Investigation of water quality and ecosystem health in the upper Georges River: focus on the influence of West Cliff wastewater discharge and recommendations for new discharge conditions for EPL 2504.

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Collecting water samples and water quality data in Brennans Creek June 2012

Figure 1. Sampling sites for this study June and July 2012: Photo 1: (top left) Brennans Ck (about 400 downstream of the coal mine dam and discharge point – 100m above Georges River)

Photo 2: (top right) Georges River at Site G2 (400 m below Brennans Ck)

Photo 2: (lower left) Reference site 2 (O'Hares Ck) (upstream of the Woolwash)

Photo 3: (lower right) Reference Site 1 (Site G1) Georges River 150 m above Brennans Ck

Summary

In June and July 2012 I investigated water quality in the upper Georges River focussing on the assessment of any impact from Brennans Ck, which contains wastewater discharged from an active coal mine (West Cliff Colliery). Water quality was measured on three occasions (19 June; 26 June and 3 July) using a calibrated field meter, and water samples were also collected and they were tested by an accredited analytical laboratory for a range of water contaminants. The results revealed that Brennans Ck and Georges River, in the Appin to Airds area, suffered water quality impairment as a direct consequence of the inflow of Brennans Ck into the Georges River. The majority of flow in Brennans Ck is from the West Cliff coalmine wastewater discharge that is licensed under an Environment Protection Licence (EPL). This licence (Environmental Protection Licence 2504) is currently under review by the NSW EPA and this report makes recommendations for detailed contaminant discharge limitations that should be included in EPL 2504 to provide improved protection for water quality and the natural ecosystems of Brennans Creek and the Georges River.

The investigation found that Brennans Creek was contaminated with elevated levels of salt and heavy-metals, and it acted as a major point-source of contamination to the upper Georges River. The water quality contaminants of most concern in the upper Georges River and Brennans Creek are salt, measured as electrical conductivity, and its constituent major anions and cations and heavy-metals (Aluminium, Arsenic, Copper, Nickel, Zinc, and Lead). All results were assessed against the ANZECC (2000) water quality guidelines (where applicable), particularly using guidelines for protection of aquatic ecosystems, and the locally derived Georges River guidelines (Tippler *et al.* 2012a). It was determined that salt, copper, nickel, zinc, aluminium and pH all exceeded guideline levels for ecosystem protection and each was at risk of contributing to toxic conditions for downstream aquatic ecosystems. In addition, I found that highly elevated concentrations of major anions and cations discharged by the coal mine to Brennans Creek caused unnatural (and potentially ecologically stressful) changes to the ionic composition of the Georges River. I viewed data from other parties that indicated that water quality problems, caused by wastewater releases from the coal mine, identified in this report were not isolated to only the days of my testing (three days in 2012).

Based on all results from other sources (Cardno Ecology Lab / Ecoengineers 2009, 2010; OEH 2012; EPL 2504 annual returns) and my own results, I conclude that the coal mine discharge has caused many changes in the chemical condition of the Georges River and Brennans Ck through the inflow of

wastewater discharge. Macroinvertebrate data from GRCCC indicates that the Brennans Creek and Georges River ecosystems are impaired.

In my opinion, based on the results presented in this report, the inflow of the Endeavour Coal West Cliff mine wastewater discharge into Brennans Creek and the Georges River has adversely changed the physical, chemical and biological condition of the water. Endeavour Coal's environmental monitoring data reported as Annual Returns to the EPA (as part of the monitoring requirements under EPL 2504), demonstrated that the discharge point labeled as 'Discharge and Monitoring Point 10' in EPL 2504, has released water contaminated by high salt levels, and elevated Copper, Zinc, Nickel, Arsenic, Salt and pH levels which were consistently recorded in Brennans Creek from 2008 to 2010. Multiple ecotoxicology studies have detected ecotoxicity in Brennans Creek and the West Cliff mine waste water (Cardno Ecology Lab / Ecoengineers 2009, 2010; NSW OEH, 2012). Macroinvertebrate data collected by the GRCCC has demonstrated ecological impairment of aquatic ecosystems (particularly with the lower abundance of sensitive taxonomic groups such as Decapod crustaceans, Mayflies, Stoneflies and Caddisflies) within Brennans Creek and in the Georges River below Brennans Creek.

Finally, this document recommends new discharge limits for EPL 2504, based on this investigation and the review of further information (Table 13). It recommends that the biological, physical and chemical attributes (listed in table 13) be included as new EPL 2504 discharge limits to provide comprehensive measures that will help protect Georges River from adverse water quality and ecosystem health impacts.

(Table 13). Coal mine wastewater discharge conditions under *Protection of the Environment Operations Act* (1997) NSW, as specified in the following 'Environmental Protection License' (EPL) 100 % discharge limits.

Attribute (biological, physical or chemical)	Current discharge limits EPL 2504	Recommended discharge limits for EPL 2504
Toxicant / attribute	Brennans Ck (trib. of Georges R)	
Macroinvertebrate species assemblages		The inflow of Brennans Creek to the Georges River will cause no measurable adverse impact for 99 % of diatom species assemblages.
Algal diatom species assemblages		The inflow of Brennans Creek to the Georges River will cause no measurable adverse impact for 99 % of diatom species assemblages.
Oil & Grease (mg/L)	10	(based on background level recorded at reference sites)
pH (pH units)	6.5-9.0	Max 7.1 (Tippler *et al.* 2012a)
Total Suspended Solids (mg/L)	50	Lack of comparative data (based on background level recorded at reference sites)
Turbidity		(based on background level recorded at reference sites)
Copper		Max. 1.4 µg/L (ANZECC, 2000)
Aluminium		Max. 55 µg/L (ANZECC, 2000)
Cobalt		(based on background level recorded at reference sites)
Nickel		Max. 11 µg/L (ANZECC, 2000)
Zinc		Max. 8 µg/L (ANZECC, 2000)
Arsenic		(based on background level recorded at reference sites)
Total Nitrogen		Max. 200 µg/L (Tippler *et al.*, 2012a)
Salinity		Max. 212 µS/cm (Tippler *et al.*, 2012a)
Ionic composition		Cause no modification of reference creek ionic composition and concentration (e.g. bicarbonate, sodium, calcium)

1. Introduction

I have investigated water quality of the upper Georges River and its tributaries, with a particular focus on Brennans Creek (containing EPL 2504 coal mine drainage) and its condition and influence on the Georges River (water quality and ecological condition).

1.1 Study area - Upper Georges River catchment and waterway uses, values and management objectives.

The coalmine discharges wastewater to the environment (local waterways) under specified conditions contained in NSW EPA *Environmental Protection Licence* issued to Endeavour Coal (**EPL 2504**). Of particular concern is the discharge from the coal mine to Brennans Ck, a tributary of the Georges River (Photograph on cover).

The study area includes the Georges River and two tributaries (Brennans Creek, O'Hares Creek) in the upper Georges River sub-catchment (Figure 2). The area of particular interest in this investigation is the section of the Georges River downstream of Brennans Ck. Two reference sites are the upper Georges River above Brennans Creek, and O'Hares Creek. Both represent water quality in the most undisturbed waterway 'reference sites' available in the area (see Figure 1).

Uses of the upper Georges sub-catchment waterways include heritage protection, conservation and public recreation. A large percentage of the upper Georges River catchment is protected and valued for conservation purposes (flora and fauna, endangered species and cultural heritage) as National Park reserves (Tippler et al. 2012b), defence land and drinking water catchment. Its lower reaches are one of the most urbanised catchments in Australia and it is reported to house approximately 1.2 million people. This makes the relatively undisturbed upper Georges catchment of great value. The strategic importance of the catchment is expressed by NSW Planning:

> '*These waters are the lifeblood of a diverse natural environment - a catchment that is home for more than one million people and that plays host to the recreational and economic interests of many, many more...'*

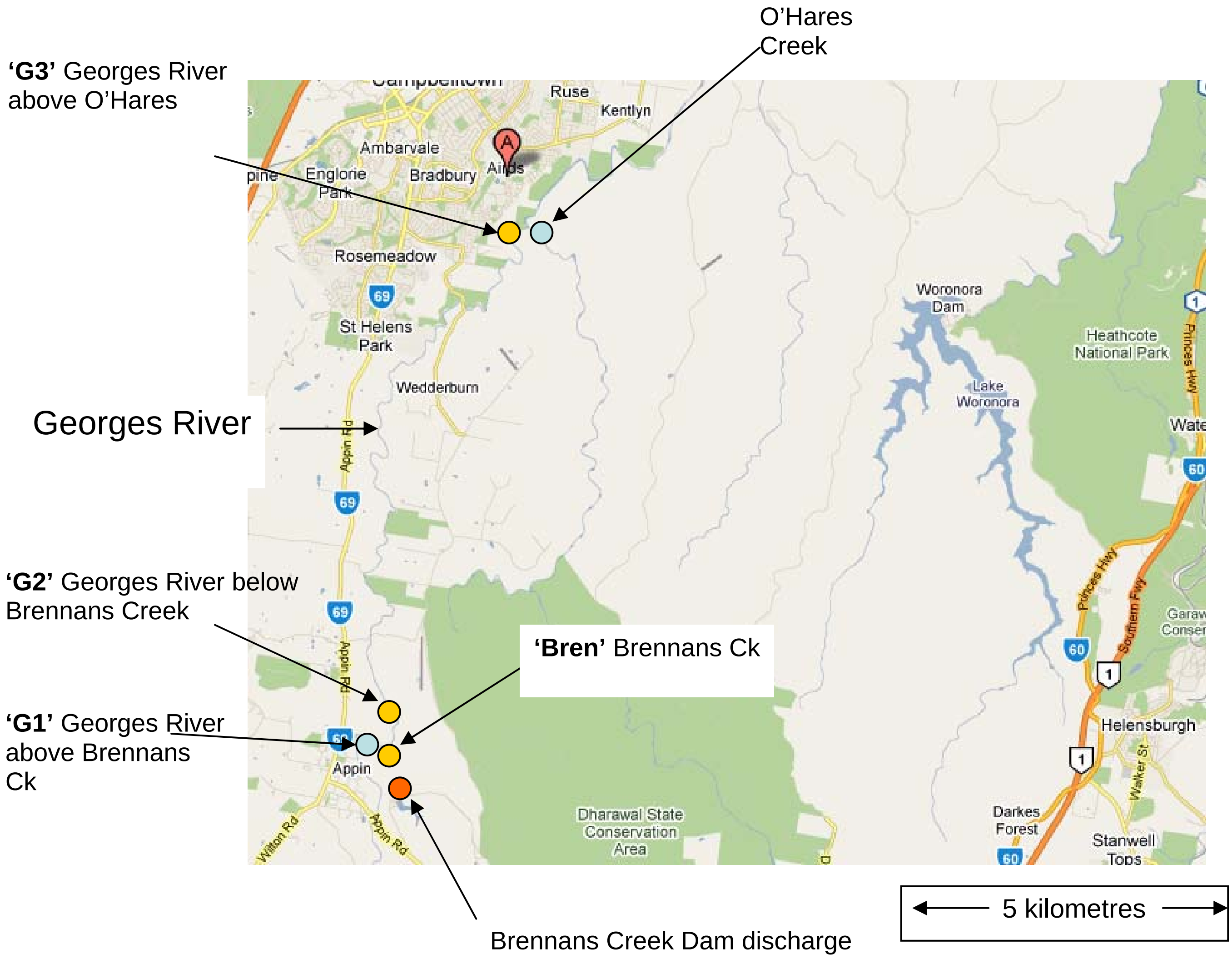

Figure 2. Upper Georges River sub-catchment and major waterways. Approximate location of investigation study area and sampling sites (blue symbol = reference sites and yellow are below the coal mine discharge)

1.2 Investigation methodology

I collected water samples from a total of five sites, four of which are closely related to Brennans Creek and are the basis of this report (Table 1; Figures 1, 2). ‘G1’ was the Georges River 200 m upstream of Brennans Creek. ‘G2’ was the Georges River 200 m downstream of Brennans Creek. ‘Bren’ was Brennans Creek itself. ‘G3’ was the Georges River about 13 km below Brennans Creek (near Airds) about 50 upstream of the confluence with O’Hares Creek (above the Woolwash). The final site was O’Hares Creek above the Woolwash (about 200 m upstream of the confluence with the Georges River). I collected the samples at all sites on three occasions (19 June 2012; 26 June 2012 and 3 July 2012), and reviewed results in conjunction with data reported as part of EPL 2504 Annual Returns to DECC/OEH/EPA.

When I collected water samples I used unused sampling bottles provided by Australian Laboratory Services (ALS) and filled the bottles with water from flowing sections of each waterway, mid-stream, from below the water surface. Samples were collected at the sites between 8:30am to 2:00pm. Each sample bottle was pre-labelled with the site, project and date details.

Samples were immediately stored in a sample esky, which was cooled with ice or with an ice brick. I kept all samples under my custody during the day, transporting them directly to the ALS Smithfield laboratory, and relinquished them into their custody, on the same day of sample collection. All samples were tested by the laboratory within 7 days of their collection. The ALS laboratory is a National Association of Testing Authorities (**NATA**) endorsed commercial laboratory for analysis of water and sediment chemistry samples. They have NATA accreditation based on using appropriate sample analysis methods within a quality assured analytical chemistry environment.

At each sampling site, on the three sampling occasions, I also collected replicated field meter results for stream pH, EC (electrical conductivity) and water temperature using a handheld TPS Model Aqua CD TPS Instruments, Queensland. The meter was tested for calibration (and adjusted if necessary) on each day of testing with reference solutions for pH and EC. At each site I waited for the meter to equilibrate before recording the data.

