9. SUBSIDENCE PREDICTIONS AND IMPACTS ON HYDROLOGY

Strains due to differential subsidence, leading to 'upsidence' and 'valley closure' and accompanying surface fractures caused by longwall mining beneath incised creeks and riverbeds can produce a complex suite of physico-chemical effects. These effects, noted below for the case of Southern Coalfield, have been investigated rigorously in the case of the proposed Longwalls 705 to 710 using relevant data on hydrological measurements, visual observations and water quality monitoring over recent years. The potential impacts on the environment and water quality were evaluated and predicted to be minor or insignificant. These effects include:

- 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 rock bar controlled pools in no and low flow situations.

- Diversion of stream flows through the fractured bedrock leading to loss of surface flows and pool storage.

- 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.

- 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.

- 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.

These effects will not necessarily be observed in Nepean River, the largest watercourse in the General SMP area or its tributaries, as it will not be directly mined beneath. The water level in the Nepean River within the SMP area is controlled by the Menangle Weir. The Menangle Weir has caused the Nepean River within the SMP to become a permanently flooded single pool, thereby precluding any loss of water from cracking within the base of the waterway as the pool is the lowest point in the hydrological landscape. In addition, the proposed longwalls have been set back at least 180 metres from the bank of the Nepean River. These safeguards that have been put in place will ensure that the effects of any subsidence / upsidence from mining will not significantly impact on the surface and groundwater regimes in the General SMP area in terms of changes in water quality, water levels, flow rates and the appearance of watercourses. Any impacts that may result are predicted to be minor and temporary.

This section discusses the assessments of the potential subsidence impacts on surface water (**Section 9.1**) and groundwater (**Section 9.2**). The potential impacts of subsidence on aquatic ecology, presented in **Section 10.2,** uses the surface water quality information presented in **Section 9.1** and **Appendix B** to complement their own independent water quality monitoring studies.

9.1. POTENTIAL SUBSIDENCE IMPACTS ON SURFACE WATER

Ecoengineers have completed an assessment of potential water effects in the SMP Area including the Nepean River and associated creeks, and the full report is provided in **Appendix B**.

The investigation of possible mechanisms inducing water quality effects has been principally restricted to the identification, classification and quantification of effects caused within the General SMP Area i.e. the Nepean River, in tributaries on the western side of the Nepean River such as Harris Creek, Foot Onslow Creek and Navigation Creek, farm dams west of the River, and tributaries on the eastern side of the River such as Ousedale Creek, Leafs Gully Creek and Nepean Creek. The report also considers potential down-river far field effects in the Nepean River north of the General SMP Area.

A summary of the impacts on surface water is provided below. The mechanisms that may give rise to any water quality impacts are the mining-induced gas emissions and mine subsidence-induced ferruginous springs discharging directly into the Nepean River. The ecological consequences of ferruginous spring formation and gas emissions are evaluated. In both cases, based on the available data and observations from recent case studies on such environmental effects, the impacts are considered to be minor. Further monitoring and analysis of the influence of gas emissions at different flow rates on water quality has been proposed.

Detailed assessments of the expected fluctuations in the Nepean River within the SMP area due to mining have revealed that water levels will essentially remain unchanged. This is because the water level in the Nepean River within the SMP area is determined by the Menangle Weir. This weir will not be affected by subsidence from the proposed mining (MSEC, 2008).

Based on the conservative predictions of upsidence and relatively small amounts of predicted subsidence, the maximum uplift along the river is expected to be between 255 and 345 mm. However, judging from the observations of mining-induced impacts on the recently mined Longwall 701 the actual fluctuation is not expected to be measurable. In general; water levels in the Nepean River fluctuate in response to changes in water flow rates. Water level data suggests that the river typically rises and falls within a range of ±150 mm. It has also been observed that water levels rise by 600 mm when flows reach a peak of approximately 730 ML/day at Maldon Weir (located approximately 13 km upriver from the proposed longwalls), which is an event that occurs only approximately 8% of the time. These observed changes in water levels are consistent with the predicted maximum of 345 mm uplift (MSEC, 2008) of the river banks.

