarded as an 'elevated' flow event triggered by rainfall in the catchment, although during the study a dam release in the middle of the catchment triggered flows at CR3 in excess of this. In total, eight 'elevated flow' events were manually sampled between March 1999 and August 2001. Nutrient samples were taken from five of these events. One event from the 15th to the 18th of March 1999 (Figure 3.2) had samples collected manually on 4 separate occasions during the event. At this time continuous monitoring of turbidity was operational, and the results of this clearly show the change in turbidity with flow. The pattern of turbidity response is typical of that which occurs during flood events in most rivers, although the turbidity spikes early on in this event may relate more to drainage and runoff from the local area in and around Richmond than to the broader catchment.

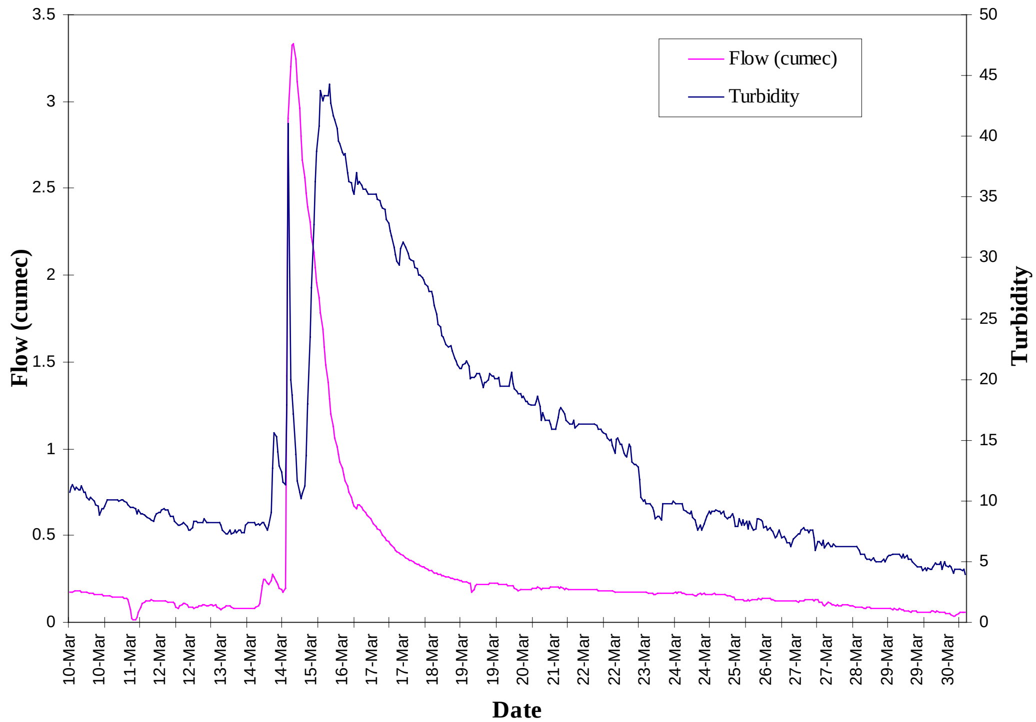

Figure 3.3: Graph of discharge and turbidity collected from CR3 (Coal River at Richmond) during a flood event that occurred between 14th and 30th of March 1999.

3.4 Load Estimation

As mentioned above, load estimates for the Coal River were hindered by the fact that unreliable flow and turbidity records were obtained by the monitoring equipment at this site for much of this 3-year project. Because of this, it has only been possible to calculate nutrient load estimates for the periods Jan-Sep 1999 and Nov-Dec 2001. For these periods, the continuously recorded hydrographic and turbidity datasets enabled the calculation of load estimates based on the development of turbidity/nutrient relationships for total nitrogen and total phosphorous. Samples collected during flood events were analysed to determine nutrient concentrations and these concentrations were related to turbidity levels at the time of sampling. Due to the limited number of flood samples collected during the study, it was necessary to extract flood event data that were collected in 1995 and 1996 from the historical database to assist with this process. By developing these turbidity/nutrient relationships, a surrogate continuous record of nutrient concentration can be generated, which can then be used along with the discharge record to estimate instantaneous transport loads for both nitrogen and phosphorous. For these estimates, continuous data was aggregated into hourly blocks to simplify the calculations. Figures 3.4 and 3.5 show correlations determined for turbidity versus total nitrogen and total phosphorous respectively for the Coal River at Richmond (CR3).