Weather conditions were assessed prior to collecting water samples to avoid periods of heavy rain, which could have resulted in confounded results due to catchment runoff.

2.1 Salinity in Georges River and tributaries

I collected salinity data from all sites on three occasions (19 June 2012; 26 June 2012 and 3 July 2012; Figure 3; Table1).

The upstream salinity level at Georges River 'G1' (the first reference site, Georges River upstream of Brennans Ck) ranged from 142.2 to 179.7 μS/cm, averaging 160.3 μS/cm from all replicates collected on the three sampling occasions. The salinity level in the Georges River downstream of Brennans Ck (site 'G2') ranged from 913.8 to 1338 μS/cm, averaging 1108.8 μS/cm from all replicates collected on the three sampling occasions. These results indicated that the salinity rose an average of 948.5 μS/cm. This translates to an increase of 592% in the salinity of the Georges River immediately below Brennans Creek compared to immediately above.

Approximately 13 km further downstream, the Georges River (at site G3) the average salinity was measured at 825 μS/cm (Figure 3). The range of the salinity at this site varied from 641.7 to 1029 μS/cm. This indicated that elevated salinity from the site above Brennans Creek to G3 (conservatively estimated at 10 km below site G2) was 664 μS/cm. This is an increase of salinity of 414 %. The second reference sites (O'Hares Ck) flows into the Georges River immediately below site G3. It ranged from 100.5 to 120.7 μS/cm and averaged 110.6 μS/cm.

During my three days of sample collection the salinity in Brennans Creek ranged from 1733 to 1852 μS/cm and averaged 1794.9 μS/cm.

Endeavour Coal's EPL 2504 Annual returns confirm that salt levels are highly elevated in Brennans Creek as a result of the discharge from Brennans Creek Dam:

- Endeavour Coal's 2010 Annual Returns to DECCW for EPL 2504 reported that salinity in the piped discharge from Brennans Creek dam to Brennans Creek (measured on 102 occasions in 2010 from *LDP10*) varied from 1184 μS/cm to a maximum of 3482 μS/cm, with an average of 2305 μS/cm.
- Endeavour Coal's 2009 Annual Returns to DECCW for EPL 2504 reported that salinity in the piped discharge from Brennans Creek dam to Brennans Creek (measured continuously 1 February 2009 to 6 Novemner 2009 from *Discharge and Monitoring Point 10*) varied from 1763 μS/cm to a maximum of 3536 μS/cm, with an average of 2550 μS/cm.

These results indicate that the level of salt in the Georges River had increased as a result of the inflow of Brennans Ck and that the West Cliff coalmine is the source of this increase in salt. The flow in Brennans Ck is due to the discharge from West Cliff Mine (Brennans Creek Dam). The source of the elevated salinity in study area section of the upper Georges River is the coal mine discharge given the lower concentration at the upstream sites (Sites G1) compared to the sites downstream of the Brennans Ck and the very high salt levels in Brennans Ck.

Therefore I conclude that West Cliff coal mine acts as a point source of salt to the upper Georges River. Endeavour Coal EPL 2504 annual returns support this conclusion. Endeavour Coal's Annual Returns to DECC/OEH for EPL 2504 give a broader timescale to the salinity data collected in relation to my data collected June and July 2012, and they have consistently been above ANZECC guideline levels for ecosystem protection, indicating the ongoing nature of saline discharge into the Brennans Ck and Georges River.

These values ranged between 3.6 and 18.3 times the salinity level recorded at the two reference sites, indicating the very large and unnatural increase above natural background salinity levels in the upper Georges River catchment due to the licensed EPL 2504 coal mine waste discharge.

The ANZECC salinity guideline (trigger value) for protection of aquatic ecosystems in upland NSW slightly disturbed ecosystems is 30-350 μS/cm (ANZECC, 2000, 3.3. Physical and chemical stressors, Table 3.3.3). In Brennans Ck, below the Endeavour coal discharge, salinity level of the 1853, 1734 and 1800 μS/cm is 5.3, 4.9 and 5.1 times the maximum guideline level, respectively.

Based on this evidence, I consider that the levels of salt in all study sites (except for the two reference sites), on all occasions were likely to be stressful to aquatic ecosystems (ANZECC, 2000, Section 3.4 Water quality guidelines for toxicants). Such levels of salt are at high risk of being 'harmful to aquatic life' and probably contribute to damage to the biodiversity of aquatic biota (Kefford *et al.*, 2006; Philibert *et al.*, 2006).

In my opinion, the level of salt in Brennans Creek has remained at elevated and at ecologically stressful levels over the period 2009 to July 2011 (EPL 2504 annual returns and my results from June and July 2012; Figure 3). Also see section 2.6 'Major anions and cations'. The concentration and relative composition of major anions and cations, which collectively determine the level of salt, also has major consequences for aquatic ecosystems.

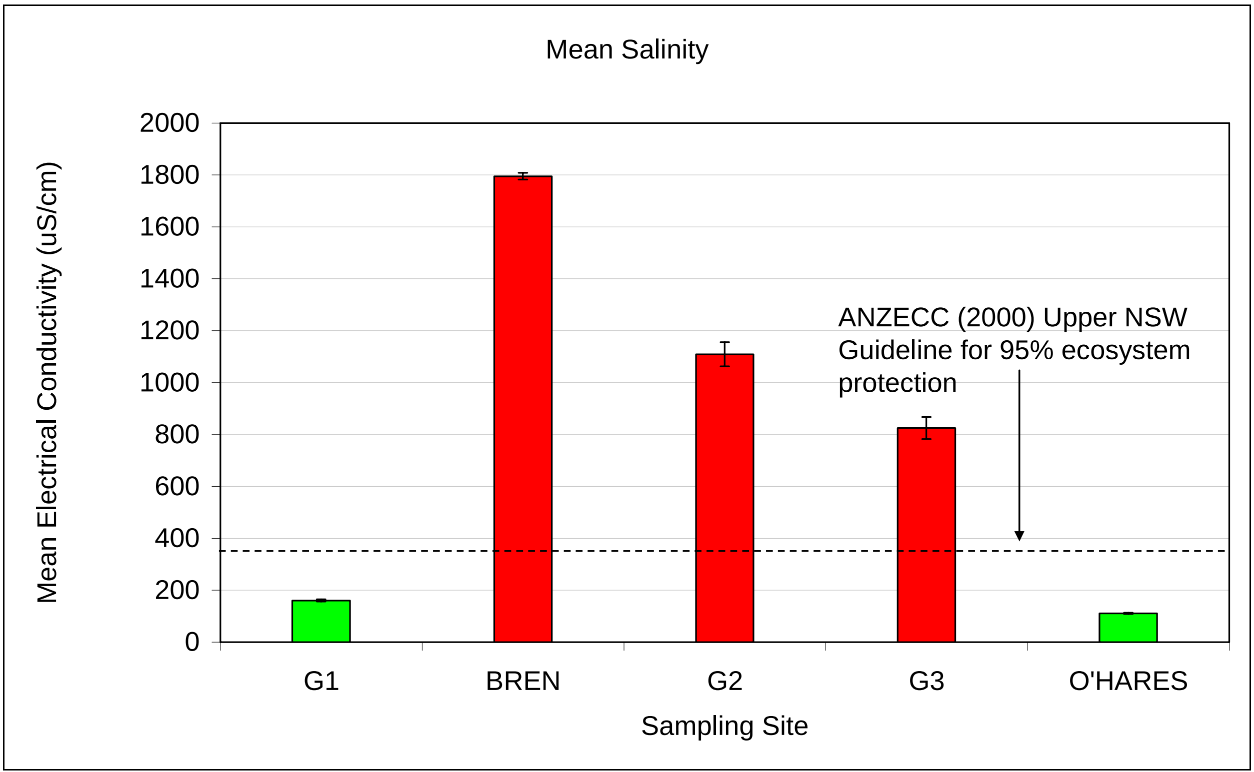

Figure 3: Mean salinity (*μ*S/cm) in Upper Georges River and tributaries on from three sampling occasions in June/July 2012 (levels above guidelines are in red)

Table 1 Raw Salinity (Electrical conductivity in µS/cm) data collected on the three sampling occasions (on each occasion five replicate readings were recorded).

	G1	BREN	G2	G3	O'HARES
19/06/2012	179.5	1851	1074	641.8	100.9
	179.7	1851	1075	641.7	100.4
	179.4	1851	1074	642.6	100.7
	179.1	1851	1074	641.7	100.5
	179.2	1851	1074	641.7	100.5
26/06/2012	159	1733	1338	804.1	110.7
	159	1735	1338	804.3	111.1
	159.5	1734	1338	804.4	111.1
	159.3	1734	1338	804.1	110.8
	159.1	1734	1338	804.1	110.8
3/07/2012	142.5	1799	913.9	1029	120.7
	142.3	1801	914	1029	120.6
	142.4	1799	913.8	1029	120.3
	142.2	1800	914.4	1029	120.1
	142.4	1800	914.3	1029	120.1

2.2 pH in Georges River and tributaries

I collected pH data from all sites on three occasions (19 June 2012; 26 June 2012 and 3 July 2012; Figure 4; Table 2).

The upstream pH level at Georges River 'G1' (the first reference site, Georges River upstream of Brennans Ck) ranged from 7.04 to 7.74 pH units, averaging 7.34 pH units from all replicates collected on the three sampling occasions. The pH level in the Georges River downstream of Brennans Ck (site 'G2') ranged from 8.56 to 8.68 pH units, averaging 8.63 pH units from all replicates collected on the three sampling occasions. These results indicated that the pH raised an average of 1.29 pH units. This translates to an increase of 17.6 % in the average pH of the Georges River immediately below Brennans Creek compared to immediately above.

Approximately 13 km further downstream, the Georges River (at site G3) the average pH was measured at 8.37 pH units (Figure 3). The range of the pH at this site varied from 8.21 to 8.54 pH units. This indicated that elevated pH in the Georges River rose from the site above Brennans Creek to G3 (conservatively estimated at 10 km below site G2) and was 1.03 pH units. This is an increase of pH of 14 %. The second reference sites (O'Hares Ck) flows into the Georges River immediately below site G3. Its pH ranged from 6.52 to 6.64 and averaged 6.58 pH units.

During my three days of sample collection the pH in Brennans Creek ranged from 8.51 to 8.80 pH units and averaged 8.66 pH units.

Endeavour Coal's Annual returns confirm that pH levels are generally highly elevated in Brennans Creek as a result of the discharge from Brennans Creek Dam:

- Endeavour Coal's 2008 Annual Returns to DECCW for EPL 2504 reported that pH in the piped discharge from Brennans Creek dam to Brennans Creek (measured continuously from *Discharge and Monitoring Point 10*) varied from 7.37 to a maximum of 8.91, with an average of 8.49.
- Endeavour Coal's 2009 Annual Returns to DECCW for EPL 2504 reported that salinity in the piped discharge from Brennans Creek dam to Brennans Creek (measured continuously 1 February 2009 to 6 November 2009 from *Discharge and Monitoring Point 10*) varied from 7.74 to a maximum of 8.94, with an average of 8.61.

These results indicate that the level of pH in the Georges River has increased as a result of the inflow of Brennans Ck and that the West Cliff coalmine is the source of this increase. The flow in Brennans Ck is due to the discharge from West Cliff Mine (Brennans Creek Dam). Therefore I conclude that West Cliff coal mine acts as a point source of elevated pH to the upper Georges River.

The ANZECC pH guideline (trigger value) for protection of aquatic ecosystems in upland NSW slightly disturbed ecosystems is 6.5-7.5 (ANZECC, 2000, 3.3. Physical and chemical stressors, Table 3.3.2). The study by Tippler et al. (2012a) recommends a pH range of 5.1 to 7.1 for protection of aquatic ecosystems for the Georges River region. In Brennans Ck, below the Endeavour coal discharge, the mean pH level recorded in June/July 2012 of the 8.66 is 1.56 pH units higher than the maximum guideline level recommended for the Georges River catchment (Tippler *et al.* 2112a).

Based on this evidence, I consider that the levels of pH in all study sites (except for the two reference sites), on all occasions were likely to be stressful to aquatic ecosystems ANZECC, 2000, 3.3. Physical and chemical stressors, Table 3.3.2). In my opinion, the level of pH in Brennans Creek has remained at elevated and at potentially ecologically stressful levels over the period 2008 to July 2011 (EPL 2504 annual returns and my results from June and July 2012; Figure 4; Table 2).