The potential for sub-bed diversion of surface water in the Nepean River is very low as the river bed is flooded and the gradient of the river is very flat. This is consistent with subsidence predictions which have also shown that the potential for surface water flow diversion to occur as a result of the extraction of the proposed longwalls is very low. Any fractures in the bedrock that may develop as a result of mining (refer **Section 9.2**) are likely to be filled immediately by water or sediment, and the volumes of water that fill up these

fractures are likely to be extremely small compared to the total volume of water that is retained by Menangle Weir.

The potential for infiltration of water into the groundwater system is also very low as the Nepean River represents the regional low point in the water table. The potential for loss of surface water into the mine is also unlikely due to the depth of cover, the offset of the longwalls in relation to the river, and the presence of Bald Hill Claystone aquitard in the regional stratigraphy, which as discussed below acts as an aquiclude between the river and the mine and will thus prevent vertical connectivity between them.

Any acid released by oxidation of the marcasite in the Sandstone will be largely attenuated naturally in the river water further downstream principally by dilution, and by reactions with the low concentrations of carbonate / bicarbonate ions released by iron and manganese carbonates from soils derived from Wianamatta Shale as they dissolve in the creek or river water. These sources of continuous alkalinity in water afford an augmented acid buffering potential in the Nepean River, and thus there is a natural mitigation measure for small pH changes already in place.

The formation of ferruginous springs due to mining has previously been observed in the Bulli Seam mining areas, especially when they are in proximity to areas of Wianamatta Shale, although their occurrences are rare. Mining to date in Appin Area 7 (Longwalls 701 to 702) has not led to the creation of any ferruginous springs, and it is therefore most likely that the catchments further to the north of these longwalls where the proposed Longwalls 705 to 710 are to be mined will not be affected. In general terms 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 discharging to Nepean River, up to a maximum recharge/discharge rate of approximately 0.2 ML/day and a mean recharge/discharge rate of approximately 0.1 ML/day.

Modeling has been conducted using this information and the observed iron and manganese ion concentrations in order to obtain probabilistic information on the impact of ferruginous springs discharging directly into Nepean River. It has been found that for all discrete spring flows into Nepean River below approximately 0.2 ML/day and above approximately 4.0 ML/day i.e. above 50 percentile flows, the DO in the water will be consistent with the default guideline for DO in the national water quality guidelines for NSW lowland rivers.

A minor consequence of ferruginous spring formation by oxidation of iron and manganese ions is the lowering of DO in river and creek water, and the problem could be exacerbated if the receiving water bodies have low re-aeration coefficient which is the case for the section of the Nepean River adjacent to the General SMP Area. However, on the basis of field observations, such ferruginous springs would be more prone to arise, or if pre-existing, enhanced in draining catchments in the general SMP Area i.e. Harris Creek, Upper Foot Onslow Creek and Upper Navigation Creek rather than in the Nepean River itself. Given that the volumes of low DO level water discharged from the creeks will be small compared to the volume and larger flow rates of water in Nepean River, DO levels should recover to normal values quite quickly.

Emissions of methane gas during longwall mining may be linked to some extent to the reduced DO levels but this is known to occur only at very low flow rates. The concentrations will depend on a number of factors; (i) whether full saturation of methane will ever be reached when the water will be depleted of majority of the dissolved oxygen, (ii) that biological consumption of the dissolved methane does not occur, and (iii) the rate of methane bubbling relative to the flow rate of the water and the presence of rock formations in the flow path which can provide surfaces where methane gas release into the atmosphere can occur. DO levels measured within the Nepean River at low flow conditions during baseline

monitoring and during Longwall 701 extraction have revealed that DO conditions can fall below 60% independent of any impacts associated with gas releases from mining. Field based water quality parameter monitoring undertaken by Illawarra Coal during Longwall 701 has identified minor DO changes associated with gas emissions in the Nepean River at low flow rates.

The reduced DO levels observed to date cannot be definitively attributed to methane gas releases from mining only. Other sources such as agricultural/nutrient runoff and discharge of low DO water from tributaries such as the Cataract River Backwater are more likely to be the reasons for the observation. Currently limited measured data investigating the numerous factors that contribute to the reduced DO levels in water exist, and further validation of any such effect is warranted.