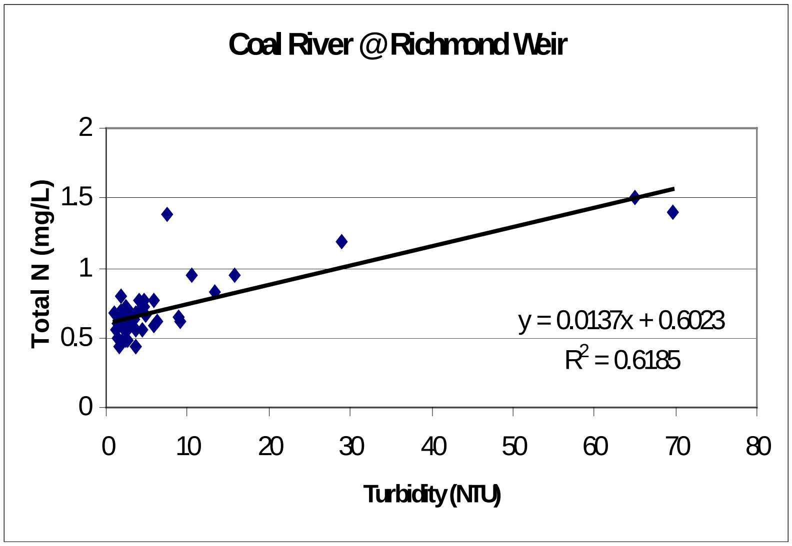

Figure 3.4: Correlation between turbidity and total nitrogen concentrations at the Coal River at Richmond weir (CR3).

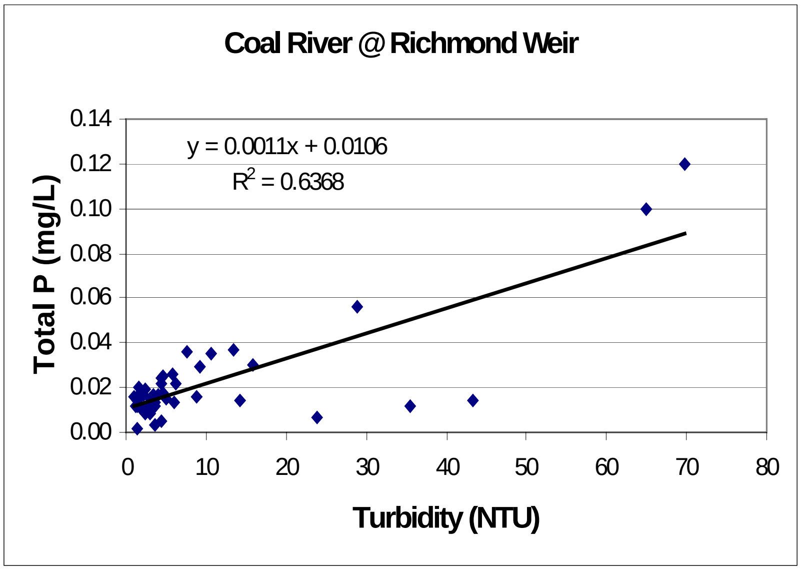

Figure 3.5: Correlation between turbidity and total phosphorous concentrations at the Coal River at Richmond weir (CR3).

The equations describing the relationship between turbidity and nutrient concentrations are shown below;

Total Nitrogen	Y=0.0137x + 0.6023	(R^2=0.6185)
Total Phosphorous	Y=0.0011x + 0.0106	(R^2=0.6368)

This type of load estimation is reasonably accurate, however it depends on the accuracy of the flow record, the collection of good quality continuous turbidity data and sufficient nutrient samples collected from a range of flows. For the Coal River at Richmond, because of the relative lack of 'elevated flow' events and the substantial breaks in the turbidity record, it was only possible to estimate nutrient loads for those periods when the quality of turbidity data could be verified. Unfortunately, the lack of quality turbidity data for lengthy periods combined with the fact that the flow records between October 1999 and November 2001 are not reliable has made it impossible to determine nutrient loads for that period of the study.

