New South Wales
Government

Impacts of Underground Coal Mining on Natural Features in the Southern Coalfield

Strategic Review

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Impacts of underground coal mining on natural features in the Southern Coalfield: strategic review

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Cover photo: A rock bar and small waterfall on Sandy Creek, just downstream of Fire Road 6C, within Dendrobium Area 3 (Source: Sydney Catchment Authority)

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Glossary

Notes: Terms relating to coal mining systems are defined within section 2.5.4. While definitions of key terms relating to subsidence are included below, terms relating to subsidence are generally defined within section 4.1. Definitions of terms relating to risk assessment are shown together in a box at the end of this Glossary.

ACARP: Australian Coal Association Research Program, an industry-wide research program administered by the Australian Coal Association and funded by a per-tonne levy on all coal production.

AEMR: Annual Environmental Management Report.

Aquatic dependent: aquatic dependent species and ecological communities occur primarily in aquatic or wetland habitats, as well as species that may use terrestrial habitats during all or some portion of their life cycle, but that are still closely associated with, or dependent upon, aquatic or wetland habitats for some critical component or portion of their life-history.

Aquiclude: An impermeable body of rock that may absorb water slowly but does not transmit it.

Aquifer: A permeable body of rock or regolith that both stores and transports groundwater.

Aquitard: A layer of rock having low permeability that stores groundwater but delays its flow.

Banksia Thicket: characterised by a tall dense shrub layer of *Banksia* and *Hakea* with a low shrub layer and sedges. Occurs patchily around the periphery of large swamps on damp soils.

Cyperoid Heath: heath characterised by a dense stratum dominated by cyperaceous sedges. Widespread on relatively deep organic sands in wet areas surrounding drainage lines of large swamps and in the wettest parts of smaller swamps.

DECC: Department of Environment and Climate Change. This agency regulates impacts to air, flora and fauna, water and Aboriginal heritage.

Director-General's Requirements: requirements provided by the Director-General of the Department of Planning for an environmental assessment or environmental impact statement.

DoP: Department of Planning.

DPI: Department of Primary Industries.

DWE: Department of Water and Energy.

Diadromous: (used of fish) migratory between fresh and salt waters.

Edaphic: pertaining to or influenced by soil.

Environmental consequences: the environmental consequences of ***subsidence impacts***, including loss of surface flows to the subsurface, loss of standing pools, adverse water quality impacts, development of iron bacterial mats, cliff falls, rock falls, damage to Aboriginal heritage sites, impacts on aquatic ecology, ponding, etc.

Eutrophication: the process whereby a body of water becomes rich in dissolved nutrients, through either natural or man-made processes. This often results in a deficiency of dissolved oxygen, producing an environment that favors plant over animal life.

GDE: Groundwater dependent ecosystem.

MOP: Mining Operations Plan, required under all mining leases granted under the *Mining Act 1992*.

Piezometer: a non-pumping well or borehole, generally of small diameter, used to measure the elevation of the water table or potentiometric surface.

Restioid heath: has a low, open shrub layer and a groundcover dominated by forbs. Widespread wet heath community occurring where drainage is moderately impeded, on relatively drier sites.

Regolith: the blanket of soil and loose rock fragments overlying bedrock. It includes dust, soil, broken and weathered rock, and other related materials.

Riparian Zone is the area of land adjacent to a river or stream. It includes the riverbanks and land immediately adjacent to riverbanks.

Sedgeland: dominated by a continuous stratum of small restionaceous and cyperaceous sedges. Restricted to local seepage zones on shallow soils around the margins of larger swamps and on sandstone benches perched on the sides of gullies.

SCA: Sydney Catchment Authority, the lead agency controlling water supply infrastructure for both Sydney and the Illawarra.

SMP: Subsidence Management Plan, required under any mining lease granted for underground coal mining under the *Mining Act 1992.*

Special Areas: areas surrounding SCA's dams which are subject to additional management measures to protect the quality of drinking water. These areas are declared under the *Sydney Water Catchment Management Act 1998* for their value in protecting the quality of the raw water used to provide drinking water to greater Sydney and for their ecological integrity.

Subsidence *or* subsidence effects: the deformation of the ground mass surrounding a mine due to the mining activity. The term is a broad one, and includes all mining-induced ground movements, including both vertical and horizontal displacement, tilt, strain and curvature.

Subsidence impacts: the physical changes to the ground and its surface caused by ***subsidence effects***. These impacts are principally tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence but also include subsidence depressions or troughs.

Ti-Tree Thicket: has a tall to short, relatively dense stratum dominated by ti-tree and banksia and a tall, very dense understorey of sedges and ferns. Occurs in major seepage zones of large swamps, which typically have deep, highly organic waterlogged soils.

Upsidence: relative upward movement, or uplift, created by the horizontal compression and buckling behaviour of the rock strata in the vicinity of a valley floor. It generally reflects shearing and buckling of near surface strata, generally at or close to the valley centreline, caused by valley closure. It generally is measured as a reduction in overall vertical subsidence, rather than an absolute increase in surface height.

Valley closure: a phenomenon whereby one or both sides of a valley move horizontally towards the valley centreline, due to changed stress conditions beneath the valley and its confining land masses.

Risk Assessment Terms

Acceptable risk / acceptable level of risk: the outcome of a decision process of determining an acceptable option. The choice of an option (and its associated risks, costs and benefits) depends on the set of options, impacts, values and facts examined in the decision-making process.
Consequence: outcome or impact of an event, which may be multiple, may be positive or negative, can be expressed qualitatively or quantitatively, and are considered in relation to the achievement of objectives.
Ecological risk assessment: a set of formal scientific methods for estimating the likelihoods and magnitudes of effects on plants, animals and ecosystems of ecological value resulting from human actions or natural incidents.
Environmental impact: any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organisation's activities, products or services.
Environmental objective: the overall environmental gain, arising from the environmental policy, that an organisation sets itself to achieve, and which is quantified where possible.
Likelihood: used as a general description of probability or frequency.
Probability: a measure of the chance of occurrence expressed as a number between 0 and 1.
Qualitative risk assessment: where the likelihood or the magnitude of the consequence are not quantified.
Quantitative risk assessment: where the probability of the outcome can be estimated numerically and the magnitude of consequences quantified so that risk is calculated in terms of probable extent of harm or damage over a given period.
Risk: the chance that something happening that will have an impact on objectives.
Risk analysis: systematic process to understand the nature of and to deduce the level of risk.
Risk assessment: the overall process of risk identification, analysis and evaluation.
Risk management process: the systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context, identifying, analysing, evaluating, treating, monitoring and reviewing risk.
Tolerable risk: risk which is accepted in a given context based on the current values of society.
Uncertainty: a lack of knowledge arising from changes that are difficult to predict or events whose likelihood and consequences cannot be accurately predicted.

Source: Standards Australia (2006)

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Executive Summary

This independent inquiry was established because of concerns held by the Government over both past and potential future impacts of mine subsidence on significant natural features in the Southern Coalfield. These concerns first surfaced in the community in 1994 when the bed of the Cataract River suffered cracking and other subsidence impacts. The inquiry's Terms of Reference were to:

1. *Undertake a strategic review of the impacts of underground mining in the Southern Coalfield on significant natural features (ie rivers and significant streams, swamps and cliff lines), with particular emphasis on risks to water flows, water quality and aquatic ecosystems; and*
2. *Provide advice on best practice in regard to:*
   a) *assessment of subsidence impacts;*
   b) *avoiding and/or minimising adverse impacts on significant natural features; and*
   c) *management, monitoring and remediation of subsidence and subsidence-related impacts; and*
3. *Report on the social and economic significance to the region and the State of the coal resources in the Southern Coalfield.*

The terms of reference focused on particular defined significant natural features (ie rivers and significant streams, swamps and cliff lines). The Panel considered that certain local non-natural values contributed to the significance of these features, including Aboriginal heritage, non-Aboriginal heritage, conservation, scenic and recreational values. Water flows and water quality were considered to relate not only to ecosystem functioning but also to reflect water supply catchment values. The terms of reference did not extend to advising on the 'acceptability' of particular subsidence impacts or the scale or measurement of the value or significance of individual natural features.

Socio-Economic Significance of Coal Mining in the Southern Coalfield

The Southern Coalfield is a major source of high quality hard coking coal used for production of steel, both in Australia and internationally. The unique nature of this hard coking coal resource within NSW makes it a very important contributor to the local, regional and State economy. 8 currently operating mines in the Southern Coalfield produce around 11 Mt of coal annually. Five mines use longwall mining methods, and produce the vast majority of this coal (98%). Coal mining has high economic and social significance within the communities of the Southern Coalfield and directly employs about 2,500 people. Economic data suggests that indirect employment may be as high as 12,000. Coal mining and related industries are significant generators of wealth for the local community, the State and the nation, through expenditure, taxes, receipts and royalties. Coal royalty income from the Southern Coalfield was $58.7 m in 2006-07. The Southern Coalfield contains sufficient coal resources to enable coal mining in the region to continue for many decades.

Impacts of Underground Coal Mining

The Panel has used the term ***subsidence effects*** to describe subsidence itself – ie deformation of the ground mass caused by mining, including all mining-induced ground movements such as vertical and horizontal displacements and curvature as measured by tilts and strains. The term ***subsidence impacts*** is then used to describe the physical changes to the ground and its surface caused by these subsidence effects. These impacts are principally tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence but also include subsidence depressions or troughs. The ***environmental consequences*** of these impacts include loss of surface flows to the subsurface, loss of standing pools, adverse water quality impacts, development of iron bacterial mats, cliff falls and rock falls, damage to Aboriginal heritage sites, impacts on aquatic ecology, ponding, etc.

The Southern Coalfield's significant natural features include rivers and higher order streams, associated sandstone river gorges, major cliff lines and upland swamps. It also contains important flora, fauna and aquatic ecosystems; many listed threatened species, populations and endangered ecological communities and a significant number of Aboriginal heritage sites. The major land use includes water supply catchment for the Sydney and Illawarra Regions and associated dams and other major water storage infrastructure.

Due to the geology and geomorphology of the Southern Coalfield, non-conventional subsidence effects (including valley closure, upsidence and regional far-field horizontal displacement) regularly occur. Since unpredicted impacts of subsidence on rivers and significant streams became apparent, the coal mining industry has made significant advances in its understanding of and ability to predict non-conventional subsidence effects.

The majority of subsidence impacts on significant natural features are associated with valley closure and upsidence effects, leading to impacts on ***rivers and significant streams*** and in particular the cracking of stream beds and underlying strata. This has the potential, under certain conditions, to result in:

- loss or redirection of surface water flows;
- changes in water quality (particularly ferruginous springs and/or development of iron bacterial mats);
- loss of ecosystem functionality (eg loss of pool integrity and connectivity and changes in water quality); and
- loss of visual amenity.

Stream bed cracking is most evident where the stream bed is comprised of solid rock and is less apparent where the stream bed is covered with sediment (including valley infill swamps) or deep water and sediment (such as the Nepean River). Consequences of stream bed cracking are most severe in streams with significant amounts of exposed bed rock (eg in rock bars).

The upland swamps of the Southern Coalfield fall into two categories – ***headwater*** **swamps** (which make up the majority) and ***valley infill*** swamps. The Panel was not made aware of any significant impacts on ***headwater swamps*** caused by mining subsidence. Although it is likely that subsidence impacts observed elsewhere in the landscape are likely to take place beneath such swamps, the Panel was unable to draw any firm conclusions regarding the potential for subsidence to have adverse consequences on these swamps. Most known impacted swamps are ***valley infill swamps***. However, at all sites inspected by the Panel, there had been a range of other environmental factors in play, including evidence of pre-existing scour pools, previous initiation of erosion, concurrent drought, and subsequent heavy rainfall and/or severe bushfires. The sequence of events was not clear in relation to the swamp impacts (drying, erosion and scouring, water table drop, burning, vegetation succession, etc). The Panel therefore cannot be certain that subsidence either initiated or contributed to the damage at these swamps. However, available evidence suggests a significant possibility that undermining of valley infill swamps could cause drainage, water table drop and consequent degradation to swamp water quality and associated vegetation. Further research is required before a definitive conclusion can be reached.

No evidence was presented to the Panel to support the view that subsidence impacts on rivers and significant streams, valley infill or headwater swamps, or shallow or deep aquifers have resulted in any measurable reduction in runoff to the ***water supply system*** operated by the Sydney Catchment Authority or to otherwise represent a threat to the water supply of Sydney or the Illawarra region. However, this does not discount the possibility that a reduction in runoff may be realised under certain conditions, including downwards leakage to mining operations, especially where a shallow depth of cover prevails or a structural feature provides a conduit for flow.

The Panel also observed subsidence impacts on ***cliff lines***, principally rock falls associated with river gorges or other cliffs. Most such rock falls appeared to be minor, in so far as they seem to affect a relatively small proportion of cliffs close to longwall operations. ***Aboriginal heritage*** sites are most at risk of subsidence impacts where they are located in cliff lines and/or rock overhangs. The Panel was not made aware of any significant impacts having occurred on Aboriginal heritage features in the Southern Coalfield since the 1980s.

The Panel was not made aware of any adverse impacts on significant natural features likely to have been caused by ***regional far-field horizontal displacement***. There is no evidence requiring closer management of this subsidence effect in respect of significant natural features.

Non Mining Impacts

There is clear evidence of other factors also having major environmental impacts on significant natural features in the Southern Coalfield, including:

- poorly controlled runoff from surface land uses resulting in adverse water quality impacts;
- abstraction and regulation of stream flows resulting in impacts on water flow, water quality, ecosystem function and aquatic ecology;
- dams, weirs and other water supply infrastructure resulting in habitat loss through impoundment, loss of connectivity, changes to water temperature and dissolved oxygen and impacts on threatened species; and
- major climatic and related events, such as droughts, bushfires, severe rainfall events, changed rainfall patterns, which have the capacity to impact on features such as swamps as well as stream flows and water quality.

Prediction of Subsidence Effects and Impacts

Conventional surface subsidence effects and their impacts are well understood and are readily and reasonably predictable by a variety of established methods. The understanding of *non-conventional* surface subsidence effects (far-field horizontal movements, valley closure, upsidence and other topographical effects) is not as advanced. Valley closure and particularly upsidence are difficult to predict. However, there is a rapidly developing database of non-conventional surface subsidence impacts in the Southern Coalfield which is being used to develop improved prediction.

Subsidence impact assessments in the Southern Coalfield have generally focused too much on the prediction of subsidence *effects*, rather than the accurate prediction of subsidence *impacts* and their *consequences*. While there have been substantial improvements in the industry's ability to predict impact and consequence in recent years, these predictions have generally been qualitative in nature (eg 'moderate cracking', 'a possibility that some pools will drain'). Consequently, it has been difficult for agencies to establish whether impacts were greater or less than predicted. The challenge for the mining industry and its consultants over the next few years will be to move to a new generation of predictive capacity which is essentially quantitative in nature.

Best Practice Subsidence Impact Management

Subsidence impacts can be managed by any one or more of the following:

- tolerance of the resultant impact, coupled with natural processes of remediation;
- avoidance measures (eg barriers or buffers between panel extraction and significant features, or modification of the mining system or geometry);
- mitigation measures (eg smaller buffers designed to reduce but not eliminate subsidence impacts; mine layout or system changes (in terms of panel widths, limited extraction); use of slots to isolate ground movement; increasing stream flow volume, etc);
- remediation or rehabilitation measures (eg grouting or filling of surface and subsurface cracks, drainage of ponded areas, revegetation of eroding areas).

Avoidance measures may be impractical unless adopted at an early stage of the mine planning process, since longwall mining is an expensive and relatively inflexible mining system. Some ***mitigation measures*** also depend on early planning and adoption. Others may be initiated at a relatively late stage (eg ground isolation through slots or increased environmental flows).

Remediation or rehabilitation measures have been applied with mixed success to stream bed cracking in a number of watercourses in the Southern Coalfield; notably at Marnhyes Hole, Jutts Crossing and other locations on the Georges River, in the Lower Cataract River and at Waratah Rivulet. Stream bed cracking is difficult to remediate, particularly when access is restricted and the majority of cracking extends deeper into the valley floor. Successful outcomes are largely dependent on the capacity to understand the vertical and horizontal extent, geometry and style of the fracture network resulting from subsidence, as well as the underlying ecological processes. While increasing success has been demonstrated in re-establishing stream flow and pool holding capacity, little effort has been directed towards re-establishing aquatic ecosystems or measuring their return. Remediation measures should not currently be relied upon as a forward management strategy for highly-significant features. However, remediation may be a valuable option as a contingency measure, if actual subsidence impacts exceed predictions. Mining companies should provide much more detailed information concerning proposed remediation measures and evidence as to their likely effectiveness and their secondary/consequential impacts in project applications and SMP applications. There is a need for more research by the industry into techniques for remediating natural features which may allow a greater degree of proactive remediation, as a control strategy in the future.

There are a number of examples of ***natural processes of remediation*** in the Southern Coalfield. Stream bed cracking, surface water drainage to the subsurface and ferruginous springs which occurred in the Upper Bargo River in 2002 are now barely evident. In the lower Cataract River (where subsidence caused severe stream bed cracking between 1993 and 1997 and a simultaneous period of historically low water flows led collectively to a loss of flow, drainage of pools, loss of fish life and significant water quality changes), exposed stream bed cracks have subsequently been colonised by various biota. Water quality is now sufficient to support aquatic macrophytes and small fish.