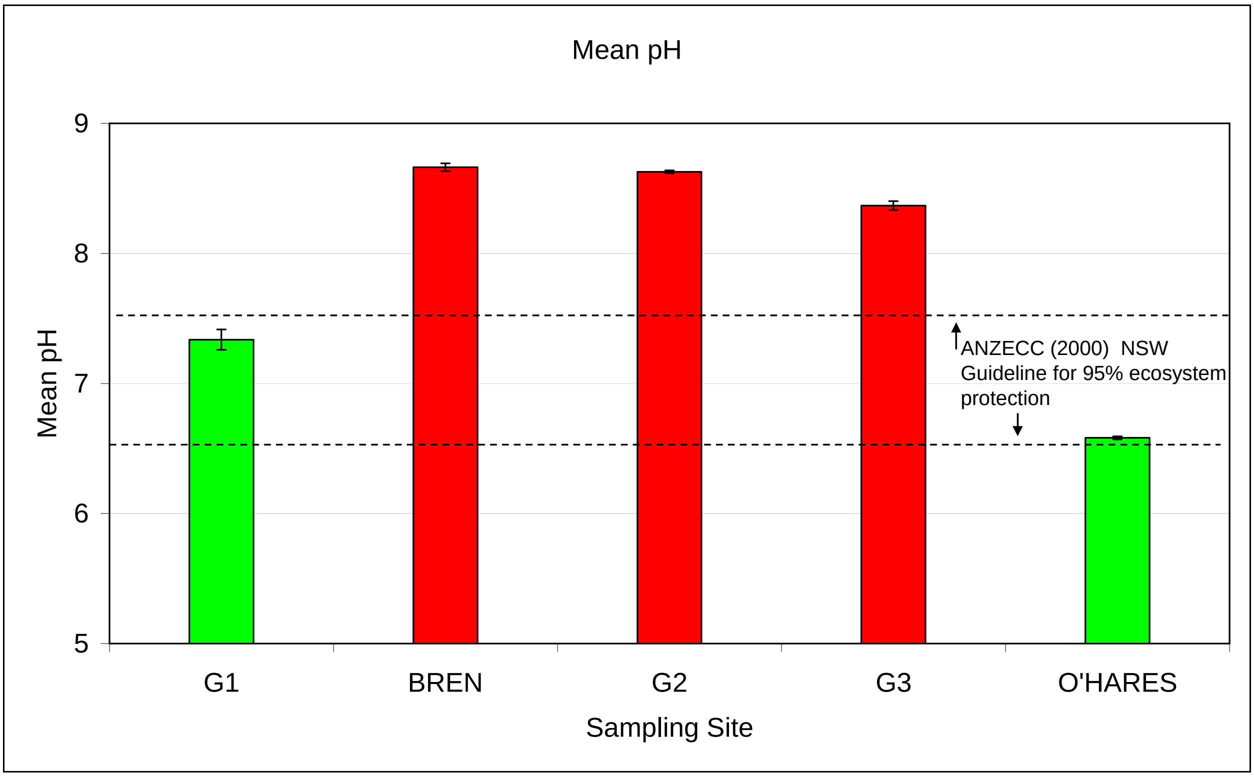

Figure 4: Mean pH *(pH units*) in Upper Georges River and tributaries on from three sampling occasions in June/July 2012 (levels above guidelines are in red)

Table 2 Raw pH (in *pH units*) data collected on the three sampling occasions (on each occasion five replicate readings were recorded).

	G1	BREN	G2	G3	O'HARES
19/06/2012	7.26	8.67	8.64	8.21	6.55
	7.24	8.67	8.65	8.23	6.54
	7.23	8.67	8.64	8.23	6.54
	7.22	8.67	8.64	8.23	6.53
	7.22	8.67	8.65	8.23	6.52
26/06/2012	7.04	8.8	8.66	8.33	6.58
	7.04	8.8	8.66	8.33	6.58
	7.05	8.8	8.67	8.34	6.57
	7.05	8.8	8.67	8.34	6.56
	7.04	8.79	8.68	8.35	6.56
3/07/2012	7.73	8.53	8.56	8.54	6.64
	7.73	8.52	8.57	8.54	6.64
	7.73	8.52	8.57	8.54	6.64
	7.73	8.51	8.57	8.54	6.64
	7.74	8.52	8.57	8.54	6.64

2.3 Turbidity in Georges River and tributaries

I collected turbidity data from all sites on three 2012 occasions (19 June; 26 June and 3 July; Figure 5; Table 3).

The upstream turbidity level at Georges River ‘G1’ (the first reference site, Georges River upstream of Brennans Ck) ranged from 1.4 to 2.5 NTU, averaging 1.88 NTU from all replicates collected on the three sampling occasions (Figure 5). The turbidity level in the Georges River downstream of Brennans Ck (site ‘G2’) ranged from 13 to 17 NTU, averaging 14.8 NTU from all replicates collected on the three sampling occasions (Figure 5). These results indicated that the turbidity raised an average of 12.9 NTU. This translates to an increase of 687 % in the average turbidity of the Georges River 100m below Brennans Creek compared to 100m upstream.

Approximately 13 km further downstream, the Georges River (at site G3) the average turbidity was measured at 10.94 NTU (Figure 5). The range of the pH at this site varied from 3.7 to 17.2 NTU. This indicated that elevated turbidity in the Georges River rose from G1 above Brennans Creek to G3 (conservatively estimated at 10 km below site G2) and was 9.06 NTU. This is an increase of turbidity of 482 %. The second reference sites (O’Hares Ck) flows into the Georges River immediately below site G3. Its turbidity ranged from 0 to 1.5 NTU and averaged 0.84 NTU.

During my three days of sample collection the turbidity in Brennans Creek ranged from 15.7 to 33.4 NTU and averaged 25.0 NTU (Figure 5).

Endeavour Coal’s Annual returns do not include data on water turbidity. However, they do contain data on confirm that suspended solids levels are generally highly elevated in Brennans Creek as a result of the discharge from Brennans Creek Dam:

- Endeavour Coal’s 2008 Annual Returns to DECCW for EPL 2504 reported that total suspended solids in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times from *Discharge and Monitoring Point 10*) varied from 0.5 to a maximum of 15 mg/L, with an average of 3.87 mg/L.
- Endeavour Coal’s 2009 Annual Returns to DECCW for EPL 2504 reported that total suspended solids in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times from *Discharge and Monitoring Point 10*) varied from 4 to a maximum of 36 mg/L, with an average of 13.7 mg/L.
- Endeavour Coal’s 2010 Annual Returns to DECCW for EPL 2504 reported that total suspended solids in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times at *Discharge and Monitoring Point 10*) varied from 3 to a maximum of 19 mg/L, with an average of 9 mg/L.

The ANZECC turbidity guideline (trigger value) for protection of aquatic ecosystems in upland NSW slightly disturbed ecosystems is 2-25 NTU (ANZECC, 2000, 3.3. Physical and chemical stressors, Table 3.3.3). In Brennans Ck, below the Endeavour coal discharge, the mean turbidity level recorded in June/July 2012 of 24.98 NTU was a fraction below the maximum guideline level, but was always above the lower trigger value. It is likely that the turbidity level regularly exceeds the upper ANZECC trigger value as on one of the three sampling occasions turbidity was at an average of 33.28 NTU.

Based on this evidence, I consider that the levels of turbidity in Brennans Ck were occasionally at levels likely to be stressful to aquatic ecosystems ANZECC, 2000, 3.3. Physical and chemical stressors, Table 3.3.2). In my opinion, the fine suspended sediment in Brennans Creek acts as a point source of elevated turbidity to the Georges River. At times the turbidity is likely to be ecologically stressful levels. Whilst the turbidity levels in the two reference sites (G1 and O'Hares Creek) was generally 2 NTU, Brennans Creek and the two Georges River sites were always above the lower ANZECC trigger levels.

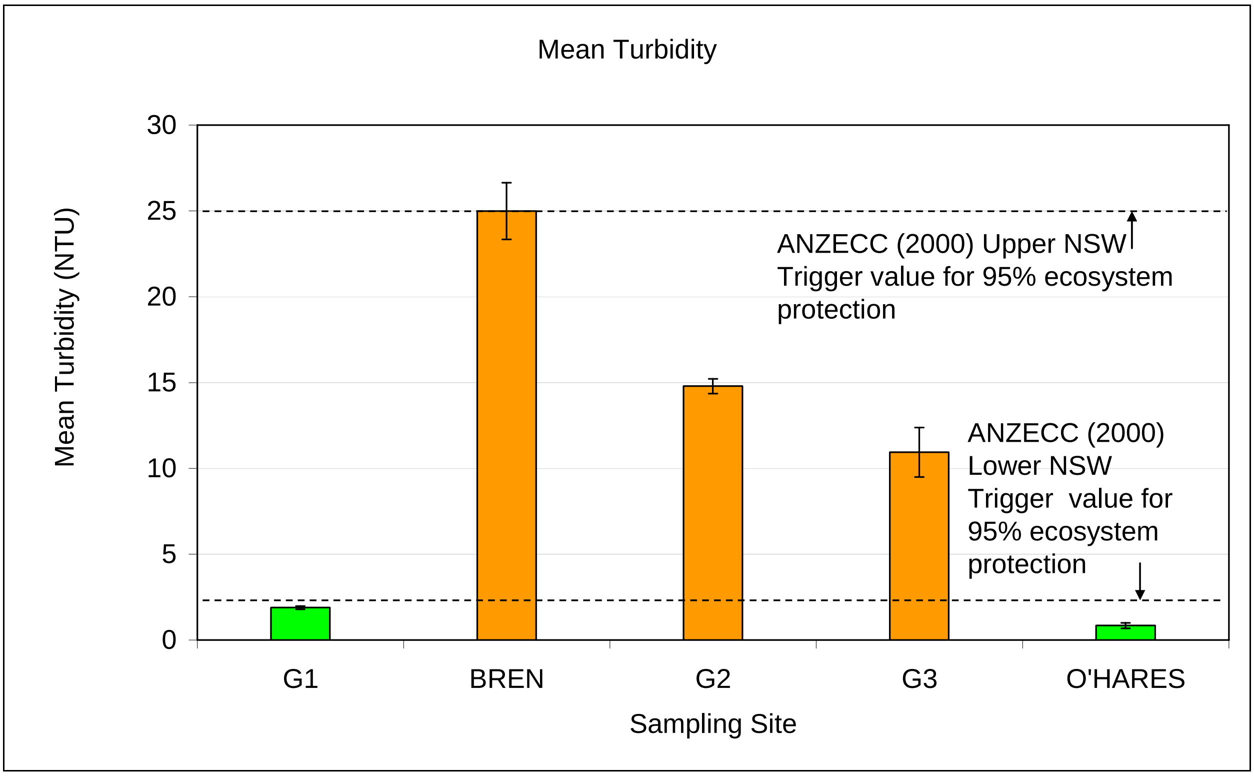

Figure 5: Mean turbidity (NTU) in Upper Georges River and tributaries on from three sampling occasions in June/July 2012 (mean levels above guidelines are in red)

Table 3 Raw Turbidity (NTU) data collected on the three sampling occasions (on each occasion five replicate readings were recorded).

	G1	BREN	G2	G3	O'HARES
19/06/2012	2.5	23.4	14.4	16	1.2
	2.1	23	14.5	15.8	1.2
	2.1	22.6	14.4	16.5	1.3
	2	22.7	14.4	16.8	1.4
	2.2	22.9	14.3	17.2	1.5
26/06/2012	2.2	15.7	16.9	9.2	1.1
	1.9	19.9	16.9	10.1	1.2
	2	19.4	**17**	14.2	1.2
	2	19.4	17	14.3	1.2
	2	19.4	17	14.3	1.3
3/07/2012	1.4	33.2	13	4.3	0
	1.4	33.2	13	4.2	0
	1.5	33.3	13	3.8	0
	1.5	33.4	13	3.7	0
	1.5	33.3	13	3.7	0

2.4 Copper in Georges River and tributaries

I collected copper samples from all sites on three occasions (19 June 2012; 26 June 2012 and 3 July 2012: Figure 6: Table 4).

The upstream copper level at Georges River 'G1' (the first reference site, Georges River upstream of Brennans Ck) ranged from below detection (<1 μg/L) for five of six samples and one sample recorded 6 μg/L, (assuming that copper levels below detection were at 0.5 μg/L) this estimated that the mean copper level was 1.4 μg/L. The copper level in the Georges River downstream of Brennans Ck (site 'G2') were all above detection limits and ranged from 3 to 9 μg/L, averaging 5 μg/L from all replicates collected on the three sampling occasions. These results indicated that the copper concentration raised an average of about 3.6 μg/L. This translates to an increase of 257 % in the average copper concentration of the Georges River 100m below Brennans Creek compared to 100m upstream.

Approximately 13 km further downstream, the Georges River (at site G3) the average copper was measured at 2.75 μg/L (Figure 6). The range of copper at this site varied from one sample below detection limits to 7 μg/L. This indicated that elevated copper in the Georges River rose from G1 above Brennans Creek to G3 (conservatively estimated at 10 km below site G2) and was 1.35 μg/L. This is an increase of copper of an estimated 96 %. The second reference sites (O'Hares Ck) flows into the Georges River immediately below site G3. Its copper concentration ranged from below detection (4 samples) to 6 μg/L and averaged 1.84 μg/L.

During my three days of sample collection the copper in Brennans Creek ranged from 5 to 8 μg/L and averaged 6.5 μg/L.

Endeavour Coal's Annual returns include data on copper. They confirm that copper levels are generally highly elevated in Brennans Creek as a result of the discharge from Brennans Creek Dam:

- Endeavour Coal's 2008 Annual Returns to DECCW for EPL 2504 reported that copper in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times from *Discharge and Monitoring Point 10*) varied from 3 to a maximum of 150 μg/L, with an average of 7.5 μg/L.
- Endeavour Coal's 2009 Annual Returns to DECCW for EPL 2504 reported that copper in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times from *Discharge and Monitoring Point 10*) varied from 1 μg/L to a maximum of 10 μg/L, with an average of 5 μg/L.

(Note: I have assumed that the 2009 annual returns for copper were under-estimated by 1000 times due to a typographical mistake and the copper levels were reported by mistake in mg/L).

- Endeavour Coal's 2010 Annual Returns to DECCW for EPL 2504 reported that copper in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times at *Discharge and Monitoring Point 10*) varied from 4 to a maximum of 8 μg/L, with an average of 5 μg/L.

The ANZECC copper guideline (trigger value) for protection of 95% of species aquatic ecosystems is 1.4 μg/L (ANZECC, 2000, Trigger values for toxicants, Table 3.4.1). In Brennans Ck, below the Endeavour coal discharge, the mean copper level recorded in June/July 2012 of 6.5 μg/L was a 4.6 times above this guideline level.