It is also unfortunate that this period encompasses a significant event in September 2000, when flow in the river exceeded 20 m^3s^{-1}. It is likely that this single event transported the vast majority of nutrients past Richmond during the entire 3-year period of the study.

Tables 3.2 and 3.3 show monthly load estimates and estimated mean monthly total nitrogen and total phosphorous concentrations from the Coal River at Richmond (CR3) in 1999 and 2001 respectively. Total discharge for the 9-month period from Jan-Sep 1999 was 2703 ML, and for the period Nov-Dec was 5208 ML. During Jan-Sep 1999 (Period 1) approximately 1,883 kg of nitrogen and 49 kg of phosphorous were transported past the weir and discharged to the estuary. During Period 2 (Nov-Dec 2001) 3,759 kg of nitrogen and 105 kg of phosphorous were transported past the weir, and from this it is obvious that there were higher nutrient loads during the latter period, when the higher river flows occurred. A peak flow of 13 m^3s^{-1} was recorded in November 2001.

Table 3.2: Estimated monthly loads of total nitrogen (TN) and total phosphorous (TP) for the Coal River between January and September 1999.

Date	**Discharge (ML)**	**Mean Monthly TN (mg/l)**	**Total Monthly TN (kg)**	**Mean monthly TP (mg/l)**	**Total monthly TP (kg)**
Jan-99	195	0.650	130	0.014	3.0
Feb-99	352	0.640	225	0.014	4.8
Mar-99	788	0.753	651	0.023	22.6
Apr-99	320	0.646	208	0.014	4.6
May-99	364	0.627	229	0.013	4.6
Jun-99	157	0.626	98	0.013	2.0
Jul-99	221	0.635	141	0.013	2.9
Aug-99	157	0.654	103	0.015	2.3
Sep-99	149	0.660	99	0.015	2.3
Totals	**2,703**		**1,883**		**49.1**

Table 3.3: Estimated monthly loads of total nitrogen (TN) and total phosphorous (TP) for the Coal River between November and December 2001.

Date	**Discharge (ML)**	**Mean Monthly TN (mg/l)**	**Total monthly TN (kg)**	**Mean monthly TP (mg/l)**	**Total monthly TP (kg)**
Nov-01	3682	0.710	2689	0.019	76.9
Dec-01	1527	0.696	1069	0.018	28.2
Total	**5,208**		**3,759**		**105.1**

The South East Irrigation Scheme extracts water from the Coal River at Richmond (CR3) during the irrigation season. These extractions reduce the volume of water passing over the weir and through to the estuary. Using the data generated above, an estimate of the load of nutrients that is extracted from the river and applied to land in Stage 2 of the Scheme can be made. Figures for this encompassing Period 1 (Jan-Sep 1999) are given in Table 3.4, and shows that about 1,041 kg of nitrogen and 26 kg of phosphorous were transported back to the catchment for irrigation purposes, along with an associated water volume of 1,783 ML.

Table 3.4: Estimated monthly loads of total nitrogen (TN) and total phosphorous (TP) exported back to the Coal River catchment by the SEIS between January and September 1999.

