ASSESSMENT OF WATER QUALITY EFFECTS

WEST CLIFF COLLIERY LONGWALLS 34 TO 36

for

CARDNO FORBES RIGBY PTY LTD

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EXECUTIVE SUMMARY

The water quality effects associated with the proposed Longwalls 34-36 at West Cliff Colliery Area 5 has been assessed. River bed flow diversions resulting from fracturing of controlling rock bars and their attendant water quality issues, as well as the inducement of ferruginous springs, are the two principal mechanisms that may give rise to water quality impacts from the proposal. Neither mechanism is likely to give rise to significant water quality impacts in the Georges or Nepean Rivers, or named creeks that flow to these rivers.

River bed flow diversions

River bed flow diversions due to river bed fracturing (exposing siderite/rhodocrosite and possibly also significant marcasite in unweathered sandstone), arising from Longwalls 34 to 36 are considered unlikely. Such river bed flow diversions were not observed for Longwalls 29 and 31 which, like proposed Longwalls 34 – 36, did not mine directly under the Georges River. Recent experience with Longwalls 301 and 302 for Appin Colliery adjacent to Cataract River also support this inference. Nevertheless, should such diversions occur, a considerable ‘mitigative effect’ against ecotoxicity effects attributable to acidity, dissolved nickel and zinc (the principal, potentially ecotoxic trace metals in the Georges River waters) is provided by the controlled release of weakly saline waters from Brennans Creek Dam at West Cliff Colliery which was made (in part) to maintain an environmental base flow in the Georges River over the 2000 – 2006 drought years. The West Cliff release contains a concentration (1000 – 1500 mg/L typically) of bicarbonate/carbonate alkalinity which serves to:

- ‘buffer out’ any acidity generated by mining-induced freshly fractured sandstone bedrock; and also
- complexes dissolved nickel and zinc, greatly reducing the concentration of ecotoxic, cationic forms of these metals.

Using geochemical modelling, the following effects have been inferred to be the <u>maximum short term ‘worst case’</u> effects at the peak of the rate of dissolution of marcasite in the Hawkesbury Sandstone bedrock of the river:

1. Only in the case where 0.5 ML/day is diverted through freshly fractured bedrock, and there was absolutely no diluting surface flow, would emerging waters be highly reduced (Oxidation Reduction Potential; ORP <0 mV) and largely devoid of dissolved oxygen, but they would have extremely low levels of the ecotoxic species of nickel and zinc.
2. Where sub-bed diversion flows are less than one third of the total river flow (which is extremely likely) there would be no exceedance of the national water quality guidelines at the emergence point for pH, dissolved oxygen and dissolved ecotoxic cationic nickel, but considerable exceedances of the default national water quality guidelines (for protection of 95% of all aquatic species) for dissolved cationic zinc would remain.
3. For river flows up to at least 2.5 ML/day, only if there were at least one third diverted through the fractured riverbed, which is extremely unlikely, would there be considerable exceedances of the default national water quality guidelines at the emergence point for dissolved oxygen, dissolved, ecotoxic

cationic zinc, and minor exceedances for ecotoxic cationic nickel but no exceedances for pH.

It has been shown that potential mining-related river bed fracturing effects do not have the capability to drive pHs in the river above 8.5 or below 6.5. It is therefore predicted that there will be no significant effect on pH from any effect resulting from the extraction of the proposed longwalls.

On the basis of the information presented in this report we conclude that:

1. the **Likelihood** of one or more sub-bed flow diversions arising within Georges River as a consequence of the mining of proposed Longwalls 34 - 36 is **Minor;** but
2. the **Consequences** of such a diversions on aesthetics of the River from visible iron staining would be **Major**; however
3. the **Consequences** of such a diversion to the **Ecological Health** of immediate downstream pool(s) would be **Insignificant** provided the River continued to receive an environmental flow e.g. from West Cliff Colliery in excess of 0.5 ML/day with an Total Alkalinity in excess of 500 mg/L expressed as $CaCO_3$ (calcium carbonate).
4. the **Consequences** of such a diversion to the **Ecological Health** of immediate downstream pool(s) in the River would be **Major** only under low flow conditions (<0.3 ML/day) which have occurred no more than 15% of the time since the introduction of the controlled discharge to the River from West Cliff Colliery BCD; and
5. the **Consequences** of such a diversion or diversions to **Property** would be **Insignificant to None**.

Ferruginous springs

A ferruginous spring (Pool 11 spring) adjacent to the Georges River was induced when Longwalls 5A1 and 5A2 were mined beneath the River. However, subsequent extraction of Longwalls 29 and 31, which were not mined directly under the River, has not led to the creation of any ferruginous spring. This applies even though they mined under an upland catchment on the western side of the river of significant size (0.72 km^2). It might therefore be inferred that the smaller catchments further to the north proposed to be mined under by Longwalls 34 to 36 are at even lower probability of risk from this phenomenon.

With respect to the possible induction of a ferruginous spring, if it should occur, then the following effects are inferred, on the basis of geochemical modelling, to be the maximum 'worst case' long term effects in Georges River:

1. For all discrete spring flows into the river above 0.1 ML/day and river flows below about 0.3 ML/day (which occur less than 15% of the time), the default lower limit for dissolved oxygen in the national water quality guidelines (85% of saturation) would not be met at the spring emergence point.
2. For all discrete spring flows into the river below 0.2 ML/day and river flows below about 0.5 ML/day (which at least 25% of the time) the 95% default limit for nickel in the national water quality guidelines would not be exceeded by the concentration of cationic ecotoxic nickel species at the spring emergence point.

3. For all discrete spring flows into the river below about 0.2 ML/day and river flows below about 0.5 ML/day (which occur 25% of the time), the 95% default limit for zinc in the national water quality guidelines would not be exceeded by the concentration of cationic ecotoxic zinc species at the spring emergence point.
4. for all discrete spring flows into the river above 0.15 ML/day and river flows below about 1.0 ML/day (which occur at least 50% of the time), the default lower limit for dissolved oxygen in the national water quality guidelines would be only marginally not met at the spring emergence point

Given the nature of Georges River bed, it is believed that typical re-aeration coefficients applying in the River would be such that, for discrete ferruginous spring flows into the River above 0.15 ML/day, and concurrent river flows above 0.5 ML/day, the minor deficit in dissolved oxygen at any spring emergence point would not have any significant impact. Geomorphological considerations suggest the river water should be quickly re-aerated over a very short distance. It is estimated that such springs would cause a considerable river dissolved oxygen deficiency at their emergence points only if their flow rate exceeded 0.1 ML/day and if flows in the river were concurrently <0.3 ML/day which, since August 2004 has occurred less than 15% of the time. There is only an extremely low likelihood of this occurring.

Such springs do not usually contain enough dissolved iron and manganese to cause a significant depression of river pHs through the oxidation and precipitation of hydrous Fe and Mn oxides simply because the River water contains significant bicarbonate alkalinity deriving from the BCD discharge from West Cliff Colliery. Again, the principal reason why concentrations of ecotoxic nickel and zinc species in the River deriving from any such springs would not exceed the default national water quality guidelines limits for nickel and zinc of 0.011 and 0.008 mg/L respectively for River flows of 1.0 ML/day and above is due to the considerable carbonate alkalinity in the water discharged from Brennans Creek Dam which constitutes the major part of the flows in the river (i.e. up to at least the 50 percentile flows).

Given the nature of the Georges River bed, it is not believed that typical re-aeration coefficients applying in the river would be such that, for discrete spring flows into the river above 0.15 ML/day, and river flows above 0.5 ML/day, the minor deficit in DO at the spring emergence point would have a significant impact. This is because geomorphological considerations suggest the river water should be quickly re-aerated over a very short distance.

It is concluded that such springs would only cause a considerable river dissolved oxygen deficiency at their emergence points if their flow rate exceeded 0.1 ML/day and if flows in the river were concurrently <0.3 ML/day (i.e. of <15% probability). While the regular 50 percentile discharge from BCD of at least 1.0 ML/day remains in place the likelihood of this sort of event occurring is very low indeed.

On the basis of the information presented in this report we conclude that:

1. the **Likelihood** of one or more ferruginous springs arising within Georges River from effects within the small western catchments draining towards the River as a consequence of the mining of proposed Longwalls 34 - 36 is **Rare;** and

2. the **Consequences** of such a spring or springs to **Property** would be **Insignificant to None;** and

3. the **Consequences** of such a spring or springs to the **Ecological Health** of immediate downstream pool(s) would be **Insignificant** provided the River continued to receive an environmental flow e.g. from West Cliff Colliery, in excess of 1 ML/day with an Total Alkalinity in excess of 500 mg/L expressed as $CaCO_3$ (calcium carbonate); but that
4. the **Consequences** of such a spring or springs on **Aesthetics** of Georges River would be **Major**.

Ferruginous saline springs may be more prone to be induced or, if pre-existing, enhanced in flow rates westward draining catchments overlying Longwalls 34 to 36 to the west of Georges River e.g. Mallaty Creek, Leafs Gully Creek and Upper Nepean Creek. This possibility has already been suggested by:

1. the drilling of Tower Colliery borehole 22 in August 2001 in which a considerable flow of a classic Wianamatta Shale water with high dissolved iron and manganese concentrations was encountered in the low part of a westward draining catchment; and
2. detection of a spring in Ingham's Tributary of Ousedale Creek at site IT30 which was detected after completion of Longwall 30 and possibly induced or enhanced by mining of that longwall; and
3. detection of a pre-existing spring in Mallaty Creek between sites MC05 and proposed site MC130.

Given that the gradients in Ingham's Tributary are similar to those in Upper Mallaty and Leafs Gully Creek, but significantly less than those in Upper Nepean Creek (within the SMP Area), and that maximum predicted systematic tilts along the alignments of Mallaty Creek are similar to those back-predicted for Longwalls 30 and 31, there would appear to be a low but finite probability of induction of, or enhancement of ferruginous springs in the Upper Mallaty and Leafs Gully Creek catchments as a consequence of the mining of Longwalls 34 – 36.

The upper sections of the westward draining streams within the SMP Area are clearly strongly ephemeral in nature. They are subject to ongoing damming and have a long history of water quality degradation due to agricultural effects such as free access by cattle etc. It is unlikely there would be any significant impact to water quality resulting from the formation of springs in these streams over and above the current anthropological effects. Inducement of ferruginous springs in the Upper Mallaty, Leafs Gully or Upper Nepean Creeks catchments as a consequence of the mining of Longwalls 34 – 36 would not have a significant impact on water quality in the Nepean River.

On the basis of the information presented in this report we conclude that:

1. the **Likelihood** of one or more ferruginous springs arising within Upper Mallaty Creek catchment from subsidence-related effects within that catchment as a consequence of the mining of proposed Longwalls (33), 34 or 35 is **Minor** as the mining of Longwalls 31 and 32 (mined from the west) has possibly not led to induction of such springs although Longwall 30 appears to have created a spring in Ingham's Tributary of Ousedale Creek to the south**;** and
2. the **Consequences** of such a spring or springs to **Property** would be **Minor** and we base this on a minor risk of potential contamination to a farm or commercial water storage dam**;** and

3. the **Consequences** of such a spring or springs to the **Ecological Health** of immediate downstream pool(s) in the Creek would be **Insignificant** <u>under high flow conditions but **Minor** under low flow conditions</u> and we principally base this conclusion on the existing effects of local agricultural land uses on stream water quality; and
4. the **Consequences** of such a spring or springs on **Aesthetics** in Nepean River would be **Minor** given that Mallaty Creek discharges to Ousedale Creek and the confluence receives additional flows from Upper Ousedale Creek.

On the basis of the information summarised above we conclude that:

1. the **Likelihood** of one or more ferruginous springs arising within Leafs Gully Creek or Upper Nepean Creek catchment from subsidence-related effects within that catchment as a consequence of the mining of proposed Longwalls 25 and 26 is **Minor;** and
2. the **Consequences** of such a spring or springs to the **Ecological Health** of immediate downstream pool(s) in the Creek would be **Insignificant** <u>under high flow conditions but **Minor** under low flow conditions</u> and we principally base this conclusion on the existing effects of local agricultural land uses on stream water quality; and
3. the **Consequences** of such a spring or springs to **Property** would be **Minor** and we again base this on a minor risk of potential contamination to a farm or commercial water storage dam; and
4. the **Consequences** of such a spring or springs on **Aesthetics** in Nepean River would be **Major**.

1. INTRODUCTION

Ecoengineers Pty Ltd ('Ecoengineers') were engaged Cardno Forbes Rigby Pty Ltd to prepare, on behalf of BHP Billiton Illawarra Coal, an assessment of water quality effects that may arise in Georges River or any other watercourse from the proposed extraction of three longwalls in the existing West Cliff Colliery Area 5, which the Colliery has been mining since May 1999.

The proposal comprises three Longwalls designated 34, 35 and 36, in an area just north of approved longwalls 31, 32 and 33 adjacent to and west of the Georges River approximately 1.8 km north of the township of Appin.

The regional location of the 'SMP Area' for Longwalls 34 to 36 is defined by Mine Subsidence Engineering Consultants (MSEC), 2007 to be that area that is likely to be affected by the proposed sections of longwalls that have not currently been approved. The extent of the SMP Area has been calculated by combining the areas bounded by the following limits:-

- the 35 degree angle of draw line,
- the predicted vertical limit of subsidence, taken as the 20 mm subsidence contour; and
- features sensitive to far-field movements.

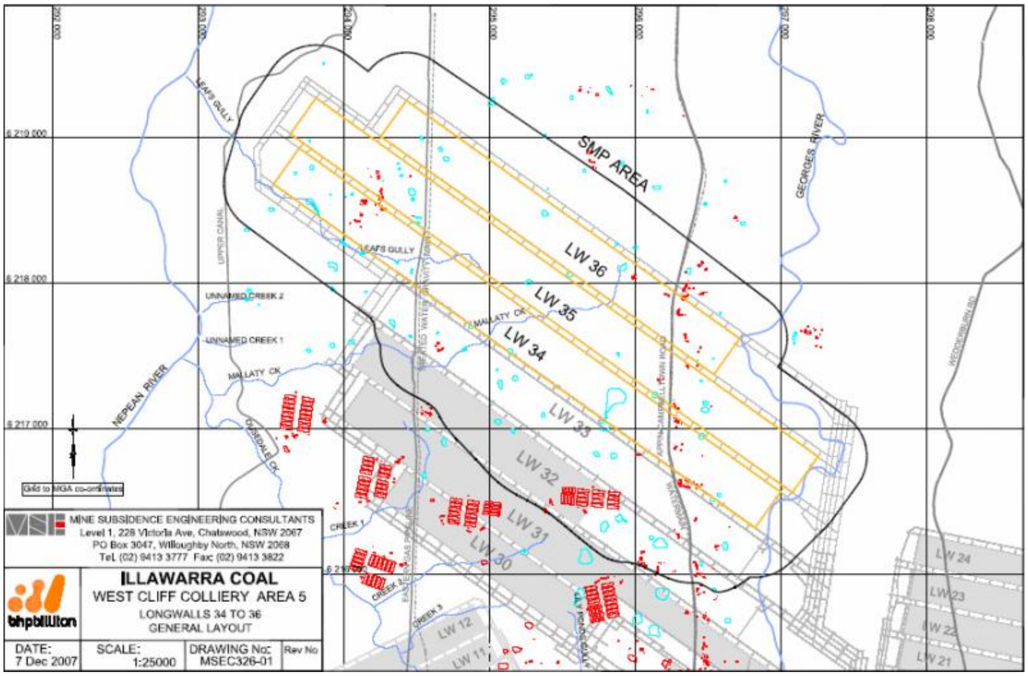
The 35 degree angle of draw line is described as the "surface area defined by the cover depths, angle of draw of 35 degree and the limit of the proposed extraction area in mining leases of the Southern Coalfield", as stated in Section 6.2 of the Department of Primary Industries (DPI) SMP Guideline 2003.

Given that the depth of cover above the proposed longwalls varies between 470 metres and 540 m, the 35 degree angle of draw line has been conservatively determined by drawing a line that is a horizontal distance, varying between 330 and 380 m from the proposed extraction areas of Longwalls 34 to 36.

The SMP Area is located largely on the western side of the Georges River.

Figure 1.1 below taken from MSEC Drawing 326-01 shows the general layout of the proposed longwalls, indicating the extents of the MSEC-defined SMP Area and showing the relative positions of previously extracted Longwall 30, current Longwall 31 and approved Longwall 33. An unlabelled extracted Longwall 29 lies to the southeast of Longwall 30.

Figure 1.1 General Layout of Proposed Longwalls 34 – 36 in Relation to Previous Longwalls.



Our investigation of possible mechanisms inducing water quality effects has been principally restricted to the identification, classification and quantification of effects caused within the so-defined SMP Area. However, the report considers and assesses potential downstream effects where appropriate.

1.1 REGULATORY CONTEXT

The Georges River is categorised as an area of environmental sensitivity for the purposes of the SMP approval process as its waters were previously classified as Class C from their source to Captain Cook Bridge under Part 3 of the Clean Waters Act 1970 (State Pollution Control Commission, 1980). The Clean Waters Regulations 1972 made under the Clean Waters Act 1970 were from 1 July 1999 taken to be regulations made under the Protection of the Environment Operations Act 1997 POEO Act No. 156.

Specifically, Part 5, Clause 6 of Schedule 6 of the POEO Act specifies that any waters classified under Part 3 of the Clean Waters Act 1970 continue to have the classification they had on repeal of that Act and that the standards applicable under The Clean Waters Regulations 1972 to waters so classified are to stand (under Part 5 of the POEO Act).

The Protection of the Environment Operations Amendment Bill 2005 ratified by the NSW Parliament on 1 May 2006 repealed the Clean Waters Regulations 1972 (and Part 5 of Schedule 6 of the POEO Act 1997 No. 156) and established a general requirement that environmental values of water (being the values set out in the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000) be considered when licensing functions are exercised or prevention notices issued under the POEO Act.

The Georges River is also the subject of the Greater Metropolitan Regional Environmental Plan No. 2 – Georges River Catchment (GMREP 2). The Plan requires consideration of environmental effects which include:

- Acid sulfate soils;
- Bank disturbance;
- Flooding;
- Industrial Discharges;
- Land degradation;
- On-site sewage management;
- River-related uses;
- Sewer overflows;
- Urban/stormwater runoff;
- Urban development areas;
- Vegetated buffer areas;
- Water quality and river flows; and
- Wetlands.

While mining is not directly referred to in GMREP 2, this report aims to address the water quality and river flow-related matters the Plan raises.

This assessment is based upon past experience in the investigation and assessment of water quality effects induced by mining in the Illawarra Region and from:

- specific hydrologic and water quality monitoring studies conducted in Georges River above Area 5 by BHP Billiton Illawarra Coal (BHPBIC) since May 1998 (e.g. BHP Billiton 2002a, 2002b, 2004a, 2004b) and by Coffey Geosciences between 1998 and 2002 (Coffey Geosciences 1998, 1999, 2000a,b,c, 2001a,b, and 2002);
- regional aquatic ecological studies conducted in Georges River, and tributaries of the Nepean River namely; Ousedale Creek, Mallaty Creek and Upper Nepean Creek since 2003 by The Ecology Lab (e.g. The Ecology Lab 2004a,b,c,d,e, 2005, 2006a,b and 2007); and
- regional water quality and geochemical studies conducted at West Cliff Colliery, in Georges River and Cataract River since 2003 by Ecoengineers Pty Ltd (e.g. Ecoengineers 2005a, b, c, 2006a, b and 2007).

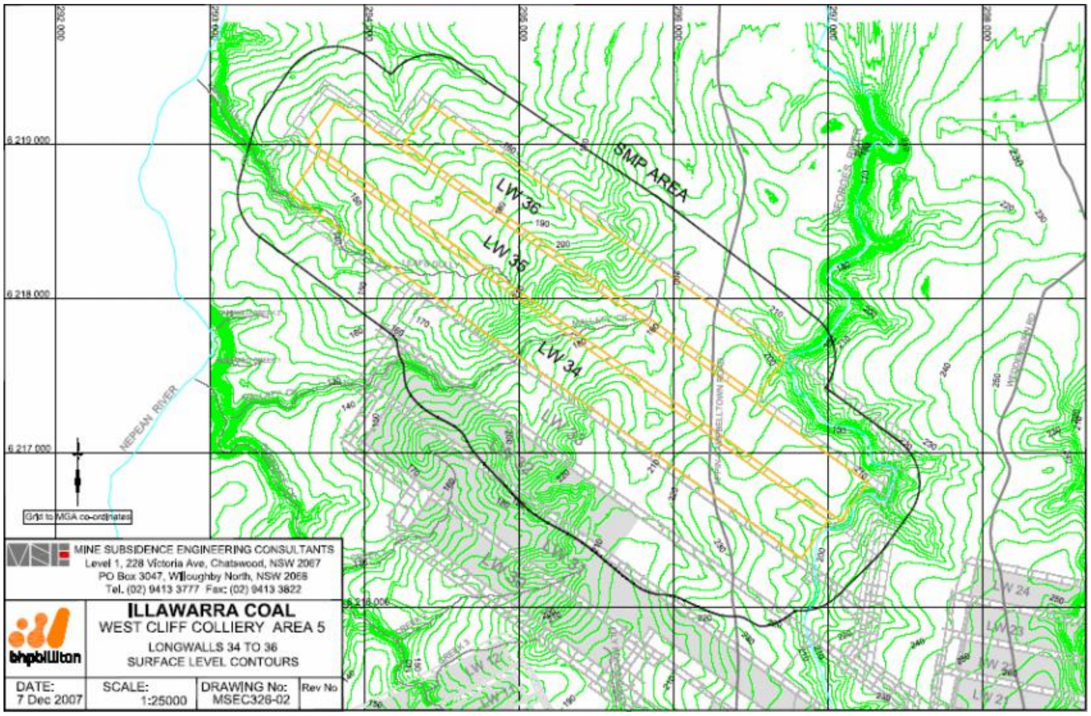
There are no Water Quality Objectives arising from the Independent Inquiry in to the Hawkesbury Nepean River System by the Healthy Rivers Commission and the Commission recommended using the trigger values in the national water quality guidelines (ANZECC&ARMCANZ, 2000).

2. BACKGROUND

2.1 LOCAL GEOMORPHOLOGY, SOILS AND NEAR-SURFACE GEOLOGY

Figure 2.2 below shows the surface topography in the SMP Area.

Figure 2.2 Surface Topography and Major Watercourses in SMP Area.



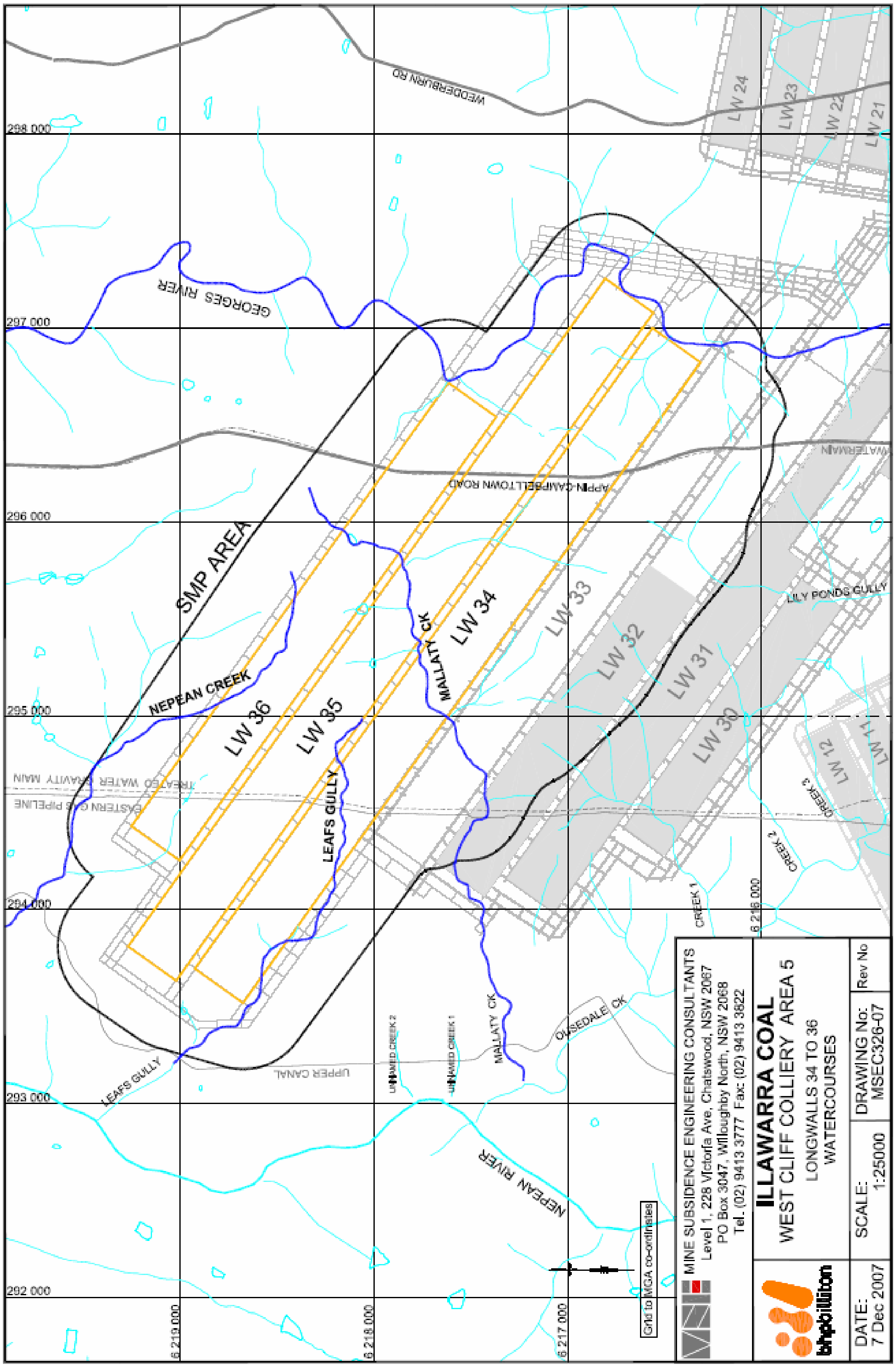
The land in the eastern part of the SMP Area generally drains into the Georges River, while the land in the central and western parts of the SMP Area generally drain into Mallaty Creek, Leafs Gully or Nepean Creek, which in turn drain into the Nepean River. **Figure 2.3** shows the watercourses within and adjacent to the SMP area.