Based on this evidence, I consider that the levels of copper in Brennans Ck were at levels likely to be stressful to aquatic ecosystems. In my opinion, discharge of mine wastewater into Brennans Creek acts as a point source of elevated copper to the Georges River. The copper levels are likely to be ecologically hazardous and contribute to downstream aquatic ecosystem stress. Whilst the copper levels in the two reference sites (G1 and O'Hares Creek) was generally under 2 μg/L, Brennans Creek and the two Georges River sites were above the ecosystem protection trigger levels.

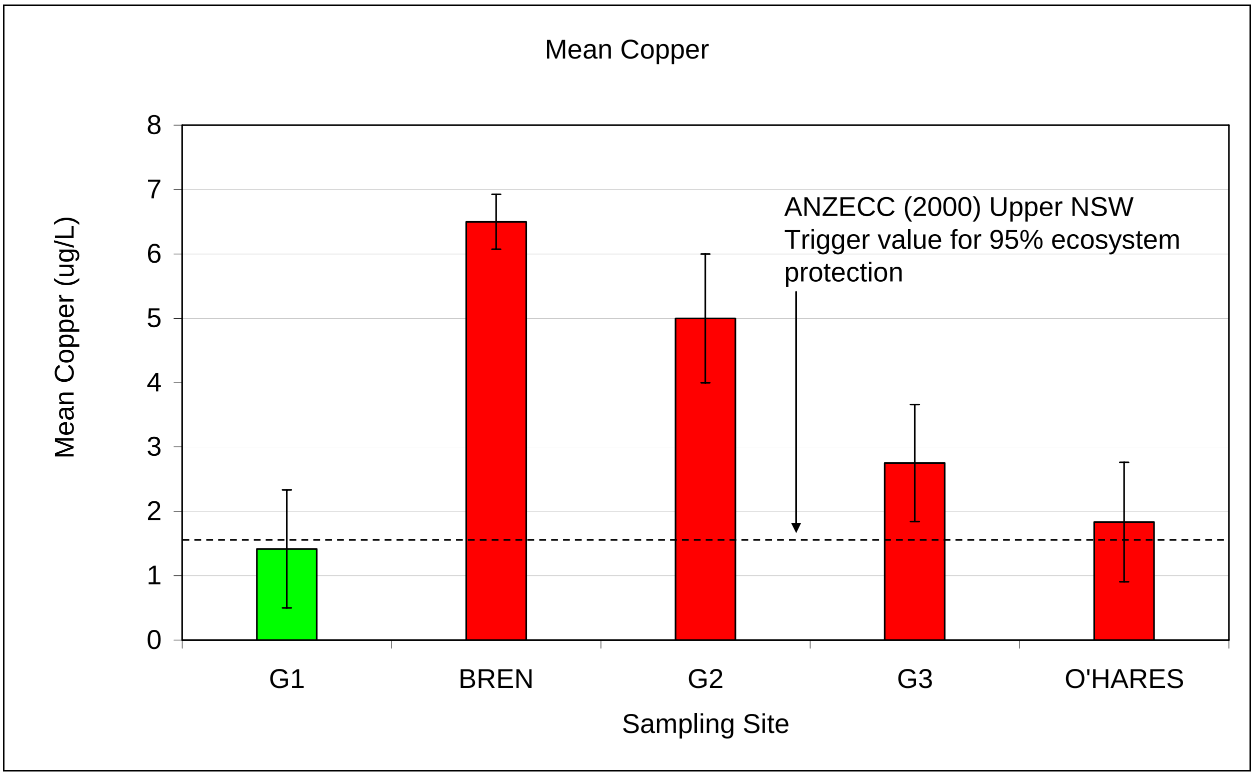

Figure 6: Mean copper in Upper Georges River (levels above guidelines are in red)

Table 4. Raw Copper (μg/L) data collected on the three sampling occasions (on each occasion two replicate samples were collected). Note <1 indicates that the sample concentration was below the analytical detection limit of 1 μg/L.

	G1	BREN	G2	G3	O'HARES
19/06/2012 (1)	<1	6	3	2	<1
19/06/2012 (2)	<1	5	3	2	<1
26/06/2012 (1)	<1	7	6	2	3
26/06/2012 (2)	<1	8	6	3	<1
3/07/2012 (1)	6	6	9	7	6
3/07/2012 (2)	<1	7	3	<1	<1

2.5 Aluminium in Georges River and tributaries

I collected aluminium samples from all sites on three occasions (19 June 2012; 26 June 2012 and 3 July 2012; Figure 7; Table 5).

The upstream aluminium concentration at Georges River 'G1' (the first reference site, Georges River upstream of Brennans Ck) ranged from 90 to 170 μg/L, with an average of 125 μg/L (Figure 7). The aluminium level in the Georges River downstream of Brennans Ck (site 'G2') ranged from 450 to 590 μg/L, averaging 513 μg/L from all replicates collected on the three sampling occasions (Figure 7). These results indicated that the aluminium concentration raised an average of 388 μg/L. This translates to an increase of 310 % in the average aluminium concentration of the Georges River 100m below Brennans Creek compared to 100m upstream.

Approximately 10 km further downstream, the Georges River (at site G3) the average aluminium concentration was measured at 423 μg/L (Figure 7). The range of aluminium concentrations at this site varied from 290 to 670 μg/L. This indicated that elevated aluminium in the Georges River rose from G1 above Brennans Creek to G3 (conservatively estimated at 13 km below site G2) and was 298 μg/L. This is an increase of aluminium of 238 %. The second reference sites (O'Hares Ck) flows into the Georges River immediately below site G3. Its copper ranged from 90 to 150 μg/L and averaged 117 μg/L.

During my three days of sample collection the aluminium concentration in Brennans Creek ranged from 520 to 860 μg/L and averaged 732 μg/L (Table 5).

Endeavour Coal's Annual returns do not include data on aluminium.

The ANZECC aluminium guideline (trigger value) for protection of 95% of species aquatic ecosystems is 55 μg/L (ANZECC, 2000, Trigger values for toxicants, Table 3.4.1). In Brennans Ck, below the Endeavour coal discharge, the mean aluminium level recorded in June/July 2012 of 732 μg/L was a 1330 % above this guideline level.

Based on this evidence, I consider that the levels of aluminium in Brennans Ck were likely to be stressful to aquatic ecosystems.

In my opinion, discharge of mine wastewater into Brennans Creek acts as a point source of elevated aluminium to the Georges River. The aluminium levels are likely to be ecologically hazardous and contribute to downstream aquatic ecosystem stress. Whilst the aluminium levels in the two reference sites (G1 and O'Hares Creek) were also above the guideline, Brennans Creek inflow caused a sustained elevation of aluminium in the Georges River, for at least 12 km, several hundred percent above the ecosystem protection trigger levels.

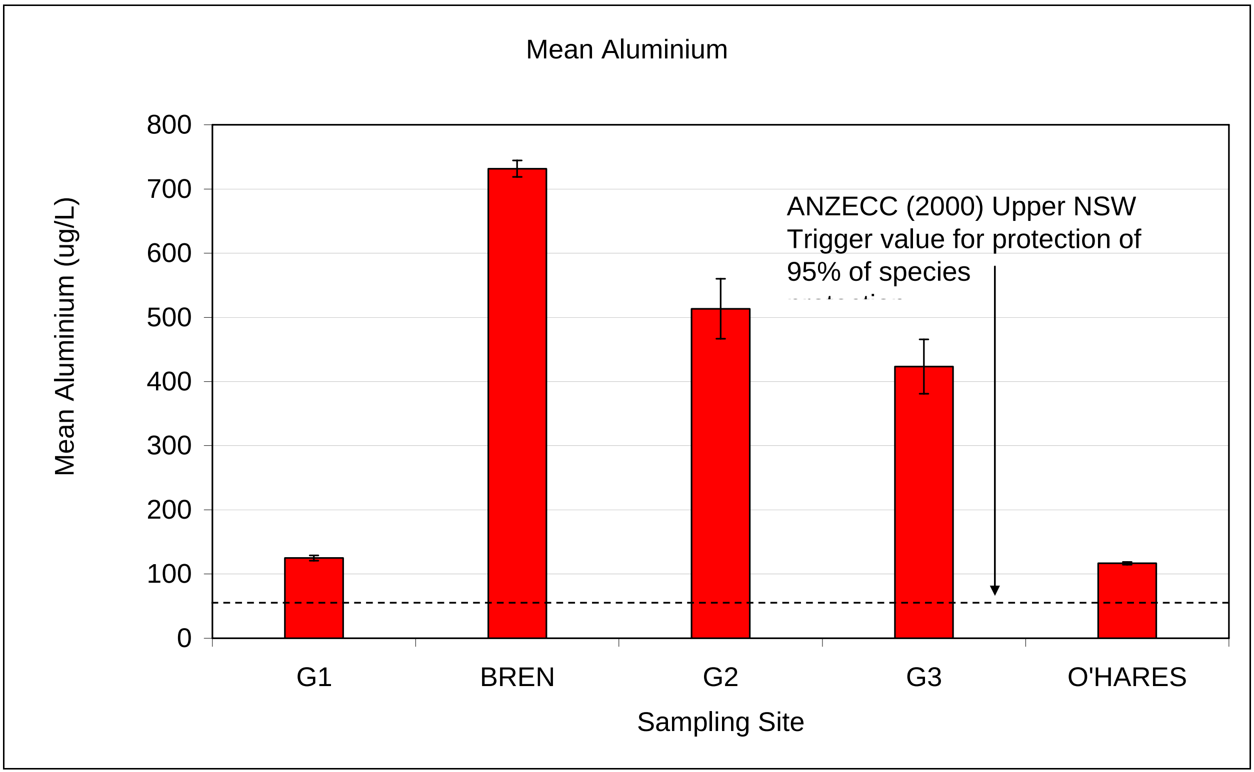

Figure 7: Aluminium in Upper Georges River (levels above guidelines are in red)

Table 5. Raw Aluminium (μg/L) data collected on the three sampling occasions (on each occasion two replicate samples were collected).

	G1	BREN	G2	G3	O'HARES
19/06/2012 (1)	160	700	490	580	140
19/06/2012 (2)	170	770	510	670	150
26/06/2012 (1)	90	720	550	350	100
26/06/2012 (2)	90	520	450	320	110
3/07/2012 (1)	130	860	590	330	110
3/07/2012 (2)	110	820	490	290	90

2.6 Zinc in Georges River and tributaries

I collected zinc samples from all sites on three occasions (19 June 2012; 26 June 2012 and 3 July 2012; Figure 8; Table 6).

The upstream zinc concentration at Georges River ‘G1’ (the first reference site, Georges River upstream of Brennans Ck) ranged from <5 (below detection) to 9 μg/L, with an average of 5.9 μg/L (Table 6). The zinc level in the Georges River downstream of Brennans Ck (site ‘G2’) ranged from 14 to 26 μg/L, averaging 20.5 μg/L from all replicates collected on the three sampling occasions (Table 6). These results indicated that the zinc concentration raised an average of 14.6 μg/L. This translates to an increase of 247 % in the average zinc concentration of the Georges River 100m below Brennans Creek compared to 100m upstream.

Approximately 10 km further downstream, the Georges River (at site G3) the average zinc concentration was measured at 15.5 μg/L (Figure 8). The range of zinc concentrations at this site varied from 13 to 21 μg/L. This indicated that elevated zinc in the Georges River rose from G1 above Brennans Creek to G3 (conservatively estimated at 13 km below site G2) and was 9.6 μg/L. This is an increase of the zinc concentration of 163 %. The second reference sites (O’Hares Ck) flows into the Georges River immediately below site G3. Its zinc level ranged from <5 (below detection) to 12 μg/L and averaged 5 μg/L (assuming that readings below the zinc detection limit of 5 μg/L were 2.5 μg/L).

During my three days of sample collection the zinc concentration in Brennans Creek ranged from 26 to 35 μg/L and averaged 29.8 μg/L (Table 6).

Endeavour Coal’s Annual returns include data on zinc. They confirm that zinc levels are generally highly elevated in Brennans Creek as a result of the discharge from Brennans Creek Dam:

- Endeavour Coal’s 2008 Annual Returns to DECCW for EPL 2504 reported that zinc in the piped discharge from Brennans Creek dam to Brennans Creek (measured 11 times from *Discharge and Monitoring Point 10*) varied from <10 to a maximum of 90 μg/L, with an average of 60 μg/L.
- Endeavour Coal’s 2009 Annual Returns to DECCW for EPL 2504 reported that zinc in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times from *Discharge and Monitoring Point 10*) varied from 16 μg/L to a maximum of 140 μg/L, with an average of 50 μg/L[#].

([#]Note: I have assumed that the 2009 annual returns for zinc were under-estimated by 1000 times due to a typographical mistake and the zinc levels were reported by mistake in mg/L against labelled units of μg/L).

- Endeavour Coal’s 2010 Annual Returns to DECCW for EPL 2504 reported that zinc in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times at *Discharge and Monitoring Point 10*) varied from 22 to a maximum of 51 μg/L, with an average of 35 μg/L.

The ANZECC zinc guideline (trigger value) for protection of 95% of species aquatic ecosystems is 8 μg/L (ANZECC, 2000, Trigger values for toxicants, Table 3.4.1). In Brennans Ck, below the

Endeavour coal discharge, the mean zinc level recorded in June/July 2012 of 29.8 µg/L was a 372 % above this guideline level. The mean zinc concentration of 15.5 µg/L in the Georges R (G3) more than 10 km downstream of Brennans Creek was 193% higher than the guideline level.