Notwithstanding the above, it is recommended that more comprehensive monitoring be undertaken to monitor the impacts of gas releases on overall water quality in the Nepean River. It is recommended the magnitude and composition of gas emissions within the river, the detailed water quality analysis within close proximity up and down stream of gas emission site(s) be undertaken during low river flow conditions, to better understand any potential impacts. Water quality analyses should be expanded from the current suite of analytes to include dissolved methane, hydrogen sulfide and biogenic phenols.

9.2. POTENTIAL SUBSIDENCE IMPACTS ON GROUNDWATER

Geoterra have completed an assessment of potential groundwater effects of mining induced subsidence in the SMP Area and the full report is available in **Appendix E**. In this section the impacts on groundwater are summarized.

Using data from previous studies it has been predicted that any mining-induced fracturing of strata over the extraction area will be confined to the plateau in the general SMP area, and in the extreme case may extend to 20 m below surface with some potential for volumetric dilation of strata below the tensional zone and spatial and temporal rock permeability / porosity changes in the bedrock. Subsidence may cause the dominant horizontal flowing water in watercourses in the SMP area to change to a combination of vertical and horizontal flows above the aquitards.

Groundwater systems in the general SMP area may experience standing water level changes due to mining-induced bedrock fracturing especially if this is accompanied with changes in the permeability in the bedrock. It is known that the regional piezometric surface lies beneath the potential fracture zone (20 m from the plateau surface) and there may be a temporary lowering of the piezometric surface over the subsidence area due to horizontal dilation of strata and resultant increase in secondary porosity. However, this effect will only be notable directly over the area of greatest subsidence and dilation, and will dissipate laterally out to the edge of the subsidence zone. Based on previous observations in the Southern Coalfield, groundwater levels may reduce by up to 10 m, and may stay at that reduced level until maximum subsidence develops at a specific location. The duration of the reduced levels will depend on the time:

- it will take to develop maximum subsidence;
- for subsidence effects to migrate away from a location as mining advances; and
- required to recharge the secondary voids by rainfall.

It is predicted there will be no permanent reduction in groundwater levels underneath the Nepean River. Once any subsidence-induced cracks are filled with water, there will be no vertical discharge path through which the groundwater can flow out of the system, so there will be no ongoing water flow into the cracked basement of the gorge and riverbed. Any water loss that does potentially occur would be replenished by the large volume of water in the river pond (a minimum of approximately 1,400 ML) and the daily flow down the river (a minimum of 3 ML/day). Therefore, due to the short term nature of any groundwater level reductions, any impact to groundwater resources in the plateau areas resulting from the proposed extraction is likely to be insignificant.

The overall groundwater quality in the general SMP area is not expected to be adversely affected based on previous observations in the Southern Coalfield, and due to the proposed mitigation measures to be put in place during mining. During the mining phase, iron and manganese hydroxide precipitation may occur if the aquifer is exposed to "fresh" manganese carbonates in the strata. A lowering of pH (by about 1 pH unit) in the discharged water can occur if there is exposure to iron sulfides (marcasite) which will cause dissolution of unweathered minerals. The extent to which these effects will change the groundwater quality will depend on the balance between the mining-induced pH changes and the availability of the neutralizing carbonate / bicarbonate ion levels already present in the groundwater. Since the Southern Coalfield already has significant iron hydroxide levels a comparison of the baseline data acquired in the pre-mining survey with the groundwater quality data acquired during the mining phase will provide an on-going assessment of the water quality and which will readily detect any significant changes. The appropriate action, as proposed in the trigger / action / response / plan (TARPs) refer **Table 24.1** in **Volume 2**, will be used to manage and mitigate any changes detected.

An assessment of the effect of subsidence on seeps, springs and baseflow to the Nepean River will occur if subsidence causes fracturing in the low permeability layers in the plateau strata. No large seeps were identified during the study along the potentially affected stretch of river. The current intermittent seeps which occur after rainfall are generally short lived, with the volume and duration of flow directly related to the amount and intensity of rainfall.