Georges River arises about 5 km south east of Appin, and flows broadly north towards Liverpool in a tortuous fashion through a shallow river valley that becomes increasingly incised as it proceeds north.

The section of the Georges River skirting around the eastern ends of Longwalls 34 – 36 within the SMP Area is moderately incised with Hawkesbury Sandstone outcropping to the east and Wianamatta Shale to the west (of the river) and the depth of the river bed varies between 20 and 35 m. The bedrock of the Georges River is invariably Hawkesbury Sandstone.

The natural gradient of the Georges River within the SMP Area varies between <1 mm/m and a maximum of 50 mm/m with an average of approximately 8 mm/m (0.8%).

Figure 2.3 Watercourses within and Adjacent to Longwalls 34 – 36 SMP area



The creeks draining to Nepean River are as follows:

Mallaty Creek is an ephemeral creek which is located directly above the proposed Longwalls 34 to 36. The creek generally flows in a westerly direction until it joins Ousedale Creek, approximately 1.4 kilometres south-west of Longwall 34. The natural gradient of the creek within the general SMP Area varies between 10 mm/m and 100 mm/m, with an average gradient of approximately 30 mm/m.

Leafs Gully Creek is an ephemeral creek which is located directly above proposed Longwalls 34 and 35. The creek flows in a north-westerly direction until it joins the Nepean River approximately 830 metres west of Longwall 36. The natural gradient of the gully within the general SMP Area varies between 10 mm/m and 125 mm/m, with an average gradient of approximately 50 mm/m.

Nepean Creek lies north of the SMP Area which enters Nepean River just above Menangle Weir. It is ephemeral in its upper reaches, one upper tributary of which runs along Longwall 35 in a south-easterly direction. This tributary flows northwest from a small farm dam (with an area of roughly 50 m^2) through cattle pasture. There is a thin riparian strip in the upper reaches, flowing through tea tree shrubbery within eucalypt woodland. The creek is ephemeral with only small standing pools. The natural gradient of the creek in the vicinity of the proposed longwalls varies between 10 mm/m and 150 mm/m, with an average gradient of approximately 40 mm/m.

There are also a number of minor tributaries of the abovementioned creeks within the SMP Area. The minor tributaries are located directly above and across the extents of the proposed longwalls.

A cliff has been defined by MSEC (2007) as a continuous rock face having a minimum height of 10 metres and a minimum slope of 2 to 1, i.e.: having a minimum angle to the horizontal of 63°. The locations of cliffs within the SMP Area were determined from site investigations and from the 2 metre surface level contours which were generated from an aerial laser scan of the area.

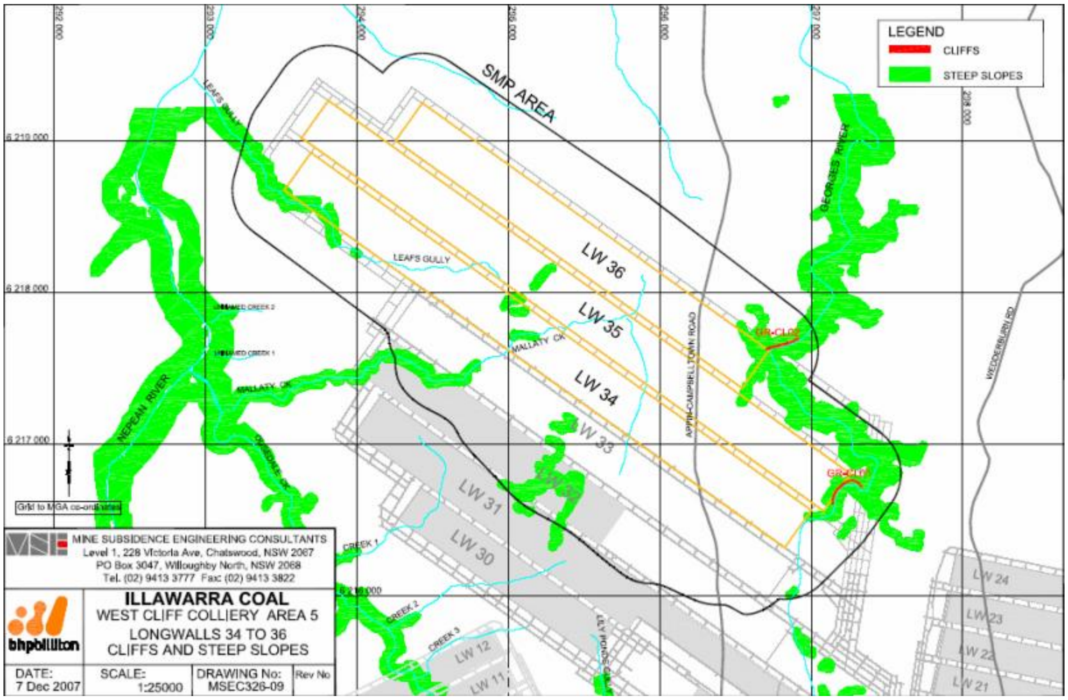
A number of areas containing steep slopes have been identified within the SMP Area. The reason for identifying steep slopes is to highlight areas in which existing ground slopes may be marginally stable. For the purposes of this report, a steep slope has been defined as an area of land having a natural gradient between 1 in 3 (i.e.: a grade of 33 %, or an angle to the horizontal of 18°) and 2 in 1 (i.e.: a grade of 200 %, or an angle to the horizontal of 63°).

The maximum slope of 2 to 1 represents the threshold adopted for defining a cliff. The minimum slope of 1 to 3 represents a slope that would generally be considered stable for slopes consisting of rocky soils or loose rock fragments.

Clearly the stability of natural slopes varies depending on their soil or rock types, and in many cases, natural slopes are stable at much higher gradients than 1 to 3, for example talus slopes in Hawkesbury Sandstone.

Figure 2.3 shows the disposition of steep slopes and cliffs within the SMP Area.

Figure 2.3 Cliff and Steep Slopes within the SMP Area



The upper catchments of Ousedale, Mallaty, Leafs Gully and Nepean Creeks are all characterised by outcropping Wianamatta Shale. The landscape types are classified as Cumberland Plains Lowlands and Hawkesbury-Nepean River Valley.

The Wianamatta Shale has a maximum thickness of about 20 m and the lower valley slopes and walls of these creeks are characterised by Hawkesbury Sandstone outcropping with the lower creek lines being incised into the Sandstone.

Local inspections suggest the actual extent of the Shale may vary somewhat from this at a finer scale and soils derived from the Shale may exhibit a greater extent than shown in **Figure 2.4** above.

Soils within the SMP Area have been mapped by the Soil Conservation Service of NSW and are described by Hazelton and Tille (1990) to be of only two soil landscape types:

1. **Hawkesbury type** developed on very steep slopes of Hawkesbury Sandstone of greater than 25% within creek main valleys and lower sections of tributaries. Local relief 100 – 200 m with slopes >25%. The soils are shallow (typically <50 cm) discontinuous Lithosols/siliceous sands associated with rock outcrops, Earthy sands, Yellow Earths and locally deep sands on the inside of benches, along joints and fractures and narrow valley flats. There are some localised Yellow and Red Podzolics associated with shale lenses. These soils may be found in proximity to Georges River and Nepean River and the lower sections of Mallaty and Leafs Gully Creek.

2. **Blacktown type** developed on gentle undulating country of Wianamatta Group Shales. Local relief to 30 m, slopes usually <5%. Broad rounded crests and ridges with gently inclined slopes. The soils are shallow to moderately deep (<150 cm) Red and Brown on crests, upper slopes and well-drained areas; deep (150 -300 cm) Yellow Podzolics and Soloths on lower slopes and in drainage depressions and localised areas of poor drainage. These are moderately reactive soils, with highly plastic subsoils.

Figure 2.4 below shows the mapped general extents of Hawkesbury Sandstone (pale blue) and Wianamatta Shale (green) surface outcropping respectively in the local area.

Figure 2.4 Surface Geology Within and Adjacent to the SMP Area.

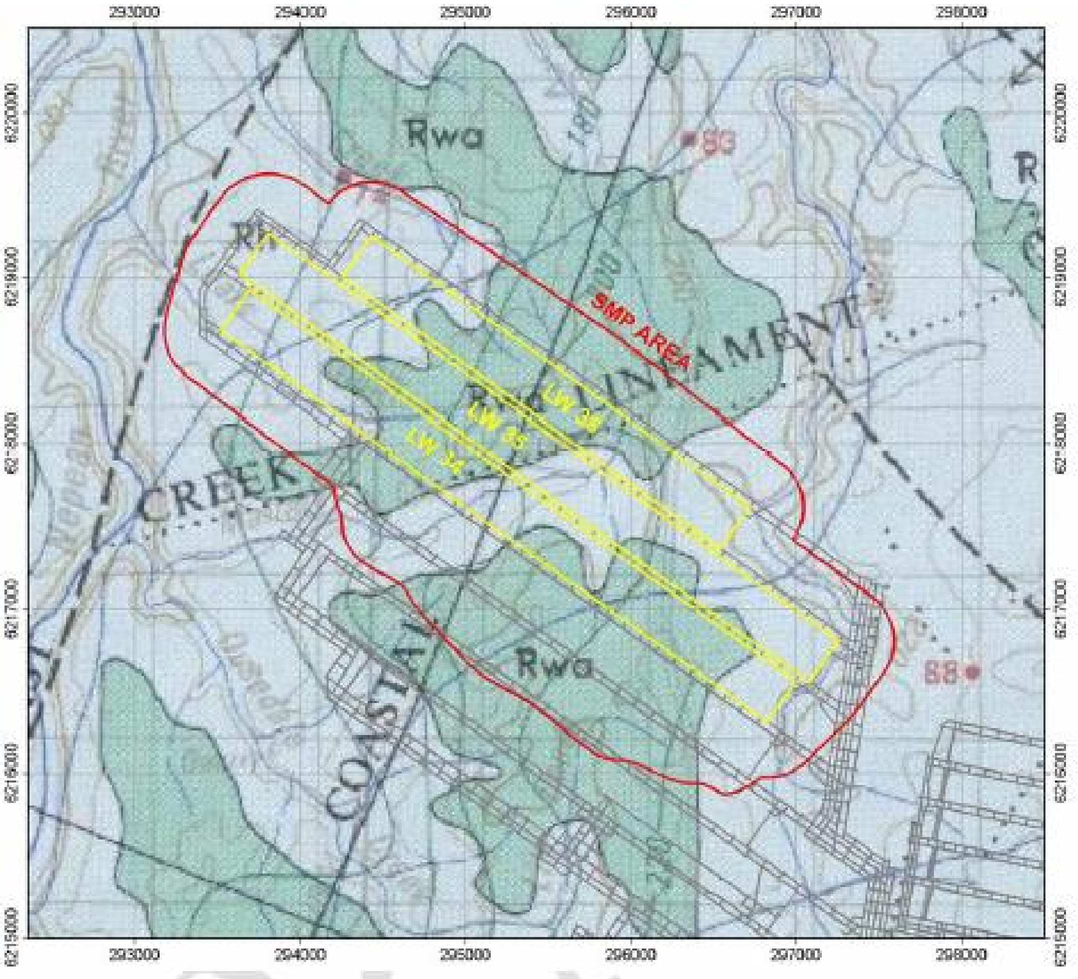
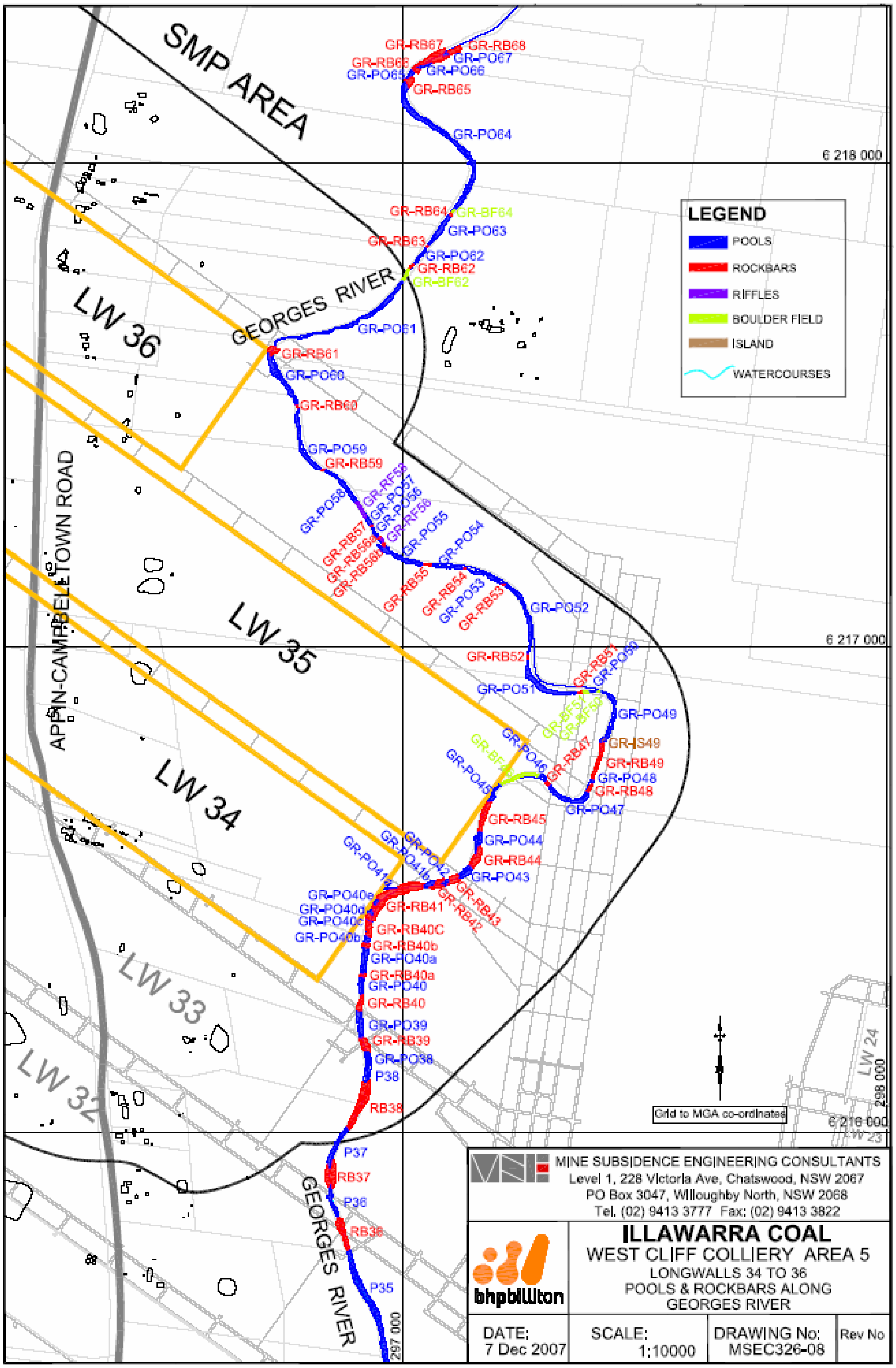


Figure 2.5 below shows the disposition of geomorphological features in Georges River within the SMP Area and up river and down river of it.

Figure 2.5 Disposition of Pools, Rock bars, Riffles, Boulder Fields and Islands in Georges River in the Vicinity of the SMP Area



2.2 LOCAL HYDROLOGY

Table 2.1 shows the annual rainfalls recorded at West Colliery since 1998. It is noted that the record for 2007 at the time of preparation of this report finished on 18 December.

TABLE 2.1 ANNUAL RAINFALLS AT WEST CLIFF COLLIERY SINCE 1998

Year	**Rainfall (mm)**
1998	1262
1999	1307
2000	790
2001	865
2002	651
2003	903
2004	856
2005	578
2006	681
2007 (**to 18 December** only)	1565
Average 1998 - 2007	**Greater than 946±324 (due to lack of full 2007 record)**

As can, be seen, between 2000 and 2006, the area was in drought and experienced significantly lower than average rainfalls than applied over the previous decade. Annual rainfall in the upper river catchment as measured at West Cliff Colliery averaged about 789 mm over those 7 years.

This is more than 20% lower than the long term median annual rainfall at nearby Cataract Dam which, over the 100 years since recording commenced in 1904 has been about 1000 mm, a value that is similar to the mean rainfall for the last 10 years at West Cliff which was <u>at least</u> 946 mm.

This suggests that total rainfall for the year 2007 which will be nearly exactly 2 standard deviations above the 10 year mean approaches a 95 percentile year i.e. a wettest year in 20. We have previously identified the BOM-listed Lucas Heights weather station as having the closest and most similar long term rainfall record to West Cliff Colliery and comparison with that record suggests that, at West Cliff, the year 2007 will approximates a 95 percentile rainfall year.

Hounam (1961) reported that evaporation from a non-standard tank located at Cataract Dam (elevation 293 m) averaged 785 mm over a 31 year period. This implies that long term actual evapotranspiration (ET) from local catchments should not exceed about 0.9 x 785 = 706 mm.

However, the Bureau of Meteorology (BOM) national map for Annual Areal ET for the period 1960 – 1991 indicates that Woronora Plateau catchments should have a lower mean annual ET in the 500 – 600 mm/year range, refer:

http://www.bom.gov.au/cgi-bin/climate/cgi_bin_scripts/evapotrans/et.html

Actual ET as estimated from model long term water balances for the Cataract and Nepean Sydney Water Catchments over the 35-year period 1961 to 1996 averaged only 416 and 581 mm respectively (Thyer and Kuczera, 2000). This is because some fraction of incident rainfall on Hawkesbury Sandstone terrain penetrates to depths below ~2 m too rapidly to be subject to ET processes.

As actual ET in the Upper Georges River Catchment (which drains a mix of Hawkesbury Sandstone and Wianamatta Shale outcropping terrain) therefore averages around 500 – 600 mm/year. As such, there would have been little excess water available to sustain a baseflow in the Upper Georges River over the drought period 2000 - 2006.

The water flows in the Georges River within the SMP Area are derived from two main sources:

(a) flows sourced from the catchment areas; and

(b) flows sourced from Dept. of Environment and Climate Change (DECC) Licensed Discharges from Appin and West Cliff Collieries.

Water flows upstream of the licensed discharges have been routinely measured at a site called Upper Flow Station by BHP Billiton and its consultants since October 2002, and the results are summarised in **Table 2.2**.

TABLE 2.2 SUMMARY OF FLOW RATES RECORDED AT GEORGES RIVER UPPER FLOW STATION

Period of Data :-	**16 Oct 2002 to 19 July 2005**
Total No. of Recordings	92 recordings
Minimum Flow	0.0 ML/day
Maximum Discharge	4.2 ML/day
Mean Flow Rate	0.3 ML/day
Median Flow Rate	0.1 ML/day

It can be seen from the above table that the flows upstream of the licensed discharge points are relatively low, however it is noted that the monitoring period lay wholly within the 2000 – 2006 drought period.

The Upper Georges River, including that passing through the SMP Area, has been regarded as a naturally ephemeral watercourse since at least the year 2000 (when the drought commenced).

Catchment seepage water is likely to migrate both laterally down the hydraulic gradient of any perched water storages and vertically through the Hawkesbury sequence to discharge to the Georges River. The highest permeabilities are expected in a horizontal direction, usually along bedding planes, and palaeo-deposition or palaeo-erosion surfaces. Vertical migration is dependent on the local vertical permeability (variable through the sequence) and on the horizontal surface area of ‘leakages’ between adjacent stacked strata.

Natural water sources on the upland areas to the west of the Georges River are restricted to shallow gullies. Some of these gullies drain towards the River. Surface drainage in upland areas is consistent with only partial direct run off. Significant direct infiltration of precipitation into overlying soils is predicted in areas of Wianamatta Shale outcrop on the western side of the river. Significant water storage is believed to be likely in the clay-rich Wianamatta Shale soils to the west of the River.

In general, water flows along the Georges River within the SMP Area are continuous as there is always some water being discharged into the River, particularly from the DECC-licensed discharges from Appin and West Cliff Collieries that were the main source of flow for the section of River within the SMP Area until about late September 2005. Both discharge points are located well upriver of the SMP Area.

After mid-2004 the discharges from Appin Colliery were made up largely of stormwater runoff. The runoff that accumulates on the Colliery site becomes saline due to exposure to stockpiled coal and other site runoff so that it occasionally needed to be mixed with other water, principally town water prior to discharge to achieve a discharge salinity <1000 µS/cm.

Licensed discharges from Appin Colliery after 2005 only occurred when the site's stormwater dam was nearly full. After 2005, when revised water management measures at Appin Colliery were implemented, licensed discharges from the Colliery have been negligible by comparison with discharges from West Cliff Colliery.

West Cliff Colliery does not have a town water supply and of necessity operates a relatively sophisticated water management (and recycling) system (WMS) based on the harvesting of runoff from Brennans Creek catchment and of ground water inflows to underground workings. As part of the WMS water is released nearly continuously to the Georges River from Brennans Creek via a bottom drain valve at the base of Brennans Creek Dam (BCD) wall. The controlled discharge component of the WMS has been trialled continuously since 2 August 2004 (Ecoengineers Pty Ltd, 2005b) and is operating to the present day.

The aims of the trial (Pollution Reduction Program No. 7) were to:

1. restrict discharges from DECC Licensed Point 10 to the Georges River to a maximum pH limit of 8.5 whenever possible under the revised conditions of West Cliff Colliery's Environment Protection Licence (EPL) No. 2504;
2. steadily reduce overall salinity levels with the WMS (which derive from the groundwater inflow component and the washing of raw coal); and
3. provide an environmental flow in Georges River especially during periods of drought (as applied from 2000 to 2006) and to help mitigate any water loss effects from past longwall mining or residual after remediation especially during drought conditions.

In order to meet these aims, water is continuously discharged from the base of the BCD dam wall so that an OPSIM model-designed freeboard (Water Solutions, 2004) is maintained in BCD and consequently, fresh storm water runoff capture is maximized and uncontrolled spillages are minimized.

This deliberate discharge, along with other minor waters such as leakage through the dam wall and natural groundwater seeps, are released from a small Reclaim Pond (Licensed Discharge Point 10) into Brennans Creek, and flow into the Georges River.

In addition to these flows, BCD occasionally overtops its spillway (located above 12.5 m maximum dam depth) during large rainfall events but the frequency of, and magnitude of this type of occurrence was greatly reduced between August 2004 and August 2006 until the breaking of the drought in September 2006.

The PRP7 Trial has proven to be relatively successful with salinity of water discharged from West Cliff Colliery as expressed by Electrical Conductivity (EC) falling from an average value around 4000 µS/cm in 2004 to an average value of around 2000 µS/cm in 2007, despite drought condition applying over the first three years of the Trial and it is likely that this 'best practice' mode of operation of the West Cliff WMS will continued into the foreseeable future.

Given that the flow conditions within the Georges River have been modified by the above Trial and due to the dry conditions that applied in the area between 2000 and

2006 the controlled discharge from BCD (LDP10) has constituted the major flow component of Georges River over the last 3 years.

During the initial part of the PRP7 Trial period remediation works were periodically conducted by BHP Billiton in previously affected sections of the Georges River and no water was discharged from either colliery for short periods during the works. Rehabilitation works associated with Longwalls 5A1-5A4 were finalized in late 2005.

Water flows in the River during this period were therefore not strictly representative of the flow conditions that will occur within the Longwalls 34 – 36 SMP Area.

Daily discharges from Appin and West Cliff Collieries and measured flows in the River were previously examined for the period between 2 August 2004 and October 2005 and are summarised in **Table 2.2** (Ecoengineers, 2005c). The results do not include periods of remediation works, which occurred on two occasions and occupied a total of 41 days.