Best Practice Assessment and Regulatory Processes

Both Part 3A and SMP approval processes already take into account the economic, social and environmental costs and benefits of any mining development proposal and involve significant elements of risk assessment. With few exceptions, at depths of cover greater than about 200 m coal cannot be mined economically by any mining method without causing some degree of surface subsidence. If mining of hard coking coal in the Southern Coalfield is to continue, then a certain level of subsidence impact must be accepted as a necessary outcome of that mining.

The decision making framework provided by Part 3A of the EP&A Act, together with recent amendments to the *Mining Act 1992*, provides a good foundation for the future management of coal mining subsidence in the Southern Coalfield and elsewhere in the State. Part 3A provides a process through which performance standards and environmental outcomes can be developed following scientific studies and stakeholder input and then set within a robust approval document. The project approval process under Part 3A is a case-by-case process that recognises the variability of sites and remains flexible within the growing body of knowledge regarding subsidence effects, impacts and consequences. The introduction in 2004 of the requirement for mines to obtain approval for a Subsidence Management Plan (SMP) was a substantial improvement in the regulatory process for subsidence impacts, which has led to many improved outcomes.

However, there are a number of areas where the Panel considers that management of mining subsidence can be strengthened in both the Part 3A and SMP processes, including:

- clarified relationships between Part 3A and SMP approvals;
- improved identification of natural features which require detailed assessment and careful management, using the concept of ‘Risk Management Zones’;
- improved guidance by Government agencies on the significance and value of the natural features of the Southern Coalfield;
- earlier engagement of all stakeholders by mining proponents and involvement by all key stakeholders in the identification of significant natural features;
- improved timeliness of applications and approvals;
- improved documentation for environmental assessments for project applications lodged under Part 3A, involving:
    - improved baseline data (a minimum of 2 years for significant natural features, collected at an appropriate frequency and scale);
    - better distinction and articulation of subsidence effects, impacts and consequences;
    - increased communication between subsidence engineers (re subsidence effects) and specialists in ecology, hydrology, geomorphology, etc (re impacts and consequences);
    - increased transparency, quantification and focus in describing anticipated subsidence impacts and consequences;
    - increased use of peer reviewed science and independent expert opinion;
    - the use of a net benefit review;
- a reverse onus of proof, with contingency planning, for mining where insufficient assurance can be provided that highly-significant natural features would not be unacceptably impacted;

- increased monitoring and back analysis of predicted subsidence effects, impacts and consequences;
- increased security deposits and rehabilitation responsibilities; and
- improved regional data sets.

The key role of the Part 3A approval should be to clearly define required environmental outcomes and to set appropriate performance standards. The subsequent role of the SMP should be one of management. SMPs should demonstrate how the required environmental outcomes will be achieved, what monitoring will occur and how deviations and contingencies will be addressed.

Risk Management Zones (RMZs) should be identified to focus assessment and consideration of potential impacts on significant natural features. RMZs should be identified for all significant environmental features which are sensitive to valley closure and upsidence, including rivers, significant streams, significant cliff lines and valley infill swamps. Due to the extent of current knowledge gaps, a precautionary approach should be applied to mining which might unacceptably impact highly-significant natural features. The approvals process should require a 'reverse onus of proof' from the mining company before any mining is permitted which might unacceptably impact highly-significant natural features.

Government has a responsibility to provide improved guidance - on which natural features are of significance and to what extent and what level of environmental risk is acceptable - in order to properly inform company risk management processes, community expectations and the approvals process. Currently, there is a lack of clear guidance regarding which features are of what level of significance, and what level of protection is required for each. Longwall mining is a large scale, high productivity, capital intensive mining process with long lead times to establish extraction panels. Consequently it needs timely approvals to facilitate continued production.

Recommendations

Assessment and Regulatory Processes

1) Risk Management Zones (RMZs) should be identified in order to focus assessment and management of potential impacts on significant natural features. RMZs are appropriate to manage all subsidence effects on significant natural features, but are particularly appropriate for non-conventional subsidence effects (especially ***valley closure*** and ***upsidence***). Consequently, RMZs should be identified for all significant environmental features which are sensitive to valley closure and upsidence, including rivers, significant streams, significant cliff lines and valley infill swamps.

2) RMZs should be defined from the outside extremity of the surface feature, either by a 40° angle from the vertical down to the coal seam which is proposed to be extracted, or by a surface lateral distance of 400 m, whichever is the greater. RMZs should include the footprint of the feature itself and the area within the 40^{o} angle (or the 400 m lateral distance) on each side of the feature.

3) RMZs for watercourses should be applied to all streams of 3rd order or above, in the Strahler stream classification. RMZs should also be developed for valley infill swamps not on a 3rd or higher order stream and for other areas of irregular or severe topography, such as major cliff lines and overhangs not directly associated with watercourses.

4) Environmental assessments for project applications lodged under Part 3A should be subject to the following improvements in the way in which they address subsidence effects, impacts and consequences:
- a minimum of 2 years of baseline data, collected at an appropriate frequency and scale, should be provided for significant natural features, whether located within an RMZ or not;
- identification and assessment of significance for all natural features located within 600 m of the edge of secondary extraction;
- better distinction between subsidence effects, subsidence impacts and environmental consequences;
- increased transparency, quantification and focus in describing anticipated subsidence impacts and consequences;

- increased communication between subsidence engineers and specialists in ecology, hydrology, geomorphology, etc;
- key aspects of the subsidence assessment (particularly in respect of predicted impacts on significant natural features and their consequences) should be subject to independent scientific peer review and/or use of expert opinion in the assessment process; and
- increased use of net benefit reviews by both mining proponents and regulatory agencies in assessing applications.

5) Due to the extent of current knowledge gaps, a precautionary approach should be applied to the approval of mining which might unacceptably impact highly-significant natural features. The approvals process should require a ‘reverse onus of proof’ from the mining company before any mining is permitted which might unacceptably impact highly-significant natural features. Appropriate evidence should include a sensitivity analysis based on mining additional increments of 50 m towards the feature. If such mining is permitted because the risks are deemed acceptable, it should be subject to preparation and approval of a contingency plan to deal with the chance that predicted impacts are exceeded.

6) Approved mining within identified RMZs (and particularly in proximity to highly-significant natural features) should be subject to increased monitoring and assessment requirements which address subsidence effects, subsidence impacts and environmental consequences. The requirements should also address reporting procedures for back analysis and comparison of actual versus predicted effects and impacts, in order to review the accuracy and confidence levels of the prediction techniques used.

7) Part 3A of the *Environmental Planning and Assessment Act 1979* should be the primary approvals process used to set the envelope of acceptable subsidence impacts for underground coal mining projects. This envelope of acceptability should be expressed in clear conditions of approval which establish measurable performance standards against which environmental outcomes can be quantified. Once a project has approval under Part 3A, the Subsidence Management Plan approval should be restricted to detailed management which ensures that the risk of impacts remains within the envelope assessed and approved under Part 3A. In cases where a mining project approval under Part 3A of the EP&A Act does not yet exist, the SMP process should take a greater role in assessing and determining the acceptability of impacts.

8) The acceptability of impacts under Part 3A (and, in the interim, the SMP process) should be determined within a framework of risk-based decision-making, using a combination of environmental, economic and social values, risk assessment of potential environmental impacts, consultation with relevant stakeholders and consideration of sustainability issues.

9) Mining which might unacceptably impact highly-significant natural features should be subject to an increased security deposit sufficient to cover both anticipated rehabilitation costs (as at present), and potential rehabilitation costs in the event of non-approved impacts to the highly significant feature. The higher deposit should be commensurate with the nature and scale of the potential impact and should be attached to the mining lease by DPI under powers available to its Minister under the *Mining Act 1992*. If non-approved impacts occur and the feature is not able to be remediated by the mining company, then the deposit should be able to be forfeited as compensation for the loss of environmental amenity.

10) Consideration should be given to the increased use within Part 3A project approvals of conditions requiring environmental offsets to compensate for either predicted or non-predicted impacts on significant natural features, where such impacts are non-remediable.

11) Mining companies should ensure that they consult with key affected agencies as early as possible in the mine planning process, and consult with the community in accordance with applicable current industry and Government guidelines (eg NSW Minerals Council’s *Community Engagement Handbook* and DoP’s *Guidelines for Major Project Community Consultation*). For key agencies (eg DECC and SCA), this engagement should begin prior to the planning focus stage of a project application.

12) Government should provide improved guidance to both the mining industry and the community on significance and value for natural and other environmental features to inform company risk management processes, community expectations and Government approvals. This guidance should reflect the recognition that approved mining would be expected to have environmental impacts.

Subsidence Impact Management

13) The coal mining industry and Government should undertake additional research into the impacts of subsidence on both valley infill and headwater swamps. This research should focus on the resilience of swamps as functioning ecosystems, and the relative importance of mining-induced, climatic and other factors which may lead to swamp instability.

14) The coal mining industry should undertake additional research into means of remediating stream bed cracking, including:

- crack network identification and monitoring techniques;
- all technical aspects of remediation, such as matters relating to environmental impacts of grouting operations and grout injection products, life spans of grouts, grouting beneath surfaces which cannot be accessed or disturbed, techniques for the remote placement of grout, achievement of a leak-proof seal and cosmetic treatments of surface expressions of cracks and grouting boreholes; and
- administrative aspects of remediation, in particular, procedures for ensuring the maintenance and security of grout seals in the long term.

15) Coal mining companies should develop and implement:

- approved contingency plans to manage unpredicted impacts on significant natural features; and
- approved adaptive management strategies where geological disturbances or dissimilarities are recognised after approval but prior to extraction.

16) Government should review current control measures and procedures for approval and management of non-mining related impacts on Southern Coalfield natural features. These include various forms of discharge into rivers and streams, as well as water flow control practices. The impacts of such non-mining factors must be recognized when assessing the value of significant natural features in the region, and the assessment of appropriate control strategies.

Prediction of Subsidence Effects and Impacts

17) The coal mining industry should escalate research into the prediction of non-conventional subsidence effects in the Southern Coalfield and their impacts and consequences for significant natural features, particularly in respect of valley closure, upsidence and other topographic features.

18) Coal mining companies should place more emphasis on identifying local major geological disturbances or discontinuities (especially faults and dykes) which may lead to non-conventional subsidence effects, and on accurately predicting the resultant so-called ‘anomalous’ subsidence impacts.

19) In understanding and predicting impacts on valleys and their rivers and significant streams, coal mining companies should focus on the prediction of valley closure in addition to local upsidence. Until prediction methodologies for non-conventional subsidence are more precise and reliable, companies should continue to use an upper-bound, or conservative, approach in predicting valley closure.

20) Mining companies should incorporate a more extensive component of subsidence impact prediction with respect to natural features, in any future planning submissions. Such predictions should be accompanied by validation of the prediction methodology by use of back-analysis from previous predictions and monitoring data.

Environmental Baseline Data

21) Regulatory agencies should consider, together with the mining industry and other knowledge holders, opportunities to develop improved regional and cumulative data sets for the natural features of the Southern Coalfield, in particular, for aquatic communities, aquifers and groundwater resources.

22) Coal mining companies should provide a minimum of two years of baseline environmental data, collected at appropriate frequency and scale, to support any application under either Part 3A of the *Environmental Planning and Assessment Act 1979* or for approval of a Subsidence Management Plan.

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1 Introduction

1.1 CONTEXT

On 6 December 2006, the NSW Government established an independent Inquiry into underground coal mining in the Southern Coalfield and appointed an Independent Expert Panel to conduct the Inquiry. The Inquiry was established by the Minister for Planning, the Hon Frank Sartor MP, and the Minister for Primary Industries, the Hon Ian Macdonald MLC.

The Inquiry was established because of concerns held by the Government over both past and potential future impacts of mining-induced ground movements on significant natural features in the Southern Coalfield. These concerns first surfaced in the community in 1994 when the bed of the Cataract River suffered cracking and other impacts caused by mine-related subsidence from the underlying Tower Colliery.[1] Sections of the local and broader community have continued to express concerns at further subsidence-related impacts associated with this and other coal mines in the Southern Coalfield.

From 2010 all proposed extensions to underground coal mining operations will require approval under Part 3A of the *Environmental Planning and Assessment Act 1979*. Given the community concerns and the changes in the planning system, the Government announced the inquiry to provide a sound technical foundation for assessment under Part 3A (and other regulatory and approval processes) and long term management of underground mining in the Southern Coalfield by both the Department of Planning (DoP) and the Department of Primary Industries (DPI) and other key agencies (such as the Department of Environment and Climate Change (DECC), the Sydney Catchment Authority (SCA) and the Department of Water and Energy (DWE)).

1.2 TERMS OF REFERENCE

The Terms of Reference for the Inquiry were to:

1. *Undertake a strategic review of the impacts of underground mining in the Southern Coalfield on significant natural features (ie rivers and significant streams, swamps and cliff lines), with particular emphasis on risks to water flows, water quality and aquatic ecosystems; and*
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   a) assessment of subsidence impacts;
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   c) management, monitoring and remediation of subsidence and subsidence-related impacts; and
3. *Report on the social and economic significance to the region and the State of the coal resources in the Southern Coalfield.*

The terms of reference required the Panel to focus its examination on the subsidence-related impacts of underground mining on ‘significant natural features’. These features were defined as ‘rivers and significant streams, swamps and cliff lines.’ Other natural features, for example plains, plateaus and general landforms, and any impacts of subsidence on infrastructure, buildings or other structures were not within the Panel’s terms of reference. Similarly, impacts associated with constructing and operating surface facilities were considered beyond the scope of the inquiry. However, it was considered that certain values contributed to the significance of some natural features. These include values in respect of Aboriginal heritage, non-Aboriginal heritage, conservation, scenery, recreation and similar values.

In considering impacts on rivers, significant streams and swamps, the Panel was asked to place particular emphasis on ‘risks to water flows, water quality and aquatic ecosystems’. The reference to water flows and water quality was considered to relate not only to ecosystem functioning but also to reflect the water catchment values of large sections of the Southern Coalfield, which contains a

[1] Tower Colliery is now known as ‘Appin West Coal Mine’. Appin West also includes the Douglas mining area.

number of water supply catchments, dams and other water supply assets. The reference within the terms of reference to 'aquatic ecosystems' was considered by the Panel to also include groundwater dependent ecosystems.

The Panel does not consider that its terms of reference extended to advising on the 'acceptability' of particular subsidence impacts. The Panel was not given this role. The role of determining the acceptability of environmental impacts rests with the Government and its agencies, as informed and influenced by the mining industry and other key stakeholders and the general community. The acceptability of predicted impacts is assessed and considered through various Government approval processes, in particular approval processes under the *Environmental Planning and Assessment Act 1979* and the *Mining Act 1992*. Similarly, the terms of reference did not ask the Panel to scale or measure the value or significance of individual examples of the listed significant natural features.

The Panel has focused its inquiry on those parts of the Southern Coalfield which are subject to historic, current and prospective underground coal mining. This is principally the Illawarra Region extending westward to the townships of Tahmoor and Bargo.

1.3 PANEL COMPOSITION

The Panel comprised the following members:

- Professor Bruce Hebblewhite (Chair, subsidence expert);
- Emeritus Professor Jim Galvin (subsidence expert);
- Mr Colin Mackie (groundwater expert);
- Associate Professor Ron West (aquatic ecologist); and
- Mr Drew Collins (economist).

Professor Bruce Hebblewhite is the Head of the School of Mining Engineering at the University of New South Wales and Executive Director of Mining Education Australia.

Professor Jim Galvin is the Managing Director of Galvin and Associates and Emeritus Professor of Mining Engineering at the University of New South Wales.

Mr Colin Mackie is the Principal of Mackie Environmental Research and has experience in undertaking groundwater assessments for major projects, including open cut and underground coal mining projects.

Associate Professor Ron West is part of the School of Biological Sciences at the University of Wollongong and the Chair of the NSW Fisheries Scientific Committee.

Mr Drew Collins is Managing Director of the BDA Group and was previously employed for many years by the NSW Environment Protection Authority.

1.4 PANEL PROCESS

1.4.1 Preliminary Briefings

Following its appointment, the Panel sought a number of briefing sessions from relevant Government agencies (including DPI, DECC, SCA and DWE), industry groups (including the NSW Minerals Council and mining companies active in the Southern Coalfield) as well as community organisations actively expressing concern at subsidence-related impacts in the area.

These briefings provided the Panel with an understanding of the NSW regulatory environment as it relates to underground coal mining, the various mining operations currently underway in the Southern Coalfield, a broad understanding of their impacts and current impact mitigation strategies, and the issues of concern to the community.

1.4.2 Call for Submissions

The Panel, through the Department of Planning, advertised its terms of reference and asked for written submissions from the wider community as well as offering the opportunity for presentations to be made before the Panel at public hearings. The advertisements appeared in the following newspapers:

- Sydney Morning Herald (1 June 2007);
- Illawarra Mercury (1 June 2007); and
- Wollondilly Advertiser (3 June 2007)

In addition, the Inquiry was advertised on the Department of Planning's website.

The advertisements sought submissions from the community, the industry and agencies and other interested parties by 30 July 2007. The Panel received 53 submissions by this date. A further 3 submissions were received after that date which, for their relevance to the Inquiry, were accepted by the Panel.

Of the submissions received, 6 were from Government agencies and statutory bodies, 26 were from interest groups (including community and other interest groups and local Government authorities), 7 were from industry bodies (including mining companies) and 17 were from individual community members. Submissions received are summarised in Table 1.