Date	Discharge (ML)	Mean monthly TN (mg/L)	Total monthly TN (kg)	Mean monthly TP (mg/L)	Total monthly TP (kg)
Jan	345	0.649	222	0.014	4.8
Feb	191	0.640	3	0.093	2.6
Mar	62	0.750	46	0.022	1.4
Apr	65	0.646	42	0.031	0.9
May	111	0.627	70	0.013	1.4
Jun	264	0.627	166	0.013	3.3
Jul	42	0.636	27	0.013	0.6
Aug	169	0.655	113	0.015	2.7
Sep	534	0.662	353	0.015	8.2
Totals	**1,783**		**1,041**		**25.9**

3.5 Export coefficients

The calculation of export coefficients for catchments enables valid comparisons of nutrient loads to be drawn between catchments with different surface areas and yield characteristics, by standardising load estimates to take these into account. The equations used for the determination of export coefficients are included in the glossary at the beginning of this report. Table 3.5 shows export coefficients for 12 Tasmanian rivers examined over the last 10 years as part of the ‘State of Rivers’ program. The Coal River catchment received very low rainfall for the period during which load estimates were made, and this will affect the magnitude of the export coefficients that have been calculated for the catchment.

The export coefficients for the Coal River at Richmond (CR3) for the 9-month period Jan-Sep 1999 was 0.4198 kg/mm/km^2 for nitrogen and 0.0109 kg/mm/km^2 for phosphorous with a total discharge over this period of 4,485ML. A proportion of the flow at this site goes through to the estuary passing over the weir with the remainder being extracted for use within the catchment by Stage 2 of the South East Irrigation Scheme. In comparison with other rivers around the State, the Coal River has a relatively low export coefficient for both nitrogen and phosphorous.

Table 3.5: Export coefficients for catchments in Tasmania that have been monitored as part of the State of Rivers program over the last decade. Results for rivers where data has been collected over several years have been averaged.

Catchment	Years of Data	Catchment Area (km^2)	Mean Annual Discharge (ML)	Total P ($kg/mm/km^{-2}$)	Total N ($kg/mm/km^{-2}$)
North Esk River at Ballroom	2	362.6	138,949	0.005	0.098
North Esk River at Corra Linn	2	870	417,204	0.002	0.046
Duck River at Scotchtown	3	339	141,172	0.532	1.67
Montagu River at Stuarts Road	3	323	98,778	0.800	2.66
Inglis River at railway bridge	3	175	116,030	0.081	1.16
Pipers River	1	298	96,700	0.083	1.17
Brid River	1	136	40,986	0.066	1.13
Meander River at Strathbridge	3	1,012	427,904	0.058	0.67
Liffey River	3	224	80,661	0.052	0.78
South Esk at Perth	3	3,280	624,508	0.034	0.66
Break O'Day River	3	240	53,177	0.065	0.94
Huon River above Judbury	1	2,097	2,562,475	0.010	0.33
Kermandie River**	1	130	36,760*	0.122	1.42
This study - Coal at Richmond	<1	540	4,485 (9 mths)	0.011	0.420

* Estimated flow data

** Export figures include nutrients discharged to the river from the Geeveston wastewater treatment plant.

3.6 Salinity Load Estimates

Given the relatively saline nature of waterways in the Coal Valley, it is appropriate and useful to examine the transport of salt from the catchment, as this may have some bearing on conditions in Pitt Water estuary and associated wetlands. Salt enters the Coal River via surface runoff and through groundwater and sub-surface drainage. The mobilisation of salts within the catchment has not been investigated as part of this study, and the following salt load estimates are based on salt transport within the river as measured by monitoring at CR3, where river flow and conductivity is continuously recorded.

Laboratory measurements of total dissolved salts (TDS), involves filtering water and drying the residue until a constant weight is achieved. The filter and residue is then heated to 550°C, which effectively burns off the organic matter leaving inorganic ash, which represents the total salt content of the water (Boulton *et al.*, 1999). A quicker and cheaper method for estimating dissolved salt in water is using electrical conductivity. Once the relationship between conductance and TDS has been established, it is possible to estimate the total dissolved salt in water.

As discussed in an earlier section, river flow monitoring at CR3 was intermittent. As a result, a complete and parallel dataset for conductivity and river flow is only available from Jan-Sep 1999. Data on TDS concentrations were collected during the study, and these were related to conductivity at the time of sampling. This enabled calculation of load estimates to be based on the development of TDS vs. conductivity relationships. Figure 3.7 shows the good correlation that was found between conductivity and TDS for the Coal River at Richmond (CR3).