TABLE 2.3 SUMMARIES OF LICENSED DISCHARGES FROM APPIN AND WEST CLIFF COLLIERIES 2 AUGUST 2004 – 20 OCTOBER 2005

	Appin Discharge	West Cliff Colliery Licensed Discharge Point 10	Brennans Creek Dam Overflows (Licensed Discharge Point 1)	Combined Discharge & Overflows
Period of Data:	2 August 2004 to 20 October 2005			
Total No. of Recordings	403 days	403 days	403 days	403 days
Total No. of Days of Zero Flow	194 days	0 days	336 days	0 days
Minimum Flow	0.0 ML/day	0.01 ML/day	0.0 ML/day	0.2 ML/day
Maximum Flow	2.5 ML/day	1.7 ML/day	4.6 ML/day	7.2 ML/day
Mean Flow Rate	0.6 ML/day	0.9 ML/day	0.1 ML/day	1.6 ML/day
Median Flow Rate	0.1 ML/day	0.9 ML/day	0.0 ML/day	1.5 ML/day

The water flows in the Georges River within the SMP Area are now largely derived from two main sources:

- flows sourced from the upriver catchment areas; and
- flows sourced from Dept. of Environment and Climate Change (DECC) Licensed Discharges LDP1 and LDP10 at West Cliff Mine.

Current flow conditions within the SMP Area for the proposed Longwalls 34 – 36 are therefore best represented by the 26 month period after sporadic releases from Appin Colliery finished i.e. from 21 October 2005 to 21 December 2007. Calculated frequencies for the combined controlled licensed discharge (Licensed Discharge point 10) and uncontrolled overflow rates (Licensed Discharge Point 1) from West Cliff Collieries estimated from 563 daily measurements over the 26 month period between 21 October 2005 and 21 December 2007 are shown in **Table 2.4.**

TABLE 2.4 ESTIMATED PERCENTILES OF TOTAL RECORDED DISCHARGE FROM WEST CLIFF COLLIERY LESS THAN OR EQUAL TO SELECTED FLOW RATES FOR PERIOD 21 OCTOBER 2005 TO DECEMBER 2005 (N = 563 MEASUREMENTS.

FLOW RATE (ML/day)	PERCENTILE
0	10.0
0.307	15.0
0.405	20.0
0.519	25.0
0.61	30.0
0.79	40.0
1.07	50.0
1.22	60.0
1.48	70.0
1.64	75.0
1.75	80.0
1.90	85.0
2.92	90.0
4.85	95.0
32.9	99.0

It can be seen from **Table 2.4** above that controlled discharges from West Cliff lie typically in the range 0.3 to 1.90 ML/day. The 25 percentile flows are around 0.5 ML/day, the 50 percentile flows around 1.0 ML/day and the 75 percentile flows exceed 1.5 ML/day. Flows less than or equal to 0.3 ML/day are quite rare as they have occurred for less than 15% of the time.

It is noted that lowest frequency high flow rates i.e. >99 percentile (less than 1% of the time) were weighted towards very high discharge rates. This is a consequence of the very high rainfalls in the Upper Georges River catchment in the first half of 2007 inducing high rates of overflow from BCD due to high rates of runoff from the West Cliff Pit Top and Coalwash Emplacement Areas within Brennans Creek Catchment.

Most of the overflow of BCD over the spillway (LDP1) occurred between 25 May and 25 June 2007. Total water loss by spilling is estimated at approximately 896 ML from the single daily V notch weir observations made. This is equivalent to 2.9 times the volume of BCD (307 ML to the spillway) and over 2 years supply for the Colliery at current water usage rates. The major part of this overflow was comprised of only two 3-day spill events over 8 – 10 June 2007 in which about 281 ML was discharged and 15 – 17 June 2008 when about 511 ML was discharged, following 72 hour rainfalls events of about 191 and 210 mm.

If the licensed West Cliff Colliery discharge from Brennans Creek Dam (BCD) were not released into the River, water flows would not be continuous along many sections of the upper Georges River. In times of dry weather, the River would most likely consist of a series of disconnected pools, some of which may completely or partially drain and/or dry out. It has been observed that the drying out process leads to a natural increase in salinity in disconnected pools (Jarvis, 1997). It is also likely that surface flow diversions in the River have occurred as a result of natural weathering and erosion.

Locations of Georges River flow monitoring sites are shown in **Figure 2.1**.

Figure 2.1 Georges River Flow Monitoring Sites

The following **Table 2.5** shows paired spot flow rate measurements at sites RB16, RB16B and RB20, up river of the SMP Area, sites RB25 and RB29 adjacent to the SMP Area and sites RB36, the Wedderburn Airstrip Weir and RB40 down river of the SMP Area for the period after 2 August 2004 (i.e. following commencement of the West Cliff WMS PRP 7 Trial and establishment of an environmental low flow in the River) to recently. Note NA = Not Available i.e. not measured.

TABLE 2.5 SPOT PAIRED LOW FLOW RATE MEASUREMENTS AT LONGWALL 34 – 36-RELATED GEORGES RIVER SITES AFTER 2 AUGUST 2004

Date	Up River Sites	Flow Rate (ML/day)	Sites Adjacent-to SMP Area	Flow Rate (ML/day)	Down River Sites	Flow Rate (ML/day)
23/08/04	RB16B	1.82	RB25B	1.22	RB40	0.82
01/09/04	RB16B	NA	RB25B	0.84	RB36/Airstrip Weir	0.77/0.81
17/09/04	RB16B	NA	RB25B	0.87	Airstrip Weir	0.92
16/11/04	RB16	2.34	RB25B	NA	RB36/40	1.59/1.86
23/12/04	RB16	2.35	RB25B	NA	RB36	1.59
29/04/05	RB16B	0.11	RB25B	0.22	RB36	0.09
21/07/05	RB20	NA	RB25B	1.10	RB36	0.84
16/08/05	RB20	0.68	RB25B	0.58	RB40	0.41
05/10/05	RB16B	0.52	RB29	0.43	RB36	NA
02/11/05	RB16	NA	RB25B	2.85	RB36	2.46
09/11/05	RB16	NA	RB25B	2.82	RB36	2.45
16/11/05	RB16B	NA	RB25B	2.08	RB36	1.97
23/11/05	RB16B	NA	RB25B	0.38	RB36	0.32
29/12/05	RB16	0.73	RB25B	NA	RB36	0.93
10/01/06	RB16B	0.77	RB25B	0.83	RB40	0.69
12/01/06	RB16B	NA	RB25B	0.63	RB36	0.54
20/01/06	RB16B	1.47	RB25B	1.18	RB36	1.56
14/02/06	RB16	NA	RB25B	0.25	RB36	0.10
25/05/06	RB16B	0.70	RB25B	0.55	RB36	0.04?
29/06/06	RB16	NA	RB25B	0.15	RB36	0.02
31/07/06	RB16B	0.50	RB25B	0.30	RB36	0.13
11/08/06	RB16B	0.52	RB25B	0.55	RB36	0.30
08/09/06	RB16B	0.76	RB25B	1.26	RB36	1.40
15/11/06	RB16B	NA	RB25B	0.49	RB36	0.17
05/01/07	RB16B	NA	RB25B	0.75	RB36	0.58
22/02/07	RB16B	NA	RB25B	1.26	RB36	1.16
13/04/07	RB16B	NA	RB25B	1.89	RB36	1.43
19/04/07	RB16B	NA	RB25B	1.99	RB36	1.84
Average		1.02±0.73		1.02±0.77		0.94±0.74

Water flows in the Georges River have generally been determined by calculating measured cross-sectional areas and velocities of the stream in a defined channel. In some cases, water flows have been measured by calculating the depth of water passing through a temporary or permanent V-notch weir.

The monitoring of water flows has been restricted to where flow monitoring was physically possible. It is only possible to measure such flows under dry weather conditions up to about 3.0 ML/day and the average precision of such measurements has been estimated by us to only be about ±0.17 ML/day (±2 L/s) at the one standard deviation level in local riverine terrain.

Given that the precision with such manual flow measurements, it is concluded that, at low flows where diversions around the gauging point and losses or gains to local shallow groundwater would be most apparent the baseline flow measurement data confirms the Georges River is neither a gaining or losing system adjacent to the Longwalls 34 – 36 SMP Area.

It is also noted that these dry weather flows averaged very close to 1.0 ML/day up river, adjacent-to and down river of the Longwalls 34 – 36 SMP Area.

Dry weather low flows in the Georges River upstream of, adjacent-to and immediately down river of the SMP Area through this section of the River are therefore very similar in magnitude to the median and average dry weather flows released from the West Cliff Colliery WMS LDP10 licensed discharge i.e. when BCD is not overflowing (refer **Tables 2.4** and **2.5** above).

2.3 LOCAL HYDROGEOLOGY

There are, however, a number of registered groundwater bores in the vicinity of the proposed longwalls, the locations of which are shown in Drawing No. MSEC326-27 in MSEC (2007) and details provided in Section 2.7.11 of MSEC (2007). The work summary sheets provided by DIPNR, however, indicate that the intended use for the majority of these bores is for irrigation, stock or drainage, rather than for the supply of potable water. There has been no systematic study of near-surface groundwater systems in the SMP Area other than in close proximity to Georges River.

Previous piezometer arrays established close to Georges River i.e. associated with Longwalls 5A1 - 5A4 were originally designed to measure the combined near surface water system hydraulic potential to 10 metres below the River base. The upper section of the borehole is cased to isolate the hole from near surface rainfall inflow.

Subsequent installation of deeper piezometers confirmed the sub-horizontal and “perched” nature of individual near surface water storage zones.

The fact that separate perches were identified after the extraction of Longwalls 5A1, 5A2, 5A3 and 5A4 confirms that significant vertical permeability enhancement was <u>not</u> induced by their extraction.

In other words, it appears that vertical fracturing of pristine (i.e. previously competent) sandstone between pre-existing bedding planes had not been significant.

The depression of the near surface water table just north of Jutts Crossing coincided with a similar depression in the lower perch. This was caused by either a much localised vertical fracture system or an accidental borehole connection between the two systems.

Past observations and measurements of surface water and the near surface water systems in the upper Georges River identified:

1. natural pre-existing sub-bed flow diversions;
1. localised compressive failure of the bed of the River due to mining;
2. horizontal permeability enhancement in shallow strata on the flanks of the River due to mining;
3. discrete zones of horizontal permeability enhancement due to mining;

4. interaction between surface water and the near surface groundwater systems;
5. minimal systematic vertical conduits between upper and lower fracture zones;
6. pre-extraction permeability profiles did not necessarily agree with post extraction profiles;
7. the general river system is "losing" during dry periods and "gaining" during wet periods;
8. groundwater flow is locally modified by the extreme river bend from Jutts Crossing to Pool 21; and
9. some inter-level groundwater flow was caused by the Marhnyes Hole remedial slot.

It is suspected that the River would consist of a series of disconnected or drained pools during extended periods of low rainfall if the Appin and West Cliff licensed discharges did not enter the River.

2.4 PRIOR LONGWALL MINING-RELATED EFFECTS

Mining related subsidence movement can have the effect of delaminating erosion surfaces and bedding planes within strata. These effects are predicted to occur preferentially on the interfaces between materials with different elastic properties.

Upsidence is the term used to describe the upward vertical movement or reduced downward vertical movement of the uppermost strata of the river bed as the underlying rock is compressed and dilated due to mining-induced valley closure.

Rock failure in the river bed occurs as a result of a reduction in the bulk strength of the surface layers of rock due to bedding plane delamination, an increase in surface tensile stress due to bending or a combination of both processes. The magnitude of both processes rapidly declines with depth due to increasing vertical confinement generated by the weight of overlying strata.

Complex surface-groundwater interactions are observed all along the River, and the river system may generally be described as a 'losing' system for most of the time, where the predominant flow direction is from surface to groundwater storage (BHP Billiton, 2004a).

West Cliff Colliery Longwalls 5A1-5A4, 29 and 30 south of the proposed Longwall 34 – 36 mining area have previously been extracted.

Longwall 29 was mined in a westerly direction between April 2003 and July 2004. Longwall 30 was mined in a west to east direction between July 2004 and June 2005. Longwall 31 was mined in a west to east direction between July 2005 and December 2006.

Longwall 32 was commenced in February 2007 is currently being mined (in an easterly direction) and it is understood it has been approximately two thirds completed as at the end of 2007.

The Georges River has also been previously directly mined beneath by Longwalls 24 to 26 at Appin Colliery and by Longwalls 5A1 to 5A4 at West Cliff Colliery. Longwalls that have also previously mined adjacent to the Georges River include

Longwalls 20A to 23 at Appin Colliery and Longwalls 1 to 10, 16 to 24 and 29 at West Cliff Colliery.

The outcomes of prior longwall mining in the Southern Coalfield and in the Georges River in particular have been summarized in Appendix D in MSEC (2007).

Predicted groundwater hydrology of the Longwalls 34 to 36 SMP Area is partly based on knowledge gained from previous investigations associated with the extraction of former Longwalls 5A1, 5A2, 5A3 and 5A4 which was reviewed and summarized in BHP Billiton, 2004a, as follows:

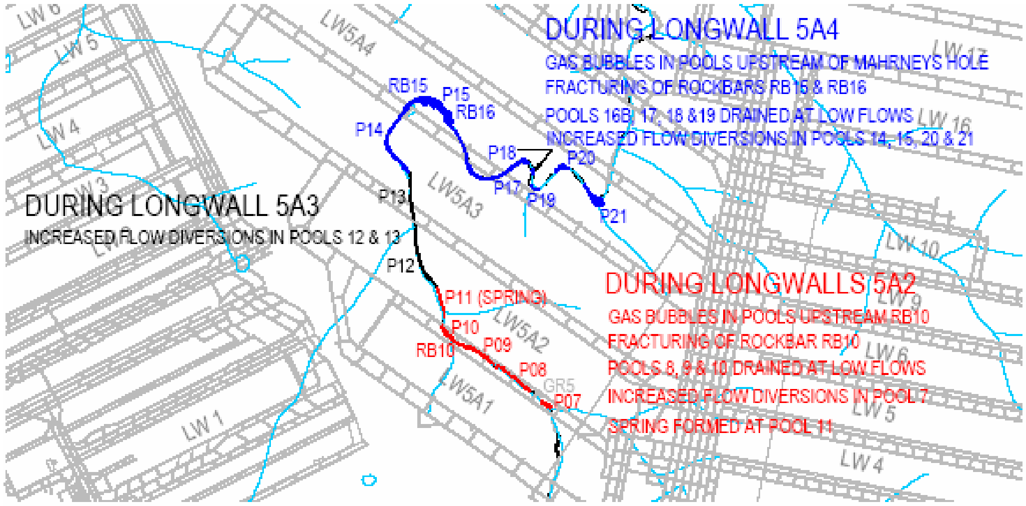
- Some minor gas releases were observed at Marhnyes Hole during the extraction of Longwall 5A3. The emission of gas suggests that some fracturing or shear occurred in this location prior to the mining of Longwall 5A4. Marhnyes Hole is located directly above Longwall 5A4.
- Fracturing at Marhnyes Hole was first noted during the extraction of Longwall 5A4. Minor fracturing of rock bars was first visible when the longwall face had just passed directly under the rock bar. New fracturing was identified when the longwall face had passed the rock bar by 100 m (BHP Billiton, 2002).
- No fracturing was reported at Jutts Crossing when Longwall 5A1 was extracted. Fracturing was first noted during extraction of Longwall 5A2 (BHP Billiton, 2004a). Jutts Crossing is located directly above the coal pillar between Longwalls 5A1 and 5A2.
- By way of comparison, fractures have also been observed in the Cataract River in six (6) locations in areas that have not been directly mined beneath. Four of these have occurred in areas near the side of a longwall panel. One fracture has been observed near the end of Longwall 405, which is located in the base of the river valley. The furthest distance of an observed fracture from a goaf edge is approximately 415 m from Longwall 401 at the base of Broughtons Pass Weir. This fracture occurred in a thin layer of shale.
- By way of comparison, fractures have also been observed in a number of locations beyond the goaf edge in the Bargo River. The furthest distance of an observed fracture from the extracted longwall is approximately 125 m. All of these fractures were observed to be off the side of a longwall panel.

The locations and the timing of the observed impacts during the mining of Longwalls 5A1 to 5A4 which mined directly beneath the Georges River was more recently summarized in Sections D.2.1 and D.2.2 of MSEC (2007) as follows:

- Gas in the pools adjacent to Jutts Crossing and from Marhnyes Hole;
- Fracturing of rock bars, including rockbar RB10 at Jutts Crossing and rockbars RB15 and RB16 at Marhnyes Hole;
- Reduction in the water level of some pools during times of low and no flow;
- Greater interaction between surface water and groundwater;
- Formation of a long lived ferruginous, weakly saline spring at Pool 11 over Longwall 5A2; and
- Oxidation of ferrous iron, producing reduced dissolved oxygen levels and the formation of ferruginous precipitates in the river.

These effects are graphically summarized in **Figure 2.1** below taken from Figure D.1 in MSEC (2007).

Figure 2.1 Observed Impacts along the Georges River Resulting from the Extraction of West Cliff Longwalls 5A1 to 5A4



It is not certain whether all of the ferrous iron appearing down river arose from the ferruginous spring in Pool 11 in Georges River but it is likely it was responsible, soon after its appearance, for the iron staining of Marnyhes Hole immediately to the north which occurred in late 2000.

However water quality monitoring carried out over the period from when those longwalls mined under the river up to the present day failed to identify any significant degree of vertical fracturing of pristine sandstone in the river bed leading to the oxidative dissolution of marcasite and hence measurable geochemical effects on river water.

This is ascribed to the hydrogeologically complex nature of the river. It is concluded that the principal effect of upsidence and subsidence on the river bed from the mining of Longwalls 5A1 to 5A4 was to produce lateral movement and dilation of only pre-existing, well weathered bedding planes (causing sub-bed flow diversions) but conversely with very little (vertical) fracturing of pristine sandstone between such planes.

Some minor mobilization of iron may have occurred as a result of reducing conditions developing within the shifted and dilated bedding planes (e.g. from dissolution of siderite following anaerobic decomposition of organic matter accumulated in them).

Fracturing of rockbars in Georges River observed following extraction of Longwalls 5A3 and 5A4 may have also contributed to the appearance of ferruginous precipitates in the River and the observed reduced dissolved oxygen levels due to dissolution of siderite.

This effect is known to also occur under natural conditions. It is known that much Hawkesbury Sandstone contains siderite (ferrous carbonate) as cement and as discrete more massive bodies resulting from diagenetic alteration of original sedimentary conglomerate clastic material. Although siderite is distributed very heterogeneously in the Sandstone it is believed to occur overall at an average level of around 4%.

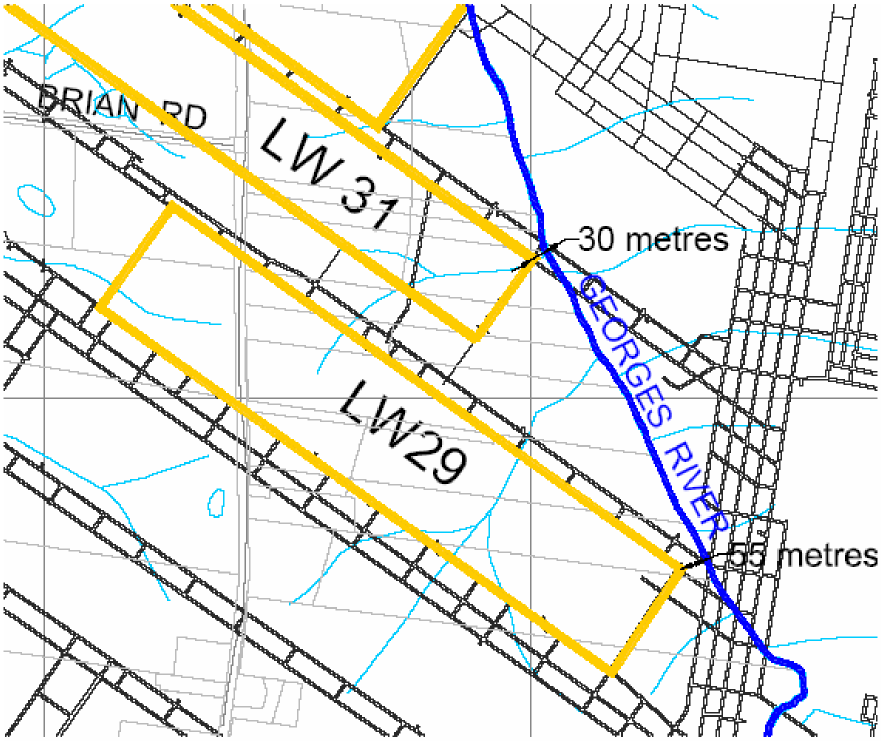
There was no clear evidence for systematic mobilization of sulfate, manganese, nickel or zinc such as would occur from fracturing of pristine sandstone (to expose marcasite). This is in marked contrast to other situations within the Southern Coalfield discussed in **Sections 3.1.1.2 – 3.1.1.4** above.

MSEC (2005) in their Section 3.3.9 carefully assessed the potential for fracturing in the Georges River bed and of rock bars in the SMP Area for Longwalls 31 – 33. Some upsidence was predicted within the River as a result of the extraction of Longwalls 31 to 33 and was described in Section 3.3 of the report prepared by MSEC (2005).

They noted that the majority of observed mining-induced fractures in stream and river beds were located directly above extracted longwalls and the predicted ground movements following extraction of Longwall 31 would only be slightly greater than those that were predicted following Longwall 29. They also noted that only a small number of mining-induced fractures have been observed in riverbeds that have not been mined directly beneath.

The layout of Longwalls 29 and 31 in relation to Georges River is shown in **Figure 2.2** below taken from Figure D.6 in MSEC (2007). It is noted that Longwall 29 was offset from Georges River by a minimum of 55 m at its northeastern corner and Longwall 31 was offset from the River by a minimum of 30 m.

Figure 2.2 Layout of West Cliff Longwalls 29 and 31 in relation to Georges River



Only minor gas release was observed during the extraction of Longwall 29 (completed July 2004) and during the extraction of Longwalls 31 (completed December 2006).

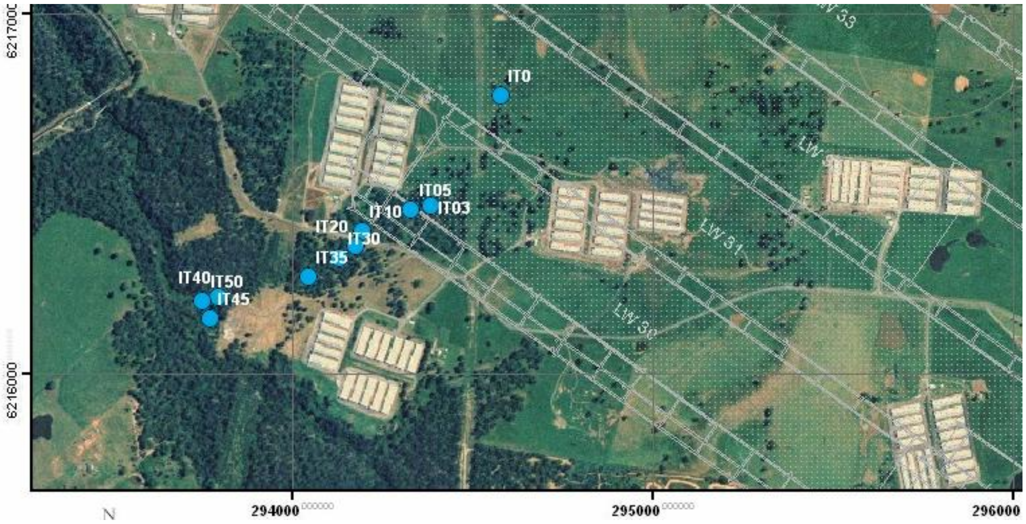
Longwalls 32 and 33 were also designed to completely avoid coal extraction directly beneath the Georges River. These longwalls, like the proposed longwalls 34, 35 and 36 largely underlie undulating areas to the west of the River that drain largely to the Nepean River.

Longwall 30, which did not mine close to Georges River, did however mine under the upper catchment of the arbitrarily named Ingham's Tributary of Ousedale Creek (which flows into Nepean River) as shown in **Figure 2.3** below. It is expected that the upper part of the catchment of Ingham's Tributary is mantled by Wianamatta Shale or soils derived from the Shale (refer **Figure 1.3** above).

MSEC (2007) do not discuss this, and it is acknowledged that it is unclear whether the mining of Longwall 30 was actually responsible, but a ferruginous, moderately saline spring was detected in November 2005 at site IT30 in Ingham's Tributary, only 5 months after completion of the longwall, as shown in **Figure 2.3** below.

However, given that the spring lies immediately to the east of the route of the Eastern Gas Pipelines, it seems unlikely that the IT30 spring pre-dated the mining of Longwall 30.

Figure 2.3 Location of Existing Water Quality Monitoring Sites in Ingham's Tributary (of Ousedale Creek) Including Location of Ferruginous Spring (IT30) Detected in November 2005.