1.4.3 Public Hearings

The Panel held public hearings in Camden from 18 – 21 September 2007. At the hearings 28 persons made oral presentations. Of these presentations, 2 were made on behalf of Government agencies (DECC and SCA), 14 were made on behalf of community groups, interest groups and local Government authorities, 4 were made on behalf of industry bodies and 8 were made by individual community members.

Following the public hearings, all submissions were placed on the Department of Planning's website to give all submitters the opportunity to make a supplementary submission based on their review of other parties' submissions together with the information provided by way of presentation at the hearings. The Panel received 13 supplementary submissions through this process.

Table 1. Submissions Received by the Panel

	Government agencies and statutory bodies	Community and interest groups and local government authorities	Mining companies and mining industry groups	Individual community members
Primary submissions	6	26	7	17
Oral presentations	2	14	4	8
Supplementary submissions	2	4	4	3

1.4.4 Field Inspections

The Panel undertook field trips to various locations affected by mining-related subsidence in the Southern Coalfield. The purpose of the field trips was to gain an understanding of the significant natural features of the area and the previous, recent and potential impacts of longwall mining on those natural features. The locations which the Panel visited are shown in Table 2.

Table 2. Locations Inspected by the Panel

Location	Relevant Coal Mine	Features Inspected	Date

Waratah Rivulet	Metropolitan Colliery	4th order stream impacted by mine subsidence – stream bed cracking, drainage of pools, ferruginous springs and iron bacterial matting	14 August
Flatrock Swamp	Metropolitan Colliery	Drained and eroded valley infill swamp	14 August
Maddens Plains	South Clifton Colliery (closed)	Headwater swamps (not impacted)	14 August
Upper Cataract River Gorge	Tower Colliery (now Appin West)	River bed cracking, terrestrial vegetation dieback, cliff falls	30 August
Nepean River	Tower Colliery (now Appin West)	Regulated river subject to previous gas releases and some cliff falls	30 August
Drillhole Swamp	Elouera Colliery	Drained and eroded headwater swamp	17 September
Swamp 18	Elouera Colliery	Drained and eroded valley infill swamp	17 September
Lower Cataract River Gorge	Tower Colliery (now Appin West)	River bed cracking, other stream impacts, 'natural remediation'	19 September
Georges River near Appin - Marnhyes Hole and Jutts Crossing	West Cliff Colliery	Artificial remediation of stream bed cracking	19 September
Bargo River, south of Tahmoor	Tahmoor Colliery	River bed cracking, 'natural remediation'	20 September
Ousedale Creek	Tower Colliery (now Appin West)	Aboriginal site	20 September
Simpsons Creek	Tower Colliery (now Appin West)	Aboriginal site, stream bed cracking and pool drainage	20 September
Bargo River - Mermaids Pool and Bargo River Gorge	Tahmoor Colliery	River gorge and cliffs potentially subject to future impacts	4 October

1.5 PANEL REPORT

The Panel notes that many significant features of the landscape and their associated values are inter-related. Some swamps are found within stream environments (valley infill swamps) while upland swamps discharge into streams which in turn feed the rivers. Many of the significant cliff lines of the Southern Coalfield are located in river gorges.

In order to consider these various natural features, their interrelationships and the impacts on them of mining related subsidence, the Panel has adopted a structured approach by first characterising the significant natural features of the Southern Coalfield and their context. This context is advanced in Section 2 of the report (a description of the natural environment, human use, coal resources and coal mining operations) and Section 3 (socio-economic significance of coal mining).

The effects of subsidence and the impacts on natural features arising thereby are central to the Inquiry and are discussed in Section 4. It is important to note that, throughout section 4 and beyond, the Panel has drawn a distinction between *subsidence effects*, *subsidence impacts* and the environmental *consequences* of those impacts.

The Panel has used the term *subsidence effects* to describe subsidence itself – ie deformation of the ground mass caused by mining, including all mining-induced ground movements such as vertical and horizontal displacements and curvature as measured by tilts and strains.

The term *subsidence impacts* is then used to describe the physical changes to the ground and its surface caused by these subsidence effects. These impacts are principally tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence but also include subsidence depressions or troughs.

The environmental *consequences* of these impacts include loss of surface flows to the subsurface, loss of standing pools, adverse water quality impacts, development of iron bacterial mats, cliff falls and rock falls, damage to Aboriginal heritage sites, impacts on aquatic ecology, ponding, etc.

Best practice management of subsidence assessment, monitoring and reporting, and mitigation and remediation is also considered in Section 4.

The Panel has sought to develop a means of appropriately predicting subsidence effects and impacts, and appropriately assessing and managing their consequences via a risk-based mechanism that can be included in regulatory processes. Section 5 therefore provides a summary of current regulatory processes and an analysis of risk-based decision making with particular emphasis on a reverse onus of proof with respect to subsidence effects and impacts.

Sections 6 and 7 provide summaries of the Panel's conclusions and recommendations, respectively.

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2 Background

2.1 SIGNIFICANT NATURAL FEATURES

The Southern Coalfield exists beneath a topographic environment defined largely by the Woronora and Illawarra Plateaus as shown on Map 1. These flat-lying plateaus slope gently to the west, away from the Illawarra Escarpment. Geologically they are comprised of Wianamatta Group sediments (the Bringelly Shale) overlying Hawkesbury Sandstone which in turn overlies deeper strata associated with the Narrabeen Group of rocks. These Triassic to Permian age geological units host a distinctive hydrologic system with narrow, deeply incised valleys, steep cliffs, swamps and watercourses sculptured over geologic time.

2.1.1 Valley Forms and Cliff Lines

The essential landscape feature which has determined the valley forms and cliff lines is the Hawkesbury Sandstone, which is highly resistant to weathering. This has meant that weathering and erosion caused by moving water has been concentrated along the networks of faults and joints which occur naturally in this rock as the result of stresses imposed during geologic time.

Erosion along this system of faults and joints (predominantly oriented northwest-southeast and northeast-southwest) has led to the development of a system of deeply incised river gorges which drain the plateaus. The river valleys, particularly the downstream sections as they approach the Hawkesbury River Valley, are often narrow with steep sides and stream beds largely composed of the sandstone bed rock, with rock bars and boulder-strewn channels. These steep-sided valleys, particularly the downstream sections, may take the form of a gorge, with imposing sandstone cliffs on one or both sides of the river.

A notable example is the Bargo River Gorge, located between Pheasants Nest and Tahmoor. Here the Bargo River flows through a winding 4.5 km long gorge which contains fifteen to twenty rock pools, including the well-known Mermaid Pool. The landscape around the pools is diverse and spectacular. In many places, near vertical sandstone walls, 20 m to 105 m high, rise from the river, including directly from river pools and cascades. Other river gorges in the Southern Coalfield include the Cataract River Gorge and the Nepean River Gorge. The cliff faces within these gorges may vary between 10 and 50 m in height.

Further upstream in most catchments, the rivers are less incised and their valleys are broader and more open in form. Nonetheless, the sandstone bedrock remains the key geomorphological determinant. Stream beds are still generally composed of exposed sandstone bedrock, with rock bars and channels strewn with smaller boulders and cobbles. The sandstone bedrock becomes a drainage surface (either at the base of swampy vegetation draping the landscape or below the regolith) which sheds groundwater towards the streams. The groundwater provides base flow for the streams and supports the generally perennial character of the larger streams and rivers.

At its eastern extent, the Hawkesbury Sandstone forms the steep and imposing cliffs of the Illawarra Escarpment, which tower over Wollongong and the settled coastal plains of the Illawarra. However the Panel notes that the Illawarra Escarpment has not been a particular focus because most active mines are set well back from its cliffs. The closest mining in recent times was in Area 1 of the Dendrobium Mine. The two longwalls in this small longwall domain were set back a minimum of 1 km from the Escarpment to avoid the potential for cliff falls. Mining of this small domain has now been completed.

The cliff lines which have been of most focus to the Panel are those directly associated with the river gorges but there are other cliff lines which are associated with steep topography around the river valleys, for example in Area 2 of the Dendrobium Coal Mine. The extent of cliffs in the Southern Coalfield is not accurately known. At least one agency GIS data set exists, and has been considered by the Panel. However, this data set appears to be incomplete, and for this reason no map of cliff lines in the Southern Coalfield has been included with the report.

2.1.2 Watercourses

While it is straight forward that all named rivers within the Southern Coalfield come within the Panel's Terms of Reference, careful consideration has been given to which smaller watercourses should be considered as 'significant streams'. The Panel accepts that the significance of a stream is not simply a measure of particular characteristics like whether it is perennial or ephemeral or whether it is regulated or not. Significance can reflect a wide variety of natural values or human uses. Consequently, there is no universally-agreed definition of stream significance, and this must be seen (to some degree) as being 'in the eye of the beholder'. Nonetheless, it seems clear that the significance of a stream is in some way connected to its size. For example, this is the case in respect of its hydrological significance and its contribution to the water supply catchments managed by the Sydney Catchment Authority (SCA).

The way in which stream size or scale is most commonly measured is the internationally recognised Strahler system of stream order classification which identifies a catchment's tributary hierarchy.[2] Most submissions to the Panel which considered watercourses referred to streams which are third order or higher under this system. All such rivers and streams within the Southern Coalfield are shown on Maps 1, 3 and 7 while Table 3 lists examples. The Nepean River is the topographically lowest and the largest of the rivers.

Table 3. Examples of Third and Higher Order Streams Potentially Impacted by Mining in the Southern Coalfield

Strahler Stream Order	Stream Examples Within the Southern Coalfield
3	Wongawilli Creek, Waratah Rivulet (above Flat Rock Creek), Brennans Creek, Elladale Creek, Simpsons Creek, Flying Fox Creek (Nos 1,2 and 3), Kembla Creek, Sandy Creek, Native Dog Creek, Rocky Ponds Creek, Ousedale Creek, Foot Onslow Creek, Mallaty Creek, Harris Creek, Navigation Creek
4	Georges River, Cordeaux River (above Kembla Creek), Waratah Rivulet, Stokes Creek
5	Bargo River, Avon River, Cataract River (above Lizard Creek), Cordeaux River (below Kembla Creek)
6	Cataract River (below Lizard Creek), Cordeaux River (below Avon River)
7	Nepean River

A large part of the drainage system is contained within the SCA Special Areas which include Woronora, O'Hares Creek and Metropolitan areas shown on Map 5. Water storages within these areas provide supply to the Illawarra region with a capacity to augment Sydney water supply via the Upper Canal system.

Flows in all drainages are sustained by rainfall runoff and by base flow sourced from groundwater. During a streamflow event, rainfall initially provides the greater part of the flow as direct runoff which first rises, peaks and then declines. This is commonly known as quick flow. The rainfall also recharges both the surficial and deeper groundwater aquifers contained within the rock strata. Consequently, groundwater seepage contributions to streams also rise and fall during a flow event but this contribution, known as base flow, typically lags the quick flow contribution. In the Southern Coalfield, base flow is attributed in part to seepage from the sandstones and in part to contributions from the numerous upland swamps.

[2] Strahler's 1964 stream order system is a simple method of classifying stream segments based on the number of tributaries upstream. A stream with no tributaries (ie a headwater stream) is considered a 'first order stream'. A segment downstream of the confluence of two first order streams is a 'second order stream'. When two second order streams join, they form a 'third order stream', and when two third order streams meet, they form a 'fourth order stream'. Streams of lower order joining a higher order stream do not change the order of the higher stream. Thus, if a first-order stream joins a second-order stream, it remains a second-order stream. In this report, stream order is defined by those watercourses represented on the State 1:25,000 topographic map series.

The water quality or salinity of stream runoff (both quick flow and base flow) is influenced by a number of factors including the organic and inorganic fabrics within swamps, groundwater-rock interactions in shallow and deep aquifers, and by anthropogenic inputs. Anthropogenic inputs to water quality in the SCA special areas are negligible, but increase downstream beyond the special areas.

Base flow is the main source of salts in stream flow. Runoff with a weak base flow component yields a very high quality water which is typically low in total dissolved salts (TDS commonly less than 100 mg/l) and weakly acidic (pH range of 5 to 7). Increasing contributions from base flow during dry and drought periods are reflected in a higher TDS, possibly as high as 250 mg/l, and a pH range from 4 to 8. This variability is normal and consistent with a quasi-stable catchment system where water-rock interactions have been occurring over geologic time and minerals have been progressively leached away The Panel notes, however, that unstable conditions can sometimes occur at a local scale through, for example, rapid changes in swamp geomorphology or through natural movements in the sandstone bedrock. The latter is especially noticeable when certain iron rich minerals facilitate 'iron springs' at discrete fractures or along strata bedding planes.

2.1.3 Swamps

The swamps of the Woronora Plateau have been studied in some detail. Pioneering work was done in the 1980s by Dr Ann Young (Young 1982, 1986a, 1986b). Other work has been undertaken by DECC, Illawarra Coal (through its consultants Biosis and Ecoengineers) and by Macquarie University as part of a collaborative research effort with SCA. Localised studies have also been conducted by the SCA as part of impact assessments in respect of development of the Kangaloon aquifer, and by other mining companies, including Helensburgh Coal.

The swamps are identified by their distinct wetland vegetation composition (primarily sedges and heaths) compared with the surrounding dry sclerophyll forest which occurs on the better drained ridge tops and hill slopes. They are mostly hosted on Hawkesbury Sandstone and can be broadly classified as either headwater or valley infill swamps (Tomkins and Humphreys 2006). Mapped swamps of both types are indicated on Maps 4 and 6 and Figure 1.

Headwater swamps are the significant majority of the upland swamps and are generally situated in areas near catchment divides where plateau incision is weak and topographic grades are shallow. These upland swamps can be quite extensive and 'drape' over the undulating Woronora Plateau (see Figure 2). They can fill shallow valley floors and extend up the valley sides and drainage lines to straddle catchment divides in areas of shallow, impervious substrate formed by either the bedrock sandstone or clay horizons (Young 1986a). DECC has recognised four large clusters of headwater swamps on the plateau areas, which it considers have particular significance in providing large contiguous areas of related habitat. It has described these swamp clusters as Maddens Plains (O'Hares and Cataract catchments), Wallandoola Creek (Cataract catchment), North Pole (southern Avon catchment) and Stockyard (southern Avon catchment). The swamp clusters were identified following a vegetation survey of the catchments of Nepean, Avon, Cordeaux, Cataract and Woronora Rivers and O'Hares Creek by the NPWS and SCA during 2003 (NPWS 2003). A total of 6,444 ha of upland swamp was mapped by this project within the 105,039 ha of its study area (see Table 4).

The other form of swamp is much less commonly developed. These 'valley infill' swamps form as isolated pockets blanketing the floor of incised second or third stream valleys and therefore tend to be elongate downstream (Tomkins and Humphreys 2006). They are believed to be initiated by rapid transportation of sediment material downstream and equally rapid deposition possibly as a result of channel profile-restriction (eg by log jams). Once initiated, the swamps are probably self-reinforcing, trapping more sediment, raising the water table and fostering the growth of organics and formation of peat (Tomkins and Humphreys 2006). Examples include Flatrock Swamp, on Waratah Rivulet above Metropolitan Colliery, Swamps 18 and 19 on Native Dog Creek above Elouera Colliery and Martins Swamp above the closed Nebo Colliery (see Figure 3).