Once these relationships had been verified, salt concentrations were derived from the conductivity record and related to the discharge to calculate salt loads. Continuous data was aggregated into hourly blocks to simplify these calculations. As with the estimation of nutrient loads, it is essential that there is good quality conductivity and river flow data, as well as sufficient data to develop robust TDS vs. conductivity relationships.

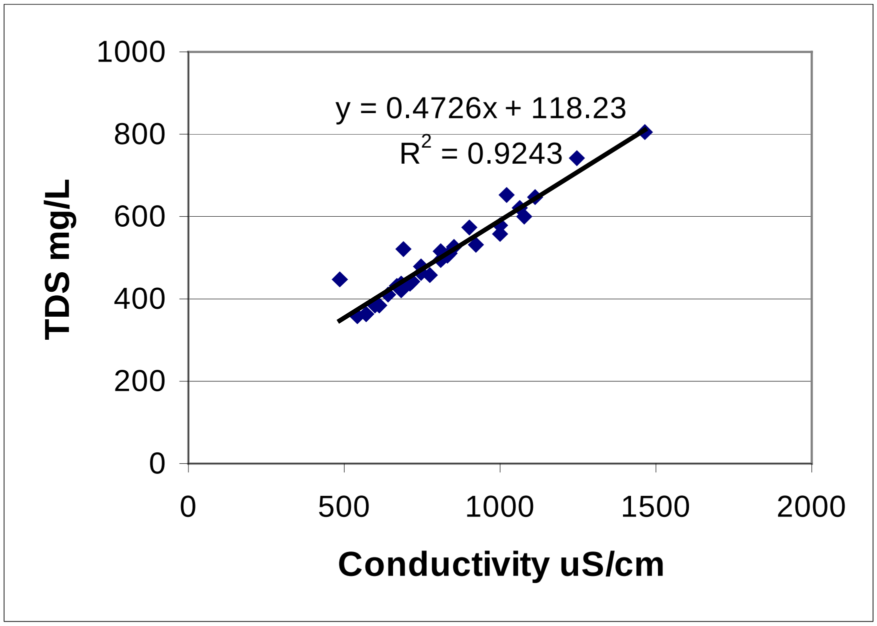

Figure 3.7: Correlation between conductivity and total dissolved salt concentrations at the Coal River at Richmond (CR3).

Table 3.4 shows the mean monthly TDS concentration and monthly load (in tonnes) transported past CR3 and delivered to the Coal River estuary for the period Jan-Sep 1999. The total volume of water discharged into the estuary for this 9-month period was 2,703 ML. During this time 1,278 tonnes of dissolved salt were transported from the Coal River catchment. The maximum monthly load was recorded during March, when discharge was high, despite salt concentration being at it lowest.

Table 3.4: Estimated monthly loads, entering the estuary, of total dissolved salts (TDS) for the Coal River at CR3 for the period Jan-Sep 1999.

Date	Discharge (ML)	Mean monthly TDS (mg/L)	Total monthly TDS (tonnes)
Jan-99	195	402	71.6
Feb-99	352	449	157.9
Mar-99	788	404	306.2
Apr-99	320	504	161.2
May-99	364	519	188.2
Jun-99	157	529	81.7
Jul-99	221	605	132.9
Aug-99	157	644	101.5
Sep-99	149	518	76.9
Totals	**2,703**		**1,278**

The monthly load that has been estimated as being transported back to the lower catchment via Stage 2 of the irrigation scheme is depicted in Table 3.5. The total volume of water extracted from the Coal River for irrigation during this period was 1,783 ML, and it has been estimated that this water carried with it a total load of 248 tonnes of salt. This may have serious implications for the long-term sustainability of agriculture in Stage 2 of the Coal Valley, particularly as this salt is being introduced to the catchment, and not simply being 'recirculated' as could probably be assumed for land within Stage 1.

Table 3.5: Estimated monthly loads, transferred back to Stage 2 of the SEIS, of total dissolved salts (TDS) for the Coal River at CR3 for the period Jan-Sep 1999.