Nevertheless, the effect of induction of ferruginous springs as a consequence of upland subsidence from longwall mining has been observed before in the Southern Coalfield in subcatchments of the Cataract and Georges River, most notably by producing:

1. the very large, and long-lived (ongoing) 'SW2 Spring' in Cataract River just west of Back Gully Creek induced by Appin Longwall 21 B in 1996; and
2. the moderately large and moderately long-lived 'Pool 11 Spring' in Upper Georges River induced by West Cliff Longwall 5A2.

Induction or exacerbation of such springs is believed to result from strata dilation and bed separation leading to increased storage of perched groundwater, especially at and near to the interface between Wianamatta Shale and underlying Hawkesbury Sandstone. Such springs do not appear to occur in terrain where Wianamatta Shale and Shale-derived soils do not outcrop.

It has previously been observed that water perched water storage occurs in the base of the Wianamatta Shale (Hazelton and Tille, 1990).

The interface between the Hawkesbury Sandstone and the Wianamatta Shale sequences appears likely to undergo a mine subsidence-induced permeability enhancement along the sub-horizontal interface between these units due to dilation and bed separation induced by a combination of subsidence and tilt.

Geochemically the Shale, being a marine sediment, continues to contain traces of connate water with an elevated (seawater composition) salt load and a significant load of major cations on cation exchange sites in ratios that are still relatively similar to that of seawater. These may be displaced by protons in weakly acidic infiltrating meteoric water, so increases in salinity are predicted to occur from the subcrop of the basal interface between the Shale and the underlying Hawkesbury Sandstone.

The Shale also contains a high concentration of finely disseminated crystalline iron and manganese oxides (after siderite and rhodocrosite).

Hence an elevated dissolved iron (Fe) and manganese (Mn) load (largely due to microbiologically-mediated reductive dissolution of oxides within the base of the weathered Shale during saturation (Lovley and Phillips, 1986) is expected from waters that have become stored in the catchment of the spring. Enhancement of vertical percolation of this more saline, iron-rich water into the upper Hawkesbury Sandstone strata (or at least a surficial Mittagong Formation) due to subsidence-induced dilation and valley closure effects is also conceivable.

We have comprehensively discussed the mine subsidence-related mechanisms driving the induction and maintenance of such ferruginous springs in a number of previous reports (Ecoengineers Pty Ltd., 2005b, 2005c, 2006a, 2006b and 2007). The geochemistry of this process and its consequences for any receiving stream is described in more detail in **Section 2.8.4**.

2.5 PREDICTED WATER-RELATED IMPACTS FOR LONGWALLS 34 - 36

Predicted impacts of the mining of Longwalls 34 – 36 on Georges River are presented in Section 5.1 of Chapter 5 of MSEC (2007).

Although the River has a relatively shallow natural gradient within the SMP Area, it is unlikely that there would be any significant increases in the levels of ponding, flooding, or scouring of the river banks, as the maximum predicted changes in grade along the river are very small, being less than 0.1 %. It is possible, however, that there could be some very localised increased levels of ponding or flooding where the predicted maximum tilts coincide with existing pools, steps or cascades along the river, however, any changes are not expected to result in significant impacts.

The predicted changes in the cross-bed gradients are very small and are expected to be an order of magnitude smaller than the natural River cross-bed gradients. The potential impacts associated with changes in the stream alignment, resulting from the extraction of the proposed longwalls are, therefore, not expected to be significant. The potential impacts of the changes in the stream alignment are expected to be minor when compared to the changes in the River depth and width that occur during times of high flow. The potential impacts of scouring are also likely to be minimal due to the nature of the sandstone river bed.

The experience gained from previous longwall mining in the Southern Coalfield indicate that mining induced fracturing in bedrock and rock bars are commonly found in sections of rivers and creeks that are located directly above extracted longwalls. However, minor fracturing has also been observed in locations beyond extracted longwall goaf edges, the majority of which have been within the limit of systematic subsidence. In a few isolated cases, minor fracturing has been observed up to 400 metres outside extracted longwall goaf edges.

The proposed Longwalls 34 to 36 mine up to, but not beneath the Georges River.

The maximum predicted closure movements along the Georges River, resulting from the extraction of proposed Longwalls 34 to 36, are therefore generally less than those back predicted for all case studies which had observed significant impacts such as river flow diversions.

The exceptions to this are rock bars 56A and 56B in the Georges River, which are located adjacent to the maingate of proposed Longwall 35 (refer **Figure 2.5**). For these, the predicted closures slightly exceed the back-predicted closure for the Elouera Colliery Native Dog Creek case study. It is noted that the back-predicted closure at bracketing Rock Bars 55, 57 and 59 are also of a similar magnitude to that back-predicted for the Native Dog Creek case study.

The maximum predicted upsidence along the Georges River, resulting from the extraction of the proposed Longwalls 34 to 36, is less than those back-predicted for all but three case studies which had observed significant impacts. However, the following should be noted for these case studies:-

- The back-predicted upsidence of 130 mm along Native Dog Creek was accompanied by a back-predicted closure of greater than 200 mm. The impact associated with these movements was a single drained pool located at a distance of 75 metres from the longwalls;
- The back-predicted upsidence of 165 mm along the Bargo River was accompanied by a very large back-predicted closure of 400 mm, and
- The back-predicted upsidence of 185 mm along the Georges River was accompanied by a back-predicted closure of greater than 200 mm. The impact associated with these movements occurred at Marhnyes Hole which was directly mined beneath by longwalls.

It should be noted that the case studies occurred during a time of severe drought and the surface water and groundwater levels around the rivers and creeks are likely to have been at lower levels and, hence, the rate of surface water diversion would have been much greater than during normal periods. In this regard, the selected limit for surface water diversions is considered to be conservative and represents significant protection against flow diversions, even in drought periods.

The impacts at Jutts Crossing and Marhnyes Hole occurred only after Longwalls 5A2 and 5A4 mined past these rock bars by distances greater than 100 metres. In addition to this, the maximum predicted total closure movements along the Georges River, resulting from the extraction of the proposed Longwalls 34 to 36, is generally less than 200 mm. The exception to this is a 110 m section of river which is located adjacent to the maingate of Longwall 35, which includes Rock Bars 56A and 56B.

It has been assessed, therefore, that minor fracturing could occur along the Georges River as a result of the extraction of the proposed longwalls. While it is possible for fracturing to occur anywhere along the river, the most likely area is adjacent to the maingate of Longwall 35, where the predicted movements are the greatest.

It is possible that minor fractures could occur up to 400 metres from the proposed longwalls. Given that any fracturing of the river bed is likely to be minor and localised in nature, it is unlikely that any remediation would be required following mining. In the unlikely event that any large surface fractures were to occur that resulted in pool water loss, MSEC (2007) recommended that they be remediated.

Successful remediation has occurred in the Georges River at rock bars that have been directly mined beneath by previous longwalls. As described in Section 2.4.2 of MSEC (2007), natural flow diversions have been observed along sections of the Georges River which has not been affected by mining. It is therefore possible, but unlikely, that the extraction of the proposed longwalls 34 – 36 could slightly increase the current rate of surface water flow diversions in the River.

However, that there have been no reported significant increases in surface flow diversions in rivers which have been previously mined adjacent to but not directly underneath.

The depth of surface water flow diversions as a result of longwall mining has been estimated to be less than 10 metres.

Recent studies into the depth of dilation of the near-surface strata due to upsidence and closure have been reported by Mills and Huuskes (2004). Extensometer readings were taken at five depths up to a maximum of 27.2 metres across a creek valley with a valley depth of approximately 60 m. The valley was directly mined beneath by a series of longwalls. Maximum incremental subsidence across a nearby monitoring line was approximately 500 mm, with maximum observed total subsidence of approximately 1300 mm. In this case, extensometer readings indicated that the bedrock had dilated vertically from deeper strata by 140 mm at the surface, but the extent of dilation was extended to a depth of only 9 metres from the surface.

There have been no natural springs identified along the Georges River within the SMP Area. However, a ferruginous, weakly saline spring developed along the Georges River at Pool 11, which is located directly above Longwall 5A2, after the river was directly mined beneath by this longwall. No springs developed during the extraction of Longwalls 29 and 31, which did not mine directly beneath the Georges River.

Although the proposed longwalls do not mine directly beneath the Georges River, it is possible that mining-induced springs could develop following the extraction of the proposed longwalls. The chemical characteristics of mining-induced springs suggest that the water passes through upland Wianamatta Shale and permeates through natural or mining-induced fractures in the Hawkesbury Sandstone before emerging in the Georges River.

Vertical dilation between Wianamatta Shale and Hawkesbury Sandstone is possible along the tributaries to the Georges River, particularly if the thickness of the Shale is less than 10 metres, as field studies suggest that vertical dilation in creeks and rivers extend, as a maximum, to these depths (Mills and Huuskes, 2004). Where these tributaries flow into the Georges River, however, the vertical dilation is expected to be small as they are located at the ends of the proposed longwalls.

Predicted impacts on Mallaty, Leafs Gully and Upper Nepean Creek are presented in Section 5.4 of Chapter 5 of MSEC (2007).

The maximum predicted systematic tilts along the alignments of Mallaty Creek, Leafs Gully and Nepean Creek are 5.3 mm/m (i.e.: 0.5 %), 4.4 mm/m (i.e.: 0.4 %) and 3.4 mm/m (i.e.: 0.3 %), respectively, or changes in grade of 1 in 190, 1 in 240 and 1 in 315, respectively. The maximum predicted systematic tilt along the alignments of the tributaries within the SMP Area is 6.0 mm/m (i.e.: 0.6 %), or a change in grade of 1 in 165.

The natural grade along the alignment of Mallaty Creek within the SMP Area varies between a minimum of 10 mm/m and a maximum of 100 mm/m, with an average natural grade of 30 mm/m. The natural grade along the alignment of Leafs Gully within the general SMP Area varies between a minimum of 10 mm/m and a maximum of 125 mm/m, with an average natural grade of 50 mm/m. The natural grade along the alignment of Nepean Creek within the general SMP Area varies between a minimum of 10 mm/m and a maximum of 150 mm/m, with an average natural grade of 40 mm/m.

The predicted systematic tilts along the alignments of the creeks and gullies are therefore small when compared to the existing natural grades and are unlikely, therefore, to result in any significant increase in the levels of ponding, flooding or scouring. The predicted changes in the surface level along the alignments of Mallaty Creek and Leafs Gully, resulting from the extraction of Longwalls 29 to 36, are also illustrated in Fig. 5.6 and Fig. 5.7 of MSEC (2007).

If the predicted systematic tilts along the alignments of the creeks and gullies were increased by factors of up to 2 times, the maximum predicted changes in gradient would be in the order of 1%, which is still small when compared to the existing natural gradients. It is possible that there could be localised areas along the creeks and gullies which could experience a small increase in the levels of ponding and flooding, however, any changes are expected to be minor and not result in any significant impact on the creeks and gullies.

If the predicted systematic strains at the creeks and gullies were increased by factors of up to 2 times, the likelihood and extent of cracking in the beds and the likelihood and extent of fracturing and dilation in the bedrock would increase accordingly directly above the proposed longwalls.

The predicted systematic strains would still be less than those predicted along the drainage lines above Dendrobium Longwalls 1 and 2, where minor fracturing was observed in only one of six drainage lines directly mined beneath.

If the predicted valley related movements at the creeks and gullies were increased by factors of up to 2 times, the likelihood and extent of fracturing and dilation of the topmost bedrock would increase accordingly directly above and adjacent to the proposed longwalls. It is noted, however, that the method used to determine the valley related movements is conservative and it has been found that observed movements rarely exceed those predicted.

Compressive strains resulting from valley-related movements are more difficult to predict than systematic strains. Based on the relationship between closure movements and compressive strains due to closure movements observed with previous mining directly beneath creeks and rivers in the Southern Coalfield, it is expected that compressive strains due to closure movements at drainage lines which are directly mined beneath by the proposed Longwalls 34 to 36 would be much greater than 2 mm/m.

MSEC (2007) consider it possible, therefore, that some compressive buckling and dilation of the uppermost bedrock could occur along the alignments of Mallaty Creek and Leafs Gully and, to a lesser extent, along the alignments of Nepean Creek and the tributaries within the SMP Area. It has been observed in the past, that the depth of buckling and dilation of the uppermost bedrock resulting from valley related movements is generally less than 10 to 15 metres.

It is noted that the upper sections of Mallaty, Leafs Gully and Nepean Creek are characterised by Wianamatta Shale outcrop, the Shale having an estimated maximum depth of about 20 m.

Predicted impacts on Nepean River are presented in Section 5.3 of Chapter 5 of MSEC (2007). The Nepean River is located outside the general SMP Area and is at a distance of 800 metres west of Longwalls 34 and 35, at its closest point to the proposed longwalls. It is unlikely, therefore, that the river would be subjected to any significant systematic subsidence movements resulting from the extraction of the proposed longwalls.

The Nepean River could be subjected to small valley related upsidence and closure movements resulting from the extraction of the proposed longwalls. At the distance of the river from the proposed longwalls, the maximum predicted upsidence and closure movements, resulting from the extraction of the Longwalls 34 to 36, are both expected to be less than 20 mm. It is unlikely, therefore, that the river would be impacted by valley related movements resulting from the extraction of the proposed longwalls.

The Nepean River could be subjected to very small far-field horizontal movements as a result of the extraction of the proposed longwalls. Far-field horizontal movements have, in the past, been observed more than 1 kilometre from longwall extractions, however, these movements tend to be bodily movements associated with very low levels of strain and in any event have not been associated with any water flow or quality-related effects.

2.6 BASELINE WATER QUALITY AND LOCAL WATER QUALITY ISSUES

Figure 2.4 below shows all the existing water quality monitoring sites established by BHPBIC in Georges River upriver, adjacent-to and down river of the Longwall 34 – 36 SMP Area.

Table 2.5 below shows the major mean (not median) characteristics of baseline water quality at the GRQ17, GRQ17A and GRQ18 sites since August 2004 (when the West Cliff Colliery PRP7 controlled discharge trial described in **Section 2.2** above commenced). Errors are expressed at the ± standard deviation level. N = number of field and laboratory measurements (generally monthly for lab.).

TABLE 2.5 AVERAGE BASELINE WATER QUALITIES IN GEORGES RIVER SITES AUGUST 2004 – OCTOBER 2007

Site	N (field) /N (lab.	Field pH	Field EC µS/cm	DO % Sat.	Ca mg/L	Mg mg/L	Na mg/L	T. Alk. mg/L as $CaCO_3$	SO_4	Cl	Tot. Fe mg/L	Tot. Mn mg/L	Filt. Ni mg/L	Filt. Zn mg/L
GRQ17 **(upstream)**	128 /27	8.53 ±0.39	1586 ±652	113 ±25	5 ±2	5 ±2	364 ±185	592 ±311	29 ±11	162 ±72	0.99 ±0.55	0.050 ±0.044	0.083 ±0.049	0.019 ±0.01
GRQ17A **(adjacent)**	81 /18	8.51 ±0.38	1568 ±694	102 ±27	5 ±2	4 ±2	374 ±192	593 ±320	28 ±11	160 ±74	0.86 ±0.58	0.066 ±0.076	0.080 ±0.052	0.014 ±0.01
GRQ18 **(downstream)**	29 /27	8.15 ±0.38	1247 ±548	89 ±35	6 ±2	5 ±2	316 ±142	508 ±228	22 ±13	152 ±61	1.24 ±0.81	0.074 ±0.075	0.069 ±0.037	0.019 ±0.01

As can be seen from **Table 2.5** there is very little difference in mean River baseline water quality immediately upriver, adjacent to and immediately downriver of the SMP Area. Baseline water quality is clearly dominated by flows from the West Cliff licensed discharge, albeit diluted by further runoff into the River north of Brennans Creek confluence, especially over the very wet (approximately 95 percentile) year of 2007.

Figure 2.4 Established Water Quality Monitoring Sites in Georges River

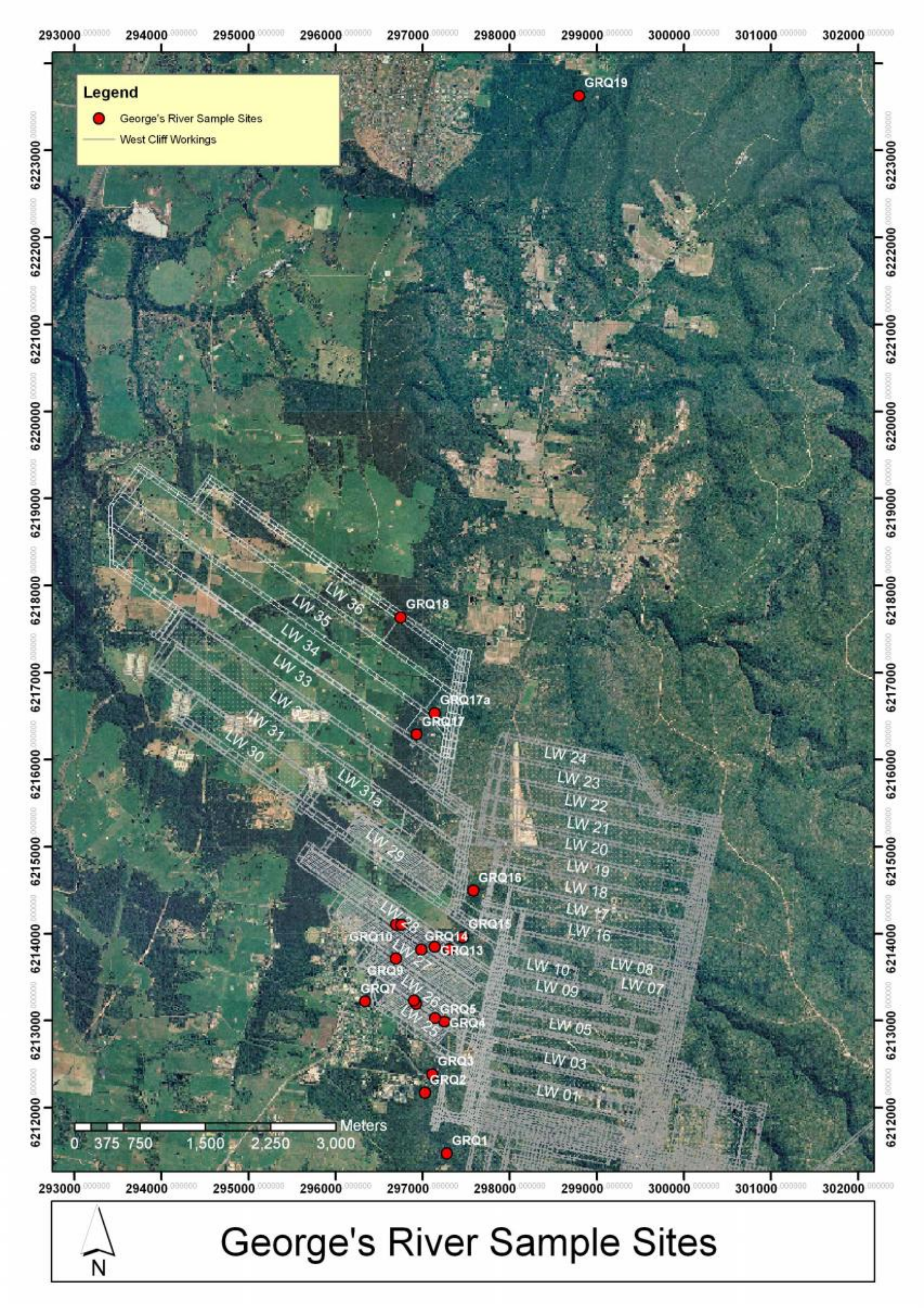


Figure 2.5 shows all the existing water quality monitoring sites established by BHPBIC in Mallaty Creek to date (in orange) and the proposed water quality monitoring sites. **Figure 2.5** also shows previously established water quality monitoring sites in the arbitrarily named Ingham's Tributary of Ousedale Creek.

Figure 2.5 Established and Proposed Water Quality Monitoring Sites in Mallaty Creek

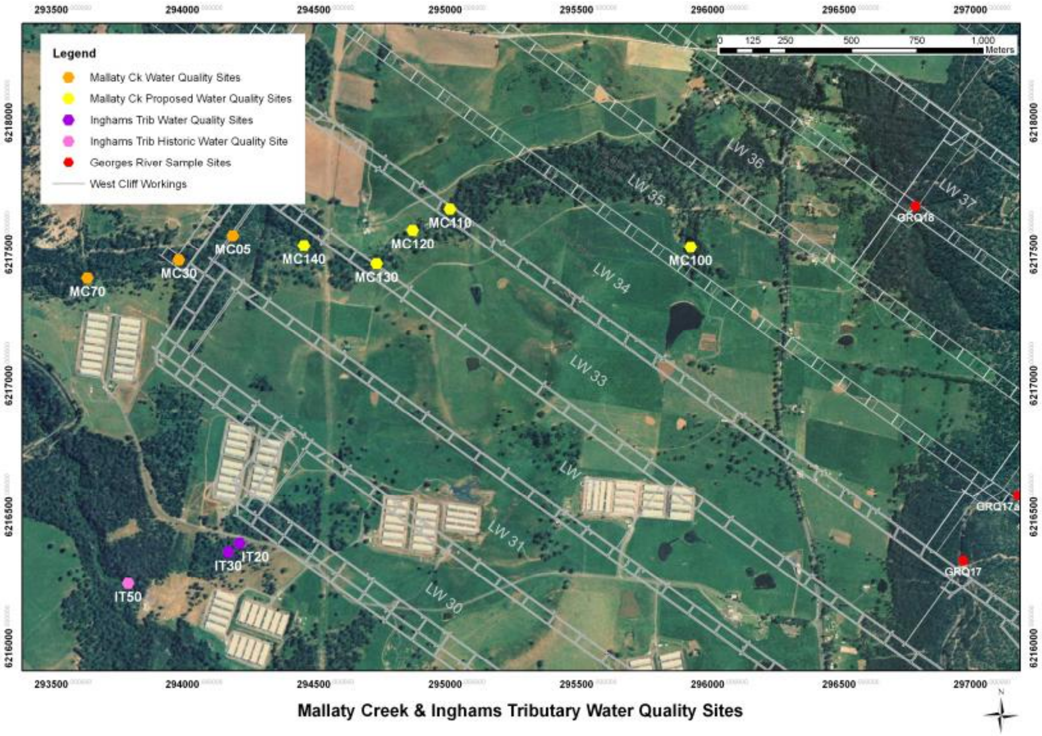


Table 2.6 shows the major <u>mean</u> (not median) characteristics of baseline water quality at the MC05 site SINCE December 2005. We have also inserted some field data obtained for site MC30 by The Ecology Lab (2007) in August 2007. Errors are expressed at the ± standard deviation level. N = number of field and laboratory measurements (generally monthly for lab.).

TABLE 2.5 AVERAGE BASELINE WATER QUALITIES IN SOME MALLATY CREEK SITES AFTER 8 DECEMBER 2005

Site	**N (field) /N (lab.**	**Field pH**	**Field EC µS/cm**	**DO % Sat.**	**Ca mg/L**	**Mg mg/L**	**Na mg/L**	**T. Alk. mg/L as $CaCO_3$**	**SO_4**	**Cl**	**Tot. Fe mg/L**	**Tot. Mn mg/L**	**Filt. Ni mg/L**	**Filt. Zn mg/L**
MC130	2?	7.54 ±0.06	285.5 ±4.5	60 ±2										
MC05	84 /20	7.04 ±0.55	4836 ±1732	54 ±26	58 ±21	176 ±74	676 ±280	349 ±135	53 ±23	1462 ±629	1.92 ±1.35	0.604 ±0.873	<0.005	0.009± 0.008

So far, no water quality monitoring sites have been established in Leafs Gully or Upper Nepean Creek. It is understood these will be established after further inspections of these catchment and baseline water quality data will be accumulated well before any commencement of extraction from the proposed Longwall 34.

The issue of salinity is highly relevant to the assessment of potential impact(s) on aquatic ecology for Longwalls 34 – 36 because mine subsidence-related effects deriving from their mining can potentially affects two chemically very different classes of aquatic ecosystem namely the following:

1. The lower salinity (lowland river) context of Georges River where runoff into the River is dominated by a mix of Hawkesbury Sandstone Woronora Plateau landscape (on the eastern side of the River) and Cumberland Plain (Lowlands) landscape (on the western side of the River and on the eastern side from Wedderburn north), salinity of the river water expressed in Electrical Conductivity (EC) units, even taking into account the West Cliff Colliery environmental discharge from BCD is unlikely to ever exceed about 4000 µS/cm and chloride and sulfate concentrations are unlikely to frequently exceed about 250 and 25 mg/L respectively.
2. The water quality context of Mallaty, Leafs Gully and Nepean Creeks which arise exclusively in Cumberland Plain (Lowlands) landscape dominated by Wianamatta Shale outcrop and Shale-derived soils are such that salinities in the middle and lower sections of these creeks frequently exceed 10,000 µS/cm and chloride and sulfate concentrations are likely to frequently exceed 1500 mg/L and 50 mg/L respectively.

For more than 10 years there has been an increasing tendency in Australia to focus on assessments of the effects of salinity on ecosystem health (e.g. Bluhdorn and Arthington, 1995; Bailey et al. 2002; Dunlop et al. 2005; Rutherford and Kefford, 2005). More recently, these efforts have been systematically funded by the National Action Plan for Salinity and Water Quality (NAP) in a move to set salinity targets or guidelines for specific rivers or catchments (NAP, 2006).