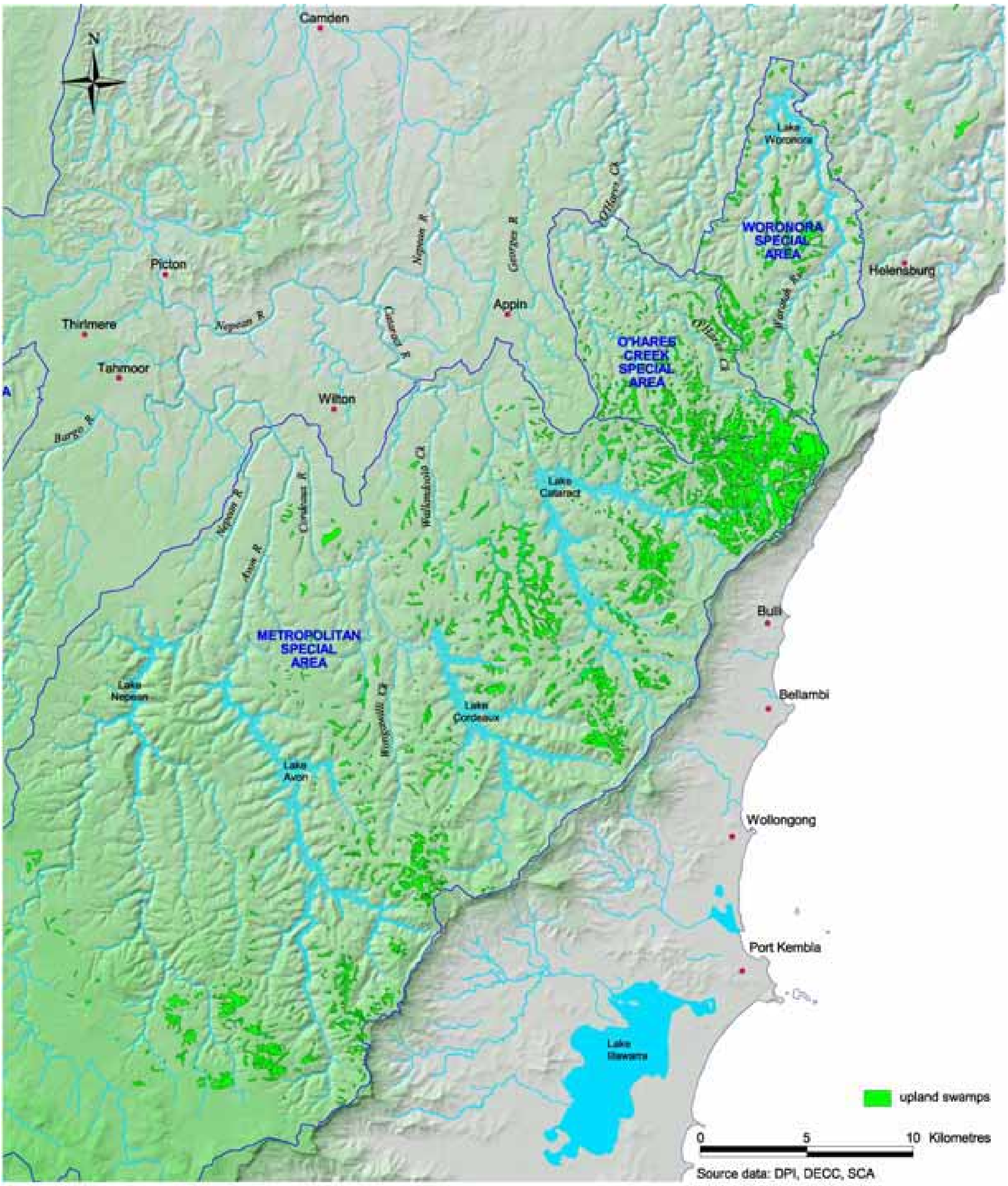

Figure 1: Mapped Upland Swamps in the Southern Coalfield

Source: DECC

The swamps are exceptionally species rich with up to 70 plant species in 15 m^2, in one reported instance (Keith and Myerscough 1993) and were considered by the NSW Scientific Committee to be habitats of particular conservation significance for their biota (NSW Scientific Committee 2005a). Many swamps are characterised by ti-tree thicket, cyperoid heath, sedgeland, restioid heath and *Banksia* thicket (see Table 4) with the primary floristic variation being related to soil moisture and fertility (Young 1986a, Keith and Myerscough 1993). Similar swamp systems can be found in the upper Blue Mountains including the Blue Mountains Sedge Swamps, Newnes Plateau Shrub Swamps and Coxs River Swamps (Keith and Myerscough 1993, NSW Scientific Committee 2005a, NSW Scientific Committee 2005b). The swamps provide habitat for a range of fauna including birds, reptiles and frogs. Reliance of fauna on the swamps also increases during low rainfall periods.

Figure 2: Upland Swamp at Maddens Plains, above the Closed South Clifton Colliery

The controls on upland swamp initiation and development are commonly cited as regional climate, gentle topography, low slope and low stream power (eg Young 1986a, in Tomkins and Humphreys 2006). A number of swamps have been subjected to radiocarbon dating (see Table 8 in Tomkins and Humphreys 2006). The basal dates vary between roughly 2,000 – 17,000 years suggesting their initiation and development during the Late Pleistocene and throughout the Holocene.

The importance of swamps as significant water stores is evident from Map 6 and Figure 2 which illustrate their regional extent. Contained surface water and groundwater storage from the larger swamps contributes to base flow in respective catchments but contributions from some of the smaller swamps may be limited and seasonally variable. Direct connectivity between swamps and underlying groundwater systems appears to depend on location. Monitoring of swamps in the Kangaloon area by SCA suggests the water table in the swamps is perched; the water table in the underlying sandstone is situated some 4 to 5 m below the swamp(s).

In contrast, contained groundwater within the valley infill swamps has a higher likelihood of direct connection to surrounding groundwater in rock strata as a result of the incised host topography. For example monitoring of Swamp 18 (Elouera Colliery) by Illawarra Coal included installation of a number of piezometers both within the swamp and beyond the swamp in hardrock ridge line areas. Groundwater levels measured in these piezometers support potential exchange of groundwaters between the swamp and the hardrock – levels beyond the swamp were found to be generally higher than levels within the swamp at the downstream end.

Table 4. Upland Swamp Vegetation Communities in the Metropolitan, Woronora and O'Hares Creek Special Areas

Map Unit No	Upland Swamp Vegetation Community	Area (ha)
MU42	Banksia Thicket	1120
MU43	Ti-Tree Thicket	170.5
MU44	Sedgeland-Heath Complex (Sedgeland, Restioid Heath and Cyperoid Heath)	3448.6
MU45	Fringing Eucalypt Woodland	1580
MU46	Mallee Heath	124.5
Total	Upland Swamps	**6443.6**

Source: NPWS 2003

The Panel notes that the hydrologic properties of the Southern Coalfield swamps are poorly studied, with measurements being restricted to water table monitoring at a few locations. Intuitively, it is likely that the swamps exhibit high porosity but moderate to low permeability. These characteristics, coupled with a shallow topographic grade would result in relatively slow gravity drainage under natural conditions. There has also been limited study of groundwater quality associated with the swamps. However, as a general rule, the water quality of swamps would be reflected in the water quality of the drainages immediately downstream. Where measured, these water qualities generally exhibit very low dissolved salts.

The Panel is unaware of research which suggests that the two types of swamp may overlap or interrelate. However, this is not unlikely. Situations are likely to exist where valley infill swamps are adjacent to, or else set within, a broader expanse of headwater swamps.

Figure 3: Martins Swamp, Headwaters of the Cordeaux Catchment, above the closed Nebo Colliery

Source: Tomkins and Humphreys 2006

2.1.4 Groundwater

The Panel considers groundwater to be a significant natural feature as a result of the various interactions with other natural features.

Within the Southern Coalfield there are essentially two types of groundwater systems that are often referred to as aquifers. These are:

- ***shallow unconsolidated sediments***, comprising soils and the underlying weathered bedrock (collectively, the 'regolith'), the swamp lands, and the alluvial deposits associated with the stream channels. These are commonly regarded as unconfined aquifers since they interact with rainfall recharge and retain a water table at atmospheric pressure;
- ***consolidated rocks***, including porous matrix and fractured rocks. These are regarded as unconfined aquifers if their depth is sufficiently small that a water table occurs, or confined aquifers if the groundwater is stored under pressures greater than atmospheric. Aquifers within the Hawkesbury Sandstone may be unconfined near the surface but confined at depth, depending upon the permeability of specific strata or layers within the sandstone. Siltstones and claystones are considered to be aquitards and aquicludes rather than aquifers, due to their inherently low permeability. They typically impede groundwater exchange between adjacent strata. The Bald Hill Claystone, which separates the Hawkesbury Sandstone from the deeper Bulgo Sandstone, is an example of an aquitard (see Figure 4).

The contrast in matrix permeabilities between shallow unconsolidated aquifer systems (moderate to high permeability) and deeper consolidated rocks like the Hawkesbury Sandstone (low permeability) means that rates of groundwater flow through the pore matrix of surficial unconsolidated sediments are many orders of magnitude higher than rates of flow through consolidated rocks. As a result, contributions to stream base flows from shallow unconsolidated sediments (contained within the swamps and the regolith), are generally much larger than contributions from deeper, unweathered consolidated rock. Consequently the groundwater emanating from unconsolidated deposits is very young while groundwater emanating from the deeper hardrocks is likely to be very old. SCA has determined the age of groundwaters in parts of the Hawkesbury Sandstone to be in the range 5,000 to 10,000 years old.

The aquifer systems have been recharged by rainfall and runoff over geologic time. While long term regional monitoring of aquifer systems in the Southern Coalfield is sparse, the water table in the shallower systems is expected to respond to climatic variability more rapidly than the deeper systems. Indeed, monitoring of deeper systems when compared to shallow systems could exhibit decadal lag times in response to sustained drought conditions.

Thus, at a regional scale, a natural hydrophysical system has evolved whereby:

- rainfall provides runoff to the regional drainage system and recharge to any unconsolidated materials within that system, and to underlying consolidated sandstone strata;
- the retention of recharge in the groundwater system is governed by the prevailing permeability and porosity of materials and other factors including natural evaporation and evapotranspiration;
- runoff is impeded in upland areas where swamps are prevalent, or in areas where a soil or regolith profile is well developed and rainwater can infiltrate and surcharge groundwater. These areas act as water stores and provide a base flow component to stream flow runoff. They also support groundwater dependent ecosystems (GDE);
- runoff is rapid in the remaining areas where outcrop occurs or where the regolith is thin. These areas are unlikely to accommodate substantive groundwater recharge or to contribute significantly to stream base flow unless substantial secondary permeability and porosity is developed in fractures.

Hawkesbury Sandstone			Up to 120
Narrabeen Group		Newport Formation	10
		Garie Formation	3
		Bald Hill Claystone	12
		Bulgo Sandstone	95
		Stanwell Park Claystone	20
		Scarborough Sandstone	30
		Wombarra Shale	25
		Coalcliff Sandstone	15
Illawarra Coal Measures		BULLI COAL	1.5
	Eckersley Formation	Unnamed Member	10
	Eckersley Formation	Balgownie Coal Member	1
	Eckersley Formation	Lawrence Sandstone Member	9
	Eckersley Formation	Cape Horn Coal Member	0.3
	Eckersley Formation	Unnamed Member	1
	Eckersley Formation	Hargrave Coal Member	0.1
	Eckersley Formation	Unnamed Member	3
		WONGAWILLI COAL	9.4
		KEMBLA SANDSTONE	14
	Allan's Creek Formation	American Creek Coal Member	3
	Allan's Creek Formation	Unnamed Member	27
		APPIN FORMATION	
		TONGARRA COAL Upper Split	2
		TONGARRA COAL Lower Split	0.5
	Wilton Formation	Unnamed Member	15
	Wilton Formation	Woonona Coal Member	4
	Wilton Formation	Unnamed Members	26
		ERINS VALE FORMATION	
		PHEASANTS NEST FORMATION	
		Figtree Coal Member	0.5
		Unnamed Member	20
		Unanderra Coal Member	2
		Unnamed Member	>84

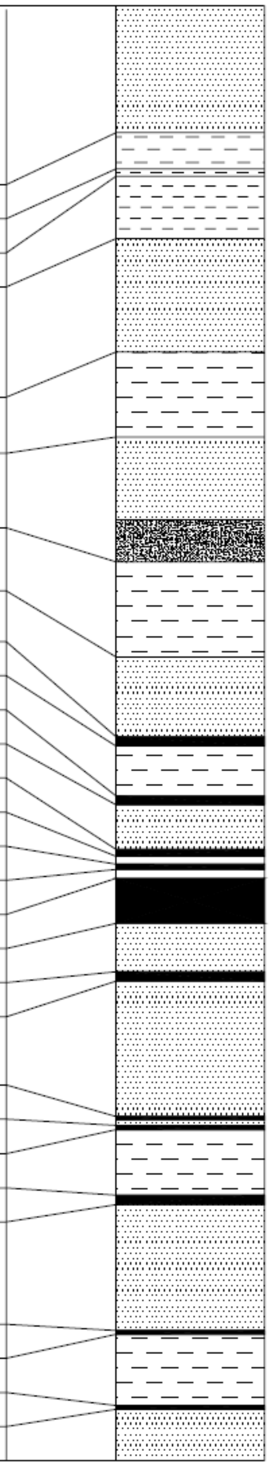

Figure 4: Stratigraphic Column for the Southern Coalfield

Source: MSEC, after Williams 1979.

The groundwater quality within the natural system varies from place to place but typically exhibits low ionic concentrations in shallow strata (<1000 mg/L as stream baseflow and a pH range from 4 to 8) depending upon the local stratigraphy (eg SCA 2006, Ecoengineers 2007). The basic chemistry of the groundwater in undisturbed areas is the result of groundwater/rock interactions over geologic time and as noted previously, is likely to reflect a quasi steady state condition. That is, the chemistry of groundwaters is likely to exhibit stability within narrow and predictable ranges mostly attributable to recharge processes.

However, changes in groundwater flow paths, perhaps induced by natural stress relief within the sandstone aquifers, may invoke new localised water/rock interactions that lead to changes in groundwater chemistry (increased iron for example). Over time and through the weathering process, these upset conditions will stabilise and the groundwater chemistry could be expected to migrate towards a constituent profile reflective of conditions prior to upset.

Where the natural conditions are disturbed by agriculture, urbanisation, industrialisation or other large-scale factors, sustained changes in groundwater quality may become more evident. The existence of the SCA Special Areas and the high level of protection given to them are designed to minimise exposure to these impacts.

2.1.4.1 Regional Water Table Geometry

Recharge by rainfall results in a shallow water table that, while poorly mapped, probably mimics the general topography in a subdued way. The geometry of this surface is governed by the drainage system which acts regionally to relieve groundwater pressures and constrain elevations of the groundwater table to stream levels within the valleys and gorges. Away from the valleys, rainfall continues to recharge the system thereby creating an elevated water table and sustaining groundwater flows toward the creeks and rivers. The water table is, however, often complicated at a local scale either by perching due to reductions in strata permeability, or by accelerated flow along structural defects like joints or bedding shears that are contained within the rock mass.

Perching of the water table is expected in the upland swamps and the regolith during rainfall events as rainwater slowly infiltrates to depth. Perching also persists through subsequent dry periods although in drought periods some drying can be expected.

Accelerated groundwater flow occurs along underlying structural defects and is often evident as seepages and hanging swamps on the exposed rock faces in many of the steep-sided gorges in the coalfields (eg the Bargo and Cataract Gorges). These features occur when infiltrating groundwater reaches an impermeable layer and the piezometric head subsequently builds above the layer.

2.1.5 Flora and Fauna

The Southern Coalfield region, particularly the Illawarra and Woronora Plateaus, is predominantly covered by natural bushland, interspersed with wetlands and waterways, which has been protected from agricultural development by the generally infertile nature of the land. Since the early 1900s, it has been protected from urbanisation or other development by being substantially dedicated as water supply catchments (currently as ‘special areas’ under the *Sydney Water Catchment Management Act 1998*) for the Illawarra and Sydney Regions.

The Upper Nepean and Woronora catchments (ie the Metropolitan, Woronora and O’Hares Creek Special Areas) are regionally significant for flora and fauna due to the low level of vegetation disturbance. 48 separate vegetation communities were mapped in the three Special Areas by the NPWS and SCA in 2003 using aerial photo interpretation and field surveys. 87% of the 105,000 ha study area is native bushland and 83% displayed low levels of disturbance, with impacts largely confined to freehold agricultural land along the southern and western edge of the Special Areas (NPWS 2003). Extensive terrestrial fauna and flora surveys have been conducted within the Upper Nepean and Woronora catchments and the broader region (NPWS 2003, DECC 2005) and representative data from these surveys were provided to the Panel by DECC. A range of threatened species and ecological communities are known to occur in the region and as a consequence, the ‘alteration of habitat following subsidence due to longwall mining’ is listed as a ‘key threatening process’ in Schedule 3 of the *Threatened Species Conservation Act 1995* (NSW Scientific Committee 2005a).

Likewise, there is a wide variety of aquatic environments in the Southern Coalfield region, reflecting the diversity of watercourses. These watercourses include the thousands of small, often intermittent springs and gullies which, in turn, flow to more substantial creeks and streams across the upper catchments, and finally combine to form the large upland and lowland rivers (see above).

This vast network of surface watercourses is intrinsically, but not always directly, linked to the groundwater resources, and forms a complexity of inter-related aquatic habitats, some intermittent in nature, that are often difficult to quantify accurately.

Since 1974, fisheries researchers from the Department of Primary Industries (DPI - Fisheries) have conducted some 17 projects at over 300 sites within the Hawkesbury-Nepean Basin, a number of which were within the catchments of the Southern Coalfield. However, none of these data were specifically collected for the assessment of aquatic biodiversity in the region, and most relate to the lower catchment, outside the study area. The bulk of current information concerning the aquatic ecology of the region comes from consultant reports or impact investigations. These types of investigations are usually directed at local sites, which provide very little in terms of a regional overview of significance of the aquatic species, populations and communities.

Various submissions and consultant reports (eg from the NSW Minerals Council) were made available to the Panel which provided site-specific information on the occurrence of large aquatic plants, macroinvertebrates and fishes within particular watercourses across the Southern Coalfield region. From these and other data, it is known that at least one threatened fish species is present in the region, and that several other threatened aquatic species may be present. Further details of the flora and fauna of the area are included in Appendix C to this report.

2.2 CULTURAL HERITAGE

The Southern Coalfield region was originally occupied by people of the Dharawal (or Tharawal), and Gundungurra Aboriginal language groups. Their presence in the area is estimated by DECC to extend back at least 15,000 years. The Dharawal people's territory covered an area from Botany Bay to south to the Shoalhaven River and Jervis Bay and inland to Moss Vale and Camden (DEC, 2005). The Gundungurra lived inland of the Dharawal tribe. The Wadi Wadi (or Wodi Wodi) is a separate language group of the Dharawal people which lived on the coastlands of the Illawarra and Shoalhaven districts.

The Dharawal people moved throughout their territories subject to season and purpose. They had favoured travel routes running north-south (the Princes Highway route, Meryla Pass, Kangaroo River route) and east-west (Bulli Pass, Bong Bong route, Cordeaux River), but travelled widely across their country. People from other language groups, including Gundungurra and Wiradjuri, travelled from the inland to the coast to exchange foods, raw materials and artifacts (DEC, 2005).