	Water Vol (ML)	**Mean monthly** TDS (mg/L)	**Total monthly** TDS (tonnes)
Jan-99	345	402	139.0
Feb-99	191	449	86.8
Mar-99	62	404	0.8
Apr-99	65	504	1.1
May-99	111	519	1.8
Jun-99	264	529	4.7
Jul-99	42	605	0.8
Aug-99	169	644	3.6
Sep-99	534	518	9.3
Total	**1,783**		**248**

3.7 Summary

Nutrient load estimates for the Coal River catchment were based on continuously logged turbidity and discharge data collected at the Coal River at Richmond (CR3) together with monthly and flood nutrient concentration data. During this 11 month period during which load estimates could be made, 5,642 kg of nitrogen and 154 kg of phosphorous were transported past the weir at the Coal River at Richmond. Maximum monthly nutrient loads were recorded during November and December of 2001, when higher flows occurred. Water is extracted from this location on the river by the South East Irrigation Scheme for use in Stage 2 further down the catchment. In total, approximately 1,782 ML were extracted for irrigation over the period Jan-Sep 1999. As well as the load of nutrients this water carried, this water also carried an estimated 248 tonnes of salt, which may have serious implications for the sustainability of agriculture in this part of the Coal Valley. The estimated load that is being discharged to the Pitt Water estuary and associated wetlands is also considerable (1,278 tonnes) though the ecological consequences of this are likely to be negligible.

It is difficult to compare nutrient export loads form the Coal River with other catchments due to the short period over which loads could be estimated, and the extremely dry period during which the study was undertaken. Export coefficients derived from this study indicate that phosphorous export from the Coal River catchment is low and nitrogen export is low-moderate within the Tasmanian context.

4 Summary and Discussion

A number of water quality issues have been highlighted during the water quality component of the 'State of River' study of the Coal River catchment. The most serious issue to arise from the study has been the high surface water salinities within the catchment and the associated salt loads being carried by the Coal River into Pitt Water estuary and back to the catchment via irrigation water. Baseline salinity throughout much of the catchment is high relative to other rivers in Tasmania. Soils in the Coal River catchment have naturally high salt stored, and this impacts on groundwater and surface waters. However, the level of landclearing that has taken place and some agricultural practices are likely to be contributing to elevated salt levels in waterways. The problem is further exacerbated in years of very low rainfall, when highly saline groundwater sources sustain surface flow in waterways.

While not yet a significant or common event, an additional issue associated with salinity within the Coal River catchment is the potential impact on environmental health that may result from the release of saline water from dams to waterways. Studies prior to this one have shown that water in some on-farm dams tends to become saline, especially during extended periods of dry weather, making this water of little use for agricultural purposes. In one case, water from a reasonably large storage was released into the Coal River. Such releases of saline water can pose significant risks to key ecological processes within river systems and have the capacity to negatively impact on the overall health of the Coal River. Further thought as to the management of this issue is required.

The loss of nutrients and salt from the catchment may have consequences for the Pitt Water estuary and associated wetlands. In their study to determine the environmental flow requirements for the Lower Coal River and Pitt Water Estuary, Davies *et. al.*, (2002) suggested that the estuary may be vulnerable to eutrophication if the capacity of any nutrient sinks are exceeded, particularly in upper Pitt Water where the exchange rate is low. The size of such sinks and the rate of loss of nitrogen through denitrification are not known, so these authors have recommended limiting nutrient inputs to this system until this situation is better understood.

Further inland, blooms of blue-green algae within Craigbourne Dam are becoming an annual occurrence and this poses problems for the health of the system. Craigbourne Dam is likely to be acting as a barrier for the passage of particulate matter from the upper catchment, and an 'instream' store for nitrogen and phosphorus, which during extended periods of stable weather are supporting a large biomass of blue-green algae. To overcome this situation and minimised the incidence of seasonal blooms, long-term management strategies are required, and these need to focus on minimising the delivery of sediment and nutrients to the storage from the catchment upstream.