In order to develop these targets there is a need to assess the effects of salinity on the aquatic environment. This information can then be applied in a probabilistic risk assessment framework to derive guidelines for salinity and will allow predictions to be made regarding the effects of forecasted rises in salinity in the aquatic environment. This information may be used to scenario test or evaluate relative impact of various management options that can alter the salinity of inland waterways.

In nature, salinity rarely changes in isolation to other aspects of water quality, and these other changes have the potential to modify the effect of salinity. Physical water quality variables (e.g. temperature, flow rates etc) have been found to have relatively minimal effects on lethal salinity tolerance but more effect on sub-lethal salinity tolerance. Water temperature has been observed to have a slight effect on the acute lethal salinity tolerance of three species of microinvertebrates, but its effect was minor and inconsistent between these species and likely represents the temperature tolerance of the particular species (Kefford et al. 2006b).

A major USEPA-sponsored American study published in 1997 (Mount et al. 1997) studied the acute toxicity of over 2900 ionic solutions using the daphnids *Ceriodaphnia dubia* and *Daphnia magna* as macroinvertebrate and fathead minnows as the fish targets. In general, relative ion toxicity (both lethal and sub-lethal) was found to be significant in the order potassium (K)> bicarbonate (HCO_3) ~ magnesium (Mg) > chloride (Cl) >sulfate (SO_4). Sodium (Na) and calcium (Ca) were not found to be significant variables and the toxicity of Na and Ca were ascribed to the corresponding anion. The importance of HCO_3 ecotoxicity has long been recognized, both in aquatic systems (e.g. Hoke et al. 1992) and in grassland ecosystems.

Sub-lethally, ionic proportions with high calcium concentrations have been found to be more detrimental than other common ionic proportions in south-eastern Australian waters. Low (acid) pH had no measurable effect on both acute lethal and sub-lethal salinity tolerance. High (alkaline) pH, however, increased the effect of salinity in one species only (Kefford et al. 2006b).

There are many differences in common patterns of ionic proportions throughout southeastern Australia. A previous study identified broad geographical patterns in the surface waters of Queensland according to the proportion of major ions present. In the study, three of these water types were simulated in the laboratory and their toxicity was tested using a sub-lethal algal test, an acute lethal toxicity test using a freshwater cladoceran (water flea) test, and acute larval fish imbalance test.

- Type 3 was found to be the most toxic to all taxa tested and had the highest magnesium content of all the water types.
- Type 2 was the second most toxic and also had the second highest Mg content but low $HCO_3$and high Cl. Type 2 and 3 were both more toxic to the cladoceran than algae.
- Type 1 had the least toxicity to the cladoceran and has the highest sodium chloride concentration and the lowest calcium and magnesium.

All these findings (reviewed and summarized in Kefford et al. 2006b) are broadly in line with the aforementioned earlier major USEPA-sponsored American study published in 1997 (Mount et al. 1997).

These findings indicate that saline waters having high concentrations of magnesium and/or concentrations of calcium low enough to produce deficiencies in this element may result in greater effects than sea water type salinity, especially when long term and/or sub-lethal effects of salinity are being considered. In such cases lower salinity guideline values are needed compared to those waters with ionic proportions similar to sea water.

The salinity of waters discharged from Brennans Creek Dam and hence that in Georges River, is principally based upon the cation sodium (Na^+) and the anion bicarbonate (HCO_3^-). It is now well established that:

1. the anion bicarbonate is the principal and most variable driver of salinity-based ecotoxicity in such waters (e.g. Cowgill and Milazzo,1991; Hart, 1992; Hoke et al., 1992; Williams et al. 1993; Mount et al., 1997; USEPA, 1994); and that
2. as the pH is lowered the proportion of alkalinity in the water comprised of bicarbonate increases (e.g. Stumm and Morgan, 1996) and hence the ecotoxicity due to salinity alone must by definition increase (per unit of salinity).

It is important to note that as the pH is of the river water is lowered (e.g. due to dilution by fresh water runoff and/or the addition of dissolved CO_2 from exogenous sources decomposition of natural organic matter) the ratio of bicarbonate to carbonate (i.e. HCO_3^- to CO_3^{2-}) rises (e.g. Toran and Saunders, 1995) and there is less CO_3^{2-} available to complex nickel (Ni) and zinc (Zn), the principal, potentially ecotoxic metals found in the River waters. Consequently, the proportion of Ni and Zn in the river water that is complexed by carbonate and rendered non-ecotoxic by being converted to anionic or neutral species decreases with decreasing pH and thus the ecotoxicity due to these metals also tends to <u>increase</u>.

It is also relevant to note that the effect of the West Cliff EPL, i.e. limiting the maximum pH of the West Cliff licensed discharge to 8.5, is to maximize the ratio of bicarbonate to carbonate and, all other things being equal, would also increase the effect of salinity-based sub-lethal ecotoxic response over that which would apply should the pH be allowed to be higher than 8.5 (where the ratio of the less ecotoxic carbonate to the more ecotoxic bicarbonate increases).

An important issue is the effect of variable salinity on macroinvertebrates. While work in this area in Australia is preliminary, two general observations have emerged (Kefford et al. 2006b):

1. Firstly, it has been found that sudden drops in salinity can be lethal to salinity-acclimated freshwater macroinvertebrates. This result was unexpected and suggests that adverse effects from sudden drops in salinity may occur.
2. Secondly, a gradual increase in salinity was found to cause lower mortality than a sudden increase in salinity. In another set of experiments the freshwater snail *Physa acuta* and a species of corbiculid bivalve were acclimated to increasing salinity over three days and then exposed to even higher salinity in an acute lethal salinity tolerance test. For both species individuals acclimated to increasing salinity exhibited greater salinity tolerance than individuals directly transferred to test salinity.

These results with macroinvertebrates, where gradual rises in salinity increase salinity tolerance are in accordance with numerous previous studies of fish.

However, the finding that rapid falls in salinity can be lethal to salt-adapted individuals has not been previously reported.

Whether there are critical rates of change and drops in salinity and whether variable salinity alters sub-lethal effects of salinity, require further investigation (Kefford et al. 2006b).

In the interim, however, it is agreed that environmental flows, saline water disposal schemes and other activities that rapidly alter salinity <u>should be managed to minimize sudden salinity changes (e.g. The Brisbane Declaration; Water, 2007).</u>.

As noted in **Section 1.2**, there are no Water Quality Objectives regarding salinity arising from the Independent Inquiry in to the Hawkesbury Nepean River System by the Healthy Rivers Commission and the Commission recommended using the trigger values in the national water quality guidelines (ANZECC&ARMCANZ, 2000).

We are of the view that Upper Georges River should be regarded a lowland river where the default EC trigger value in the national water quality guidelines is 2200 uS/cm (ANZECC/ARMCANZ, 2000). This conclusion is based on:

Past studies collecting data from 1995 onwards e.g. Jarvis, 1997; Marine Pollution Research, 1999, the latter also reviewing studies by Campbelltown City Council. These studies have shown that the salinity of unconnected pools in the River almost invariably rise above the 30 – 350 uS/cm range set down for upland rivers in in the national water quality guidelines during extended dry weather. These studies have shown that below Brennans Creek the River has long been affected not only by discharges from Appin and West Cliff Collieries but also by Appin township and agricultural land uses; and

The western side of the River's catchment is dominated throughout by Wianamatta Shale-derived soils, the Shale being a marine sediment (Hazelton and Tille, 1990). It is well known that such marine sediments continue to provide salinity to runoff and groundwater seepages (interflow, throughflow etc) right up to the present day.

The Upper Nepean River is also considered to be a lowland river due to the known occurrence of large areas of the River catchment i.e. Cumberland Plains Lowlands and Hawkesbury-Nepean Valley mantled with Wianamatta Shale-derived soils.

It can easily be demonstrated that some tributaries of the Upper Nepean River into which it flows naturally contribute relatively saline water to the River.

For example, we have previously shown (Ecoengineers, 2006b) that the long term mean salinity of lower Elladale Creek west of Appin at site NR8, a catchment which is largely mantled by Wianamatta Shale-derived soils (and drains to Nepean River), is 2899±1775 μS/cm at the one standard deviation level, a value which is not only highly variable with respect to salinity but most of the time significantly exceeds the default trigger value (2200 μS/cm) even for lowland rivers for southeastern Australia in the national water quality guidelines (ANZECC/ARMCANZ, 2000).

Operation of the West Cliff WMS along the lines adopted in August 2004 has had the effect of significantly minimising both the salinity and volume of uncontrolled discharges from the Brennans Creek Catchment which would otherwise occur via the spillway of BCD.

The Australian literature evidence for ecotoxicity up to about TDS 2000 mg/L (EC ~3200 uS/cm) is not only sparse, but reliable field studies are generally restricted to locations in the wet tropics where rainfall is plentiful and frequent through the wet season and salinity has been low even throughout the Holocene (last 10,000 years).

Following on from this, the lack of a clear pattern in sub-lethal and chronic responses to salinity for species within an individual taxon and between taxa also makes it unsafe to suggest a safety factor below that can be applied to known acute lethal tolerance of species from other regions within Australia where sub-lethal and chronic effects where site- or region-specific acute sensitivities have not been measured.

Fortunately, such studies <u>have</u> been carried-out within the Southern Coalfield. Three recent studies using control sites and accepted methodology have been conducted The Ecology Lab in the Upper Georges River, in tributary streams of Nepean River <u>and</u> in Tea tree Hollow Creek, a tributary of Bargo River and Bargo River itself.

Those studies <u>consistently</u> found that it is likely that in the rivers of the Southern Coalfield (e.g. Bargo River, Nepean River, Georges River) most macroinvertebrate taxa (families) are well acclimatized to TDS up to at least 2000 mg/L (i.e. EC up to approx 3200 uS/cm).

We infer that this is simply because over the long term, such (moderate salinity) conditionsarise sufficiently frequently in local rivers due to either:

1. the long term frequency of drought conditions during which time these demonstrably became a series of poorly connected or unconnected pools subject to evaporative concentration; and/or

2. anthropogenic discharges (e.g. from farming activities, settlements due to the length of time that Europeans have been in the area; and/or
3. effects of the relatively ubiquitous occurrence in at least parts of the catchments of the major rivers of soil profiles derived from the marine Wianamatta Shale sediment which can naturally result in moderate salinities (i.e. well in excess of 2200 uS/cm) in tributary streams.

2.7 BASELINE AQUATIC ECOLOGY

The Ecology Lab (TEL) (2003) previously assessed the potential aquatic ecological impact of subsidence upon three waterways within a region draining to Nepean River, namely, Rocky Ponds Creek, Simpson Creek and Cataract River. Some benthic macroinvertebrate, water quality and fish sampling was undertaken by The Ecology Lab where suitable habitat was present, including Simpson Creek which catchment is almost completely mantled by Wianamatta Shale derived soils and which flows into the above-noted lower Elladale Creek). The Ecology Lab found in their 2003 study that local macroinvertebrate communities were mildly – moderately tolerant of water salinity.

More recent studies within the local region on Upper Georges River etc (The Ecology Lab, 2006), strongly indicate that locally, aquatic macroinvertebrates locally can, and do, acclimatize to some degree to salinity levels particularly within about the 1000 – 4000 µS/cm (TDS approx. 625 - 2500 mg/L) range.

Benthic macroinvertebrate population and diversity studies conducted by The Ecology Lab (2006) suggest that the ecological health of the Upper Georges River below the Brennans Creek confluence, by comparison with pristine baseline sites established by them around the Region, is good.

As noted in **Section 2.1** above, the recent The Ecology Lab studies in Upper Georges River (The Ecology Lab, 2005, 2007) were conducted in a context where most of the time flow in the River is dominated by a controlled, continuous discharge from Brennans Creek Dam to Upper Georges River via Brennans Creek which has been occurring since August 2004 and which has ranged in EC over the 3 years from an EC of about 2300 - 3100 uS/cm with a relatively constant mean EC of 2702±196 uS/cm at the one standard deviation level.

This is a level of salinity which significantly exceeds the default trigger value for lowland rivers for southeastern Australia in the national water quality guidelines of 2200 uS/cm.

Studies carried out by The Ecology Lab (2007) in August 2007, following a relatively wet period in which 1161 mm had been recorded since 1 January 2007 at West Cliff indicated that the upstream section of the Georges River (above the SMP Area) was characterized by long, shallow pools connected by sections of shallow rapid flow over retaining sandstone rock bars.

In the middle and downstream reaches, the pools are deeper with connecting flow through boulder fields. Some pools were considered likely to become isolated during periods of low flow. The substratum included large areas of sandstone bedrock, accumulations of sand and silt within pools and areas of boulder and cobble. Large stands of bull rush and patches of spike rush and *Isolepsis* sp occur throughout the reach within the SMP area. Mat rush, saw grass and numerous ferns, grasses and sedges were common along the banks.

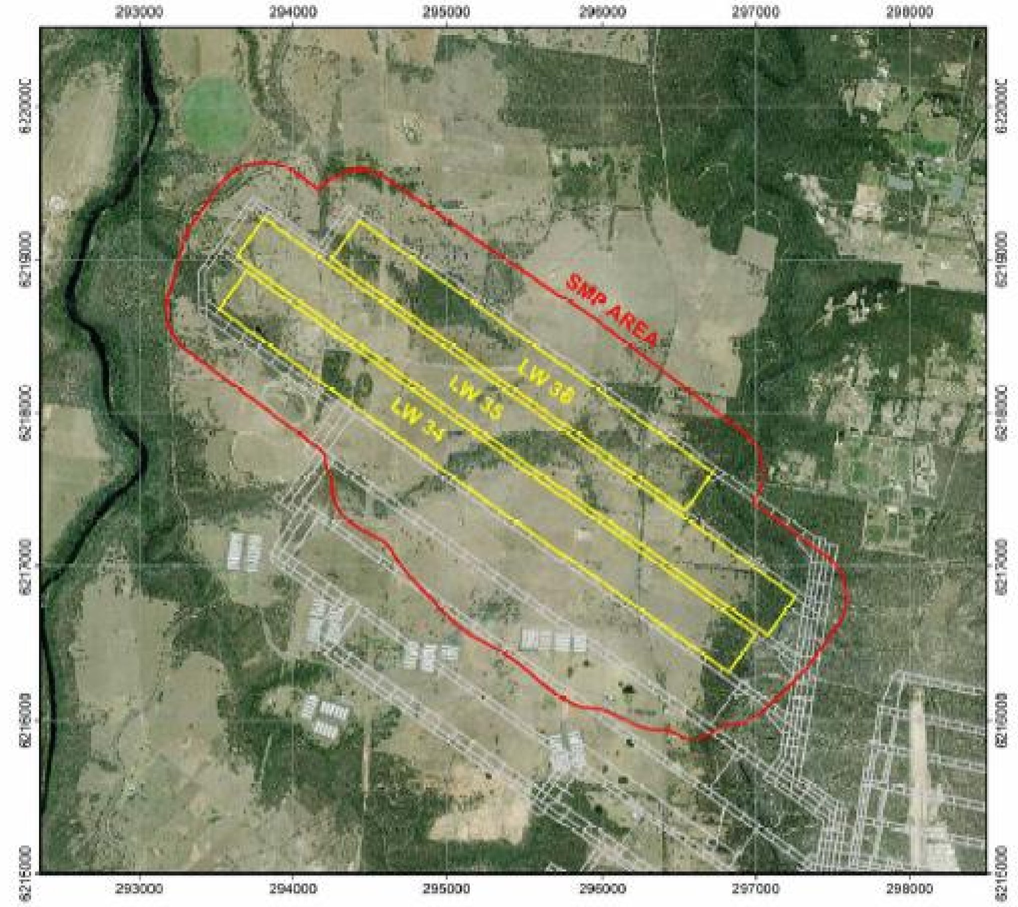
This reach of the River has extensive areas of fish habitat, including large deep pools, large snags, overhanging bank vegetation, stands of aquatic macrophytes and sections of fast-flowing water.

Several barriers to fish passage were identified, including small waterfalls at rockbars and the pipe culvert at the Blackburn Road crossing. However, it was considered that fish may be able to surmount these barriers during high flow events.

The Ecology Lab (2007) concluded this reach of the Georges River contains Class 1 fish habitat (major fish habitat), but its tributaries contain only Class 3 to 4 (minimal to moderate) fish habitat.

As can be seen in **Figure 2.6** below the local landscape over proposed Longwalls 34 – 36 is largely given over to farming and only relatively narrow zones of native bushland occupy the western banks of Georges River and the watercourses of Upper Mallaty Creek, Leafs Gully Creek and Upper Nepean Creek. The catchment area to the west of the River also includes rural properties, where surface runoff is retained by numerous farm dams. Natural vegetation is typically located within the catchment area on the eastern side of the river.

Figure 2.6 Aerial Photograph Showing Longwalls 34 to 36 and the General SMP Area



The Ecology Lab (2007) observed Mallaty Creek runs through cattle pasture and has a narrow fringing strip of riparian vegetation, dominated by privet, an exotic species. The bank structure has been degraded by cattle. The natural flow has been modified by farm dams and by the Eastern Gas Pipeline crossing which traverses the creek within the SMP area. This watercourse was regarded as ephemeral and would consist of a series of semi-permanent pools, except during periods of high rainfall.

The Ecology Lab (2007) observed substratum in the upper reaches to be dominated by soft sediments no doubt derived from Wianamatta Shale, but consisted of large boulders and sediment accumulations in pools in steeper sections of the creek, no doubt founded on Hawkesbury Sandstone.

Mallaty Creek was considered as Class 3 (moderate) fish habitat, for species including freshwater crayfish and eels. The Ecology Lab established a sampling site in a semi-permanent series of pools upstream of the eastern gas pipeline.

The Ecology Lab (2007) observed Leafs Gully Creek to have a clearly defined, narrow channel with a substratum consisting of boulder, cobble and silt. Riparian vegetation is dense on the upper slopes, but limited to a thin band in the middle and upper reaches.

The surrounding land use is predominantly cattle pasture. The large farm dam in the middle of the reach within the SMP Area forms a significant barrier to fish passage and interrupts natural flows. The Ecology Lab (2007) observed the watercourse below the dam to have turbid flowing water and considered it would probably be reduced to isolated pools during dry periods. The natural channel of Leafs Gully was considered to contain Class 3 (minimal) fish habitat.

At the time of inspection by The Ecology Lab (2007), Nepean Creek consisted of small standing pools, despite recent rainfall. There were a few isolated sandstone rockbars in the lower reaches of the creek within the SMP Area, but flow was limited. There was a small pool approximately mid-reach within the SMP area, containing floating pondweed, spikerush, ribbonweed and *Isolepsis* sp. Common rush occurs along the rest of the creek.

The riparian vegetation of Nepean Creek was observed to be thin in the upper reaches, but wider downstream. It is dominated by native species, but there are also exotics, such as blackberry and lantana. Iron floc was observed in Upper Nepean Creek within the SMP Area. This is possibly indicative of the presence of a pre-existing ferruginous spring in the upper reaches of Nepean Creek. Fish habitat was classed as minimal to unlikely within the SMP Area.

Forty-two macroinvertebrate taxa were collected by The Ecology Lab (2007) at 9 sites in the Georges River and 20 taxa at a single site (‘Site 10’) in Mallaty Creek in their baseline survey for this SMP application.

The aquatic fauna at the 5 upriver sites in the Georges River (Sites 1 – 5) were found to be less diverse than at the 4 sites (Sites 6 – 9) within the SMP Area.

However, the fauna at most of the sites within the SMP Area and at all the upstream sites were rated as slightly impoverished relative to the AUSRIVAS reference condition (Turak and Waddell, 2001).

Fauna at one site in the George River within the SMP Area and at the site in Mallaty Creek, however, were rated as similar to the AUSRIVAS reference condition. The

AUSRIVAS-generated SIGNAL scores indicated that the fauna were subject to moderate to severe pollution.

2.8 MINING-RELATED POTENTIAL AQUATIC STRESSORS

2.8.1 Erosive Effects of Closure in Georges River

Closure of valley walls may lead to erosion and loss of soil materials into the creek or river though rock falls or slumping of steep talus slopes. However, these landforms are not significant in the SMP Area.

In terms of water quality issues the key question with respect to the valley closure effect is whether it leads to significantly increased erosion on the slopes of the gorge such that increased levels of turbidity over longer period occur in the river, independent of other effects such as rainfall/runoff intensity and/or duration and bushfires.

Monitoring and inspection of mining areas in the region over the past five years suggests there has been no visual evidence in the more heavily incised catchments studied by BHP Billiton Illawarra Coal and its consultants (specifically Cataract River, headwater catchments of Cordeaux River and of Lake Avon) that this erosion effect is significant.

Within the Southern Coalfields there has been no observation of cliff or slope instability relating to longwall mining unless the cliff or steep slope has been directly mined beneath. As the Georges River will:

- not be directly mined beneath by the proposed longwalls; and
- the river is not deeply incised into the surrounding countryside; and
- slopes on either side of the River are relatively gentle and well vegetated,

it is not anticipated that increased erosion of rock or movement of talus slope material into the River will occur (MSEC, 2007).

Consequently this potential effect on river water quality was not considered further.

2.8.2 Geochemical Effects of Riverbed and Rock Bar Fracturing

Strains due to differential subsidence, leading to ‘upsidence’ and ‘valley closure’ caused by longwall mining beneath incised creeks and riverbeds can produce a complex suite of physico-chemical effects. Hydrological measurements, visual observations and water quality monitoring over recent years in the Southern Coalfield indicate these effects are:

1. Compressive or tensile (strain) failure fracturing of the Hawkesbury Sandstone bedrock leading to increased permeability and storage, possibly reduced surface flows, especially at the low end of the flow rate regime and more rapid draining of defined pools in no and low flow situations.
2. Diversion of stream flows through the fractured bedrock leading to loss of surface flows and potential loss of catchment yield to deep aquifer storage. This effect has been described in our previous reports as ‘sub-bed diversion’ (Ecoengineers Pty Ltd., 2005b, c; 2006b).

3. Dispersion of small quantities of kaolinite from freshly fractured unweathered sandstone in the bedrock and its re-emergence from the bedrock immediately downstream of upsidence-affected areas. This effect has only been detected visually, occurs very early in the fracturing sequence, does not significantly affect downstream turbidities at anywhere near the levels that natural rainfall/runoff events cause and decays very rapidly.
4. Dissolution and oxidation of accessory siderite/rhodocrosite (ferrous/manganous carbonate; $Fe/MnCO_3$) and marcasite (a form of pyrite, FeS_2) within freshly fractured or dilated groundwater pathways in the Sandstone, leading to release of sulfuric acid (H_2SO_4), dissolved iron (Fe), manganese (Mn), nickel (Ni) and zinc (Zn) and re-emergence of more acidic waters of lower pH, lower redox potential (Eh) and dissolved oxygen (DO) concentrations and higher concentrations of the above metals from bedrock immediately downstream of upsidence-affected areas.
5. Increased concentrations of dissolved aluminium (Al) in water emerging immediately downstream of fracturing-affected areas due to the dissolution of aluminium from kaolinite in the walls of flow paths conducting acidic water through the fractured bedrock.

In 2005 we made an assessment and modelling of the potential magnitude of the above geochemical effects using data obtained over past years from Lower Cataract River (Appin Colliery), from Bargo River (Tahmoor Colliery) and, in most detail, from Native Dog Creek (Elouera Colliery).

For the assessment, a detailed study of the markedly fractured 2 – 3 m high rock bar at location NDC2A in upper Native Dog Creek was conducted. The assessment compared monthly flow measurements at an immediately downstream (site NDC3) and monthly chemistry sampling at upstream site NDC1, the rock bar site NDC2A and the downstream site NDC3 from the beginning of monitoring in mid March 2002 onwards.

Estimates of diverted sub-bed diversion flows through the Native Dog Creek NDC2A rock bar were found to be relatively accurate using the SO_4 concentration immediately downstream of the bar as a conservative tracer to site NDC3.

The study found the following:

1. The acid generation rate of the NDC2A rock bar was approximately dependent upon the rate of flow through the rock bar up to a maximum flow rate of about 0.1 ML/day.
2. *The highest observed rates of acid generation by the fractured rock bar occurred between March and May 2003*. The observed maximum daily mass of acid generated occurred on 21 May 2003 when the SO_4 concentration generated was 118 mg/L for an observed flow rate through the rock bar, back-calculated from a downstream flow meter at site NDC3, equivalent to 0.0791 ML/day. This is equivalent to a maximum H_2SO_4 generation rate of 97.2 moles/day. The pH of the diverted water on that day was also the lowest observed over the 12 month period at 3.16 (= field measurement; 3.19 laboratory sample check).
3. The acid generation rate of the rock bar then declined strongly over several years (Ecoengineers Pty Ltd., 2003; Ecoengineers Pty Ltd., 2004a, b; Ecoengineers Pty Ltd, 2005a).