The Panel has been advised by DECC that surveys of the northern section of the Woronora Plateau have revealed over 1,000 Aboriginal sites. No comparable surveys of the Avon, Cordeaux or Nepean catchments have been undertaken, but limited investigations indicate they also contain sites of cultural significance. The Woronora Plateau is estimated by DECC to potentially contain over 15,000 Aboriginal sites. Examples of rock paintings, engravings and stone arrangements are either unique to the Plateau region or indicate that the area had contact with tribes from both the Sydney and South Coast regions.

DECC reports that the Woronora Plateau contains perhaps the best intact record of Aboriginal habitation remaining in coastal NSW. Sites are particularly concentrated at the heads of creeks in areas of swamp development and the gullies below the swamps. Art sites on the plateau are known to be technically complex compared with those to the north of the Georges River.

The relationship of Aboriginal people with the region and their knowledge is recorded as stories, many of which survive today. Knowledge of country was also displayed as artworks in caves, shelters, rock engravings and stone arrangements (DEC, 2005).

The Dharawal Nature Reserve protects several Aboriginal sites, including well-preserved drawings, stencils, axe-grinding grooves and paintings. Three of these sites have been listed on the Register of the National Estate.

The Panel's role was only to examine the potential impacts of underground coal mining on those Aboriginal sites which are directly associated with rivers and significant streams, swamps and cliff lines. The Aboriginal sites which are most commonly associated with these features include rock shelters (which may contain artifacts, art work and/or potential archaeological deposits). Sandstone shelter sites are the most frequent type of site recorded in the Southern Coalfield (Sefton 1988). This is a reflection of the favourable geology and topography of the region, providing many shelters suitable for occupation and protected rock faces for the expression of engraved, and more commonly pigment art. Sandstone shelter sites occur in the steep sided valleys and gorges of the escarpment and plateau areas; they are shelters formed either by natural block fall, cavernous weathering or a combination of both. Axe grinding groove sites are also common, and are usually located on sandstone outcrops where there is a supply of water from potholes, seeps or streams to aid the sharpening of stone axes. In the upland parts of the Plateau, grinding grooves are considered likely to occur on water pans at ridge top level or on sandstone associated with swamps (Sefton 1994). Rock shelters are commonly found in the sides of cliffs, particularly where they are adjacent to streams or other permanent water sources, and the more so if significant food sources were to be found nearby.

On the western side of the Southern Coalfield, the Bargo River Gorge and nearby river areas have strong significance for the Dharawal people. Of archaeological interest are numerous charcoal drawings and a cave containing natural salt deposits, which were used for healing purposes. Of significance is the mythology surrounding the Bargo River Gorge, and in particular the Mermaids Pool site. The legend of the mermaid has been preserved and charcoal drawings illustrate the fishwoman's (mermaid's) revenge on men who harvested more fish than they needed.

The Panel received submissions from two Aboriginal groups, the Cubbitch Barta Native Title Claimants Aboriginal Corporation and the Northern Illawarra Aboriginal Collective (NIAC). The Cubbitch Barta ('people of the river') is a traditional owner group which is a family or clan of the Dharawal tribe. NIAC represents the Wadi Wadi, Wulungulu and Gundungurra traditional owner groups.

2.3 HUMAN USES

2.3.1 Water Supply Management

The single most important land use in the Southern Coalfield is as water catchment. Around four million people in Sydney, the Illawarra and the Southern Highlands rely on the catchments of the Warragamba, Upper Nepean, Shoalhaven and Woronora river systems to supply their drinking water.

Mining currently occurs mainly under the Cataract and Cordeaux Dam catchments (see Map 7), which form part of the Upper Nepean water supply system and are protected by the Metropolitan Special Area, and the Woronora Dam catchment. Until recently, mining has also taken place in the Avon Dam Catchment (by the Elouera, Huntley and Avondale Coal Mines), and mining is being reinstituted in this area by Gujarat NRE. There is currently no coal mining in the Warragamba catchment to the west, although significant underground coal mining has taken place there in the past (until the mid 1990s in the case of the Nattai Coal Mine). It is unlikely that mining will be reinitiated in the Warragamba Catchment in the foreseeable future. There is also no coal mining within the Shoalhaven catchment. Consequently, the catchments within which mining has recently occurred and continues to occur are the Upper Nepean and Woronora River systems.

The catchments which support the SCA water supply system extend over 16,000 km^2. The SCA owns 1,440 km^2 of land within the catchments and manages 21 dams and a range of water storages, weirs, pumping stations and 170 km of pipelines, tunnels and canals. The catchments are the source of the raw bulk water stored in the SCA dams, which is supplied to Sydney Water Corporation, Shoalhaven City Council and Wingecarribee Shire Council (see Figure 5).

These catchments, known as the 'outer catchments', contain a wide variety of land uses; which range across urban development, industry, intensive agriculture, grazing, rural residential, surface and underground mining, quarrying, State forests and various types of conservation reserve (eg national parks and State conservation areas).

The Upper Nepean River system is the largest sub-catchment, comprising the Upper Nepean River and most of its major tributaries - the Burke, Avon, Cordeaux and Cataract Rivers. The Bargo River, while also a tributary of the Nepean, is considered to be a separate, smaller sub-catchment (130 km^2). The Georges River, the Woronora River and the Hacking River are also smaller river systems with separate sub-catchments.

All these river systems are regulated to some degree. That is, they have their natural flows interrupted by major dams and/or small weirs. This is particularly the case with the Upper Nepean River sub-catchment, which contains the Cataract, Cordeaux, Avon and Nepean Dams. It also contains the Pheasants Nest, Maldon, Douglas Park and Menangle Weirs on the Upper Nepean, the Broughtons Pass Weir on the Cataract and Upper Cordeaux Dams No 1 and No 2 above Lake Cordeaux. The Woronora Dam is located on the Woronora River and also impounds parts of Waratah Rivulet. The Hacking River contains the Audley Weir. Brennans Creek Dam is located on Brennans Creek while the Bargo River contains the Bargo Reservoir and Picton Weir.

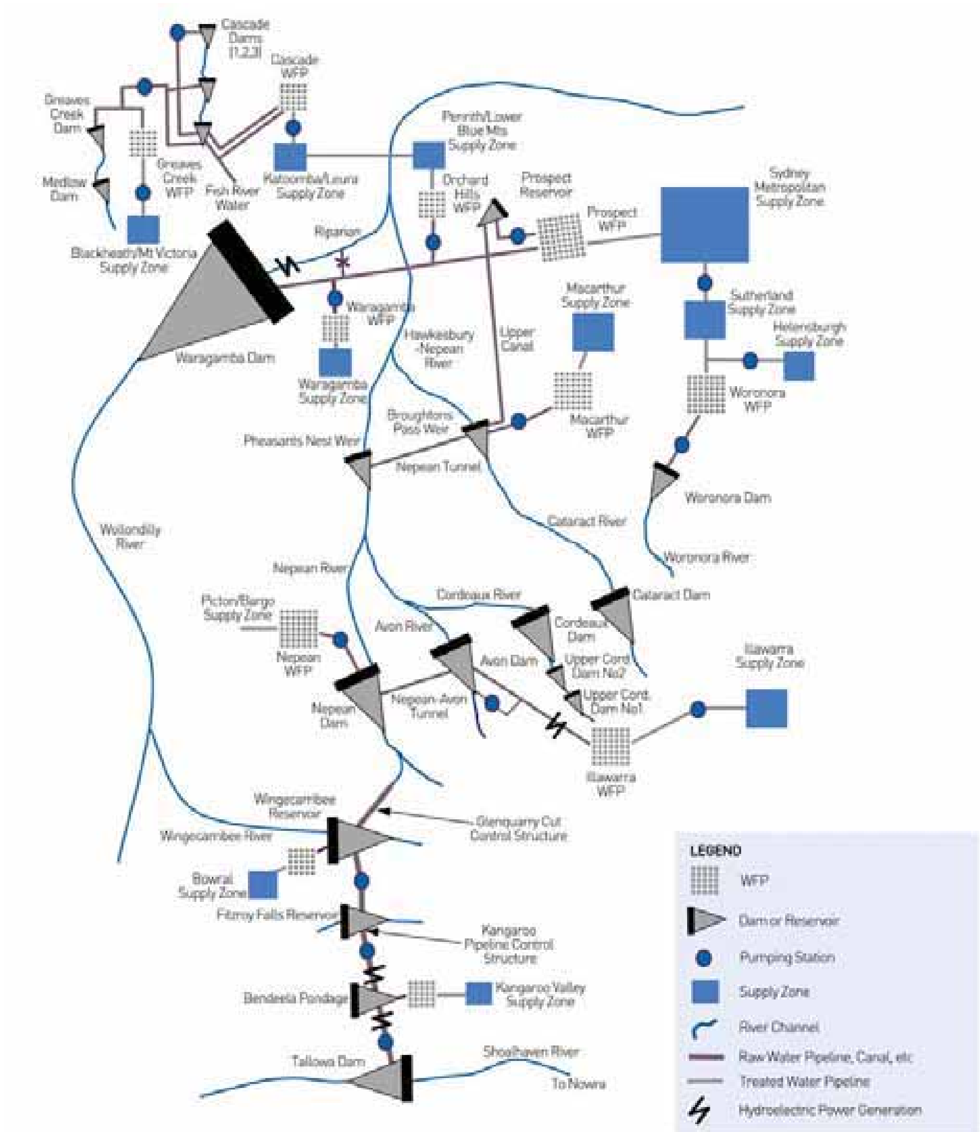

Figure 5: Schematic Representation of SCA's Water Supply System

Source: SCA

The impacts of regulation of rivers and streams are significant. Flood flows are held back for water storage, flow rates decrease dramatically over significant stream lengths, sediment loads are captured within stored waters, significant lengths of rivers and streams become flooded (even if only to a relatively shallow depth) and fish passage is interrupted. Regulation also changes the natural flow characteristics downstream of the water storages by either diverting volumes of water from the stream for human use or by extending the base flow regime as an environmental flow. These issues are further addressed in section 4.2.3.

2.3.1.1 SCA Special Areas

Areas surrounding SCA dams and storages are subject to additional management measures to especially protect the quality of water. These areas, known as Special Areas, are lands declared under the *Sydney Water Catchment Management Act 1998* (SWCM Act) for their value in protecting the quality of the raw water used to provide drinking water to greater Sydney and for their ecological integrity. The SCA manages around 3,700 km^2 of Special Areas (see Map 5).

SCA states that the Special Areas are a critical element in its multi-barrier approach to protecting drinking water quality. This approach includes managing the hydrological catchments, the storages, quality treatment and delivery of water to retail customers. The Special Areas essentially act as a filtration system for water entering water storages by reducing nutrients, sediments and other substances that can affect water quality. The ecological integrity of the Special Areas is therefore important in their role of protecting water quality.

The Special Areas within the area of the Southern Coalfield which are subject to current or prospective coal mining are (see Map 5):

- ***Metropolitan Special Area*** – which includes all land draining to Pheasants Nest Weir on the Nepean River or Broughtons Pass Weir on the Cataract River (a total of 89,000 ha). This Special Area includes the Cataract Dam (upstream of Broughtons Pass Weir) and the Cordeaux, Avon and Nepean Dams (upstream of Pheasants Nest Weir) which are all within the Upper Nepean catchment;
- ***Woronora Special Area*** – which applies to the catchment of Woronora Dam (7,600 ha) on the Woronora River; and
- ***O'Hares Creek Special Area*** – proclaimed many years ago when the then Government proposed to construct a dam on O'Hares Creek, which is part of the Georges River catchment. This plan was abandoned some years ago and the SCA is currently seeking amendments to legislation to remove the Special Area classification that applies to this area of 7,400 ha as it is not part of the water supply system.

2.3.2 Other Human Uses

There are a wide variety of other human uses within the Southern Coalfield. These are noted by the Panel partly for the sake of establishing the context within which underground mining takes place, and partly because the impacts of subsidence associated with underground coal mining must be compared with the impacts of other human uses in order to be fairly and properly considered.

2.3.2.1 Existing Residential and Rural Residential Use

There is substantial residential and rural residential development in sections of the Southern Coalfield. This includes the townships of Helensburgh, Tahmoor and Picton and the villages of Appin, Wilton, Thirlmere and Douglas Park, as well as the surrounding rural and rural residential areas (see Map 1). The district between Appin and Picton (which encompasses Douglas Park, located close to the Nepean River) is an established rural district that is becoming increasingly popular for rural residential living.

2.3.2.2 Proposed Urban Development

Urban development already exists along the northern margins of the Southern Coalfield around the districts of Camden South, Spring Farm, Menangle, Menangle Park and the suburbs which comprise the southern fringe of Campbelltown (Gilead, Glen Alpine, Rosemeadow and St Helens Park). There are also 6,000 housing lots approved for development in Spring Farm and Elderslie, south of Narellan. A new development is also proposed at Wilton (Wilton Parklands), which will include around 1,165 housing lots.

Under the Government's Metropolitan Strategy, further urban growth is proposed for the Southwest Growth Centre, although it will be concentrated in the area around Narellan, which is located midway between Camden and Campbelltown, and north of Narellan Road.

2.3.2.3 Grazing, Agriculture and Intensive Agricultural Industries

The areas around Appin, Wilton, Camden, Tahmoor and Douglas Park have been subject to development of the purposes of grazing and agricultural production since early in the history of European settlement. Much of the land is undulating, with relatively fertile soil derived from the Bringelly Shale. The dominant agricultural use has been cattle grazing and, until recently, dairy production. The Elizabeth Macarthur Agricultural Institute is located at Menangle.

There are also a number of intensive agricultural industries located in the region. These include a large Chicken Broiler Complex operated by Inghams Enterprises, located between Mallaty and Ousedale Creeks, and a disused piggery located close to the Nepean River west of Leafs Gully.

2.3.2.4 Wastewater Management

There are two major wastewater management systems located within the Southern Coalfield. These are the sewage treatment plants (STP) at Picton and West Camden. The Picton Regional Sewerage Scheme collects sewage from the urban areas of Tahmoor, Thirlmere and Picton and transports it by gravity to the Picton STP. The West Camden STP is currently being upgraded, and Menangle and Menangle Park are planned to be connected to it over the next few years. This work forms part of Stage 1 of Sydney Water's Priority Sewage Program (Sydney Water, 2008).

Stage 2 of the Priority Sewage Program includes providing sewage reticulation and treatment for the villages of Appin, Douglas Park, Wilton, Bargo, Yanderra, Couridjah and Buxton. As part of this work, Sydney Water is proposing to construct a small STP and recycled water facility north-west of Appin to service up to 2,000 residences, including existing dwellings in Appin and Douglas Park, and a new development in North Appin. Sydney Water is also proposing to build a small STP at Wilton, to service both the new Wilton Parklands development and existing dwellings. While planning and design work for Appin, Douglas Park and Wilton is proceeding, there appears to be no firm timetable for the construction of these two new STPs.

Because of the limited coverage of the two existing STPs in the area, large numbers of residences are serviced only by pump out septic tanks, or absorption pits. Pump out systems may be subject to leakages and/or overflows. Where these systems are used adjacent to rivers and streams, they can be a significant source of both nutrient and microbial pollution.

2.3.2.5 Conservation Reserves

Parts of the Southern Coalfield are within the system of parks and reserves managed by the National Parks and Wildlife Service (now part of DECC). Mining and exploration are not permitted in most types of conservation reserve. National parks and nature reserves in the Southern Coalfield are the Nattai National Park, Royal National Park, Heathcote National Park, Thirlmere Lakes National Park and Dharawal Nature Reserve.

However, mining and exploration are permitted to take place in one form of conservation reserve under strict oversight and conditions. There are seven such State conservation areas in the Southern Coalfield - the Dharawal State Conservation Area, Garrawarra State Conservation Area, Illawarra Escarpment State Conservation Area, Bargo State Conservation Area, Nattai State Conservation Area, Yerranderie State Conservation Area and the newly-created Bargo River State Conservation Area. The major conservation reserves close to existing and proposed mines are the Dharawal Nature Reserve, Dharawal State Conservation Area and the Illawarra Escarpment State Conservation Area.

2.3.2.6 Recreational Use

Recreational use of the natural areas of the Southern Coalfield is limited, largely because bushwalkers are excluded from SCA Special Areas. However, there is significant recreational swimming associated with a number of the rivers in the region. The Bargo River Gorge, particularly Mermaids Pool, is the most significant of these. Mermaids Pool is within a Crown reserve under the care and management of the NSW Scouting Association. The Scouts run a camp site within the reserve, and consequently this reserve and the adjacent Bargo River Gorge are probably used more intensively for recreation than any other site close to a coal mine within the region.

Others sites with significant recreational use include Marnhyes Hole on the Georges River at Appin and the Cataract River, near Douglas Park. Bushwalking along the more accessible creeks and rivers is also popular, with the Bargo River Gorge again being the most significant. The Nepean River is also used for swimming, fishing and canoeing.

2.4 COAL RESOURCES

2.4.1 Coal Resource Geology

The Southern Coalfield is part of the geological province known as the Sydney Basin which is exposed along the coast from the Batemans Bay area in the south, to Port Stephens in the north. To the west, it is bounded by a line running approximately from Batemans Bay through Jenolan to an area east of Mudgee. The Basin is about 350 km long and averages 100 km in width. It has a total onshore area of approximately 44,000 km^2.