The Craigbourne Dam has a direct influence on the pattern of flow and the transfer of sediment within the river system. These alterations can adversely affect the ecology and environment downstream, in particular water quality and habitat. This is evident at the site immediately downstream of Craigbourne Dam where median values for pH, total nitrogen, nitrate and total phosphorous were in the upper concentration range relative to other sites in the catchment. The changes to water quality and flow have resulted in a highly modified macroinvertebrate community, which have lost approximately 50% of the expected diversity (see the Aquatic Ecology component of this 'State of Rivers' report).

Water quality throughout the catchment is a highly modified and continues to be impacted by land and water management activities. This situation is likely to be significantly exacerbated by the trend for declining precipitation and an increasing reliance on water from Craigbourne

Dam. An integrated and strategic management response is needed if issues surrounding water quality, in particular salinity, are to be adequately addressed.

5 References

ANZECC (1992) *Australian Water Quality Guidelines for Fresh and Marine Waters.* Australian and New Zealand Environment and Conservation Council, Canberra.

ANZECC (2000) *Australian Water Quality Guidelines for Fresh and Marine Waters.* Australian and New Zealand Environment and Conservation Council, Canberra.

Bennison, G.L., (1975) Classification of the Coal River in South East Tasmania.*Thesis.*

Bobbi, C., Fuller, D., Oldmeadow, D. (1996) South Esk Basin 'State of River Report'. Technical Report of Data Collected between 1992 and 1995. Department of Primary Industry and Fisheries internal publication, WRA 96/02.

Bobbi, C. (1997) Report on a bloom of the blue-green algae, *Anabaena circinalis* at Craigbourne Dam, Colebrook (June – September, 1997). Department of Primary Industry and Fisheries internal publication, WRA 97/10

Bobbi, C. (1997a) Water Quality of Rivers in the Mersey Catchment 'State of River Report' Department of Primary Industry and Fisheries internal publication, WRA 97/02.

Bobbi, C.J. (1998) *Water quality of rivers in the Huon catchment.* No. WRA 98/01. Department of Primary Industry and Fisheries, Hobart, Tasmania.

Bobbi, C.J. (1999) *Water quality of rivers in the Ringarooma catchment.* No. WRA 99/01. Department of Primary Industries, Water and Environment, Hobart, Tasmania.

Boulton,J.B & Brock, M.A (1999) Australian Freshwater Ecology Processes and Management Ch 4 pp. 47-48 Gleneagles Publishing Australia.

CCREM (1987). *Canadian Water Quality Guidelines.* Canadian Council for resources and Environment Ministers, Inland Waters Directorate, Environment Canada, Ontario.

Cooke, J.& .Jamieson, D. (1995) How low can you go? *Water & Atmosphere - NIWA,* 3, 11 - 18.

Davies, P.E., Crawford, C.M., Wells, F.A., Dunstan, P. and Mitchell, I.M (2002) Environmental Flow Assessment of the Lower Coal River and Pitt Water Estuary. Report to DPIWE by *Freshwater Systems* and the Tasmanian Aquaculture and Fisheries Institute.

Dallas, H.F. & Day, J.A. (1993) *The effect of water quality variables on riverine ecosystems: a review.* No. TT 61/93. Water Research Commission, Pretoria.

Finnigan J., (1995) Salinity assessment in Tasmanian irrigation schema and regional areas. DPIF Final Report, Hobart Tas. 43 pp.

Finnigan, J., (1996) *SALTLINE Tasmania*. Department of Primary Industries and Fisheries Tasmania. Issue no. 7. ISSN:1326-300

Gallagher, S., (1997) *Coal River Catchment Natural Resource Assessment*. A summary of available natural resources information for the Coal River catchment undertaken as part of the development of a catchment Management Strategy for the Valley.

Grayson, R.B., Gipple, C.J., Finlayson, B.L. & Hart, B.T. (1997) Catchment-wide impacts on water quality: The use of ‘snapshot’ sampling during stable flow. *Journal of Hydrology,* 199, 121 - 134.

Kladivko, E.J., Van Scoyoc, G.E., Monke, E.J., Oates, K.M. and Pask, W. (1991) Pesticide and nutrient movement into subsurface tile drains on a silt loam soil in Indiana. *J. Environ. Qual*., 20, 264-270.