To place the above outcomes in a regional context, it is useful to note that our subsequent Appin Area 3 study (Ecoengineers Pty Ltd., 2005b) also identified that:

1. early estimated maximum acid generation rates for discrete sub-bed flow diversion zones from the Lower Cataract River during the earliest monitoring period conducted by IC lay between 68 and 124 moles H_2SO_4/day; and
2. an estimate of maximum acid generation rates of comparable precision from data supplied to us by Tahmoor Colliery obtained from studies of the Bargo River also gave a maximum rate of approximately 100 moles H_2SO_4/day.

These estimates of maximum daily acid generation rate cover a relatively narrow range. This is an understandable outcome as there is good reason to expect that, for flows over about 0.1 ML/day through a freshly fractured network of a sub-bed flow diversion zone in Hawkesbury Sandstone, the rate of acid generation would be kinetically limited by:

1. average density of exposed marcasite grains in the freshly fractured Hawkesbury Sandstone; and
2. average cross sectional area, length and typical tortuosity of flow paths; and
3. dissolved oxygen content of the inflowing water.

It appears that this rate typically lies in the region of (say) 68 – 124 mole/day and the best available evidence to date suggests that it is very unlikely to be outside this range. A mean value of about 100 mole H_2SO_4/day would be a best estimate of the maximum rate of acid generation that would occur in any discrete sub-bed diversion zone.

In turn, this means that a maximum mass of marcasite of 50 moles/day is being dissolved and hence up to 36 moles/day of Fe is being released (but see below for estimated molar proportions of other included metals in marcasite).

This value appears to represents the maximum amount of acid that may be kinetically transferred to a sub-bed diversion flow of 0.1 ML/day or greater and that any sub-bed diversion flows (i.e. through the fracture network) that are greater than this will not increase the acid and metals load transferred to the water but will ameliorate their downstream effects through dilution.

It was found that the concentrations of filterable nickel (Ni) and zinc (Zn), known accessory metals in the marcasite, at pHs below that at which released Ni and Zn concentrations would have been reduced by adsorption onto precipitated hydrous Fe oxides showed relatively constant SO_4/Zn and SO_4/Ni mole ratios of 16±5 (n=13) and 100±19 (n=13) respectively (Ecoengineers Pty Ltd., 2005c). Note that errors here are expressed at the one standard deviation level.

These values for Ni and Zn are respectively, 16 and 96 within error and appear to be broadly consistent both with the known crystallography of marcasite and with recent literature on Ni, and Zn leaching in acid drainage derived from sedimentary quartz pebble-hosted spheroidal marcasites (Falconer and Craw, 2005). The average composition of local marcasite in the Native Dog Creek area (at least) therefore approximates to (say) $Fe_{0.854}Zn_{0.125}Ni_{0.021}S_{2.}$

We believe marcasite in Hawkesbury Sandstone within the SMP Area is likely to have a generally similar composition. There was no significant correlation between manganese (Mn) and sulfate and it is inferred that most Mn would have been sourced from the dissolution of traces of rhodocrosite ($MnCO_3$) or manganiferous siderite (Fe/$MnCO_3$) in the sandstone as a consequence of the acid released though the dissolution of the marcasite.

In summary:

1. the estimated maximum daily rate of acid generation in any discrete sub-bed flow diversion zone is currently believed to be of the order of 100 mole H_2SO_4/day which is equivalent to 100 mole $CaCO_3$/day to completely neutralize it; and
2. prior experience in Native Dog Creek over the nearby Elouera Colliery founded on closely similar Hawkesbury Sandstone terrain and at other mining-affected locations in the region shows that this maximum possible peak rate is not sustained for any more than a few months.

It has been demonstrated that, subject to predictive modelling, if adequate offsets from the sides or ends of longwalls from major watercourses are provided avoidance of the above-described ‘upsidence-related’ hydrologic and geochemical effects may be achieved.

Recent examples of reductions in impacts include Longwalls 301 and 302 of Appin Area 3 adjacent to Cataract River and West Cliff Area 5 Longwalls 31 to 33 adjacent to Georges River.

The most important aspect of assessment and management of the above effects is acid-base accounting (e.g. Environment Australia, 1997).

This involves making an inventory of the capacity of any material or collection of materials that can generate H_2SO_4 and an inventory of the capacity of the same material(s) or complementary material(s) that might be mixed, layered or underlined with the acid-generating material (e.g. local country rock, limestone, dolomite etc) to generate a neutralizing basicity (alkalinity).

A possible source of alkalinity may also be simply that pre-existing in a natural watercourse.

Alkalinity is usually found to be provided by calcium and magnesium carbonates which provide carbonate alkalinity but alkalinity can also be provided by sodium, potassium and other elements potentially releasable from less basic rocks such as plagioclases (feldspars). Calcium and magnesium carbonate ($CaCO_3$ and $MgCO_3$) will neutralize the acidity generated by the reaction:

$CaCO_3 + H_2SO_4 = CaSO_4 + H_2O + CO_2$

It is important to note that one mole of sulfate (a mole being the molecular weight expressed in grams) or 96 grams of SO_4 is equivalent to one mole of sulfuric acid (or 98 grams of H_2SO_4) which is neutralized by one mole of calcium carbonate (or 100 grams of $CaCO_3$). These equivalents are often rounded to 100 grams each.

A critical characteristic of Hawkesbury Sandstone in the context of upsidence induced acid generation in Illawarra Region waterways is that the Sandstone has almost no neutralizing capacity and in most cases there is generally also very little neutralizing capacity in the chemistry of local natural stream and river waters.

Therefore the H_2SO_4 released by oxidation of the marcasite in the Sandstone is generally largely attenuated naturally downstream principally by dilution, and to a very much lesser extent by reaction with the low concentration of carbonate alkalinity in the passing creek or river water in which the H_2SO_4 dissolves and the release of sodium from the weathering of the kaolinite in the Sandstone under acidic conditions. This also releases dissolved aluminium, possibly also occurring at ecotoxic levels under low flow conditions.

However, this is not actually the case in the Georges River situation as the greater part of the water passing down the river through the SMP Area derives from the controlled release of water from the Bottom Drain of BCD as described in **Section 2.1** above.

Frequent monitoring of the quality of the water released from BCD shows that the water flowing out of Brennans Creek into Georges River contains considerable bicarbonate alkalinity – typically in the range 1000 – 1500 mg/L expressed as calcium carbonate ($CaCO_3$) and invariably at least 1000 mg/L (Ecoengineers Pty Ltd., 2005a).

This alkalinity is available to neutralize any H_2SO_4 acidity released by weathering of marcasite in the fractures of sandstone exposed through the cracking of river bed and/or rock bars.

In this sense the situation in Georges River differs fundamentally from that in other rivers such as Cataract and Bargo Rivers where mining-induced sub-bed diversions and marcasite dissolution has occurred in that:

1. it is very unlikely that acidic pHs could be induced (and this possibility is checked by geochemical modeling in Section 3.2 below); and
2. Al will not be released from kaolinite in the sandstone as both the mineral and Al itself are very insoluble within the pH 6.5 – 8.5 range.

However, the water released from BCD also contains trace concentrations of nickel (Ni) and zinc (Zn), metals also released from marcasite during dissolution. Consequently, in the Georges River there is a potential for exacerbation of potentially ecotoxic levels of Ni and Zn.

2.8.3 Effects on Pool Habitats

Associated with the phenomenon of upsidence fracturing of the river bed and consequent possible sub-bed flow diversions are ‘flow on’ effects that may impact ecologically on large pools in the River.

These pools generally constitute the major habitats for the aquatic biota, in particular attached algae, benthic macroinvertebrates, fish, insect larvae and other organisms as they contain the greatest density of refugia for organisms from the turbulent and erosive effects of high flows and drying out under conditions of low flows.

Upsidence-induced fracturing particularly occurs at rock bars where tensile stresses are highest and it is these structures which tend to confine the most significant habitat pools along the stream or river.

As a consequence of rock bar fracturing, the confined pool may drain down to a much lower minimum volume, especially under low flows that do not exceed the hydraulic maximum sub-bed flow rate. In extreme cases the pool can be drained completely under low or no flow conditions.

If pools lie immediately downstream of fractured rock bars they can be subjected to chemical stressors from flow of the sub-bed diverted waters into them.

These potential stressors are:

1. reduced pH (i.e. increased acidity);

2. dissolved oxygen (DO) depletion though oxidation of ferrous (Fe^{2+}) and manganous (Mn^{2+}) ions;
3. possible 'smothering' of pool boulder and bed surfaces by the consequent precipitated Fe and Mn hydrous oxides although it is noted this 'effect' is ubiquitous in the natural aquatic environment and are usually accompanied by large volumes of highly permeable masses of algae, bacteria and associated biofilm; and
4. possible ecotoxic effects from heavy metals, principally aluminium (Al), nickel (Ni) and zinc (Zn) released from kaolinite and marcasite in the sandstone or from other outcropping strata (e.g. Wianamatta Shale).

As noted in **Section 2.7** above, the ecosystems of the Upper Georges River have been described as moderately limited (The Ecology Lab, 2007).

It is recognized that the ecosystems of the upper Georges River have already been impacted in such a way that the diversity of benthic macroinvertebrate taxa and abundances of such organisms in the pools of the upper river may have been limited by effects deriving from discharges from Appin and West Cliff Collieries.

To date there has been no site specific evidence that any of the mining-related stressors listed in 1 – 4 above have been directly responsible (The Ecology Lab, 2007).

2.8.4 Strata Dilation Effects of Subsidence

The effect of induction of ferruginous springs as a consequence of mine subsidence has been observed before in the Southern Coalfield in subcatchments of the Nepean, Cataract and Upper Georges River, most notably by producing:

1. the very large, and long-lived 'SW2 Spring' in Cataract River just west of Back Gully Creek; and
2. the moderately large and moderately long lived 'Pool 11 Spring' in Upper Georges River.

The Cataract Gorge SW2 Spring is presumed to have arisen some time in 1991 and continues to flow strongly to this day. It is estimated the Spring obtains its water from a catchment of size in the range 1.0 – 1.5 km^2 mined under by Appin Longwalls 21B and possibly parts of 22B and 23 over the period March 1991 – March 1993.

The appearance of the spring, which has mature under canopy type rainforest tree species growing amidst masses of deposited iron oxides around and below the spring's emergence point suggests that it has been a relatively stable feature since around that time i.e. a period of about 16 years.

The following **Figure 2.8** shows the Cataract Gorge SW2 Spring.

Figure 2.8 Cataract River SW2 Spring

The Georges River Pool 11 Spring arose in November/December 2000, was responsible for the long duration pollution with ferruginous material of the popular Marnyhes Hole, and only completely dried up in early 2006.

The following two photographs (**Figures 2.9 and 2.10**) show the Spring in January 2001 and the effect it was then having on the River downstream.

Figure 2.9 Georges River Pool 11 Emergence Point Spring January 2001

Figure 2.10 Georges River Pool 11 Spring Down River View January 2001

The Pool 11 Spring lies in the centre of an area that was mined under by West Cliff Longwall 5A1 from May 1999 to January 2000 and by Longwall 5A2 from February 2000 until November 2000. Both of these longwalls mined across and under the River.

November 2000 was a relatively wet month of some 205 mm of rain, including a significant rainfall event occurring in the area in mid-November 2000 in which some 118 mm fell over a period of 11 days, with the bulk falling on 17 – 20 November. The preceding month of October was also relatively wet. Shortly thereafter the spring first appeared and discharged a considerable volume of ferruginous water into the river resulting in a heavy coating of hydrous Fe oxides down river for a distance of about 2 – 2.5 km.

It is inferred the Spring derived its water from the mined-under diverted portion (estimated to be about 0.2 km^2) of the 1.1 km^2 of catchment of the small creek flowing into the river nearby at Pool 12. The catchment providing the water supply for the Spring occupied a significant portion of the urban area of Appin (Ecoengineers Pty Ltd., 2005b).

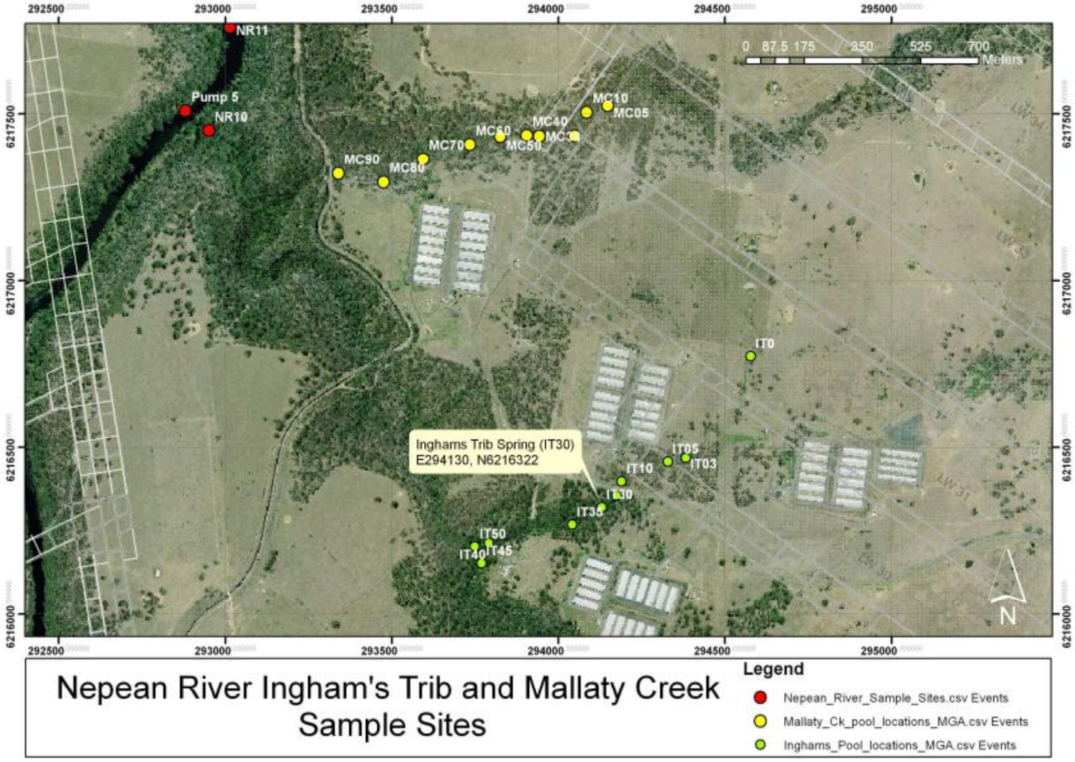
The Spring showed little evidence of decline in the four years after it was first identified but declined markedly in flow rate over late 2005 - 2006. It is unknown whether this was an effect of the drought and whether the relatively high rainfall conditions of the first 3 months of 2007 have restored its flows. The following photograph (**Figure 2.11**) shows the (much diminished) Pool 11 Spring in March 2004.

Figure 2.11 Georges River Pool 11 March 2004

As noted in **Section 2.5** above a ferruginous spring has also been detected just southwest of the Longwalls 34 – 36 SMP Area in the arbitrarily named Ingham's

Tributary of Ousedale Creek. The site is a designated BHPBIC water quality/flow monitoring site labelled IT30. The spring was detected in November 2005, some 5 months after the completion of Longwall30. **Figure 2.12** shows the location of this spring.

Figure 2.12 Location of Ingham's Tributary Ferruginous Spring



The field appearance of the IT30 Spring on 18 December 2007 is shown in **Figure 2.13** below.

Figure 2.13 Ingham's Tributary IT30 Spring site 18 December 2007

There is also further evidence for the occurrence of pre-existing springs within, or in close proximity to in the vicinity of the Longwalls 34 – 36 SMP Area.

As previously noted in **Section 2.7**, iron floc was observed by The Ecology Lab (2007) in Upper Nepean Creek within the SMP Area. This is possibly indicative of the presence of a pre-existing ferruginous spring in the upper reaches of Nepean Creek.

Further, over 5 - 8 November 2007 The Ecology Lab established an aquatic ecology monitoring site variously designated Site 10 or 5 in the middle area of Mallaty Creek in an apparent semi-permanent series of pools just upstream of the Eastern Gas Pipeline (refer Table 3 and Plate 5a of The Ecology Lab, 2007). The site is near the western end of the previous SMP Area for Longwall 31 (MSEC, 2005) and corresponds to the BHPBIC proposed water quality monitoring site MC130 (refer **Figure 2.5** in **Section 2.6** above).

As previously noted they assessed these pools as a Class 3 (moderate) habitat for fish i.e. suitable for yabbies and eels. This site has also been designated MC130 by BHPBIC for a future routine water quality monitoring site (refer **Section 2.6** above).

The Ecology Lab (2007) reported that the water quality of this site was such that the mean pH was 7.54±0.06 and the mean EC was 285.5±4.5 µS/cm. This site is situated over the northern side of Longwall 32 about 5 cut throughs from its western end. The site would have been previously mined under at the time of the The Ecology Lab field studies. It is noted that The Ecology Lab had also recorded a pH of 7.86±0.01 and an EC of 1333±1 µS/cm at this site on 16 May 2002 (refer Table 3; The Ecology lab, 2003).

On 5 November 2007 the BHPBIC field team recorded a pH of 6.69 and an EC of 5612 µS/cm at site MC05 some 500 m downstream of the aforementioned The Ecology Lab (2003, 2007) site. Again on 14 November they recorded a pH of 6.34 and an EC of 5612 µS/cm at the MC05 site. These pHs are a full pH unit lower than recorded by The Ecology Lab at the upstream site. The BHPBIC field team also recorded that DO at site MC05 was 37.3% of saturation on 5 November 2007, and only 8.9% on 14 November 2007, confirming that lower pHs are associated with lower DO as expected from its consumption through oxidation/precipitation of dissolved Fe and Mn.

These observations indicate quite clearly that a significant saline spring must be located in mid Mallaty Creek somewhere in between The Ecology Lab Site 5 and BHPBIC site MC05 which was subject to dilution under conditions of active runoff and flow in the Creek around 20 August 2007.

However, judging from previous water quality data obtained by BHPBIC prior to February 2007, this unidentified spring appears to have been in place well prior to the commencement of mining of Longwall 32 (from the western end) on 2 February 2007.

On the basis of experience with the Georges River Pool 11 Spring, it is inferred that such springs, if they do arise:

- may be generated by a catchment of as little as approximately 0.2 km^2;
- are likely to have a lifetime of at least 4 years with or without significant diminution in intensity; and in the worst case
- may be relatively permanent once instigated, depending upon the size of the dilated catchment area providing their water supply.

The experience of the Cataract Gorge SW2 Springs suggests that a catchment size of the order of only 1 km^2 appears to be sufficient to confer a lifetime in excess of 10 years.

It is known that mining subsidence can have the effect of delaminating and dilating erosion surfaces and bedding planes within and between strata. These effects are predicted to occur preferentially along the interfaces between materials with different elastic properties.

In terms of the likely mechanism giving rise to such springs, it is now known that where broad scale upland subsidence occurs as a consequence of mining, delamination, dilation and hence permeability enhancement is likely along the sub-horizontal interface between the sub-cropping Hawkesbury Sandstone, perhaps an interfacial Mittagong Formation (thin intercalated lenses of sandstone and shale) and outcropping Wianamatta Shale and Shale-derived soils (Hazelton and Tille, 1990).

This in turn apparently facilitates the increased detention and storage of infiltrating meteoric waters within the Shale and close to the Shale/Sandstone interface. The water stored at the shale/sandstone interface subsequently drains downgradient in the direction of the local creek or river. In some cases it can then travel down natural or induced vertical cracks and along widened bedding planes in the sandstone and subsequently appear as well-defined springs. That significant water storage at the

Wianamatta/Hawkesbury interface occurs and is pronounced has now been indicated by:

1. water yields recovered from various shallow boreholes drilled over the last 15 years in the Southern Coalfield on plateaux mantled with Shale (i.e. those drilled just into the upper layers of the Hawkesbury);
2. periodic longwall mining-induced seepages into the Cataract Tunnel; and by
3. the emergence of highly visible ferruginous springs in the Upper Georges and Cataract Rivers.

It has been estimated that longwall mining induced subsidence effects on Shale-mantled upland catchments in the Southern Coalfield might generate ferruginous springs from upland catchments at a maximum recharge/discharge rate of about 0.8 mm/day and a mean recharge/discharge rate of about 0.2 mm/day.

This would generate average flows of the order of 0.2 ML/day and maximum flows of the order of 0.4 ML/day per km^2 of catchment (Ecoengineers, 2005a).

Detailed geochemical investigation has shown such waters have the following pronounced geochemical characteristics:

1. A very distinctive geochemical signature characteristic of leaching of salts stored in (marine- derived) Wianamatta Shale clay soils. Specifically, the following is observed: a very high magnesium/calcium (Mg/Ca) mole ratio of +3.6 – +5.0 (noting it is +5.2 in seawater), a very low strontium/calcium mole ratio (Sr/Ca) of 0.004 – 0.009 (noting it is 0.009 in seawater), a narrow log bromide/chloride (log(Br/Cl)) mole ratio of -2.85 – -2.95 (noting it is -2.81 in seawater), a narrow log boron/chloride (log(B/Cl)) mole ratio of -11 - -18 (noting it is -12 in seawater), and a narrow log sulfate/chloride (log(SO_4/Cl)) mole ratio of typically -1.3 – 2.0 (noting it is -1.3 in seawater). In other words, these waters have the signature of a marine shale soil profile subsequently modified only by cation exchange processes on clays (for sodium, Na, potassium, K, Ca, Mg and Sr), clay adsorption (for B), and Fe and Mn oxide dissolution effects during percolation (e.g. Appelo and Postma, 1993).
2. Depending upon the depth of shale infiltrated such waters often exhibit characteristically elevated levels of dissolved iron (Fe) and manganese (Mn) typically ranging from 0.2 – 40 mg/L and 0.1 – 2 mg/L respectively. Due to the well known high concentrations of disseminated Fe and Mn oxides (after siderite and rhodocrosite) in weathered Wianamatta Shales (which gives them their distinctive brick red through dark maroon colours), reductive dissolution of those oxides (‘bleaching’) has occurred in the subsoil storage under the influence of so-called Fe and Mn dissimilatory bacteria (typically Geobacter species) that are well known to oxidize percolating dissolved organic matter (DOM) and, in that same biogeochemical process, use such oxides as their terminal electron acceptors (TEAs; Lovley and Phillips, 1986).
3. As distinct from the oxidative dissolution of marcasite that can occur in freshly fractured Hawkesbury Sandstone, the reductive dissolution (bleaching) of disseminated Fe and Mn oxides in the Wianamatta Shales does not increase SO_4 concentrations and does not produce acidity and hence lowering of pH *in situ* (although this will be created at emergence into the open air of such waters - see below). Hence these waters generally maintain constant SO_4 concentrations (albeit higher the greater the depth of Shale and extent of salts leaching involved) and generally have near neutral

to only weakly acidic pHs when properly sampled *in situ* or immediately upon emergence and if not subsequently passed through bulk fractured sandstone.

Table 2.6 gives the major chemical characteristics of key examples of such water samples that have been analysed in the Southern Coalfield over the last eight years.

TABLE 2.6 WIANAMATTA SHALE WATERS OBSERVED IN SOUTHERN COALFIELD BOREHOLES AND FERRUGINOUS SPRINGS

Sample Name	**Date**	**pH**	**EC µS/cm**	**Ca mg/L**	**Mg mg/L**	**Na mg/L**	**Filt. Fe mg/L**	**Filt. Mn mg/L**	**Cl mg/L**	**SO_4 mg/L**	**Mg/Ca mole ratio**
Georges River Borehole GRIP1	**12/05/99**	7.20	531	5.1	12	46	21.2	1.2	97	4	3.9
Georges River Borehole GRIP2	**12/05/99**	6.96	1301	4.4	11	240	21.8	0.64	130	14	4.12
Cataract Tunnel Seepage	**17/05/00**	7.07	9780	151	415	1450	<0.01	0.21	2930	171	4.53
Cataract Tunnel 404 Seepage	**22/06/01**	6.76	9230	118	354	1590	0.41	0.27	2980	146	4.95
Borehole Appin 72	**03/04/01**	7.80	9200	149	358	1360	0.01	0.30	2740	128	3.96
Borehole Appin 69	**08/08/01**	6.87	7360	147	319	1360	6.97	0.33	2760	130	3.58
Borehole Tower 22	**13/08/01**	6.65	5800	113	271	981	40.9	0.42	1930	166	3.95
Georges River Pool 11 Spring	**07/07/02 – 12/07/05 (n=13)**	7.79	1055	2.7	4.5	225	6.5	0.198	129	18	2.75
Cataract River Spring SW2	**19/07/05 – 04/04/07 (n=21)**	5.63	517	5.24	15.05	68.8	20.7	1.95	155	9.3	4.74
Site IT30 Ingham's Tributary (of Ousedale Creek)	**15/11/05 – 04/12/07 (n = 25)**	6.64	8353	102	272	1029	1.30	0.83	2199	105	4.40

When a spring of this 'Wianamatta Shale-type water' emerges into the open air it tends to immediately react with the oxygen in the air or dissolved in the water of the creek or river it may flow into. This results in the precipitation of Fe and Mn hydrous oxides, generating acidity and consuming oxygen.