Based on this evidence, I consider that the levels of zinc in Brennans Ck and the Georges River below Brennans Ck) was at levels likely to be stressful to aquatic ecosystems. In my opinion, discharge of mine wastewater into Brennans Creek acts as a point source of elevated zinc to the Georges River. The zinc levels are likely to be ecologically hazardous and contribute to downstream aquatic ecosystem stress. The zinc levels in the two reference sites (G1 and O'Hares Creek) represent the natural background of zinc and were below the guideline. Brennans Creek inflow caused a sustained elevation of zinc into the Georges River, for at least 12 km, well above the ecosystem protection trigger levels.

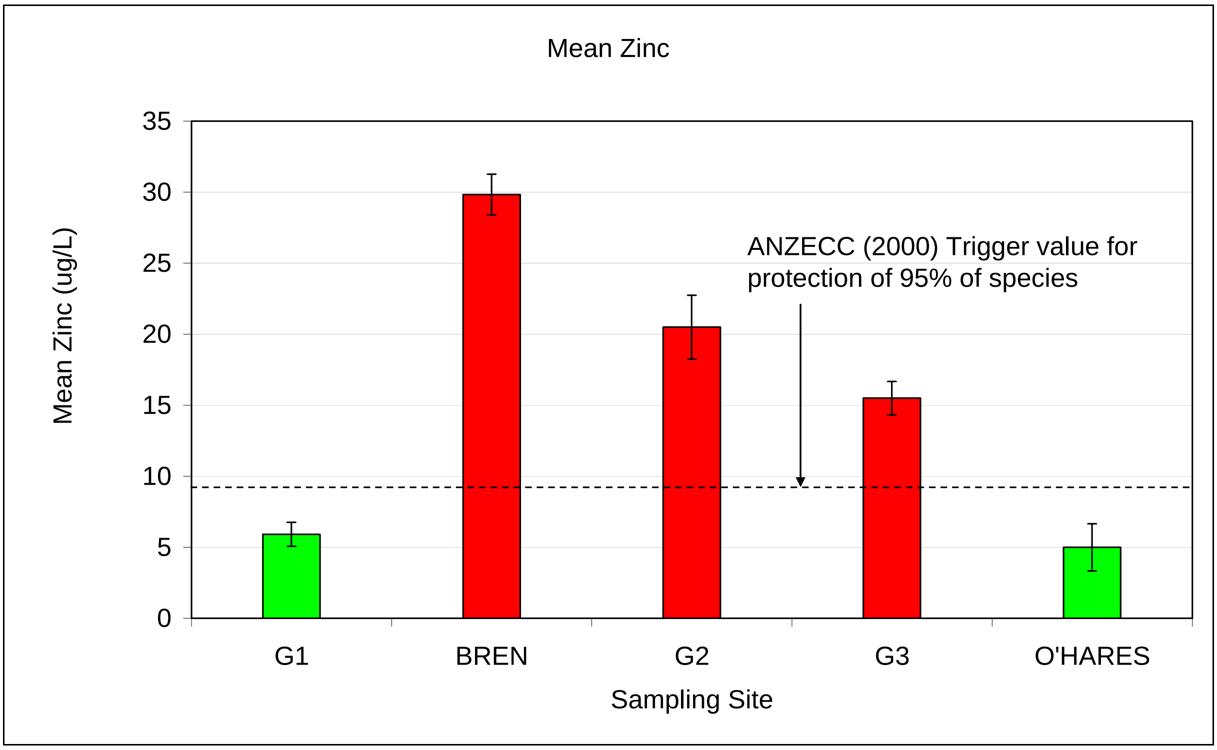

Figure 8: Zinc in Upper Georges River (levels above guidelines are in red)

Table 6. Raw Zinc (µg/L) data collected on the three sampling occasions (on each occasion two replicate samples were collected).

	G1	BREN	G2	G3	O'HARES
19/06/2012 (1)	6	35	24	21	<5
19/06/2012 (2)	<5	32	18	14	12
26/06/2012 (1)	6	30	26	15	8
26/06/2012 (2)	9	30	26	16	<5
3/07/2012 (1)	6	26	14	13	<5
3/07/2012 (2)	6	26	15	14	<5

2.7 Nickel in Georges River and tributaries

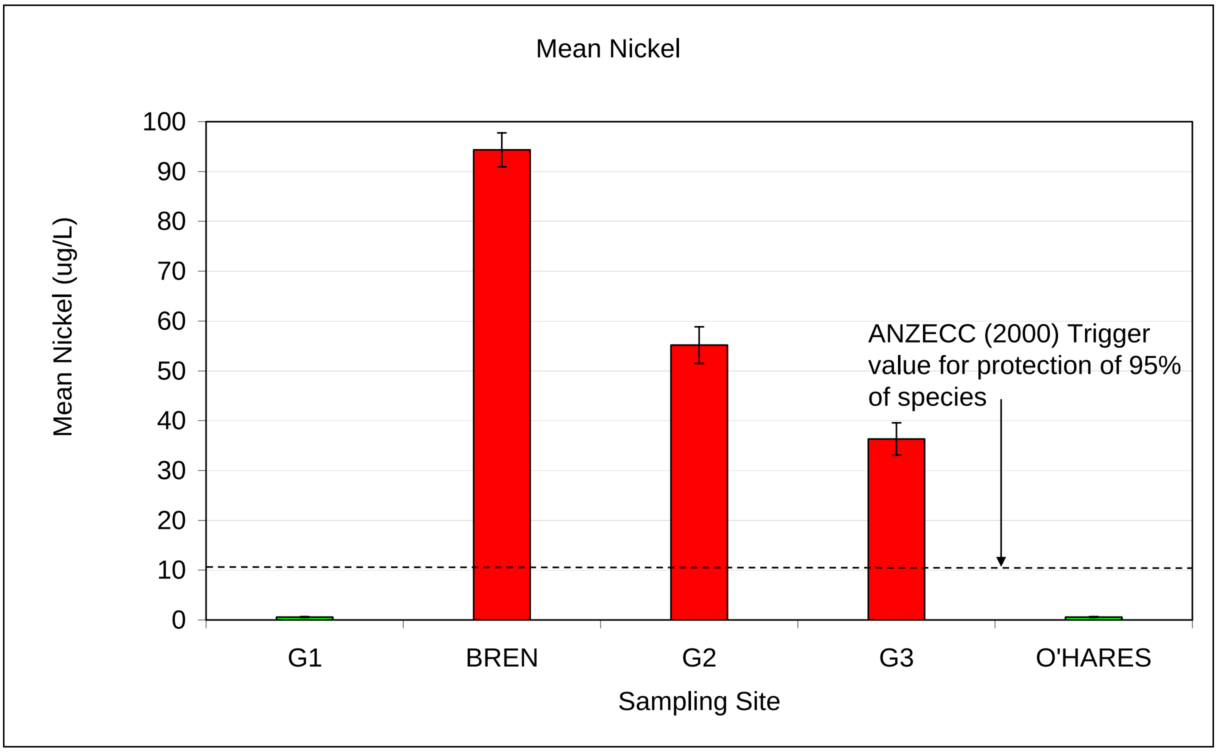

Figure 9: Nickel in Upper Georges River (levels above guidelines are in red)

I collected nickel samples from all sites on three occasions (19 June 2012; 26 June 2012 and 3 July 2012: Figure 9; Table 7).

The upstream nickel concentration at Georges River ‘G1’ (the first reference site, Georges River upstream of Brennans Ck) ranged from <1 (below detection) to 1 μg/L, with an average of 0.6 μg/L (This assumes that the nickel level was half of the detection limit). The nickel level in the Georges River downstream of Brennans Ck (site ‘G2’) ranged from 44 to 65 μg/L, averaging 55.2 μg/L from all replicates collected on the three sampling occasions (Figure 9). These results estimate that the nickel concentration raised an average of 54.6 μg/L. This translates to an increase of 9100 % in the average nickel concentration of the Georges River 100m below Brennans Creek compared to 100m upstream.

Approximately 13 km further downstream, the Georges River (at site G3) the average nickel concentration was measured at 36.3 μg/L (Figure 3). The range of nickel concentrations at this site varied from 27 to 47 μg/L. This indicated that elevated nickel in the Georges River rose from G1 above Brennans Creek to G3 (conservatively estimated at 10 km below site G2) and was 35.7 μg/L. This is an increase of the nickel concentration of 5950 %. The second reference sites (O’Hares Ck) flows into the Georges River immediately below site G3. Its nickel level ranged from <1 (below detection) to 1 μg/L and averaged 0.6 μg/L (assuming that readings below the nickel detection limit of 1 μg/L were 0.5 μg/L).

During my three days of sample collection the nickel concentration in Brennans Creek ranged from 86 to 105 μg/L and averaged 94.3 μg/L (Figure 9; Table 7).

Endeavour Coal's Annual returns include data on nickel. They confirm that nickel levels are always highly elevated in Brennans Creek as a result of the discharge from Brennans Creek Dam:

- o Endeavour Coal's 2008 Annual Returns to DECCW for EPL 2504 reported that zinc in the piped discharge from Brennans Creek dam to Brennans Creek (measured 11 times from *Discharge and Monitoring Point 10*) varied from 86 to a maximum of 225 µg/L, with an average of 170 µg/L.
- o Endeavour Coal's 2009 Annual Returns to DECCW for EPL 2504 reported that zinc in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times from *Discharge and Monitoring Point 10*) varied from 136 µg/L to a maximum of 240 µg/L, with an average of 197 µg/L[#].

([#]Note: I have assumed that the 2009 annual returns for nickel were under-reported by 1000 times due to a typographical mistake and the nickel levels were reported by mistake in mg/L against labelled units of µg/L).

- o Endeavour Coal's 2010 Annual Returns to DECCW for EPL 2504 reported that zinc in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times at *Discharge and Monitoring Point 10*) varied from 95 to a maximum of 235 µg/L, with an average of 140 µg/L.

The ANZECC nickel guideline (trigger value) for protection of 95% of species aquatic ecosystems is 11 µg/L (ANZECC, 2000, Trigger values for toxicants, Table 3.4.1). In Brennans Ck, below the Endeavour coal discharge, the mean nickel level recorded in June/July 2012 of 94.3 µg/L was 857 % above this guideline level. The mean nickel concentration of 36.3 µg/L in the Georges R (G3) more than 10 km downstream of Brennans Creek was 330% higher than the guideline level.

Based on this evidence, I consider that the levels of nickel in Brennans Ck and the Georges River below Brennans Ck) was at levels likely to be stressful to aquatic ecosystems. In my opinion, discharge of mine wastewater into Brennans Creek acts as a point source of elevated nickel to the Georges River. The nickel levels are likely to be ecologically hazardous and contribute to downstream aquatic ecosystem stress. The nickel levels in the two reference sites (G1 and O'Hares Creek) represent the natural background concentration of nickel and were both well below the guideline. Brennans Creek inflow caused a sustained elevation of nickel into the Georges River, for at least 10 km, well above the ecosystem protection trigger levels.

Table 7. Raw Nickel (µg/L) data collected on the three sampling occasions (on each occasion two replicate samples were collected).

	G1	BREN	G2	G3	O'HARES
19/06/2012 (1)	<1	104	54	29	<1
19/06/2012 (2)	<1	105	57	27	<1
26/06/2012 (1)	<1	86	65	35	1
26/06/2012 (2)	1	87	65	36	<1
3/07/2012 (1)	<1	94	46	44	<1
3/07/2012 (2)	<1	90	44	47	<1

2.5 Arsenic in Georges River and tributaries

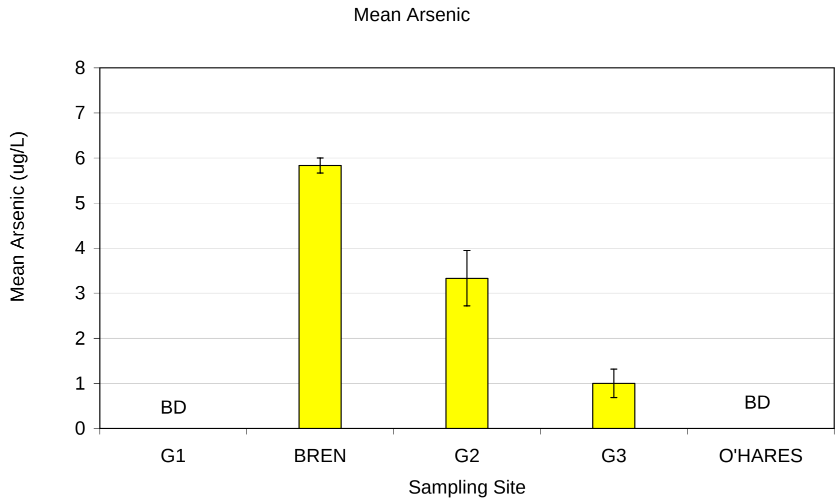

Figure 10: Arsenic in Upper Georges River (levels above guidelines are in red)

I collected arsenic samples from all sites on three occasions (19 June 2012; 26 June 2012 and 3 July 2012).

The upstream arsenic concentration at Georges River 'G1' (the first reference site, Georges River upstream of Brennans Ck) were all below detection (<1 µg/L). The arsenic concentration in the Georges River downstream of Brennans Ck (site 'G2') ranged from 2 to 5 µg/L, averaging 3.3 µg/L from all replicates collected on the three sampling occasions. These results estimate that the nickel concentration raised an average of 3.3 µg/L in the Georges River 100m below Brennans Creek compared to 100m upstream.