The Sydney Basin sediments are primarily Permian and Triassic in age (180 – 280 million years). The late Permian sediments contain a large number of coal seams which are generally understood to underlie the entire Basin. However, because the sediment sequence dips towards the centre of the basin, the coal seams tend to outcrop or are otherwise located at mineable depths around the basin perimeter. In the north, the coal seams are mined within the Newcastle Coalfield. In the northwest, they form the Hunter Valley Coalfield, which in turn grades into the Gunnedah Coalfield further to the northwest. In the west, around Lithgow and Ulan, they form the Western Coalfield. In the south, from Campbelltown and Tahmoor to the Illawarra, south to Berrima and Sutton Forest and west to Warragamba Dam, they form the Southern Coalfield.

The sequence of rocks containing the coal seams in the Southern Coalfield is known as the Illawarra Coal Measures. The Coal Measures contain a total of nine coal seams (see Figure 4). Most collieries in the Southern Coalfield extract coal from the Bulli or Wongawilli Seams, with some extraction also occurring in the Balgownie Seam. Reflecting the shape of the basin, the coal seams generally deepen from south to north, with mining in collieries to the south extracting coal from around 100 m below the surface, while in the north, mining is more than 500 m below the surface. As the collieries progress further north and northwest, mining depths are likely to exceed 700 m.

2.4.2 Coal Types and Uses

The Southern Coalfield is renowned for its premium quality hard coking coals, which are mostly used for steel production. Illawarra hard coking coal is mined for use in coke making by the BlueScope Steelworks at Port Kembla and OneSteel's Steelworks at Whyalla in South Australia. It is also exported to steelmaking customers around the world. Prime hard coking coal occurs mainly in the Bulli Seam and is mined by at depths ranging from 180 - 550 m. Lesser quantities of similar quality coal are present in the Wongawilli Seam (currently mined only near to the coast, except at Berrima) and the Balgownie Seam (not currently mined to any extent).

The Southern Coalfield is the only source of hard coking coal in NSW. However, increasing tonnages of export quality thermal coals (ie steaming coal) are recovered during the washing of the coking coals. Small quantities of coal from the Wongawilli Seam in the southwestern part of the Coalfield (from Berrima Coal Mine) are also used in cement manufacture (due to high ash content) at the nearby Berrima Cement Works.

2.4.3 *Coal Seam Methane*

The coal seams in the Southern Coalfield contain large amounts of methane and other coal seam gases and are attractive targets for gas exploration. These coals have acceptable permeabilities, good lateral continuity, appropriate maturity and are gas-saturated. It is estimated by DPI that the amount of methane contained within the coal seams is several times greater than the current reserves for conventional natural gas. DPI has estimated that the overall Sydney basin may contain some 750 billion m^3 of coal seam methane (CSM), of which up to 20% may be recoverable. There are considerable commercial advantages offered by methane drained from coal seams as an energy resource. These advantages include a relatively low exploration and production cost, and convenient location close to major markets

CSM is currently being produced as a stand-alone project (not in association with an existing coal mine) in the northern parts of the Southern Coalfield. AGL and Sydney Gas, acting as the Camden Gas Project Joint Venture, own the Camden Gas Project. Stage 1 of this project was approved in 2002, and currently includes 22 production wells generating up to 4.5 petajoules (PJ) of gas per year to AGL. Stage 2 was approved in 2004, and now comprises around 110 production wells and a gas production plant (Rosalind Park Gas Plant) which supplies an additional 10 PJ of gas to AGL.

High concentrations of methane pose a significant safety problem for underground coal mines and are a limitation to high levels of productivity. Drainage of the gas is therefore required to make the coal workings safe. As a result, these mining operations may need to remove increased amounts of CSM in order to maintain safe working conditions and high productivity. In the early 1990s, Illawarra Coal, in partnership with Energy Developments Limited (EDL), developed a system to collect methane drained from the Appin and Appin West Coal Mines and to use it to produce electricity. At 96 MW total capacity, this is by far the largest installed capacity for CSM electricity generation in the State. It is sufficient to power approximately 65,000 homes and makes a significant contribution to the State’s power generating capacity while reducing the release of greenhouse gases into the atmosphere.

In September 2007, West Cliff Coal Mine commissioned its new $30 million WestVAMP facility whereby mine ventilation air (MVA), which contains very low percentages of methane, is passed through a combustion chamber and the resulting steam is used to produce electricity used in running the mine.

Apex Energy Pty Limited is also exploring for CSM in an area from Helensburgh to Dapto. Its primary targets are goaf gas from abandoned mine workings of the Bulli Coal Seam (including at Metropolitan Colliery) and also CSM in unworked seams (primarily the Balgownie and Wongawilli Coal Seams).

2.5 COAL MINING OPERATIONS

2.5.1 *Historic Mining*

Coal was first discovered at Coalcliff by George Bass and Matthew Flinders in 1797. Mining began in 1848 at the Albert Coal Mine at Mt Keira, but it was only in 1857 that the first commercial quantities of coal were produced from nearby Mt Keira at what later became known as Kemira Colliery. By 1870, three collieries were in operation. The Metropolitan Colliery at Helensburgh opened in 1888.

The establishment of BHP’s (now BHP Billiton) first iron and steel works at Newcastle north of Sydney in 1915 provided huge demand for large quantities of suitable coking coal. In order to feed this demand, the Wongawilli Colliery opened in 1916. The industry received additional impetus from the opening of the Port Kembla Steelworks in 1928 by Australian Iron and Steel Ltd (AIS). BHP began its Illawarra mining operations in 1935 with the purchase of the Wongawilli Colliery and since then it has owned and operated a total of nine mines in the region.

From the late 1930s coal mines became viable in the Burragorang Valley and Camden district. These included Old Wollondilly (1930-1980), Wollondilly Extended (1935-1973), Nattai Bulli (1932-

1992), Nattai North (1974-1988), Valley 1, Valley 2 and Valley 3 (1959-1984) and others. However mining in this region decreased significantly from the late 1980s and finally ceased in 2000.

2.5.2 Current Mining

There are 8 underground coal mines currently operating (see Map 3 and Figure 6). These are:

- ***Metropolitan Colliery*** (owned and operated by Helensburgh Coal Pty Limited, a subsidiary of Peabody Energy Australia Coal Pty Limited);
- ***West Cliff Colliery*** (owned and operated by Illawarra Coal Holdings Pty Limited, a subsidiary of the BHP Billiton Group);
- ***Appin and Appin West Colliery*** (owned and operated by Illawarra Coal Holdings Pty Limited, a subsidiary of the BHP Billiton Group; Appin West was formerly known as Tower Colliery);
- ***Dendrobium Colliery*** (owned and operated by Illawarra Coal Holdings Pty Limited, a subsidiary of the BHP Billiton Group);
- ***NRE No 1 Colliery*** (owned and operated since December 2004 by Gujarat NRE Australia Pty Limited; formerly known as Bellpac Colliery, South Bulli Colliery and Bellambi West Colliery);
- ***Wongawilli Colliery*** (owned since December 2007 by Gujarat NRE Australia Pty Limited, but until then owned by Illawarra Coal Holdings Pty Limited and then known as Elouera Colliery);
- ***Tahmoor Colliery*** (owned and operated since September 2007 by Xstrata Coal (NSW) Pty Limited, but until then owned by Centennial Coal Company Limited); and
- ***Berrima Colliery*** (owned and operated by Centennial Coal Company Limited).

Of these eight mines, five currently extract from the Bulli Seam and three extract from the Wongawilli Seam (Dendrobium, Wongawilli and Berrima). Only NRE No 1 mine extracts both the Bulli and Balgownie Seams.

In 2006-07, Illawarra Coal's three mines produced 7.5 Mt of saleable coal of which 3.50 Mt was supplied for domestic consumption and 4.0 Mt was exported. In 2002, Illawarra Coal signed a 30 year contract with the BlueScope Steelworks to supply around 4 million tonnes per annum (Mtpa) of coking coal to Port Kembla. Whyalla in South Australia currently receives about 0.7 Mtpa.

2.5.3 Future Development Potential

There are a number of future coal mine proposals within the Southern Coalfield (see Figure 6)

The Avondale Colliery operated from 1939 until 1983, when it was closed and rehabilitated. In September 2005, it was purchased by Gujarat NRE Australia Pty Limited, which initially planned to re-open the mine as a stand alone operation. Gujarat NRE is now actively assessing options to access Avondale's remaining coal reserves from its adjoining Wongawilli Colliery, which lies immediately to the north, in order to minimise environmental impacts. The principal resources are in the Wongawilli Seam, where there is an inferred resource of the order of 100 Mt.

The Bargo Proposal is within an existing consolidated coal lease (CCL 747) located immediately south of Tahmoor Colliery. This lease is now held by Xstrata Coal (NSW) Pty Limited, but until recently was held by Tahmoor Coal, which was controlled by Centennial Coal Company Limited. Neither Centennial nor Xstrata has announced any early development proposals for Bargo and resources are not separately identified (they are instead included within resource estimates for the Tahmoor Coal Mine). The principal seam of interest is the Wongawilli Seam. The Sutton Forest Proposal is within an exploration licence for coal (Authorisation 349, held by Anglo Coal Pty Limited) and is located south of the existing Berrima Colliery Holding. The principal seam of interest is the Wongawilli Seam. Although measured resources are of the order of 315 Mt, it is understood that it is unlikely that Sutton Forest would be developed for a number of years.

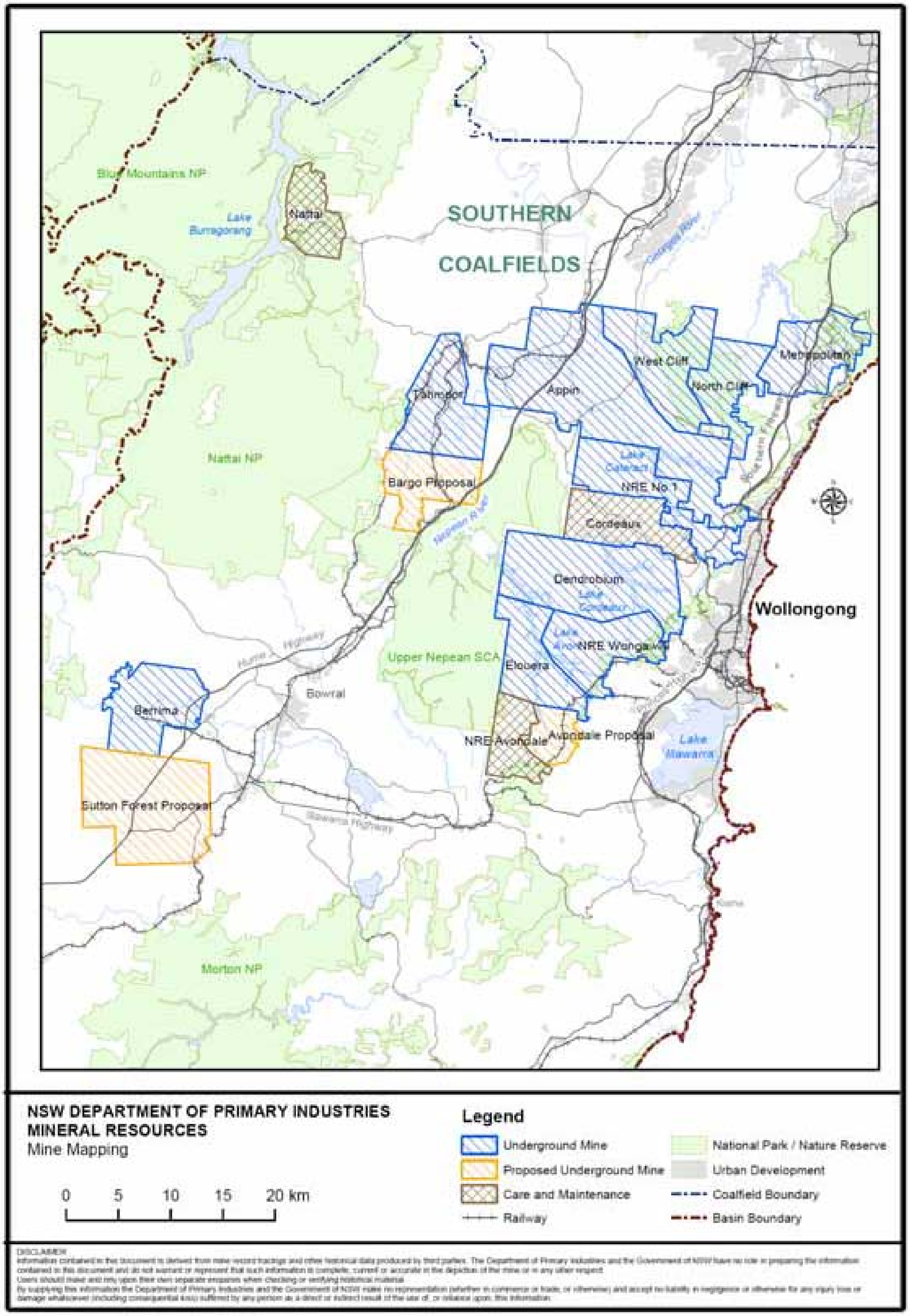

Figure 6: Current and Proposed Coal Mining Areas in the Southern Coalfield

Source: DPI

The Panel has been advised by DPI that there are sufficient resources within existing mining leases and exploration licence areas to service the needs of the domestic steel industry well into this century. However, depletion of reserves in those collieries servicing the export market may result in mine closures over the next 20 years (DPI, 2006). DPI further advised that the major remaining unallocated resources of prime coking coal occur in the Bulli and Balgownie Seams, and in particular beneath the Camden-Campbelltown-Picton region. There are also unallocated Wongawilli Seam resources in the southern half of the Southern Coalfield.

Total recoverable coal reserves are estimated by DPI at 670 million tonnes (Mt). A resource of this size has a current value of around $100 billion (at $150/tonne). Recovery of these reserves has the potential to generate over $5 billion in mining royalties to the State, at current rates of royalty.

2.5.4 Underground Coal Mining Systems

Effectively, all underground mining methods can be described as the process of developing a series of excavations in the rock mass. Each mining method can be characterised simply by reference to:

- the absolute size of each excavation; and
- the absolute size of the pillar/s between each excavation.

2.5.4.1 Bord and Pillar Mining

For Australian mines, the *bord and pillar* method is currently utilised primarily in circumstances where natural or man-made subsurface and surface features have a limited tolerance to mining-induced movement or where underground roadways have to remain stable for 'life of mine'. The success of the method depends both on restricting the width of the *bords* (excavated rooms) to minimise the likelihood of roof falls, and on making the remaining coal *pillars* sufficiently large to carry the weight of the roof overburden without failing (see Figure 7). Typically in Australia, bord width is limited to around 6 m, whilst pillars have a width of at least 1/10th of the depth of cover or 10m, whichever is greater. Wider pillars may be required if the roof or floor is soft or weak or if the mining height is greater than about 3m. Bord and pillar mining is also referred to as *first workings*.

Subsidence of the subsurface and surface in bord and pillar mining can result from a combination of sag of the roof strata between the pillars and compression of the coal pillars and surrounding strata due to the weight of overburden. However, strata disturbance is usually negligible with this mining method, typically resulting in less than 5 mm of vertical displacement at the surface. Since it is common for seasonal variations in ground level to range up to 30 mm or more, subsidence over stable bord and pillar workings is rarely of concern.

For reasons of safety, the roof and often the sides of all roadways in bord and pillar mining have to be supported. This represents a major operating cost and can impact adversely on productivity. As the depth of mining increases, larger pillars are required in order to carry the extra weight of the overburden, resulting in a substantial decrease in resource recovery and a further decrease in productivity (see Figure 8). Hence, with few exceptions, it is now uneconomic in Australia to use bord and pillar mining as the primary production method at depths greater than about 200 m. However, it is used at greater depths for primary and secondary development.

2.5.4.2 Pillar Extraction

Economic viability and resource recovery in bord and pillar operations can be improved substantially if some or all of the coal pillars are subsequently extracted. This type of mining is known as *pillar extraction* and is a type of *second workings* or *secondary extraction*.

Pillar extraction usually results in collapse of the immediate roof of the mine workings. The height to which the collapse extends and its impact on the surface are determined in part by the width of the extraction. In order to restrict the impacts of pillar extraction on the surface, the excavation width may be limited by only extracting selected coal pillars or portions of individual coal pillars. This is known as *partial pillar extraction*. It has been common practice to employ this method beneath lake foreshores and tidal waters in NSW by extracting every second row of pillars. The area from which the coal pillars are extracted is then left in an unsupported state and is known as a *goaf* (plural *'goaves'*). The goaf may or may not collapse, depending on the nature of the geology and the mining dimensions.

The wider excavations result in increased load being transferred onto the coal pillars. This results in an increase in both sag of the overlying strata and in compression of the coal pillars and the strata above and below the pillars. Significant subsidence and resulting disturbance of the subsurface and surface may occur, depending on the mining layout.

Pillar extraction is usually cheaper and much more productive than bord and pillar first workings because little or no support is installed during the pillar extraction operations. However, this also makes it potentially the most hazardous form of coal mining. There has been a rapid decrease in its use in Australia over the past 20 years and, with a few exceptions, it is now confined to a number of small mines operating at shallow to moderate depths (to 300 m).