Fe and Mn oxidation and precipitation of hydrous oxides creates acidity principally through the following reactions:

$$2Fe^{2+} + 0.5O_2 + 5H_2O => 2Fe(OH)_3 + 4H^+$$

$$Mn^{2+} + 0.5O_2 + H_2O => MnOOH + 2H^+$$

Where such springs flow directly into ephemeral or low flow creeks, the bicarbonate/carbonate alkalinity of the water should generally be sufficient to ensure that the generation of acidity through the oxidation of the dissolved Fe and Mn is insufficient to produce pHs low enough to cause any ecotoxic effects. The only situation where this could potentially not apply is where such a spring flowed into a large stream or river where the existing water was very fresh i.e. of very low salinity and hence of low alkalinity (Appelo and Postma, 1996).

However, ecotoxic effects can obviously be caused by the low DO levels induced where such springs enter a watercourse.

In summary:

1. The ferruginous springs referred-to are very unsightly and highly visible due to the voluminous precipitation of oxidised ferruginous material and unless they arise in well wooded country are readily detected by the public.
2. Increased inflows of saline waters into local creeks as a consequence of increasing infiltration into, and interflow through local Wianamatta Shale soils and outcrops due to mine subsidence-related effects (e.g. shearing) are a potential aquatic ecological stressor on local aquatic ecosystems (ANZECC/ARMCANZ, 2000), unless the waters in these creeks can be demonstrated to already receive Wianamatta Shale-derived waters of a similar salinity level and Fe and Mn concentrations.
3. As the reduced Fe and Mn load in the spring water is oxidised, and if it discharges to a creek, it consumes all dissolved oxygen (DO) in the creek water at and immediately downstream of the point of entry to the creek. This could have significant ecotoxic effects both due to the reduction in DO and a smothering effect in the creek bed (ANZECC/ARMCANZ, 2000).
4. If the magnitude of such a spring was sufficiently large and it were detected, detained and treated in some way within the catchment, then creek waters containing significant concentrations of dissolved Fe and Mn could also pass either indirectly or directly into Nepean River or Georges River. This in turn again creates a significant consumption of dissolved oxygen at the point of entry which has the potential to discharge DO from the water, and cause bed smothering of the immediately downstream major pools.

3. IMPACTS OF POTENTIAL WATER-RELATED EFFECTS

3.1 MAXIMUM EFFECTS OF UPSIDENCE OF THE RIVER BED

It was observed during the extraction of Longwalls 5A1 – 5A4 in the Georges River upstream of the SMP Area that mining induced subsidence of the surface occurred. The subsidence resulted in an increased level of interaction between surface and groundwater and reduced some pool levels.

We have made a very careful examination of all available past data from the following sources:

1. Coffey Geosciences Pty Ltd. (1998, 1999, 2000a, 2000b, 2000c, 2001a 2001b, 2002);
2. Wood, J. (2001) and
3. BHP Billiton Illawarra Coal (2004).

Unlike other analogous situations in the Southern Coalfield there are no clear geochemical data discernible in any of the Coffey Geosciences reports indicating subsidence or upsidence-induced fracturing of pristine, previously unweathered sandstone in the bed of the upper Georges River producing oxidative dissolution of exposed marcasite.

It is noted both the flow and river water chemistry monitoring performed by Coffey Geoscience over a 4 year period between the latter half of 1998 and the first half of 2002 was carried out on a relatively sporadic and random basis, rather than on a regular monthly basis.

Our review indicates the water quality sampling methodology, the parameters targeted and the quality of the water chemical analyses performed for these reports were such that the usefulness of the data for proper hydrogeochemical investigation and diagnosis of possible effects is limited.

From June 2002 onwards regular, monthly chemical and hydrological monitoring of Upper Georges River has been conducted by BHP Billiton and the samples were competently sampled and analysed.

From that time on, variable SO_4 levels and both increments and decrements of SO_4 have been observed between any two contiguous locations in the river believed to have been subject to subsidence even though:

- hydrological significant flow diversions were still occurring over some of these intervals; and
- since August 2004 relatively constant dry weather flows have applied due to the regular discharge from BCD previously discussed in **Section 2.1**.

We ascribe this outcome to the fact that all available hydrogeological evidence as discussed in **Section 2.3** above suggests that:

1. even when the river was directly mined beneath as it was by Longwalls 5A1 though 5A4, only very limited fracturing occurred and the principal effect was movement and dilation of pre-existing bedding planes under and adjacent to the riverbed; and

2. the River has a hydrogeologically complex nature, where water in the River may become elevated above the surrounding groundwater, especially during drought and hence loses water to it.

Prior studies have determined that:

1. early estimated acid generation rates for discrete sub-bed flow diversion zones from the lower Cataract during the earliest monitoring of 124 and 68 moles H_2SO_4/day;
2. an estimate of comparable precision from the Bargo River of 100 moles H_2SO_4/day; and
3. a very much more accurate estimate from rock bar NDC2A in upper Native Dog Creek at low flows of 97.2 moles H_2SO_4/day.

These estimates of daily acid generation rate cover a relatively narrow range. There is good reason to expect that for flows over about 0.1 ML/day through a freshly fractured network of a sub-bed flow diversion zone in sandstone the rate of acid generation would be limited by:

1. an average density of exposed marcasite grains in freshly fractured Hawkesbury Sandstone;
2. the average cross sectional area, length and typical tortuosity of flow paths; and
3. the saturation dissolved oxygen content of the inflowing water.

It appears that this rate typically lies in the region of (say) 68 – 124 mole/day and the best available evidence discussed above suggests that it is very unlikely to be outside this range.

We have therefore adopted a mean value of 100 mole H_2SO_4/day as our current best estimate of the maximum rate of acid generation that would occur in any discrete sub-bed diversion zone. In turn, this means that a maximum amount of marcasite (FeS_2) of 50 moles/day is being dissolved and hence up to about 50 mole/day of Fe is being released.

It is essential to appreciate that this value represents the maximum amount of acid that may be transferred to a sub-bed diversion flow of 0.1 ML/day or greater and that any sub-bed diversion flows (i.e. through the fracture network) that are greater than this will not actually increase the acid and metals load transferred to the water but will help to ameliorate their downstream effects through dilution alone.

It was also found that the concentration of Total Mn at Native Dog Creek site NDC2A during the above mentioned ‘peak acid generation’ study period did not vary significantly with pH and varied only with SO_4 concentration over a range of low pHs (where coprecipitation of hydrous Mn oxides with hydrous Fe oxides can be assumed negligible). Correcting for a constant upstream SO_4 concentration of 6 mg/L, this suggests the released SO_4/Mn mole ratio at low pH was 15±11 (n=13).

Studies carried out for nickel (Ni) and zinc (Zn), accessory metals in the marcasite at pHs below that at which released Ni and Zn concentrations would have been reduced by adsorption onto precipitated hydrous Fe oxides showed relatively constant SO_4/Zn and SO_4/Ni and mole ratios of 16±5 (n=13) and 100±19 (n=13) respectively.

These values are respectively 6 and 96 within error and appear consistent both with the crystallography of marcasite and with recent literature on Ni and Zn leaching in acid drainage derived from sedimentary quartz pebble-hosted spheroidal marcasites (Falconer and Craw, 2005).

The average composition of local marcasite in the Native Dog Creek area (at least) approximates to $Fe_{0.729}Mn_{0.125}Zn_{0.125}Ni_{0.021}S_2$ i.e. Mn and Zn atoms occupy about one in every six sites that a Fe atom occupies and Ni atoms about every one in every 36. It is noted that, like pyrite, marcasite has a cubic structure with each metal atom surrounded by 6 sulfur atoms and each sulfur atom surrounded by 8 metals atoms.

We have adopted this composition for the Georges River situation on the assumption that in general diagenetic marcasite should have formed in the Hawkesbury Sandstone with, regionally, a relatively similar composition.

At first inspection, it might be expected that Ni and Zn released during marcasite dissolution would be immediately re-immobilized due to precipitation of hydrous Fe oxides downstream of the site of dissolution and adsorption onto, and incorporation of the Ni and Zn into these hydrous oxides.

However, where pHs of the waters passing the dissolving marcasite exceed about 8.0 and carbonate alkalinities are relatively high, as found in the upper Georges River (due to the river flows being largely derived from BCD discharges) then it would not be expected that Ni and Zn are significantly adsorbed to hydrous Fe oxides. This is because these metals are both amphoteric and hence predominantly form neutral or negative carbonate complexes at weakly alkaline and higher pHs. These complexes are immune to adsorption to hydrous Fe oxides which are negatively charged above about pH 7.5.

The estimated typical river water quality upstream of Appin and West Cliff Collieries from data collected by BHP Billiton Illawarra is as given in **Table 3.1**. Note that we have assumed that this is the typical quality of all water running off into Upper Georges River other than waters discharged from the Collieries.

TABLE 3.1 ESTIMATED MEAN RIVER WATER QUALITY UPSTREAM OF APPIN COLLIERY AND WEST CLIFF COLLIERY LICENSED DISCHARGES.

Parameter	**Value**
pH	6.0
EC (µS/cm)	190
Na (mg/L)	24
K (mg/L)	1
Ca (mg/L)	1
Mg (mg/L)	3
Total Alkalinity as $CaCO_3$ (mg/L)	8
Cl (mg/L)	38
SO_4 (mg/L)	7

The estimated typical river water quality obtained just downstream of Brennans Creek from dry weather data obtained between August 2004 and September 2005, i.e. of waters discharged from DECC Licensed Discharge Point 10 at West Cliff Colliery into Brennans Creek and not subject to any significant stormwater runoff component is as given in **Table 3.2** (Ecoengineers Pty Ltd., 2005a).

TABLE 3.2 ESTIMATED DRY WEATHER RIVER WATER QUALITY DOWNSTREAM OF BRENNANS CREEK/GEORGES RIVER CONFLUENCE AND UPSTREAM OF SMP AREA FOR 50 PERCENTILE FLOW CONDITION (1.0 mL/day)

Parameter	**Value**
pH	8.5
EC (µS/cm)	2500
Na (mg/L)	560
K (mg/L)	3
Ca (mg/L)	4
Mg (mg/L)	2
Total Alkalinity as $CaCO_3$ (mg/L)	1000
Cl (mg/L)	210
SO_4 (mg/L)	35
Dissolved Ni (mg/L)	0.17
Dissolved Zn (mg/L)	0.04

3.1.1 Model-Predicted Maximum Effect of Sub-bed Diversions in River

We have assumed that up to a flow of 1.0 ML/day through the SMP Area (i.e. approximately the 50 percentile flow – refer Table 2.5) all water has the composition given in **Table 3.2** above (i.e. is equivalent to the water released from BCD) and that for flows above that 1.0 ML/day any further water has been diluted with fresh runoff or seepage with the composition given in **Table 3.1**.

In line with the discussion on river flows in **Section 2.1** above, we have adopted 0.5 ML/day as the 25 percentile flow, 1.0 ML/day as the 50 percentile flow in the River through the SMP Area. Note that DO= Dissolved Oxygen.

On the basis of the above considerations, the data presented in **Table 3.3** below are 'worst case' estimates of the likely water chemistry effects immediately down river that is, at the 'emergence and mixing point' of the acid-generating effects of discrete sub-bed flow diversion zones in the SMP Area of any fracture-impacted sub-bed flow diversion area for the 99, 75, 50 and 10 percentile flows in the river.

These estimates have been obtained by geochemical modelling using the United States Geological Survey (USGS) open source model Phreeqc (Parkhurst and Appelo, 1999) reacting a mean mass of marcasite of composition $Fe_{0.729}Mn_{0.125}Zn_{0.125}Ni_{0.021}S_2$ of 100 mole/day with various sub-bed diversion flows.

It is noted from **Table 3.2** above that the water released from BCD already exceeds the default national water quality guidelines (for protection of 95% of all aquatic species) for dissolved Ni and Zn and the extra Ni and Zn contributed by the dissolution of marcasite during sub-bed diversions would only serve to increase those exceedances.

However, only the cationic species of Ni and Zn such as Ni^{2+}, $NiOH^+$ and $NiHCO_3^+$, Zn^{2+} $ZnOH^+$ and $ZnHCO_3^+$ are believed to be ecotoxic (Tessier and Turner, 1995; Slaveykova and Wilkinson, 2005).

In accord with the well-established ‘decision tree approach’ recommended in the national water quality guidelines (ANZECC/ARMCANZ, 2000), where firstly:

- total concentrations of a toxicant are considered; then
- dissolved concentrations are considered; then finally
- the chemically actively toxic component is estimated by speciation modelling or direct methods such as anodic stripping voltametry,

we also modelled the aqueous speciation of Ni and Zn given in **Table 3.3** in these to estimate the total concentrations of the ecotoxicologically active cationic species of Ni and Zn. We have therefore also shown in italics and brackets the predicted concentrations of the ecotoxic cationic fraction of the dissolved Ni and Zn.

From the **Table 3.1** below the following may be inferred:

1. for rivers flows up to at least 2.5 ML/day where there is at least one third diversion through the fractured riverbed, there would be <u>considerable exceedances</u> of the default national water quality guidelines at the emergence point for DO, dissolved, ecotoxic cationic Zn and minor exceedances for ecotoxic cationic Ni but no exceedances for pH.
2. only in the case where 0.5 ML/day is diverted through freshly fractured bedrock, and there would no diluting surface flow, emerging waters would be highly reduced (ORP<0 mV) and essentially devoid of DO but would have extremely low levels of dissolved Ni and Zn.
3. where sub-bed diversion flows are less than one third of the total flow there would be <u>no exceedance</u> of the national water quality guidelines at the emergence point for pH <u>and</u> DO <u>and dissolved ecotoxic cationic Ni</u> <u>but</u> considerable exceedances of the default national water quality guidelines (for protection of 95% of all aquatic species) for dissolved cationic Zn would remain.

As noted previously, it is considered that sub-bed diversions are unlikely to occur adjacent to Longwalls 34 to 36 (MSEC, 2007).

TABLE 3.3: MODELLED IMMEDIATE DOWNSTREAM 'WORST CASE' ACID, DO AND HEAVY METAL CONCENTRATIONS FOR DISCRETE SUB-BED FLOW DIVERSIONS AT THE PEAK RATE OF ACID GENERATION.

Percentile Flow in River from West Cliff Colliery Licensed Discharge	**River Flow ML/day**	**Assumed Sub-bed Diverted Flow (single location)**	**Est. SO_4 mg/L**	**Est. pH**	**Est. Total Fe mg/L**	**Est. DO %Sat^n**	**Est. Total. Mn mg/L**	**Est. Diss. Ni (mg/L) & *Est. ecotoxic Ni (mg/L)***	**Est. Diss. Zn (mg/L) & *Est. ecotoxic Zn (mg/L)***
25	0.5	0.1	37	8.47	0.50	86	0.08	0.19 *(0.007)*	0.14 *(0.015)*
25	0.5	0.3	43	8.37	2.11	46	0.36	0.23 *(0.012)*	0.46 *(0.053)*
25	0.5	0.5	52	8.31	4.07	0	0.69	0.29 *(<0.001)*	0.86 *(<0.001)*
50	1.0	0.1	36	8.49	0.20	94	0.04	0.18 *(0.006)*	0.08 *(0.008)*
50	1.0	0.5	41	8.40	1.36	58	0.23	0.21 *(0.009)*	0.31 *(0.034)*
50	1.0	1.0	45	8.34	2.04	38	0.34	0.23 *(0.014)*	0.45 *(0.065)*
70	1.5	0.1	26	8.37	0.09	97	0.02	0.12 *(0.011)*	0.04 *(0.009)*
70	1.5	0.5	28	8.33	0.45	86	0.08	0.13 *(0.014)*	0.09 *(0.022)*
70	1.5	1.0	30	8.27	0.90	72	0.15	0.14 *(0.018)*	0.21 *(0.048)*
National Water Quality Guidelines (NSW lowland rivers)			NA	6.5 – 8.5	None	>85	1.9	0.011 (95% protection) 0.017 (80% protection)	0.008 (95% protection) 0.015 (80% protection)

3.2 MAXIMUM EFFECTS OF UPLAND-DERIVED SPRINGS ON GEORGES RIVER

3.2.1 Experience of the Pool 11 Spring

The Pool 11 Spring was first inspected and sampled by the author on 8 January 2001. Although flow rate of the spring was not measured at the time, visually it appeared to be about 2 L/s i.e. ~0.17 ML/day.

The Pool 11 Spring lay in the centre of an area that was mined under by West Cliff Longwall 5A1 from May 1999 to January 2000 and by Longwall 5A2 from February 2000 until November 2000. November 2000 was a relatively wet month of some 205 mm of rain, including a significant rainfall event occurring in the area in mid-November 2000 in which some 118 mm fell over a period of 11 days, with the bulk falling on 17 – 20 November. The preceding month of October was also relatively wet.

Shortly thereafter the spring first appeared and discharged a considerable volume of ferruginous water into the river resulting in a heavy coating of hydrous Fe oxides down river (including Marhnyes Hole) for a distance of about 2 – 2.5 km.

It is presumed the spring derived its water from the mined-under diverted portion (estimated to be about 0.2 km^2) of the 1.1 km^2 of catchment of the small creek flowing into the river nearby at Pool 12 in a similar manner to that we concluded the spring in Cataract River apparently derives its water from a diverted portion of ~1.0 km^2 of the Back Gully Creek catchment over Appin Longwalls 21B, 22B and 23 (Ecoengineers, 2005b).

As noted in **Section 2.1,** annual rainfall in 2000 was 790 mm/year (= 2.15 mm/day). Evapotranspiration (ET) in the catchment which provides water for the spring would have averaged about 500 mm/year or 1.37 mm/day. This yields a mean infiltration of about 0.78 mm/day or some 156 m^3/day or 0.16 ML/day for a 0.2 km^2 catchment.

Some fraction of all potential infiltration would have occurred on days in which the soil's capacity for infiltration would have been exceeded due to significant antecedent rain (noting that Shale subsoils typically have a maximum permeability of the order of 30 mm/day).

The Pool 11 spring flow rate reduced progressively over 4 years and no longer exists.

Table 3.4 below lists the analysis of the spring water when first sampled on 8 January 2001 and compares this with a statistical analysis of 13 further analyses conducted between 7 June 2002 and 12 July 2005.

These data show quite clearly that the water quality of the spring did not vary greatly over time.

The data also show that the Pool 11 spring discharged (Wianamatta Shale-derived) weakly saline waters to Upper Georges River also invariably contained Ni and Zn above default national water quality guidelines for the protection of 95% of all aquatic species (ANZECC/ARMCANZ, 2000).

TABLE 3.4 ANALYSIS OF POOL 11 SPRING ON 8 JANUARY 2001 AND MEAN COMPOSITION OVER 13 SAMPLINGS OVER 2002 – 2005

Parameter	**Analysis of 8 January 2001**	**Mean of analyses 7 June 2002 – 12 July 2005 (±1 s.d.) (n=13)**
pH	7.08	7.79±0.24
EC	1270	1055±390
Na	274	225±195
K	2.5	1.6±0.7
Ca	2.5	2.7±1.7
Mg	6.9	4.5±3.6
SO_4	26	18±7
Cl	88	129±29
T. Alk. mg/L as $CaCO_3$	448	327±184
Tot. Fe	15.9	6.5±2.1
Filt. Mn	?	0.198±0.071
Filt. Ni	0.109	0.066±0.034
Filt. Zn	0.008	0.017±0.015

3.2.2 Model-Predicted Maximum Point Source Effect of a Spring

The upland valleys within the Georges River catchment on the western side of the River are relatively small.

Consequently the area of potential subsidence and dilation of near surface strata is expected to be comparable with the ~0.2 km^2 (20 ha) that was mined under by Longwalls 5A1 and 5A2 to create the Pool 11 spring.

From the considerations in **Section 3.2.1** above we conclude that longwall mining induced subsidence effects on upland catchments in the SMP Area might generate individual ferruginous springs from upland catchments discharging to the river up to a maximum recharge/discharge rate of about 0.2 ML/day and a mean recharge/discharge rate of about 0.1 ML/day.

We modelled the effects of the mixing of 0.15, 0.1 and 0.05 ML/day of spring waters emanating from catchment over Longwalls 34 to 36 with 0.5 and 1.0 ML/day of River water i.e. river base flows equivalent to the 25 and 50 percentile flows in the River (refer **Section 2.1** above) using PHREEQC (Parkhurst and Appelo, 1999). This was done in order to obtain probabilistic information regarding the impact of such a spring on the River.

We have assumed, by analogy with the actual Spring sampled as Pool 11 spring in upper Georges River upstream of the SMP Area as given in **Table 3.4 above** that any upland subsidence induced springs over Area 5 Longwalls 31 to 33 would have an average dissolved Fe concentration of the order of 6.5 mg/L, an average dissolved Mn concentration of 0.2 mg/L, an average Ni concentration of 0.066 mg/L and an average dissolved Zn concentration of 0.017 mg/L. We have also assumed that for river flows up to 1.0 ML/day the upstream river water would have a composition closely similar to that given in **Table 3.2** above for the BCD discharge.

The following **Table 3.5** shows the outcomes of that modelling, giving the estimated DO, Ni and Zn levels in the River at the point of mixing of spring and river waters.

TABLE 3.5: MODELLED DISSOLVED OXYGEN SATURATION AND NICKEL AND ZINC CONCENTRATIONS AT POINTS OF MIXING OF FRESH FERRUGINOUS SPRINGS OF VARIOUS MAGNITUDES IN RIVER UNDER 25 AND 50 PERCENTILE RIVER FLOW CONDITIONS (i.e. 0.5 AND1.0 ML/day – refer Table 2.4)

Spring Flow Rate (ML/day)	**Estimated DO (% saturation) in River at Point of Mixing for 25 percentile flow (0.5 ML/day)**	**Estimated Dissolved and (*Ecotoxic*) Ni Conc. (mg/L) in River at Point of Mixing for 25 percentile flow (0.5 ML/day**	**Estimated Dissolved and (*Ecotoxic*) Zn Conc. (mg/L) in River at Point of Mixing for 25 percentile flow (0.5 ML/day**	**Estimated DO (% saturation) in River at Point of Mixing for 50 percentile River flow (1.0 ML/**	**Estimated Dissolved and (*Ecotoxic*) Ni Conc. (mg/L) in River at Point of Mixing for 50 percentile River flow (1.0 ML/day**	**Estimated Dissolved and (*Ecotoxic*) Zn Conc. (mg/L) in River at Point of Mixing for 50 percentile River flow (1.0 ML/day**
0.20	67	0.14 *(0.009)*	0.03 *(0.005)*	79	0.16 *(0.007)*	0.04 *(0.005)*
0.15	73	0.15 *(0.008)*	0.04 *(0.005)*	84	0.16 *(0.007)*	0.04 *(0.006)*
0.1	80	0.16 *(0.007)*	0.04 *(0.005)*	88	0.16 *(0.006)*	0.04 *(0.004)*
0.05	88	0.17 *(0.006)*	0.04 *(0.004)*	93	0.17 *(0.006)*	0.04 *(0.004)*
National Water Quality Guidelines (NSW lowland rivers)	>85	0.011	0.008	>85	0.011	0.008

The modelling results presented in **Table 3.5** above with respect to DO, Ni and Zn are fully consistent with observed ‘baseline’ concentrations of these parameters in the river over the former proposed Longwalls 5A5 to 5A8 (a previously proposed configuration of Longwalls 29, 30, 32 and 33), downstream of the Pool 11 spring as reported in BHP Billiton (2002).

It was reported in BHP Billiton (2000) that DO concentrations observed downstream of the Pool 11 spring ranged from a minimum of 63% to a maximum of 121% (the latter indicative of high algal productivity in river pools during warm periods) with a mean value of 93%, the Ni concentrations observed downstream of the spring ranged from <0.01 to 0.10 mg/L with a mean value of 0.06 mg/L and the Zn concentrations observed downstream of the spring ranged from 0.01 to 0.07 mg/L with a mean value of 0.04 mg/L. These data are very similar to the predicted ranges set out in **Table 3.5** above.

The existing data therefore provides a measure of validation of the above model-predicted ranges for DO, Ni and Zn downstream of the Pool 11 spring and, by implication, downstream of any similar spring that might arise in the SMP Area as a consequence of the mining of Longwalls 34 to 36.