Approximately 13 km further downstream, the Georges River (at site G3) the average arsenic concentration was estimated at 1 µg/L (Figure 3). The range of arsenic concentrations at this site varied from below detection to 2 µg/L. This indicated that elevated arsenic in the Georges River rose from G1 above Brennans Creek to G3 (conservatively estimated at 10 km below site G2) and was 1 µg/L. The second reference sites (O'Hares Ck) flows into the Georges River immediately below site G3. Its arsenic levels were all below detection (<1 µg/L).

The arsenic concentration in Brennans Creek ranged from 5 to 6 µg/L and averaged 5.8 µg/L.

Endeavour Coal's Annual returns include data on arsenic. They confirm that arsenic levels are often elevated in Brennans Creek as a result of the discharge from Brennans Creek Dam:

- Endeavour Coal's 2008 Annual Returns to DECCW for EPL 2504 reported that arsenic in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times from *Discharge and Monitoring Point 10*) varied from 4 to a maximum of 14 µg/L, with an average of 8 µg/L#.

(#Note: I have assumed that the 2009 annual returns for arsenic were under-reported by 1000 times due to a typographical mistake and the nickel levels were reported by mistake in mg/L against labelled units of µg/L).

- Endeavour Coal's 2009 Annual Returns to DECCW for EPL 2504 reported that zinc in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times from *Discharge and Monitoring Point 10*) varied from 6 µg/L to a maximum of 20 µg/L, with an average of 11 µg/L#.

(#Note: I have assumed that the 2009 annual returns for arsenic were under-reported by 1000 times due to a typographical mistake and the arsenic levels were reported by mistake in mg/L against labelled units of µg/L).

- Endeavour Coal's 2010 Annual Returns to DECCW for EPL 2504 reported that arsenic in the piped discharge from Brennans Creek dam to Brennans Creek (measured 12 times at *Discharge and Monitoring Point 10*) varied from 6 to a maximum of 16 µg/L, with an average of 10 µg/L.

The ANZECC guideline (trigger value) for toxicants do not provide a trigger level for arsenic. They do provide trigger levels of two arsenic species (As III and As IV) which have respective trigger levels for protection of 95% of species aquatic ecosystems of 24 and 13 µg/L (ANZECC, 2000, Trigger values for toxicants, Table 3.4.1).

2.6 Major anions and cations

On the 26 June 2012 and 3 July 2012, bicarbonate alkalinity concentrations were investigated in the upper Georges River study area:

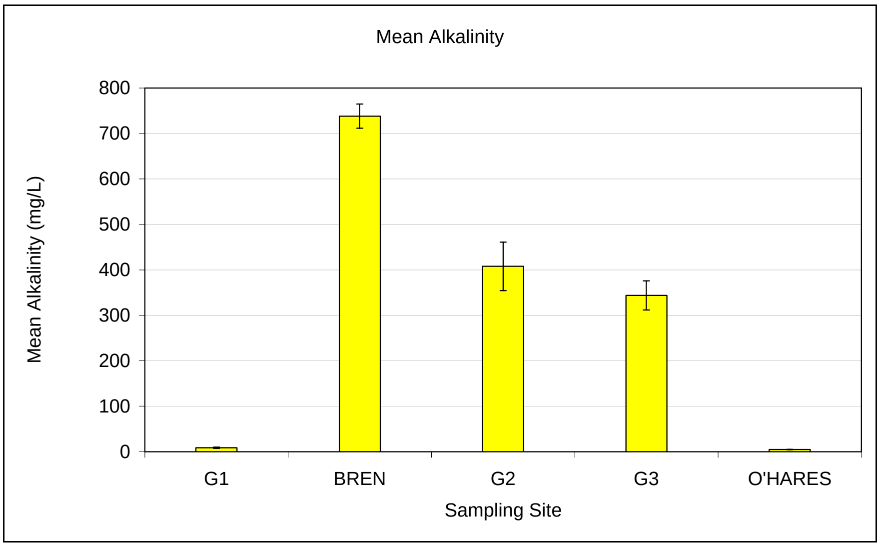

Figure 11: Bicarbonate alkalinity in Upper Georges River (no ANZECC guidelines apply)

The mean upstream bicarbonate alkalinity concentration at Georges River 'G1' (the first reference site, Georges River upstream of Brennans Ck) was 8.7 mg/L (range 6 to 10 mg/L). The bicarbonate alkalinity concentration in the Georges River downstream of Brennans Ck (site ‘G2’) ranged from 282 to 389 mg/L, averaging 407.7 mg/L from all samples collected on the two sampling occasions (Figure 11). These results estimate that the bicarbonate alkalinity raised an average of 335 mg/L in the Georges River 100m below Brennans Creek compared to 100m upstream. This translates to an increase of 4586%

Approximately 13 km further downstream, the Georges River (at site G3) the average bicarbonate alkalinity concentration was 343.7 μg/L (Figure 3). This indicated that elevated bicarbonate alkalinity in the Georges River rose from G1 above Brennans Creek to G3 (conservatively estimated at 10 km below site G2) and was 335 mg/L (an increase of 3850%). The second reference sites (O’Hares Ck) flows into the Georges River immediately below site G3. Its average bicarbonate alkalinity level was 4.7mg/L. On the two sampling occasion’s bicarbonate alkalinity ranged from 685 to 765 mg/L (Table 9).

A study of macroinvertebrates and water quality across the entire Georges River catchment (Tippler *et al.* 2012a) recommended a bicarbonate alkalinity level of <8.6 mg/L. The levels of bicarbonate alkalinity in Brennans Creek and the Georges River (G2 and G3) were 30 to 90 times higher than this guideline.

Endeavour Coal’s Annual returns do not include data on bicarbonate alkalinity.

Table 9. Raw bicarbonate alkalinity (mg/L) data collected on the two sampling occasions (on 26 June occasion a single sample was collected and on the 3 July occasion two replicate samples were collected).

	G1	BREN	G2	G3	O'HARES
26/06/2012	10	685	514	282	4
3/07/2012	6	765	352	360	5
	10	764	357	389	5

On the 26 June 2012 and 3 July 2012, sodium concentrations were investigated in the upper Georges River study area:

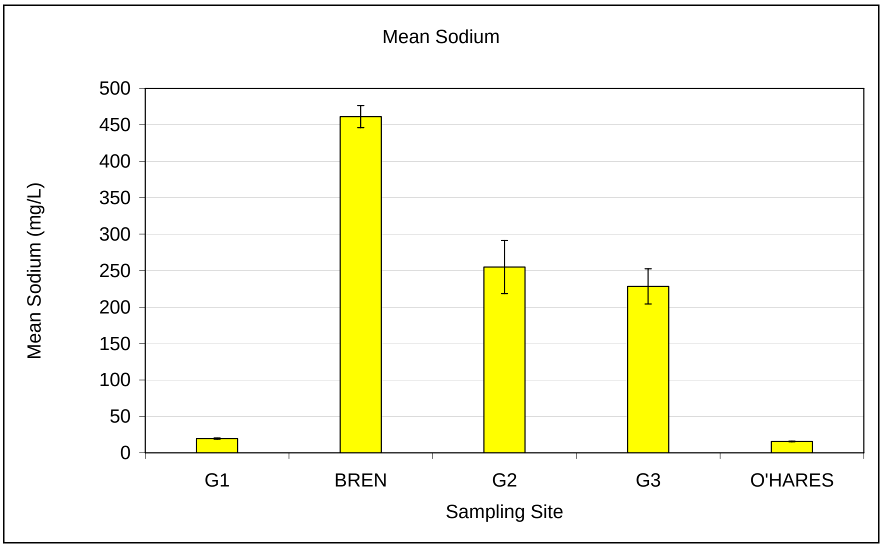

Figure 12: Sodium in Upper Georges River (no ANZECC guidelines apply)

The mean upstream sodium concentration at Georges River ‘G1’ (the first reference site, Georges River upstream of Brennans Ck) was 19.7 mg/L (range 18 to 21 mg/L). The sodium concentration in the Georges River downstream of Brennans Ck (site ‘G2’) ranged from 212 to 328 mg/L, averaging 255 mg/L from all replicate samples collected on the two sampling occasions (Figure 12). These results indicate that the sodium concentration raised an average of 235 mg/L in the Georges River 100m below Brennans Creek compared to 100m upstream. This translates to an increase of 1194%

Approximately 10 km further downstream, the Georges River (at site G3) the average sodium concentration was 228.3 mg/L (Figure 3). This indicated that elevated sodium concentrations in the Georges River rose from G1 above Brennans Creek to G3 (conservatively estimated at 10 km below site G2) and was 335 mg/L (an increase of 1058%). The second reference sites (O’Hares Ck) flows into the Georges River immediately below site G3. Its average sodium level was 15.7 mg/L.

Endeavour Coal’s Annual returns do not include data on sodium.

These results indicate that the level of sodium and bicarbonate alkalinity (as specified above) in the Georges River had increased as a result of the inflow of Brennans Ck, and that the discharge from Brennans Creek dam is the only likely source of this increase.

The ionic composition of Brennans Ck and the Georges River (below Brennans Ck) was unnatural and different to that at reference sites (see above sodium and bicarbonate results). The ionic composition of the Georges River and O’Hares Creek (reference sites) were both dominated by sodium and chloride. This suggests that the natural source of dissolved salts in natural and undisturbed waterways in the upper Coxs area is from atmospheric deposition of salts rather than weathering of soils and geology (Gibbs, 1970; Buckney, 1980; Hart and

McKelvie 1986). Other samples collected by myself in 2011 (for a research study) in the same area showed that most undisturbed catchment headwater ‘reference’ streams in the area were similar to the Coxs River reference site (Wright, 2012). I found that reference sites in the area were dilute (weakly saline with low electrical conductivity levels) and were dominated by sodium and chloride ions. In contrast, Brennans Creek was highly saline (averaging about 1800 μS/cm) and had a strongly modified ionic composition, with sodium and bicarbonate dominance. The composition of major anions and cations in the Georges River below Brennans Creek was similar to that found in Brennans Creek sites (sodium and bicarbonate dominance).

The ionic concentrations of Brennans Creek, when compared to a detailed study of water chemistry of freshwater streams in the Sydney basin and Hawkesbury-Nepean catchment, indicate that the changes are unnatural and are elevated well above regional averages (Hayes and Buckney, 1995). The concentrations of anions and cations in Brennans Ck were highly elevated. In particular, the levels of sodium, carbonate, sulfate, bicarbonate and chloride in Brennans Ck recorded on June and July 10 2012 are elevated above the highest regional average levels found by Hayes & Buckney (1995) in non-tidal freshwater streams across the Hawkesbury-Nepean catchment (and Sydney Basin) waterways. The magnitude of the difference between the highest average levels (recorded by Hayes and Buckney, 1995) and those recorded in Tortuous Watercourse on 10 June 2011 was more than 31 times (bicarbonate), 13 times (sodium) and 32 times (sulfate).

The ionic composition of Brennans Ck and the downstream Georges River (site G2 and G3) differed to that at reference waterways and are likely to have adverse implications for in-stream aquatic ecosystems. For example, benthic diatom communities in the United States were reported by Potopova and Charles (2003) to be strongly influenced by ionic composition. Variation in the concentration of each anion and cation, along with changes in electrical conductivity and pH, were all found to strongly affect diatom species composition. Other repercussions may occur throughout the food web when anthropogenic geochemical changes modify algal communities at the base of aquatic food chains.

Macroinvertebrate Data

Freshwater macroinvertebrate data was requested from the Georges River Combined Councils Committee (GRCCC) for the sampling sites in the study area (and from additional reference sites). The data was collected according to methods described in Tippler *et al.* (2012a; b) and this was collected on 4 occasions (spring/summer): Spring 2009, Autumn 2010, Spring 2010, Autumn 2011. Summary reports from the GRCCC concluded that macroinvertebrates at the study sites indicated that Brennans Creek was highly degraded, with the two Georges River sites below Brennans Creek (referred to as G2 and G3 in this report) also showing degraded ecosystem health (Tables 10-12). The two reference sites in this study (G1 and O'Hares) had higher ecosystem health (Tables 10-12).

All analyses of the macroinvertebrate data indicated that the sampling site with the most degraded ecological condition was Brennans Creek, followed by the Georges River below Brennans (G2) and then the Georges River at the Woolwash (G3). Both reference sites (GR1 = Georges River at Appin and O'Hares Creek) had the highest ecological condition.

This analysis reflected the level of taxonomic richness, SIGNAL biotic index score, and the overall assessment of the GRCCC (Tables 10-12). In addition, my own analysis of the data using the proportion of the three most sensitive invertebrate orders (Mayflies = Ephemeroptera; Stoneflies = Plecoptera and Caddisflies = Trichoptera) showed that Brennans Creek had the lowest % of EPT. The next lowest % of EPT animals was at G2 and G3.

The analysis of the all macroinvertebrate community data (multivariate data analysis) also indicates that assemblages at Brennans Creek; G2 and G3 are all distinctly different to the communities at the reference sites (Figure 15). This is apparent in the MDS ordination (Figure 15) with reference sites (green triangle symbols) clustering separately from the blue triangles (Brennans Ck, and G2 and G3). The visual differences are statistically significant according to analysis of similarity (ANOSIM) analysis. Similar statistical techniques have previously established the variation in ecological condition of macroinvertebrates across the entire Georges River catchment (Tippler *et al.* 2012a, b).