2.5.4.3 Longwall Mining

Safety, productivity and cost considerations dictate that *longwall mining* is now the only major, viable, high production mining method in the majority of Australian underground coal mines that operate at a depth of greater than about 300 m and in virtually all new coal mines (irrespective of depth). Longwall mining can be viewed as a form of pillar extraction in which one very large coal pillar is extracted within each longwall panel by progressively shaving slices of coal, or *webs*, that are about 1 m wide off one end of the pillar. Such a *longwall block* or *longwall panel* is typically between 150 to 400 m wide and 1 km to 4 km long (see Figure 7). This large panel of coal is first delineated by driving two or three *roadways* (or *headings*) down each longitudinal boundary of the block and then connecting them at the extremity of the block. The longitudinal headings are referred to as *gateroads*. The driving of longwall gateroads is referred to as *longwall development*. A set of gateroads constitutes a *longwall development panel*.

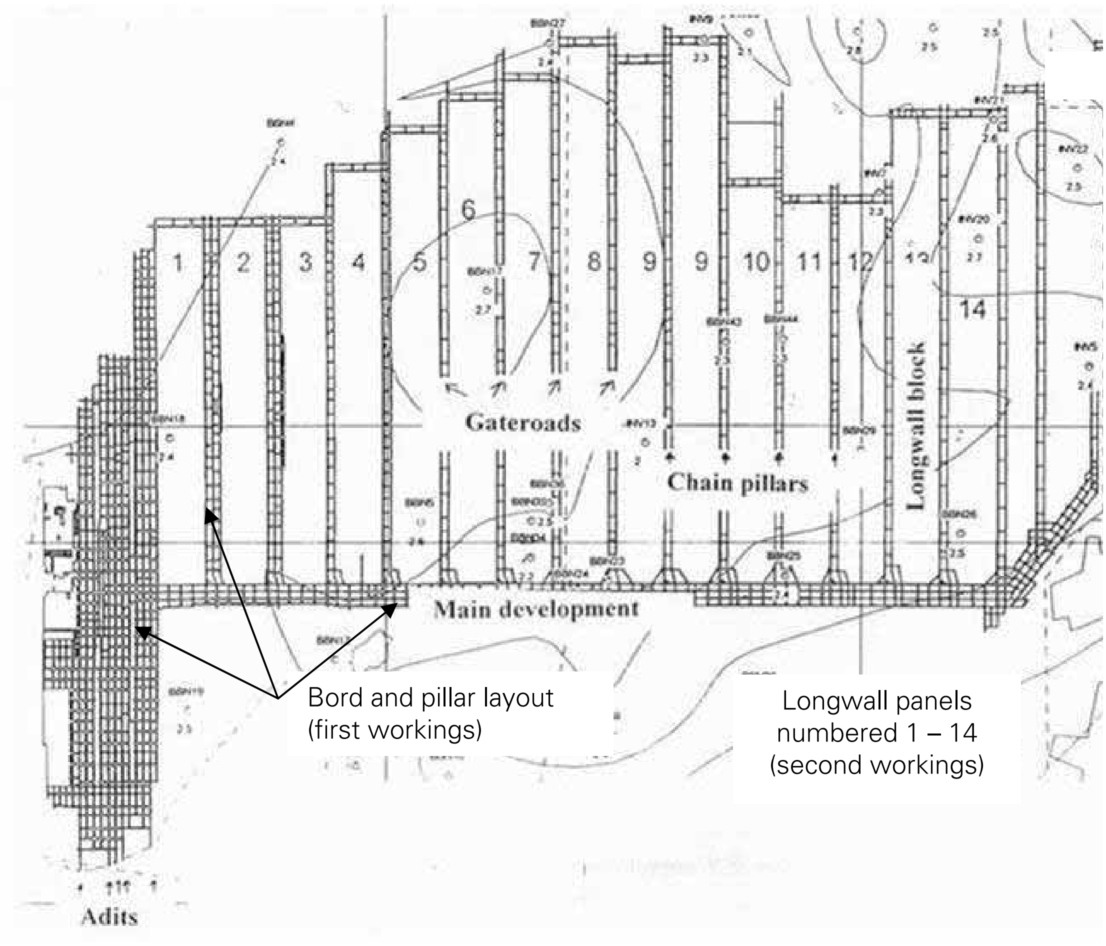

Figure 7: Layout of a Typical Longwall Mine, also showing Bord and Pillar Workings

It takes two longwall development panels to delineate the first longwall block. Thereafter, only one set of longwall gateroads needs to be driven for each new adjacent longwall panel because the new panel also makes use of one of the gateroads left over from the previous panel. The new gateroads are referred to as *maingate* roadways. The interpanel pillars that separate each gateroad are known as *chain pillars* (see Figure 7). Once a gateroad starts to be reused for the next longwall panel, it is known as a *tailgate*. Longwall extraction operations effectively result in the formation of very wide and very long excavations separated by a single or double row of relatively narrow chain pillars. Longwall mining therefore involves both *first workings* and *second workings*. The mains development and gateroads are first workings, since they involve no subsidence and the longwall panels are a type of second workings.

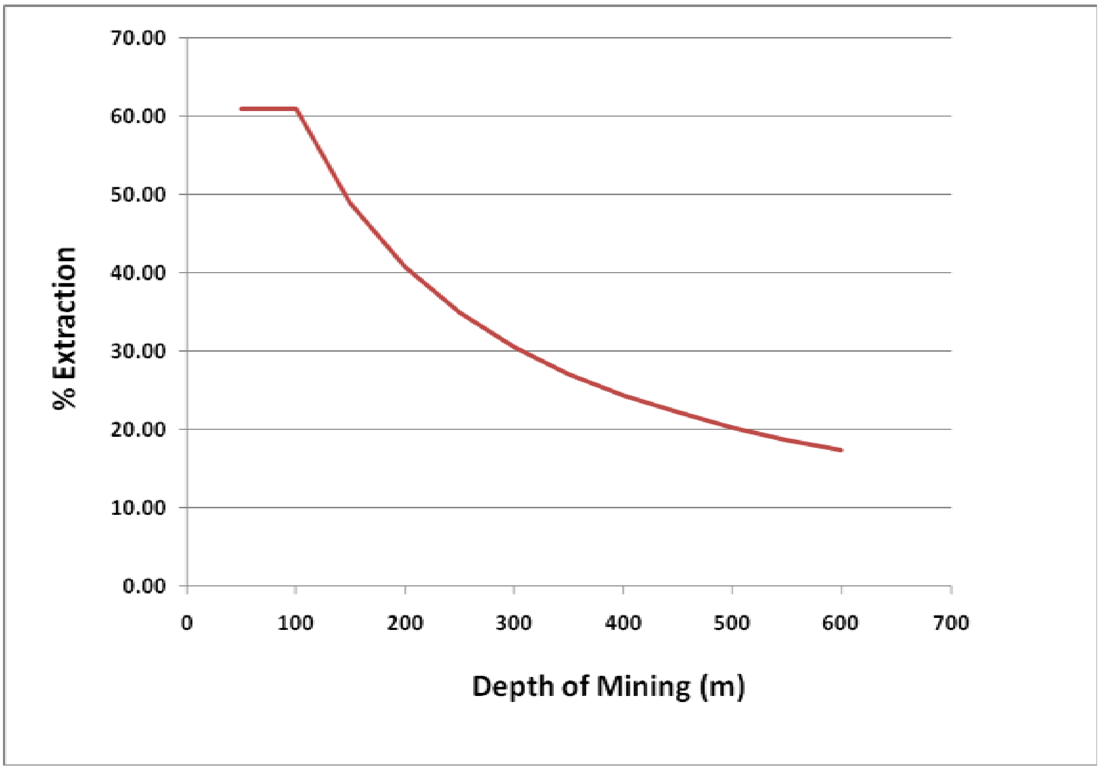

Figure 8: Effect of Mining Depth on Coal Extraction in Bord and Pillar Mining

Face operations in longwall mining take place under the protection of mobile hydraulic supports (or *chocks*) of the type shown in Figure 9. This provides a very safe working environment while minimising operating costs and maximising productivity because many millions of tonnes of coal can be extracted without the need to install permanent or semi-permanent roof supports. The hydraulic supports are advanced as each web of coal is mined, thereby progressively increasing the area of the unsupported excavation, or goaf, behind the supports. As with pillar extraction, significant subsidence and resulting disturbance of the subsurface and surface may occur, depending on the mining layout.

The high capital cost of a longwall face installation and an almost total dependency for production at any one time on a single longwall panel, make the viability of longwall mining very sensitive to interruptions in production. In order to ensure production continuity from the extraction panels, the driveage of each set of gateroads needs to commence at least 12 to 18 months ahead of when extraction of their contained longwall panel is scheduled to begin. If the sequence of longwall panels is interrupted, then two new sets of gateroads have to be developed in order to re-establish the longwall operations, which in itself can take many months. When the requirements of the current approval process in NSW are also taken into account, a complete change in longwall layout typically requires a lead time of at least 3 years if longwall continuity is to be maintained. Given the large capital costs involved and contract sales commitments associated with a longwall operation, lack of longwall continuity can quickly result in the operation becoming economically unviable.

Figure 9: An Operating Longwall Face

Note: The following features can be seen: coal seam under extraction, the coal shearer, the face conveyor and system of self-advancing hydraulic roof supports ('chocks'). Note the operator for scale, however, mining of this seam height is not typical for the Southern Coalfield.

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3 Socio-Economic Significance of Coal Mining

3.1 ECONOMIC SIGNIFICANCE OF THE COAL INDUSTRY

The economic and social significance of the Southern Coalfield was acknowledged in a large number of submissions to the Panel. For example, the Total Environment Centre (TEC) stated in its submission that:

> *'(it is) unquestionable the enormous role coal has played in shaping the environmental, social and economic fabric of communities around the Illawarra Escarpment and the Woronora Plateau'.*

The NSW Minerals Council also stated:

> *'There is no denying that the coal industry makes a significant contribution to both the economic and social prosperity of NSW residents, and that mining companies play active, positive roles in the local communities in which they operate. The mining industry in NSW's Southern Coalfield is no exception, having had a long history in the region and being uniquely placed as the only source of high quality coking coal in the State. Mining in the Southern Coalfield has created significant benefits for the local community in terms of employment, infrastructure and other community contributions, with flow on benefits extending throughout the State'.*

From the perspective of local Government, the Association of Mining Related Councils stated:

> *'The region has a long history of mining which has contributed significantly to the development of the area. Location, lifestyle and natural attributes make it a desirable place to live and an ideal tourist destination. The region continues to expand, along with the mining industry and supports the operation of Port Kembla, a significant catalyst for other associated industries and employment generation. It is clearly acknowledged that mining brings considerable economic benefit to the region, the State and the Australian economy'.*

The Panel accepts that the contribution of coal mining in the Southern Coalfield to State revenues, regional income and employment is considerable, especially when indirect employment and support industries are taken into account. Furthermore, many industry employees live in the region and donations and sponsorships provided by the coal industry play a significant role in local communities. The extent of these contributions is considered in this Section.

3.1.1 Current Mining

3.1.1.1 NSW Coal Production

NSW is Australia's second largest coal producing State. Total saleable coal production in 2006-07 was 131.3 Mt, valued at $8.1 billion. Coal exports increased to 91.5 Mt from 89.8 Mt the previous year and were valued at $6.2 billion. In 2006-07, coal made up 66% of the estimated total value of NSW mineral production of $12.3 billion. Coal is the single largest export from NSW in value terms. Approximately 70% of the saleable coal produced in NSW is exported to some 26 countries around the world. NSW coal exports are growing and the industry is investing in new rail and port infrastructure to meet this global demand for NSW high quality coal products.[3]

[3] These and other 2006/07 coal production data have been supplied by DPI. They will be published in the forthcoming *2007 Coal Industry Profile*.

3.1.1.2 Southern Coalfield Production

Five of the 8 underground coal mines currently operating in the Southern Coalfield use longwall mining methods. Of the Southern Coalfield's total production in 2006-07 of 11.08 Mt, 10.86 Mt were produced by these five mines.

The Southern Coalfield produced 10.6 Mt of saleable coal in 2006/07 (see Figure 10), representing 8.1% of total NSW saleable coal production in that year. Over 80% of coal produced is premium quality hard coking coal which is used for steelmaking, either in local coke works or in export markets.

The Southern Coalfield is the dominant supplier of coking coal to the domestic steel industry (see Table 5), of which OneSteel's plant at Whyalla in South Australia and the BlueScope Steel plant at Port Kembla account for the vast majority of Australia's steel production. In addition, some 81% of coal exported from the Southern Coalfield is hard coking or other metallurgical coal. In 2005-06, the Southern Coalfield provided 3.5 Mt (or over 99.5%) of NSW's exports of hard coking coal, and some 26% of its total coking and other metallurgical coal exports, despite representing only 5.8% of total NSW coal exports. The small component of the overall exports reflects the great preponderance of steaming coal in NSW's coal exports.

As at June 2007, hard coking coal attracted a 70-80% price premium over thermal (or steaming) coal, with average export prices in June 2007 being $107 and $60 per tonne respectively. Based on these prices, the total value of coal delivered from the Southern Coalfield in 2006-07 is estimated at $1.1 billion, with roughly $640 m coming from exports. The price for hard coking coal has increased substantially since that date.

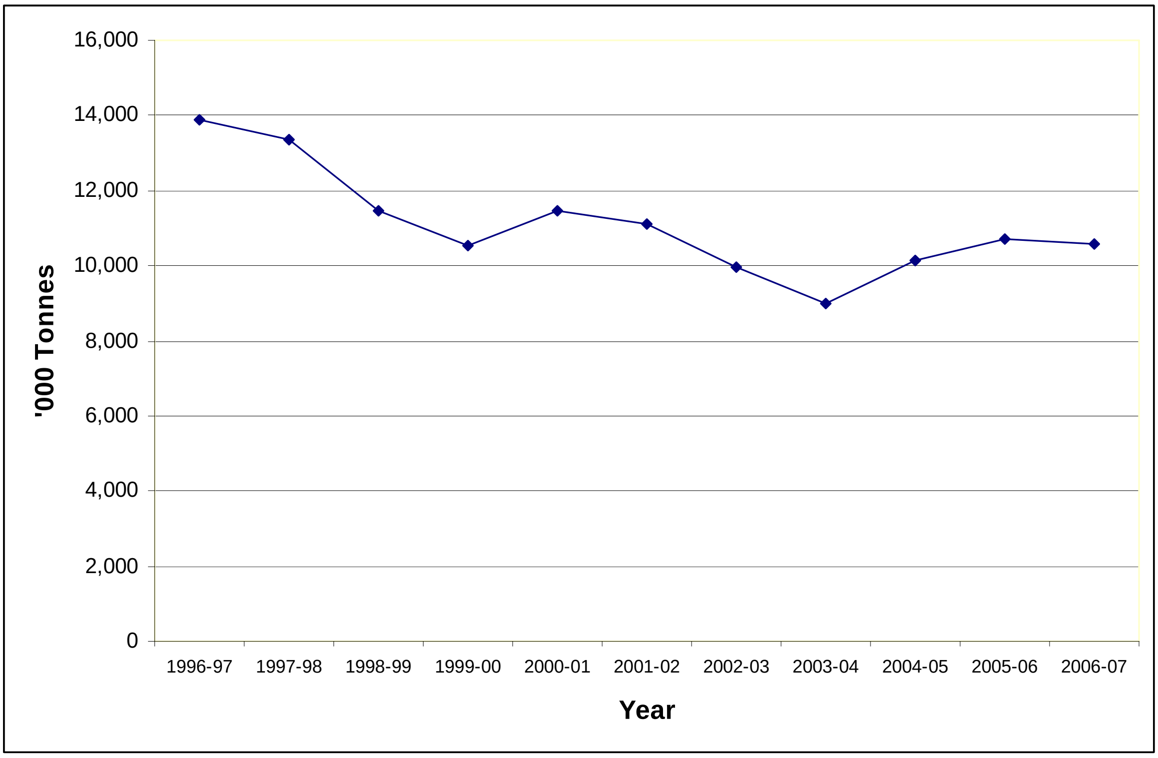

Figure 10: Saleable Coal Production from the Southern Coalfield, 1996-97 to 2006-07

Source: DPI, 2006 and DPI (pers comm)

Table 5. Total Deliveries of Coal from the Southern Coalfield and NSW, 2006-07

Customer	Southern Coalfield ('000 t)	Total NSW ('000 t)	Southern Coalfield to total NSW (%)
Steel industry	4,192	4,903	85.5
Coke works	217	254	85.4
Power stations	0	30,439	0
Cement works	213	313	68.1
Other domestic customers	49	355	13.8
Export	6,411	92,391	6.9
Total deliveries	**11,082**	**128,655**	**8.6**

Source: DPI

3.1.2 Coal Sector Potential

Forecasts for the coal sector are strong, with the Australian Bureau of Agricultural and Resource Economics (ABARE) predicting continued growth in demand for both thermal coal and coking coal (DPI, 2006). In response to strong export and domestic demand, considerable investment is underway in the Australian coal industry, with some thirteen new coal projects - six in New South Wales and seven in Queensland - completed in the six months to April 2007, with a total capital expenditure of $1.6 billion.

The Department of Planning reports that, over the past four years, the NSW Government has approved around 80 proposals for new coal mines, coal mine extensions or coal mine modifications. Since the beginning of 2006, the Government has approved five major new coal mining proposals - the Anvil Hill Coal Mine near Denman, the Moolarben Coal Mine north of Mudgee, the Abel Coal Mine east of Maitland, the Narrabri Coal Mine southeast of Narrabri and the Belmont Coal Mine east of Boggabri.