From the above **Table 3.5** the following may be inferred:

1. for all discrete spring flows into the River above 0.1 ML/day and river flows below about 0.5 ML/day i.e. below 25 percentile flows the default lower limit for DO in the national water quality guidelines would not be met at the spring emergence point.
2. for all discrete spring flows into the River below 0.2 ML/day and river flows below about 0.5 ML/day i.e. below 50 percentile flows, the 95% default limit for Ni in the national water quality guidelines would not be exceeded by the concentration of cationic ecotoxic Ni species at the spring emergence point.
3. for all discrete spring flows into the River below about 0.2 ML/day and river flows below about 0.5 ML/day i.e. below 50 percentile flows, the 95% default limit for Zn in the national water quality guidelines would not be exceeded by the concentration of cationic ecotoxic Zn species at the spring emergence point.
4. for all discrete spring flows into the River above 0.15 ML/day and river flows below about 1.0 ML/day i.e. below 50 percentile flows the default lower limit for DO in the national water quality guidelines would only marginally not be met at the spring emergence point

3.3 SITES AT HIGHEST RISK OF IMPACT

3.3.1 Sub-Bed Flow Diversions

While it is possible for fracturing to occur anywhere along the River within close proximity to the proposed longwalls, the most likely areas would be where the predicted mine subsidence related movements are the greatest, or where the rock bars are the largest. On the basis of the predictions of mine subsidence effects in the Georges River (refer Section 5.2.1 in MSEC, 2007) it is believed that as a generalization:

1. The rock bars most likely to fracture are Rock Bars 56A and 56B, which are located adjacent to the maingate of proposed Longwall 35 (refer **Figure 2.5**). This is because this is where the predicted closures exceed the back-predicted closure for the Elouera Colliery Native Dog Creek case study. It is noted that the back-predicted closure at bracketing Rock Bars 55, 57 and 59 are also of a similar magnitude to that back-predicted for the Native Dog Creek case study.
2. The pools most likely to drain (due to proximity to proposed Longwall 35) are Pools 45, 51, 55, 56, 57 and 60

3.3.2 Ferruginous Springs

At the present time we simply do not know enough about the geotechnical factors that trigger the formation of such springs as no piezometric studies have been conducted in the vicinity of recognized, nine subsidence-induced springs and no systematic back analysis has been conducted of subsidence parameters in their vicinity.

Nevertheless, on the basis of field arguments, is considered that such springs would be more prone to arise, or of pre-existing be enhanced in westward draining catchments in the SMP Area i.e. Upper Mallaty Creek, Upper Leafs Gully Creek and

Upper Nepean Creek than in Georges River. This increased probability is suggested by the following field observations:

4. the drilling of Tower Colliery borehole 22 in August 2001 in which a considerable flow of a classic Wianamatta Shale water with high dissolved Fe and Mn concentrations was encountered in the low part of a westward draining catchment; and
5. visual detection of a spring in Ingham's Tributary of Ousedale Creek at site IT30 which was detected after completion of Longwall 30 and possibly induced or enhanced by mining of that longwall; and
6. recent geochemical inference by us of a pre-existing spring in Mallaty Creek between existing BHPBIC water quality site MC05 and proposed site MC130; and
7. recent observations of iron floc in Upper Nepean Creek by The Ecology Lab.

3.4 TIMESCALES OF POTENTIAL WATER-RELATED EFFECTS

As noted above, the peak of the acid generation rate of the fractured rock bar NDC2A in upper Native Dog Creek over Elouera Colliery longwalls occurred in mid May 2003 and the acid generation rate of the rock bar declined strongly over several years thereafter. Similar effects have been observed on Wongawilli Creek, a headwater catchment of Cordeaux River (below Cordeaux Dam) where acid generation has declined sharply over about five years despite persistence of sub-bed flow diversions over sections of that Creek (e.g. Ecoengineers Pty Ltd., 2003, 2004).

The principal reasons for the observed decline in acid generation after an initial peak within one year of mining impacts are believed to be:

- the depletion of readily available siderite/rhodocrosite and marcasite in the accessible fractured Sandstone; and
- the build up of armouring over residual siderite/rhodocrosite and marcasite by precipitated hydrous Fe and Mn oxides.

The Pool 11 spring in Georges River, which was first observed in November 2000 after it had contributed substantial ferruginous staining to the water and bed of the upper Georges River declined over a period of just under 4 years.

The relatively large spring recently identified in Cataract Gorge just upriver of the Study Area would appear to have arisen between early 1991 and mid 1992 during the mining of Appin Longwalls 21B, 22B and possibly part of Longwall 23. The appearance of the spring, which has mature under canopy type rainforest tree species growing amidst deposited iron oxides around and below the spring's emergence point suggests that it has been a relatively stable feature since around that time i.e. a period of about 14 years. It is therefore concluded that if they do occur such springs may have a lifetime of at least 10 years without significant diminution in intensity and may in fact be relatively permanent once established.

4. ASSESSMENT AND RECOMMENDATIONS

4.1 ASSESSMENT OF LIKELY EFFECTS ON GEORGES RIVER

With respect to possible sub-bed flow diversions due to actual river bed fracturing (exposing siderite/rhodocrosite and possibly also significant marcasite in unweathered sandstone), such diversions arising from development of Longwalls 34 to 36 are considered unlikely for the reasons given above.

However, if they should occur, a considerable ‘mitigative effect’ against ecotoxicity attributable to acidity, Ni and Zn is provided by the moderately saline waters released from Brennans Creek Dam, which contain a significant concentration (1000 – 1500 mg/L typically) of bicarbonate/carbonate alkalinity which not only serves to:

- ‘buffer out’ any acidity generated by any dissolution of marcasite in mining-induced freshly fractured sandstone bedrock; but also
- complexes dissolved Ni and Zn, greatly reducing the net concentration of the ecotoxic, cationic forms of these metals.

The following effects have been inferred, using geochemical modelling, to be the maximum short term ‘worst case’ effects at the peak of the rate of dissolution of marcasite in the Hawkesbury Sandstone bedrock of the river:

1. Only in the case where 0.5 ML/day is diverted through freshly fractured bedrock, and there is no diluting surface flow, would emerging waters be highly reduced (Oxidation Reduction Potential; ORP <0 mV) and largely devoid of DO but they would have extremely low levels of the ecotoxic species of Ni and Zn.
2. Where sub-bed diversion flows are less than one third of the total flow there would be no exceedance of the national water quality guidelines at the emergence point for pH and DO and dissolved ecotoxic cationic Ni but considerable exceedances of the default national water quality guidelines (for protection of 95% of all aquatic species) for dissolved cationic Zn would remain.
3. For Rivers flows up to at least 2.5 ML/day only if there were at least one third diversion through the fractured riverbed, would there be considerable exceedances of the default national water quality guidelines at the emergence point for dissolved oxygen, dissolved, ecotoxic cationic zinc and minor exceedances for ecotoxic cationic nickel but no exceedances for pH.

It is concluded that sub-bed diversions through fractured river bedrock in the Georges River would generally maintain and may slightly increase ecotoxic concentrations of Zn down river partly because of the pre-existing concentrations of zinc in the moderately saline waters released from Brennans Creek Dam and partly through the further release of Zn contained within dissolving marcasite in the fractured bedrock.

The national water quality guidelines explicitly allow for the consideration of site or region specific factors (ANZECC/ARMCANZ, 2000) and, in our view pHs in the Georges River between 8.0 and 9.5 are demonstrably still within the ‘natural range’ for lowland rivers with good access of light to the river surface and many pools that can support significant algal populations.

This is because when flows in the river under ‘steady state’ conditions i.e. when pool depths remain constant due to controlled release from BCD then pHs in the river already able to be found lying in the 8.0 – 9.5 range ‘naturally’ especially under warm, sunny conditions.

Algal primary productivity in river pools maximizes under those circumstances and algae absorb dissolved CO_2 and bicarbonate from water and respire oxygen – thereby driving pH up. It is therefore common to observe pHs in pools in the river rising to levels as high as 9.5 during warm, sunny conditions.

This suggests that; to expect the pH of water in the river to lie below 8.5 at all times is unwarranted and it is very likely that local aquatic biota is acclimatized to pHs at least as high as 9.5. This in turn suggest there is no deleterious effect arising *per se* from the fact that the BCD discharge typically has a pH in the 8.0 – 8.6 range.

It is therefore predicted that there will be no significant effect on pH from any effect resulting from the extraction of proposed longwalls.

On the basis of the information presented in previous sections of this report and above we conclude that:

6. the **Likelihood** of one or more sub-bed diversions arising within Georges River as a consequence of the mining of proposed Longwalls 34 - 36 is **Minor**; but
7. the **Consequences** of such a diversion on **Aesthetics** of the River from iron floc would be **Major**; however
8. the **Consequences** of such a diversion or diversions to **Property** would be **Insignificant to None;** and
9. the **Consequences** of such a diversion to the **Ecological Health** of immediate downstream pool(s) in the River would be **Major** but only under low flow conditions (<0.3 ML/day) which have occurred no more than 15% of the time since the introduction of the controlled discharge to the River from West Cliff Colliery BCD; but
10. the **Consequences** of such a diversion to the **Ecological Health** of immediate downstream pool(s) would be **Insignificant** provided the River continued to receive an environmental flow e.g. from West Cliff Colliery in excess of 0.5 ML/day with an Total Alkalinity in excess of 500 mg/L expressed as $CaCO_3$ (calcium carbonate); but that

Locally, significant evidence for induction of at least one upland-driven ferruginous spring (the so-called Pool 11 spring) was obtained when Longwalls 5A1 and 5A2 were mined beneath the River and most likely when Longwall 30 mined beneath the catchment of the so-called Ingham’s Tributary (MSEC designated ‘Creek 1’; MSEC, 2007).

Nevertheless, as the subsequent extraction of Longwalls 29 and 31, which were not mined directly under the river has not apparently led to the creation of a ferruginous spring, even though they have mined under an upland catchment on the western side of the river of significant size (0.72 km^2), it might be inferred that the smaller catchments further to the north proposed to be mined under by Longwalls 34 to 36 are at lower probability of risk from this phenomenon.

With respect to the possible induction of a ferruginous spring while such an occurrence is considered unlikely for the reason given above, <u>if it should occur,</u> then the following effects are inferred by us, on the basis of geochemical modelling, to be the maximum 'worst case' long term effects in Georges River:

1. for all discrete spring flows into the river <u>above</u> 0.1 ML/day and river flows below about 0.3 ML/day i.e. below 15 percentile the default lower limit for DO in the national water quality guidelines would not be met at the spring emergence point.
2. for all discrete spring flows into the river below 0.2 ML/day and river flows below about 0.5 ML/day i.e. below 50 percentile flows the 95% default limit for Ni in the national water quality guidelines would not be exceeded by the concentration of cationic ecotoxic NI species at the spring emergence point.
3. for all discrete spring flows into the river below about 0.2 ML/day and river flows below about 0.5 ML/day i.e. below 50 percentile flows the 95% default limit for zinc in the national water quality guidelines would not be exceeded by the concentration of cationic ecotoxic Zn species at the spring emergence point.
4. for all discrete spring flows into the river <u>above</u> 0.15 ML/day and river flows below about 1.0 ML/day i.e. below 50 percentile flows the default lower limit for dissolved oxygen in the national water quality guidelines would be marginally not met at the spring emergence point

Again, the principal reason why concentrations of ecotoxic Ni and Zn species in the Georges River deriving from any such springs would not exceed the default national water quality guidelines limits for nickel and zinc of 0.011 and 0.008 mg/L respectively for river flows of 1.0 ML/day and above is due to the considerable carbonate alkalinity in the water discharged from Brennans Creek Dam which constitutes the major part of the flows in the river (i.e. up to at least the 50 percentile flows).

Given the nature of the Georges River bed, it is believed that typical re-aeration coefficients applying in the river would be such that, for discrete spring flows into the river above 0.15 ML/day, <u>and</u> river flows above 0.5 ML/day, the minor deficit in DO at the spring emergence point would not have a significant impact. This is because geomorphological considerations suggest the river water should be quickly re-aerated over very short distances – likely only a few metres (USEPA, 1985).

It is concluded that such springs would only cause a considerable river DO deficiency at their emergence points <u>if</u> their flow rate exceeded 0.1 ML/day <u>and if</u> flows in the river were concurrently <0.3 ML/day (i.e. <15% probability). The likelihood of this occurring is extremely low.

It is noted that such springs <u>do not</u> contain sufficient dissolved Fe and Mn to cause a significant depression of river pHs through the oxidation and precipitation of hydrous Fe and Mn oxides because the River water contains significant bicarbonate/carbonate alkalinity deriving from the BCD discharge from West Cliff Colliery.

On the basis of the information summarised above, our technical knowledge and professional judgement we conclude that:

1. the **Likelihood** of one or more springs arising within Georges River as a consequence of the mining of proposed Longwalls 34 - 36 is **Minor;** and

2. the **Consequences** of such springs to **Property** would be **Insignificant to None;** and

3. the **Consequences** of such a spring or springs to the **Ecological Health** of immediate downstream pool(s) in the River would be **Major** under low flow conditions (<0.3 ML/day); but
4. the **Consequences** of such a spring or springs to the **Ecological Health** of immediate downstream pool(s) would be **Insignificant** provided the River continued to receive an environmental flow e.g. from West Cliff Colliery in excess of 0.5 ML/day with an Total Alkalinity in excess of 500 mg/L expressed as $CaCO_3$ (calcium carbonate); but that
5. the **Consequences** of such a diversion on **Aesthetics** of the Georges River would be **Major**.

4.2 ASSESSMENT OF LIKELY EFFECTS ON WESTERN CREEKS

It is possible ferruginous saline springs may be more prone to be induced or if pre-existing enhanced in flow rates westward draining catchments overlying Longwalls 34 to 36 that ultimately flow to the Nepean River e.g. Mallaty Creek, Leafs Gully Creek and Upper Nepean Creek.

This possibility has already been suggested by:

1. the drilling of Tower Colliery borehole 22 in August 2001 in which a considerable flow of a classic Wianamatta Shale water with high dissolved Fe and Mn concentrations was encountered in the low part of a westward draining catchment; and
2. detection of a spring in Ingham's Tributary of Ousedale Creek at site IT30 which was detected after completion of Longwall 30 and possibly induced or enhanced by mining of that longwall; and
3. detection of a pre-existing spring in Mallaty Creek between sites MC05 and proposed site MC130.

Given that the gradients in Ingham's Tributary are similar to those in Upper Mallaty and Leafs Gully Creek, but significantly less than those in Upper Nepean Creek (within the SMP Area), and that maximum predicted systematic tilts along the alignments of Mallaty Creek are similar to those back-predicted for Longwalls 30 and 31 (MSEC, 2005), there would appear to be a low but finite probability of induction of, or enhancement of existing ferruginous springs in the Upper Mallaty and Leafs Gully Creek catchments as a consequence of the mining of Longwalls 34 – 36.

Notwithstanding, the westward draining streams are clearly strongly ephemeral in nature with ongoing agricultural land use and it is unlikely there would be any significant impact to water quality resulting from the formation of springs in these streams over and above current anthropological effects (The Ecology Lab, 2007).

On the basis of the information summarised above we conclude that:

1. the **Likelihood** of one or more ferruginous springs arising within Upper Mallaty Creek catchment from subsidence-related effects within that catchment as a consequence of the mining of proposed Longwalls (33), 34 or 35 is **Minor** as the mining of Longwalls 31 and 32 (mined from the west) has possibly not led to induction of such springs although Longwall 30

appears to have created a spring in Ingham's Tributary of Ousedale Creek to the south**;** and

2. the **Consequences** of such a spring or springs to **Property** would be **Minor** and we base this on a minor risk of potential contamination to a farm or commercial water storage dam**;** and
3. the **Consequences** of such a spring or springs to the **Ecological Health** of immediate downstream pool(s) in the Creek would be **Insignificant** <u>under high flow conditions but **Minor** under low flow conditions</u> and we principally base this conclusion on the existing effects of local agricultural land uses on stream water quality; and
4. the **Consequences** of such a spring or springs on **Aesthetics** in Nepean River would be **Minor** given that Mallaty Creek discharges to Ousedale Creek and the confluence receives additional flows from Upper Ousedale Creek.

On the basis of the information summarised above we conclude that:

1. the **Likelihood** of one or more ferruginous springs arising within Leafs Gully Creek or Upper Nepean Creek catchment from subsidence-related effects within that catchment as a consequence of the mining of proposed Longwalls 25 and 26 is **Minor;** and
2. the **Consequences** of such a spring or springs to the **Ecological Health** of immediate downstream pool(s) in the Creek would be **Insignificant** <u>under high flow conditions but **Minor** under low flow conditions</u> and we principally base this conclusion on the existing effects of local agricultural land uses on stream water quality; and
3. the **Consequences** of such a spring or springs to **Property** would be **Minor** and we again base this on a minor risk of potential contamination to a farm or commercial water storage dam; and
4. the **Consequences** of such a spring or springs on **Aesthetics** in Nepean River would be **Major**.

4.4 RECOMMENDATIONS

4.3.1 Hydrogeological and Geological Monitoring

The environmental monitoring proposed for the Longwalls 34 to 36 SMP Area should be based on knowledge gained from previous water quality, hydrologic hydrogeological investigations associated with the extraction of former Longwalls 5A1 - 5A4 and Longwalls 29, 31, 32 and 33.

Surface to near surface water interaction has been demonstrated by existing piezometer results in the Jutts Crossing area and elsewhere. At that time it was found that Georges River could be a 'losing river' that is, at least in some sections it tended to recharge groundwater and hydraulic gradients tends to slope away from the River especially under the prolonged drought conditions which applied locally between 2000 and 2006.

However, as 2007 was a year of very high rainfall of at least 90 percentile magnitude in the catchment of Upper Georges River and high natural flows in the River ensued, it is likely that on balance the River became a gaining river and, if rainfall over 2008/9 is near average that condition should persist.

In our view, a number of shallow piezometers should be installed in the SMP Area near to the Georges River to monitor the local groundwater interface prior to commencement of extraction to improve our understanding of the saturated thickness (i.e. transmissivity and storativity) and typical hydraulic gradients in the vicinity of the River. It is noted BHPBIC have considerable experience in the installation of such piezometers.

As the rock bars most likely to fracture are Rock Bars 56A and 56B, which are located adjacent to the maingate of proposed Longwall 35 and the predicted closures exceed the back-predicted closure for the Elouera Colliery Native Dog Creek case study this is the most suitable area in which to locate such piezometers.

Natural stress concentration in the surface of rock bars is an integral part of the potential failure mechanism of the rock bar. Close inspection of cores recovered from the installation of shallow piezometers and stress measurements on recovered core are a possible method of determining the degree of potential failure of rock bars and the relative propensity of a number of rock bars to failure.

Cores recovered from piezometer holes within the SMP Area along Georges River close to major rockbars should be routinely geologically logged and fracture system mapping conducted.

Core from piezometer holes drilled in the vicinity of major rockbars should be inspected for overall siderite content and, in particular, inspected for the presence of a distinctive low strength layer of the order of 50 to 150 mm in thickness characterised by a conglomerate comprised of small quartz pebbles and various other lithic clasts. If such a layer is identified its local dip and strike in relation to the nearest rockbar should be determined.

The presence of such a layer has recently been identified by us as a particular element of environmental risk from the perspective of failure due to upsidence and valley closure effects (leading to sub-bed diversions and sulfuric acid production) due to:

- its low strength; and because
- the conglomerate contains clasts which have completely altered to siderite and siderite cement in the conglomerate appears likely to be the major locus of marcasite and minor pyrite in Hawkesbury Sandstone.

Pre-mining ‘permeability’ testing of piezometer holes is useful but produces outcomes that don’t necessarily relate to the distribution and magnitude of local permeability enhancement by undermining. Furthermore, close to the River, the potential for linking of perched fractured ‘aquifer’ systems by any too-deep borehole is large. In our view, the risk of such interaction and the difficulty of interpretation of the groundwater migration path and the potential to lose surface water from the River outweigh the advantage of knowing the incremental vertical dilation profile after undermining.

Conversely, there is a need to better understand the incremental vertical dilation profile after undermining in the interfacial zone between the Wianamatta Shale and

Hawkesbury Sandstone and the effects of that on shallow groundwater storage and induction or enhancement of springs.

In our view, it would be advisable to install several open boreholes/piezometers through the Shale, any Mittagong Formation material between the Shale and Hawkesbury Sandstone and well into the upper Hawkesbury in their vicinity. This should occur prior to mining to enable pre- and post-mining study of strata dilation and permeability effects. Dilation may be assessed by gamma logging etc.

4.3.2 Baseline and Ongoing Water Quality Effects Monitoring

Baseline surface flow and water quality monitoring is already occurring in Georges River upriver and adjacent to proposed Longwalls 34 – 36 and in Lower Mallaty Creek.

Establishment of further surface flow and water quality monitoring sites should occur in Upper Mallaty Creek, in Leafs Gully Creek and in Upper Nepean Creek at the earliest opportunity, prior to the granting of approval to mine Longwalls 34 - 36 and ongoing water quality sampling should commence from the granting of approval to mine Longwall 34.

It is recommended that the Mallaty Creek sites be those already identified by BHPBIC from experience with Longwalls 31 and 32 and the findings of The Ecology Lab 2005 and 2007 and shown in **Figure 2.5** in **Section 2.6**.

It is recommended that the Leafs Gully and Upper Nepean Creek water quality monitoring sites be established by consultation and coordination between BHPBIC and The Ecology Lab.

In our view, a small Response Plan should be also developed by BHPBIC to deal with the possibility of a ferruginous upland spring arising within the SMP Area, particularly in Georges River and upstream of, or within a farm dam or other commercial water storage dam in the catchments of the 3 western creeks.

The Plan should include a defined methodology for timely assessment of the magnitude of spring occurrence (i.e. flow rates, iron and manganese loads) pre- and post mining and, if necessary a conceptual response methodology for modifying the geomorphology of a significant spring to affect maximum oxygenation and hence maximal iron and manganese precipitation as close to the source as possible as outlined in the following **Section 4.3.3**.

4.3.3 Best Practice Effects Management

In the event, considered by Ecoengineers to be unlikely, that future water monitoring shows that there has been significant hydrologic or aquatic ecotoxic effects within the SMP Area or immediately downstream in Georges or Nepean Rivers then it is possible that some management and mitigation measures may be required.

Current River low flow conditions based on the release of at least 1.0 ML/day from Brennans Creek Dam in accord with the West Cliff Water Management System (WMS) should be maintained throughout the Longwall 34 - 36 mining period so that accurate field monitoring can be carried out to determine whether any increased flow diversions occur as a result of extraction of the proposed longwalls.

If any upriver licensed discharges were changed during the mining period, it would be difficult to compare flow conditions with baseline data already accumulated and to be accumulated, especially in the post-drought conditions that have applied since September 2008.

In our view, based on the above discussion the estimated 'cut off' River flow rate above which any 'worst case' effects possibly induced by mining Longwalls 34 to 36 are considered to be comparable with effects deriving from natural variations in flow rate, water temperature, water quality etc in the River lies in the range of about 1.0 - 1.5 ML/day.

We recommend that consideration be given to developing a plan establishing that the minimum discharge from Brennans Creek Dam be maintained at a minimum of 1.0 ML/day as the best means of maintaining a minimum environmental flow in the River through the Longwalls 34 to 36SMP Area of 1.0 ML/day as a pre-requisite for the mining of these longwalls.

Whilst significant sub-bed flow diversions in Georges River as a result of extraction of the proposed longwalls 34 – 36 are considered highly unlikely, it is possible that, depending on the rate of environmental discharge from West Cliff Colliery, and climatic conditions, sections of river could become dry, particularly during times of interruption drought.

Pre-existing flow diversions are already known to exist in the River, both natural and residual effects after longwall mining and remediation.

On the basis of experience over the period 2004 – 2006 it is suspected that the River would consist of a series of disconnected or drained pools during periods of low rainfall if the West Cliff licensed discharge did not enter the River.

It is therefore recommended that depth monitoring continue at all pools within the SMP Area before during and following the mining of Longwalls 34 – 36.

In the unlikely event that:

1. discharges from West Cliff Colliery cease for operational purposes; and
2. antecedent rainfall conditions are such that flows in the River above the Brennans' Creek confluence cease; and
3. sub-bed flow diversion adjacent to any of Longwalls 34 – 36 is detected (through paired flow measurements and/or pool level monitoring), then

it is recommended that mitigatory flows be released from the West Cliff or Appin Collieries until such time as the flow diversions are remediated.

While the likelihood of increased flow diversions is considered to be relatively low, any flow diversions that might occur can be fully or partially restored by remediation works such as those which have been previously undertaken successfully in the Georges River (International Environmental Consultants Pty Ltd., 2004).

With respect to excessive precipitation of hydrous iron and manganese oxides and the consequent generation of depleted DO such as might occur through the induction of ferruginous springs, it is noted that this occurs as a result of reaction with atmospheric oxygen.

This implies that; if the precipitation/acid generation effect occurs too far down slope from the spring and hence impacts on a well-recognised pool ecosystem in Georges River or Lower Mallaty, Leafs Gully or Nepean Creeks or leads to an unsightly ferruginous discharge in either River, the location of the zone of maximal oxygenation can easily be moved upslope closer to the spring source.

This would simply involve the deposition of heavy rocks and boulders closer to the spring. This material could usually be obtained from local Hawkesbury Sandstone outcrops nearby and moved to the spring emergence point by manual labour. The effect of this would be to greatly increase turbulence and hence rates of oxygenation, precipitation of hydrous oxides and acid generation allowing natural effects effect downslope to play a greater role in amelioration of the effects of the spring.

Modification of drainage line and stream hydrology by deposition of boulders and local rock 'rip rap' and/or neutralization with modest masses of limestone rock are accepted 'green engineering' methods widely employed worldwide in the mining and quarrying industries for improvement of environmental performance.

It is strongly emphasized that the various mitigation measures outlined above are proposed only on the basis of existing best practice elsewhere and their description is not intended to imply that the adverse effects requiring such measures are likely to occur.

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