Table 10 Overall macroinvertebrate grades for streams in the study area (GRCCC)

	Autumn 2011	Spring 2010	Autumn 2010	Spring 2009
Georges River Appin	A	A-	B	B
Brennans Creek	D-	E+	F+	C-
Georges River downstream of Brennans Creek	D+	C-	E	C
Georges River at the Woolwash	B	B	B	B-
O'Hares Creek at the Woolwash	A	A	A-	A

Table 11 Overall macroinvertebrate taxonomic richness (order) for streams in the study area (reported by GRCCC)

	Autumn 2011	Spring 2010	Autumn 2010	Spring 2009
Georges River Appin	12	9	9	10
Brennans Creek	6	7	6	8
Georges River downstream of Brennans Creek	9	8	6	7
Georges River at the Woolwash	11	12	11	13
O'Hares Creek at the Woolwash	10	9	13	12

Table 12 Overall macroinvertebrate SIGNAL score (order) for streams in the study area (reported by GRCCC)

	Autumn 2011	Spring 2010	Autumn 2010	Spring 2009
Georges River Appin	4.55	4.70	5.30	4.24
Brennans Creek	4.96	3.58	3.80	4.73
Georges River downstream of Brennans Creek	4.17	4.84	4.26	4.70
Georges River at the Woolwash	3.40	3.96	3.15	4.50
O'Hares Creek at the Woolwash	4.96	5.96	5.05	4.82

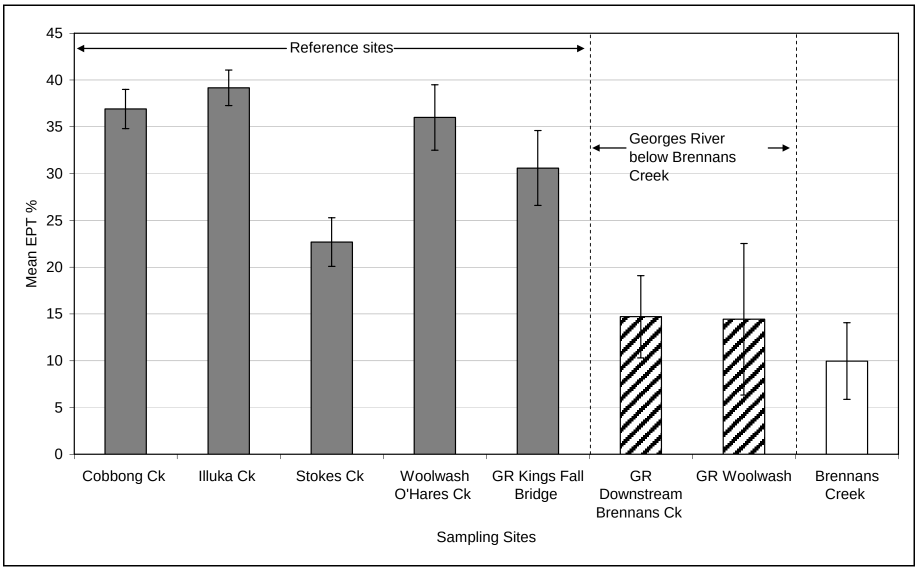

Figure 13. Mean % EPT (+/- standard error of mean) at five reference sites (shaded columns), two Georges River sites below Brennans Ck (cross-hatched columns) and Brennans Ck (unshaded column).

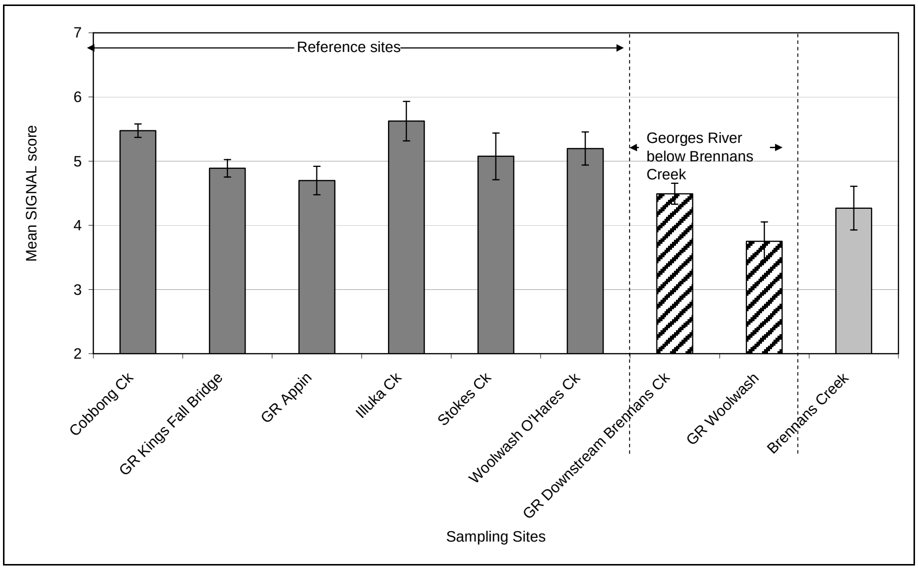

Figure 14. Mean SIGNAL scores at six reference sites (dark gray columns), two Georges River sites below Brennans Ck (cross-hatched columns) and Brennans Ck (light gray column).

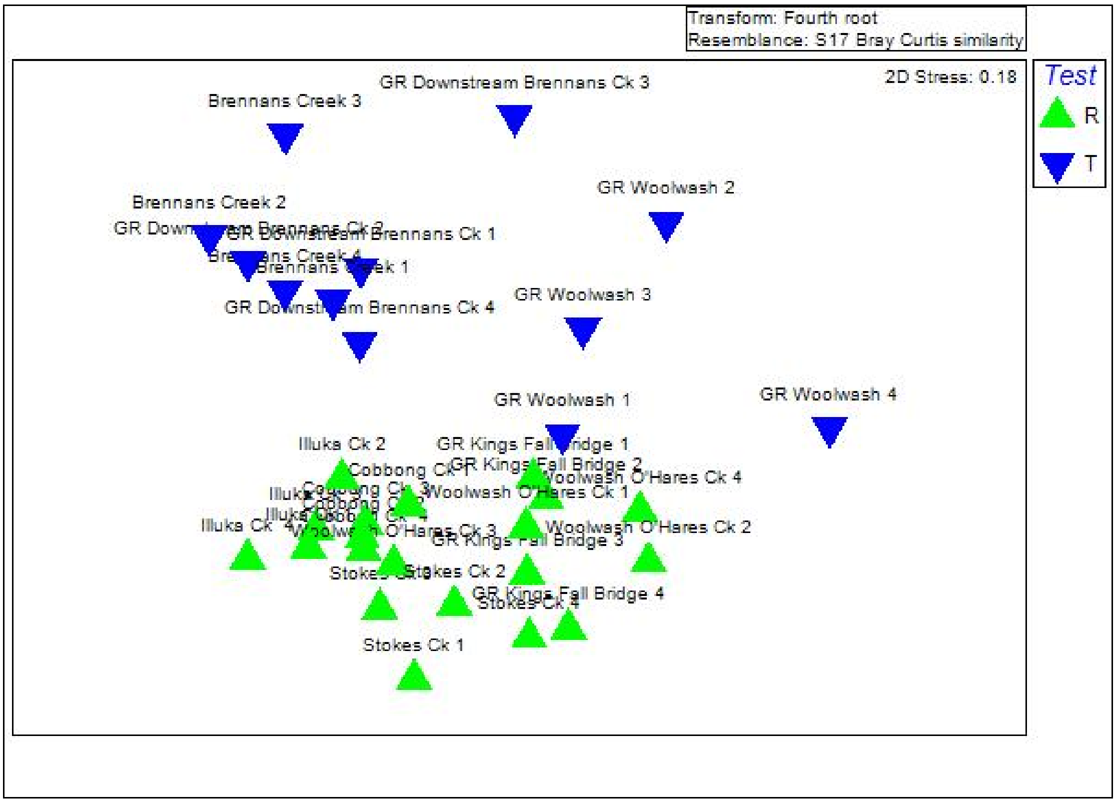

Figure 15. NMDS Ordination for macroinvertebrate samples collected by GRCCC (at reference sites (green upward pointing symbols) and sites immediately below the West Cliff coal mine (Brennans Creek and Georges River) indicated by blue symbols (downward pointing triangles).

3. Effects of pollutants in Brennans Creek and the Georges River

Given the large number of chemical contaminants and their additive natures (i.e. their impacts are not reduced by the addition of other contaminants) I am of the view the overall chemical condition of the waters in the Georges River downstream of the inflow of Brennans Creek has been substantially modified, in complex ways, as a result of the inflow from the coal mine Brennans Creek Dam and that the combined effect is a negative one for river water quality and for aquatic ecosystems.

Many of the chemical contaminants in this report is considered to be a stressor (see ANZECC 2000) on the aquatic ecological communities, and since the water quality results indicate that there are multiple, different stressors acting on the community, the total impact on the community, within Brennans Creek and the effect of the Brennans Ck inflow to the Georges River ecosystems, is likely to be large and is likely to be greater than the sum of its component stressors (Folt *et al.,* 1999).

The aquatic ecosystem (macroinvertebrate) data conducted by the GRCCC provide independent confirmation that aquatic ecosystems within Brennans Creek, and the two Georges River sites below Brennans Creek, have impaired community structure and lower abundance of the more water pollution sensitive macroinvertebrate groups (lower % EPT; Lower SIGNAL scores; dissimilar community assemblages at sites below West Cliff mine compared to reference sites). The multivariate data analysis of macroinvertebrates (GRCCC data) identified the taxonomic groups that were most influenced by the coal mine drainage verses the reference sites (Appendix 1). The SIMPER results highlight the lower abundance of sensitive mayfly, stonefly, decapod and caddisfly groups are influential in the community assemblage differences in Brennans Creek (and the two sites below Brennans) compared to clean reference creeks (Appendix 1).

A study of metal pollution and macroinvertebrate communities in England (Gower *et al.*, 1994) concluded that copper and aluminium had direct toxic effects and also interacted with pH and other chemistry attributes. Gower et al. (1994) also made the point:

> *'However since much of our understanding of interactions between metals and water chemistry is based an acute lethal studies on a limited range of species and life cycles, the toxicity of Cu under natural conditions cannot be accurately predicted from extrapolation of laboratory findings'.*

This statement is particularly appropriate for our patchy scientific understanding of what the exact combination of factors within the waste water that is most ecologically damaging in Brennans Creek and the immediate downstream reaches of the Georges River. This is expressed well in the report 'West Cliff Colliery Pollution Reduction Program 10 – Glass Shrimp Translocation Experiment' (PRP 10: Cardno/Ecoengineers, 2009):

'Statistical analysis showed that Brennans Creek and locations downstream in Georges River differed significantly in respect of water chemistry from the other locations in complex ways, with respect to pH, Major cations and anions i.e the components of salinity, and trace level components such as dissolved organic carbon, aluminium, nickel and zinc and dissolved forms of nitrogen and phosphorus nutrients.
The mortality (proportion of deaths of the glass shrimp during the experiments) was generally low at all sites. Shrimp mortality was significantly greater at the Brennans Creek site compared to all other sites, and shrimp mortality broadly decreased with distance downstream in the Georges River in both experiments, although not invariably monotonically (i.e. smoothly).'

The decapod crustacean group was shown by the macroinvertebrate data collected by the GRCCC to be one of the most influential in the ecological differences between reference sites and the Brennans Creek and G2 and G3 sites (they were less abundant in the collections at Brennans Ck and G@, G3 than at reference sites) (Appendix 1). One species of decapod demonstrated a sensitivity to pollution as part of the PRP10 experiments found that the (*Paratya australis* or the glass shrimp) showed high sensitivity to West Cliff Colliery mine water (PRP 10: Cardno/Ecoengineers, 2009) as they report:

'In experiment 1 shrimp mortality at Brennans Creek was 33 % compared to 10% in other locations...'

PRP 10.1 (Cardno Ecology Lab / EcoEngineers March 2012 'West Cliff Colliery – Discharge of Water from Brennans Creek Dam PRP 10.1' also reported ecotoxicology :

Water from West Cliff mine was the most toxic to algae and duckweed. Mayflies were sensitive to mine water, although West Cliff water had the smallest effect on these insects with a 240 hour EC50 value of 2426 uS/cm. The corresponding values for glass shrimps and water fleas were (which were most senstivie) were 2932 and 1525 us/cm, respectively. Pure salt solutions were uniformly less toxic than mine water. The test fish species (rainbow fish) was unaffected by any of the mine waters.

In May-June 2012 the NSW OEH conducted ecotoxicology assessment of waters from Brennans Creek and the Georges River. Their stated purpose was:

'*This study was implemented to provide an independent ecotoxicological assessment of the LDP10 discharge. It did not seek to reproduce the Pollution Reduction Program 11 study carried out by Ecoengineers P/L to assess the contribution of the coagulant Magnasol 572 on previously observed laboratory and field effects (but noting that the report concludes that the coagulant does not appear responsible). The PRP 11* *study (Short 2012), does provide additional information which assists in interpretation of the results of this work'.*

The OEH 2012 report made the following summary conclusions about the ecotoxicty consistency results between the two different laboratories:

Ecotoxicity tests carried out at separate facilities on similar samples, returned similar results. For example PRP11 study samples collected from the LDP10 discharge on 5/6/12 were found to cause larval fish mortalities down to a 25% sample concentration (1:3 dilution), and these mortalities primarily occurred on the last day of the 96 hour test (noting test solutions were not renewed). Comparable toxicity effects were noted in similar LDP10 discharge samples in a number of larval fish tests carried out at the OEH facility. The absence of acute toxicity to C. dubia in the current (lower than average conductivity) LDP10 samples was the same between the two laboratories.