Leaman, D., (1971) The geology and groundwater resources of the Coal River Basin. *Underground Water Supply Paper No.7*. Department of Mines, Tasmania.

McComb, A.J. and Qui, S. (1998) The effects of drying and reflooding on nutrient release from wetland sediments. In *Wetlands in a dry Land: Understanding for Management*. W.D. Williams (Ed.), pp. 147-159, Environment Australia Biodiversity group, Canberra.

MDBMC (1987) *Murray-Darling Basin Environmental resources study*. Murray-Darling Basin Ministerial Council, Canberra.

Murray-Darling Basin Ministerial Council (1999) *The Salinity Audit of the Murray Darling Basin* The Commonwealth, NSW, Vic, SA, QLD, ACT.

Murray-Darling Basin Ministerial Council (1999) *The Salinity audit of the Murray-Darling Basin*. pp 10 Publications production City Graphics.

Natural Heritage Trust Program (2002) *Discovering Tasmania’s Ramsar Wetlands* Tasmanian Environment Centre Inc. pp 20-23.

Neal, C. (2001) The water quality of eastern UK rivers: the study of a highly heterogeneous environment. In Land-Ocean Interaction Measuring and modelling fluxes from river basins to coastal seas. Huntley, D.A., *et al.*, (eds) pp 69-104 IWA publishing, UK.

Neal, C., Robson, A, A.J., Jeffery, H.A, Harrow, M.L., Neal, M., Smith, C.J and Jarvie, H.P. (1997) Trace element inter-relationships for the Humber rivers: inferences for hydrological and chemical controls. *The Science of the Total Environment* 194/195, 321-343.

Reynolds, C.S., (1987) *Cyanobacterial water blooms*. In Advances in Botanical Research, Callow J (ed.) pp 67-143 Academic Press London.

UNESCO (1992) Water Quality Assessments: A Guide To The Use of Biota, Sediments and Water in Environmental Monitoring. 1st edition. Chapman and Hall, London,

Todd, D. (1999) *Hydrogeological Investigation of Pages Creek Catchment*. Unpublished Honours Thesis. School of Earth Sciences. The University of Tasmania.

6 Appendix 1

1. General framework for applying level of protection to different ecosystems for toxicants. (ANZECC, 2000)

Ecosystem condition	Level of protection
1. High conservation/ ecological value	• For anthropogenic toxicants, detection at any concentration could be grounds for source investigation and management intervention; for natural toxicants background concentrations should not be exceeded. [a] Any relaxation of these objectives should only occur where comprehensive biological effects and monitoring data clearly show that biodiversity would not be altered. • In the case of effluent discharges, Direct Toxicity assessment (DTA) should also be required on the effluent. • Precautionary approach taken to assessment of post-baseline data through trend analysis or feedback figures.
2. Slightly to moderately disturbed ecosystems	• Always preferable to use local biological effects data (including DTA) to derive guidelines. If local biological effects data unavailable, apply 95% protection levels as default, low-risk trigger values. [b]99% values are recommended for certain chemicals as noted in table 2.4.1.[c] • Precautionary approach may be required for assessment of post-baseline data through trend analysis or feedback triggers. • In the case of effluent discharges DTA may be required.
3. Highly disturbed ecosystems	• Apply the same guidelines as for slightly-moderately disturbed ecosystems. However the lower protection levels provided in the Guidelines may be accepted my stakeholders. • DTA could be used as an alternative approach for deriving site-specific guidelines.

[a] This means that indicator values at background and test sites should be statistically indistinguishable. It is acknowledged that it may not be strictly possible to meet this criterion in every situation.
[b] For slightly disturbed ecosystems where the management goals is no change in biodiversity, users may prefer to apply a higher protection level.
[c] 99% values recommended for chemicals that bioaccumulate or for which 95% provides inadequate protection for key test species. Jurisdictions may choose 99% values for some ecosystems that are more towards the slightly disturbed continuum.