No plateau springs have been identified in the area that will be affected by subsidence. However, based on observations on the western plateau associated with previous longwall mining, it is possible that interface drainage of ferruginous (brackish to saline) seeps may be generated in streams on the plateau over Longwalls 705 to 710.

The low order creeks on the plateau will be subjected to relatively low tensile strains and are not expected to be significantly impacted by subsidence related surface cracking. Similarly, it is not expected that observable loss of water from the creeks will occur, although individual pools within creeks may be drained by subsidence induced cracks in creek beds. It is not expected that any observable change to creek flows or ponding will occur due to the low predicted tilts, which are notably less than the natural gradient of the creeks. The creeks within the general SMP area are generally degraded and have low potential for aquatic habitat. Due to the low levels of strain on the plateau area and limited potential for fracturing of rock, cracking of soil and water loss, it is unlikely that the proposed mining will significantly impact lower order streams, seeps, springs and flow to the Nepean River.

Potential water inflow from streams and groundwater to mine workings were assessed although no previous observations of such flows have been recorded in any of the mines in the Southern Coalfield at similar depths of cover to that of the proposed Longwalls 705 to 710. Modelling by CSIRO and Coffey Partners International Pty Ltd. has indicated that the horizontal permeability above the Bald Hill Claystone in the regional stratigraphy of the SMP area may be enhanced after subsidence. However, there will not be any additional vertical permeability connectivity and that the hydrologic systems above and below the Claystone will

remain separate, noting that the upper level flow is dominantly horizontal and flows to the valley floor or locally upwards from below the river bed. Since this claystone layer acts as a confining layer then vertical hydraulic connection to the mine workings will not occur. It is highly unlikely that this layer would be breached after subsidence as it is from 150 to 200 m below the surface and well below the depth of any surface cracking and overburden dilation.

Very limited reports of gas evolution from the coal seams having an adverse effect on groundwater supply have been documented in the Southern Coalfield over longwall subsided areas. Hence, it is not anticipated that any significant gas effects will be observed in the private bores over Longwalls 705 to 710.

Impact of subsidence on infrastructure for monitoring groundwater in the general SMP area will be confined to 4 DWE registered bores (located over Longwall 703 and at the edge of the SMP area, northwest of the proposed Longwall 705). Bores outside the application area are less likely to have any observable subsidence effects. 3 effects are noted below:

- Horizontal displacement of strata can occur which could make the bores inaccessible
- The bores can become damaged
- Strata dilation and subsequent refilling of the secondary voids can temporarily lower standing water levels, whilst increasing the potential yield of a bore through enhanced permeability and secondary porosity.

In all cases the effects can be readily managed. In the first 2 cases alternative water supply will be made available by Appin Mine until such time as the affected bores recover and / or are repaired. If the bore levels do not sufficiently recover and the effect is due to subsidence rather than regional climatic or anthropogenic factors, repairs or maintenance to a bore can be undertaken after maximum subsidence has developed. At this time the pump intake can be lowered, the bore extended to a greater depth or a new bore can be established.

With these mitigation measures in place it is unlikely that water supply to properties will be significantly impacted by the proposed mining.

It should be noted that the impacts of mining the proposed Longwalls 705 to 710 on the groundwater in the general SMP area have been discussed based on subsidence, strain and tilt predictions on the plateau and gorge in the area. Any deviations from predicted movements could alter stream bed and general plateau ground surface cracking, either through an increase or decrease in crack incidence and size.

Further assessments have been conducted in the event that the actual subsidence deviates from the predicted subsidence and are noted as follows:

- If the actual plateau subsidence exceeds predictions, it is not anticipated there will be significant deviation in the potential effects except for possible minor additional soil or creek bed cracking. However, this would not result in any significant change in the actual impacts on ephemeral stream flows or quality, compared to the predictions in this report.
- If greater than expected crack development occurs, it is not anticipated there will be any significant additional impacts on groundwater levels, groundwater quality or bore yields to that discussed in the previous sections.
- If additional ground movement occurs above the predicted levels, it is not anticipated that additional observable change to seepage rates will occur in the cliffs.