And they reported:

'Ecotoxic effects in Georges River samples, taken immediately downstream of the Brennans Creek confluence were primarily limited to acute lethality effects on larval fish and sublethal reproductive impairment on crustacean waterfleas.'

The complete environmental impact of the Endeavour Coal waste discharge on the Brennans Creek and Georges River and their ecosystems is complex and is very difficult to determine with total and complete scientific certainty. Much of this report has detailed the potentially harmful effects of individual contaminants (such as metals) to aquatic biota. In addition to direct harm of an individual contaminant, it is possible that the inflow of the contaminated water (from Brennans Creek Dam) to the Brennans Creek and Georges River also causes non-lethal multiple indirect effects on the river ecosystem (Fleeger *et al.*, 2003), such as; reduction in reproductive health of biota; modification of predator-prey relationships and reduction in quality of food resources. The total combined effect of the inflow of mine drainage would include all direct harmful effects on ecosystem biota and all indirect effects on the biota and their habitat.

Such complex situations are not unusual and the 'weight-of-evidence' concept has been developed for similar situations where the exact causation of ecological risk is complex and uncertain (Linkov *et al*., 2009):

'Other ecotoxicology studies have also added further 'weight of evidence' that Risk management decisions and policies based upon risk assessments result in benefits and costs to human well-being, ecological resources, and economies, affecting both the private and public sectors. Generic appeals for the use of "sound science" imply that a scientific approach to addressing a problem or question inevitably leads to only one certain conclusion or one reasonable option. This is

far from reality, given the complexities and uncertainties characteristic of most environmental problems. However, it should be the case that policy decisions are founded upon evidence-based conclusions that draw from good scientific practice.'

The total combined effect of the inflow of mine drainage would include all direct harmful effects on ecosystem biota and all indirect effects on the biota and their habitat. Of greatest concern are the consistently elevated levels of salinity (electrical conductivity), nickel, zinc, copper, aluminium, turbidity, cobalt, nitrogen and pH which have increased in the Brennans Ck and Georges River due to the inflow of mine wastewater and were found to be above ANZECC ecosystem protection guideline levels and all indicate a high risk of damage to the aquatic ecosystem in both waterways. Please note that Cobalt and Nitrogen were not tested for this study, but were identified in the work by Cardno Ecology Lab / Ecoengineers. However since so many contaminants and other water chemistry attributes from the above ecosystem protection guidelines (where guidelines are available), considered collectively the contaminants may have strongly adverse synergistic effects on natural ecosystems. The GRCCC macroinvertebrate data and multiple ecotoxicology test results (Decapod crustacean Glass Shrimp; larval fish mortality; sublethal reproductive impairment of crustacean waterfleas; algae, duckweed and mayflies).

4. Conclusions

In my opinion, based on the results presented in this report, the inflow of the Endeavour Coal West Cliff mine wastewater discharge into Brennans Creek and the Georges River has adversely changed the physical, chemical and biological condition of the water. Endeavour Coal's environmental monitoring data reported as Annual Returns to the EPA (as part of the monitoring requirements under EPL 2504), demonstrated that the discharge point labeled as 'Discharge and Monitoring Point 10' in EPL 2504, has released water contaminated by high salt levels, and elevated Copper, Zinc, Nickel, Arsenic, Salt and pH levels which were consistently recorded in Brennans Creek from 2008 to 2010. Multiple ecotoxicology studies have detected ecotoxicty in Brennans Creek and the West Cliff mine waste water (Cardno Ecology Lab / Ecoengineers 2009, 2010; NSW OEH, 2012). Macroinvertebrate data collected by the GRCCC has demonstrated ecological impairment of aquatic ecosystems (particularly with the lower abundance of sensitive taxonomic groups such as Decapod crustaceans, Mayflies, Stoneflies and Caddisflies) within Brennans Creek and in the Georges River below Brennans Creek. Community analysis has also indicated that pollution sensitive groups such as Gastropods and Diptera have become more abundance at mine drainage affected sites. My personal observations have indicated that the invasive introduced gastropod species *Physa acuta* (which tolerates poor water quality) is present at the mine-affected sites.

In my opinion the inflow of Endeavour Coal's wastewater discharge *pollutes* Brennans Creek and the Georges River, as the inflow adversely changed the physical and chemical condition of the water. The GRCCC macroinvertebrate data shows that the biological condition of the Brennans Creek and the Georges River G2 and G3) is also ecologically degraded. The cause of the degradation is due to the presence of chemical toxicants in Endeavour Coal's wastewater discharge to Brennans Creek, at levels stressful to aquatic ecosystems. This concept is supported by the multiple ecotoxicology tests (Cardno Ecology Lab and Ecoengineers and NSW OEH) that have reported different forms of toxicity to a range of aquatic organisms (algae, fish larvae, water fleas and Decapod glass shrimp). In addition, this concept is also supported by the measurement of pollutant levels higher than those recommended by the ANZECC (2000) guidelines for ecosystem protection (Aluminium, Zinc, Nickel, Copper, Cobalt Nitrogen, Salinity (uS/cm), pH and turbidity. For some chemical attributes (such as changes to ionic composition: sodium and bicarbonate) there are no ANZECC (2000) guidelines yet the implications of unnatural changes to the Brennans Creek and the Georges River ionic concentrations and composition probably has unnatural and adverse ecological impacts.

On all occasions on which I sampled I considered that the inflow of coal mine drainage to Brennans Creek posed a significant risk of harm to aquatic ecosystems in the Brennans Ck and Georges River waterways. The results of the EPL 2504 Annual returns and the Cardno Ecology Lab Ecoengineers 2009 and 2010 and the OEH 2012 ecotoxicology report also confirm that on many occasions the mine water is of high risk of harming aquatic ecosystems and resident species. This indicates that achieving healthy ecosystems in the upper Georges River catchment is made much more difficult by the mine drainage discharge of wastewater.

Water quality at Brennans Creek and the Georges River downstream of Brennans Creek on all sampling occasions was probably stressful, and possibly toxic, to aquatic ecosystems (and component biota such as waterplants, zooplankton, invertebrates and fish) particularly due to elevated levels of the toxicants salt, cobalt, pH, turbidity, copper, zinc, nickel, aluminium and nitrogen from the coal mine discharge. It is likely that the more sensitive species across many biological groups would be damaged or killed by the elevated contaminant levels. Pollution tolerant groups of biota (such as invasive species of Gastropods) are likely to have taken their place, with a resulting degradation of aquatic ecosystem community structure due to frequently toxic water quality conditions. Several Australian scientific studies have associated heavy-metal pollution with such degradation of aquatic ecosystems (e.g. Nicholas & Thomas, 1978; Norris *et al.* 1981, Norris *et al.* 1982, Norris, 1986; Wright & Burgin, 2009). A study of metal-contaminated streams in England (Gower *et al.*, 1994) found that copper, in particular, had a major role in influencing stream ecosystems. In addition, Gower et al. (1994) found that complex interactions between copper, aluminium, pH, hardness, alkalinity and organic material affected stream ecosystems.

Finally, the water chemistry of the Georges River has been modified by Endeavour Coal Brennans Ck dam inflows in many ways that probably include non-toxic effects. For example the coal mine discharge contributes to major changes to its ionic concentrations and composition. The ionic changes are likely to be ecological influential, particularly through the supply of minerals that influence plant and animal growth in the Brennans Ck and Georges River ecosystems. A study by Zalizniak *et al.*, (2009) on the effects of salinity and ionic composition on an aquatic snail (*Physa acuta*) found that '*…ionic compositions has more effect on the snail's growth than salinity*'. Algal diatoms are at the base of many aquatic ecosystem food chains and their species assemblages are known to be highly responsive to the overall salinity (Philibert *et al.*, 2006) as well as the concentration of major anion and cations (such as sodium, chloride, magnesium, bicarbonate, carbonate, calcium, sulfate) (Potopova and Charles, 2003).

Given the lack of complete scientific certainty about what exact factor, or combination of factors, contributes to the ecological impairment to the Brennans Creek and Georges River aquatic ecosystem it seems that the *precautionary principal* must be central to decisions about future EPL 2504 discharge conditions to provide protection for the biodiversity of the Georges River. We do have scientific certainty that the aquatic ecosystem is impaired due to the EPL 2504 discharge. We also have scientific certainty that the water is polluted with chemicals at levels known to be ecologically stressful. We also know that water quality is always (on each individual sampling occasion) at very high risk of being damaging to aquatic ecosystems. But we lack the knowledge about exactly which combination of factors is causing the damage. The current EPL 2504 includes three physical/chemical attributes that provide no protection at all, and are irrelevant to the most dangerous toxicants identified in this (and other referenced studies) from the West Cliff waste discharge (such as copper, nickel, zinc, aluminium, cobalt, salinity, turbidity, pH, nitrogen, bicarbonate, sodium). Surely in such circumstances we should be guided by physical, chemical and biological reference sites that exist in the upper Georges River catchment? This report provides unusually comprehensive evidence that the West Cliff coal mine waste discharge is polluting the Georges River and that EPL 2504 currently provides no effective discharge conditions to pollutants that are released. It should also be noted that at times the EPL 2504 has reported ‘spikes’ of contaminants (such as nickel) discharged to Brennans Creek at levels nearly 2.5 times higher than was observed in June/July 2012. Many natural aquatic species have life cycles of months and years and the ecological stress of short highly toxic periods may have very long lasted adverse impacts. Water samples for EPL 2504 discharge limits must be collected at more regular intervals (weekly as a minimum) to obtain a more detailed temporal understanding of contaminant levels.

5. Revised discharge conditions for EPL 2504

Based on the reasoning detailed in this report, I recommend the following discharge limits for EPL 2504, to ensure that the discharge of waste from West Cliff Colliery does not adversely impact the aquatic ecosystems of Brennans Creek and the Georges River. The recommended discharge limits includes regular (spring/autumn) assessment of in-stream macroinvertebrate and attached algal diatom communities (both identified to the species level) to more accurately quantify the health of natural ecosystems (and measure the impact of the proportion of species below the discharge relative to local reference sites). The chemical concentration limits should be based on the ANZECC (2000) guidelines and the natural background contaminant levels.

Table 13. Coal mine wastewater discharge conditions under *Protection of the Environment Operations Act* (1997) NSW, as specified in the following 'Environmental Protection License' (EPL) 100 % discharge limits.

	Current discharge limits EPL 2504	Recommended discharge limits for EPL 2504
Toxicant / attribute	Brennans Ck (trib. of Georges R)	
Macroinvertebrate species assemblages		The inflow of Brennans Creek to the Georges River will cause no measurable adverse impact for 99 % of diatom species assemblages.
Algal diatom species assemblages		The inflow of Brennans Creek to the Georges River will cause no measurable adverse impact for 99 % of diatom species assemblages.
Oil & Grease (mg/L)	10	(based on background level recorded at reference sites)
pH (pH units)	6.5-9.0	Max 7.1 (Tippler *et al.* 2012a)
Total Suspended Solids (mg/L)	50	Lack of comparative data (based on background level recorded at reference sites)
Turbidity		(based on background level recorded at reference sites)
Copper		Max. 1.4 μg/L (ANZECC, 2000)
Aluminium		Max. 55 μg/L (ANZECC, 2000)
Cobalt		(based on background level recorded at reference sites)
Nickel		Max. 11 μg/L (ANZECC, 2000)
Zinc		Max. 8 μg/L (ANZECC, 2000)
Arsenic		(based on background level recorded at reference sites)
Total Nitrogen		Max. 200 μg/L (Tippler *et al.*, 2012a)
Salinity		Max. 212 μS/cm (Tippler *et al.*, 2012a)
Ionic composition		Cause no modification of reference creek ionic composition and concentration (e.g. bicarbonate, sodium, calcium)

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Appendix 1. PRIMER OUTPUT for analysis of GRCCC macroinvertebrate data

1. ANOSIM results TESTS FOR DIFFERENCES BETWEEN Test GROUPS
(across all TIME groups)
Global Test
Sample statistic (Global R): 0.644
Significance level of sample statistic: 0.1%
Number of permutations: 999 (Random sample from 9834496)
Number of permuted statistics greater than or equal to Global R: 0

TESTS FOR DIFFERENCES BETWEEN TIME GROUPS
(across all Test groups)
Global Test
Sample statistic (Global R): -0.038
Significance level of sample statistic: 67.6%

2. SIMPER results

Groups R (reference sites) & T (downstream of the coal mine discharge)
Average dissimilarity = 36.56

Species	Group R Av.Abund	Group T Av.Abund	Av.Diss	Diss/SD	Contrib%	Cum.%
Decopoda	2.13	0.63	4.57	1.80	12.49	12.49
Acarina	1.74	0.35	4.13	1.94	11.31	23.79
Hemiptera	1.62	2.15	2.75	1.33	7.53	31.32
Gastropoda	0.15	1.06	2.75	1.11	7.52	38.84
Bivalvia	0.83	0.66	2.72	1.05	7.45	46.29
Plecoptera	0.87	0.08	2.37	1.02	6.47	52.77
Ephemeroptera	2.19	1.54	2.31	1.22	6.32	59.08
Tricoptera	2.22	1.54	2.11	1.22	5.76	64.84
Oligochaeta	0.62	0.22	1.76	1.00	4.80	69.64
Diptera	1.99	2.13	1.75	1.19	4.79	74.43
Arachnida	0.58	0.60	1.73	1.13	4.72	79.15
Turbellaria	0.24	0.56	1.65	0.90	4.52	83.67
Megaloptera	0.45	0.16	1.43	0.75	3.91	87.57
Odonata	1.80	2.01	1.22	1.20	3.32	90.90