3.1.2.1 Southern Coalfield Potential

Compared with the Upper Hunter Valley, the Gunnedah Coalfield or parts of the Western Coalfield near Ulan, the Southern Coalfield is a mature coal mining field. In addition, it primarily produces a specialty product (hard coking coal and other metallurgical coals). It is unlikely that its other resources of steaming coal can be economically developed for many decades (if ever), given the very considerable depth at which underground mining would have to take place and the thickness and quality of the target seams. Consequently, the Southern Coalfield is unlikely to be subject to significant development pressures for new mines over the next 10-20 years.

Nonetheless, the Southern Coalfield remains subject to company activity and mine development (or re-development) proposals. In November, 2005, Gujarat NRE (a subsidiary of India's largest independent producer of metallurgical coke), purchased the former Avondale Colliery and part of the Huntley Colliery leases. Subject to obtaining State Government approvals, Gujarat proposes to reopen the mine as NRE Avondale. In December 2007, Gujarat completed its $29 million acquisition from Illawarra Coal of the former Elouera longwall mine, which had been in limited operation since 2005 under a contract mining agreement with Delta Mining Company. Gujarat NRE has since renamed the mine as 'NRE Wongawilli'. The mine is expected to employ up to 100 people and produce up to 1 Mtpa of coal. Gujarat re-opened NRE Wongawilli in late April 2008, preparatory to recommencing mining.

Large reserves of coal exist in the combined Wongawilli and Avondale leases, which would provide more than 20 years of mine life. Gujarat is currently examining options to access the Avondale reserves via Wongawilli Colliery, rather than to re-open Avondale Colliery as a stand-alone mine.

Meanwhile, Illawarra Coal is proposing to extend underground longwall mining operations at its Appin coal mine. DPI approved longwall mining at Appin West (previously known as the 'Douglas Project', of which Douglas Area 7 was part) in November 2006. The project will access valuable coking coal reserves to the north of the previous Tower mine. With the commencement of mining at Appin West in the December quarter 2007, Illawarra Coal has indicated that the Company has access to coal resources for a further 30 years.

Illawarra Coal is in the process of lodging a project application under Part 3A of the EP&A Act for approval to operate its Bulli Seam mines (Appin, Appin West and West Cliff) for a further 30 years. Helensburgh Coal has also lodged a project application to extend the life of Metropolitan Coal Mine by approximately 20 years.

Recoverable coal reserves in the Southern Coalfield have been estimated at 670 Mt (DPI, 2006). DPI reports that unallocated resources of coking coal lie largely in the Bulli and Balgownie seams, while the Wongawilli seam is expected to yield both coking and thermal coal.

However, submissions from the NSW Minerals Council and Illawarra Coal both highlight that these figures do not include resources that are outside existing mining leases and exploration licences and, therefore, this figure is likely to increase significantly in the future as further resources are identified and explored.

Putting aside these potential resources outside of existing leases, DPI considers that known resources are sufficient to sustain the domestic steel industry well into this century. However, some collieries servicing the export market may close over the next 20 years as existing leases are depleted (DPI, 2006).

The NSW Minerals Council noted in its submission that:

> *'A recent economic study by ACIL Tasman (2006) for the Minerals Ministerial Advisory Council investigated the economic potential of the NSW minerals industry. Using an economic model that forecast domestic and international economic conditions, the study concluded that, given an appropriate regulatory environment the Southern Coalfield could increase exports at the rate of 7.8% each year over the years to 2020.'*

3.2 SIGNIFICANCE TO THE LOCAL AND REGIONAL ECONOMIES

The Southern Coalfield industry makes significant contributions to local, regional and state economies, through the payment of taxes to the Commonwealth and State Governments, royalties to the State Government, wages to employees, expenditure on goods and services in the region and through broader funding initiatives that support the community.

3.2.1 Income and Expenditure

A number of submissions to the Panel highlighted the significance of the Southern Coalfield mining operations to local economies, such as those from Wollondilly Shire Council and Campbelltown City Council. Wollongong City Council also noted its support for coal mining as the industry provides significant economic benefits to the City and the Illawarra region in general. Council submitted:

> *'Mining (in) the NSW Southern Coalfield is of significant economic importance to the City of Wollongong. As well as the direct employment that is provided by the mining sector, coal mined in the Southern Coalfield provides indirect employment, and is used by the BlueScope steelworks at Port Kembla. Access to this coal is critical to the operation of the steelworks, and without it the steelworks would likely cease to operate. This would have a very significant short to medium term impact on the Illawarra economy.'*

Expenditure by coal mining companies is clearly an important driver of regional economic activity in the Southern Coalfield. Expenditure on goods, service and labour that are an input to mining production are often termed 'upstream expenditures' or 'backward economic linkages'. These upstream expenditures stimulate other sectors in the economy leading to higher levels of economic activity and employment.

As noted in the NSW Minerals Council's submission, this stimulus arises from:

- ***production-induced flow-on effects*** arising where a coal mine purchases goods or services from other firms or industries in the region, which in turn generates demand for the inputs to production from these other industries and firms; and
- ***consumption-induced flow-on effects*** associated with household expenditure. These arise because coal mines employ labour and make payments to households which then acquire goods and services and so generate a stream of consumption-induced effects complementary to the production-induced effects.

Illawarra Coal cites a study by the University of Wollongong's Illawarra Regional Information Service (IRIS) based on 2004-05 data that investigated the direct and indirect impacts of Illawarra Coal on the Illawarra and Wollondilly regions (IRIS, 2005). In that year, coal production by Illawarra Coal accounted for 7.9 Mt or 65% of total Southern Coalfield production. The estimated upstream impacts (or backwards linkages) arising from Illawarra Coal's operations in 2004/05 are shown in Table 6. The economic beneficial impact of Illawarra Coal, including flow on effects, was assessed at about 5,855 jobs, $1,392 m in the gross value of regional output (including $713 m in direct output and a further $680 m in flow-on effects) and $278 m in household income. These results suggest that Illawarra Coal accounts for an average of 4.4% of total regional output and 3% of employment in the Illawarra and Wollondilly regions. In particular, the study found that Illawarra Coal had a disproportionate impact on regional output and employment, which was attributed to the high capital and resource intensity of operations and the high rates of wages paid.

Table 6. Regional Economic Benefits of Illawarra Coal, 2004-05

	Total Output ($m)	**Value added ($m)**	**Household income ($m)**	**Employment (FTE jobs)**
Direct impact	713	238	156	998
Flow-on effects	680	282	121	4,857
Total impact	1,392	520	278	5,855
Multiplier	1.95	2.19	1.78	5.87
Region total	31,862	111,712	5,233	195,542
Region %	4.4%	4.4%	5.3%	3.0%

Notes: *Source: (Illawarra Coal submission)*
Output*: equal to total sales (ie quantity sold multiplied by price per unit);*
Value added*: equal to the value of output minus the value of intermediate inputs, ie value added is the difference between the costs of production and the value of sales turnover;*
Household income*: is the wages paid to employees including imputed wages for self employed and business owners; and*
Employment*: is measured as full-time equivalent jobs.*

The IRIS study estimated that Illawarra Coal itself directly accounted for $713 m in regional output and $156 m in household income in 2004-05. Flow-on effects produce multipliers of 1.95 for gross regional output (a total of $1,392 m) and 1.78 for household income (a total of $278 m).

The NSW Minerals Council submission provides further insight concerning the significance of the coal industry to the Illawarra region:

> *'A number of factors serve to maximise the production-induced effects of coal mining in the Southern Coalfield on the Illawarra economy. Firstly, coal mining requires significant magnitudes of operational expenditure, much of which is captured by the regional economy because of the long history of coal mining in the region and the development of specialised suppliers. An NSWMC survey during the year 2004-05 found that 55% of mines' expenditure went to suppliers within the region. Secondly, the majority of employees in the Southern Coalfield reside in the Illawarra region which combined with the relatively high*

wages of the coal sector provides potential for substantial consumption-induced flow-ons. In this respect, a The NSW Minerals Council survey of 6 of the 8 mines operating in the Southern Coalfield during 2004-05 found that 73% of the wages paid to employees were to those from within the Illawarra region.

Multipliers can be used to summarise the total economic effect of coal mining in the Illawarra Region in relation to the direct effect of coal mining. Employment ratio multipliers for capital intensive industries such as coal mining tend to be high because the direct employment is relatively low compared to the level of expenditure in the regional economy with this high level of expenditure in the regional economy generating a high level of flow-on employment. Employment multipliers of the mining industry have been estimated in the range of 4.5 (ACIL Tasman 2007) and 5.87 (IRIS 2005).'

Downstream or 'forward linkages' can also be identified, and refer to impacts on sectors or businesses utilising coal as in input to their production process or handling coal once it is produced. There are a number of significant downstream linkages from coal mining in the Southern Coalfield, including BlueScope Steel (Port Kembla), OneSteel (Whyalla, South Australia), Berrima Cement Works and the export coal terminal at Port Kembla.

The NSW Minerals Council points out that the coal blend used at the BlueScope Steelworks has been optimised around the specific properties of the high grade coking coal sourced from the two principal seams in the Southern Coalfield (ie the Bulli and Wongawilli Seams). It then argues that limiting availability of coal from either of these seams could have a major impact on the steelworks, as alternative sources of this coal blend from Queensland would impose a cost penalty of at least $20 per tonne and reduce the cost-competitiveness of BlueScope Steel. It would also impose additional infrastructure costs on BlueScope Steel as an upgrade to Port Kembla Coal Terminal would be required to facilitate these domestic imports (Sub #28, App 5, p 5). BlueScope relies on a reasonably priced and secure source of coking coal in order to remain viable. The closure of the BHP coking coal mines would potentially result in the closure of the Port Kembla Steel Works and associated industries.

Helensburgh Coal's submission also notes the significance of continued production and reliable supply of high grade coking coal from the Southern Coalfield to the OneSteel operations at Whyalla, South Australia. OneSteel indicates that it is committed to sourcing coal in the medium to longer term from the Illawarra region and that it would incur significant time and dollar costs if the supply were adversely affected.

As well as the downstream economic benefits associated with domestic use of the coal from the Southern Coalfield, the industry also supports export operations. The Port Kembla Coal Terminal (PKCT) is the key coal exporting facility which services the Southern and Western coalfields of New South Wales. PKCT receives coal by road, rail and barge and has two berths and three ship loaders. It is argued by the NSW Minerals Council that any decline in throughput may result in higher terminal charges or a decline in service standards, with implications for the competitiveness of the terminal operations and the Southern Coalfield in general.

3.2.2 Employment

Direct employment in the NSW coal industry at 30 June 2007 was 13,392, an increase of 737 over the previous 12 months. Direct employment in Southern Coalfield coal mines at 30 June 2006 was 2,489, an increase of nearly 24% over the previous year and 77% since June 2000 (DPI, 2006). Total employment for coal mines in the Southern Coalfield and throughout NSW over the past 10 years in shown in Table 7. This table indicates that employment in Southern Coalfield mines has been growing since a historical nadir in 1999-00. Employment in the Southern Coalfield has risen from around 15% of the NSW total to around 19%. These figures include full-time contractors, which make up a large proportion of the total workforce.

Of the 2,489 direct employees, Illawarra Coal employed around 1,543 (692 at Appin and Appin West, 375 at Dendrobium and 476 at West Cliff (DPI, 2006). This is a substantial increase over the 998 which were employed during 2004-05. At that time, the regional economic impact assessment undertaken by the IRIS research group found that the flow-on employment effect of those 998 jobs was a further 4,857 jobs in the region (to provide total direct and indirect employment of 5,855 and a total multiplier effect of 5.87). Even so, total direct and indirect employment was just 3% of the whole of the Illawarra and Wollondilly LGAs.

Applying those same figures to today's Illawarra Coal employment suggests that it leads to over 7,500 indirect jobs. Put another way, applying the results of the IRIS study suggests that the expansion of Illawarra Coal's mines in the Southern Coalfield since 2004-05 has led to a total of around 3,200 jobs being created (545 directly and around 2,650 indirectly). In reflection of the high multiplier effects for employment in the Southern Coalfield, around 6,000 persons are employed at the BlueScope Steelworks at Port Kembla. This analysis does not include people employed at One Steel in Whyalla or other supporting industries not in the Illawarra.

Table 7. Total Employment in Coal Mines, Southern Coalfield and NSW, 1997 to 2007

Year	Southern Coalfield	Total NSW	% Southern Coalfield of NSW total
1997	3,073	14,351	21.4%
1998	2,295	11,695	19.6%
1999	1,574	10,400	15.1%
2000	1,406	9,583	14.7%
2001	1,546	9,821	15.8%
2002	1,493	10,052	14.9%
2003	1,720	9,758	17.6%
2004	1,785	9,998	17.9%
2005	2,011	11,290	17.8%
2006	2,489	12,658	19.7%
2007	2,476	13,392	18.5%

Source: DPI, 2006 and DPI (pers comm). Figures as at June of each year.

The NSW Minerals Council reports that, over the past decade, employees in the mining industry have consistently earned the highest average weekly earnings of any sector in the NSW economy. During 2005-06, average fulltime adult weekly earnings for employees in the NSW mining sector was $1,880.50 – 27% higher than the second ranked industry, and 67% higher than the average weekly earnings throughout all sectors of $1,123.30. The average weekly earnings in NSW coal mines were even greater - $2,008.50 for all open cut and underground mines and $2,131.00 for underground mines in the Southern Coalfield (DPI, 2006).

To provide an idea of the proportion of production costs which go to wages, in 2005-06, the indicative labour cost per tonne of saleable coal produced in the Southern Coalfield was $18.90. By comparison, the Statewide average for all mines was $9.10 and the average for open cut mines across the State was $6.30.

Moving west of the Illawarra Region, the Panel also notes the very significant contribution to local employment and to consequent population and community strength that the coal mines make to some of the smaller communities within Wollondilly LGA, in particular to Appin, Picton and Tahmoor.

3.3 INCOME TO GOVERNMENT FROM MINING

3.3.1 Royalties

Coal mining contributes to State Government revenues via royalties and other taxes and charges. The Local Government Association of NSW noted in its submission to the Panel that royalties from longwall mining operations are a significant contributor to the NSW economy, with direct links to front-line services provided by the NSW Government.[4]

The coal royalty rate payable to the NSW Government is between 5-7% of the value of the coal extracted. The 7% figure applies to open cut mines, 6% applies to most underground mines and 5% applies to underground mines if the depth of cover exceeds 400 m. The lesser figures are to recognise the higher costs of underground extraction of coal.

DPI reports that, during 2005-06, total mining royalty revenues were $504 million, of which coal contributed $447 million. During 2006-07, royalties totaled $489 million, of which coal mines accounted for $412 million. The drop in coal mining royalties largely reflected exchange rate variations and a consequent drop in the selling price in A$.

Table 8 shows total royalty and coal mining royalty for NSW for the past 10 years. The big jump in coal mining royalty from 2004-05 was a result of a change in both the royalty rate and the method by which coal royalties were calculated during 2004-05. On 1 July 2004, the Minister for Mineral Resources changed the royalty method to an *ad valorem* rate (ie a percentage of the selling price, rather than a fixed rate per tonne). The further jump in royalties from 2005-06 for the Southern Coalfield reflects increased production at key mines from that time. The Southern Coalfield contributed $59 m in coal royalties in 2006-07. Royalty income for 2007-08 is expected to be much higher, since coal selling prices have increased markedly.

Table 8. Mineral and Coal Royalty Income, NSW and Southern Coalfield, 1996-97 to 2006-07

Year	NSW Mining Royalties ($m)	NSW Coal Royalties ($m)	Southern Coalfield Coal Royalties ($m)
1996-97	181	168	18.3
1997-98	202	184	18.9
1998-99	202	188	17.4
1999-00	215	184	14.7
2000-01	220	197	16.0
2001-02	216	202	15.4
2002-03	233	206	15.6
2003-04	250	218	13.5
2004-05	396	354	31.6
2005-06	504	447	56.0
2006-07	489	412	58.7

Source: DPI.

3.3.2 Taxes

In addition to royalties, mining companies pay other State Government taxes and charges such as stamp duty and payroll tax. The NSW Minerals Council reported that, during 2005-06, these charges amounted to $100 m, bringing the funds paid to the State Government by the whole coal

[4] In support of this statement, the LGA cites NSW Parliament, General Purpose Standing Committee No 5, 30 March 2005.

mining industry in NSW to a total of $547 m. Of this $100 m, the Southern Coalfield contributed $9 m in Government taxes and other charges.

Illawarra Coal noted in its submission to the Panel that since 2001 it has paid some $257 m in State taxes and royalties.

3.4 SOCIAL SIGNIFICANCE

The NSW Minerals Council cites a number of ways in which coalmining has social significance in the Southern Coalfield:

- ***community infrastructure*** – mining has provided work opportunities and contributed to the retention of population within the Illawarra Region and Wollondilly LGA. As Government services are largely driven by population growth and demographics, this in turn has contributed to the provision of community infrastructure and services such as health and education;
- ***funding of local development and community programs*** – the coal mines of the Southern Coalfield fund a large range of community groups, activities and projects. A NSW Minerals Council survey during 2004-05 found that the total level of direct community investment from the mines surveyed (75% of the total) was $737,000. This investment was primarily in the areas of education and training, sponsorship and community health; and
- ***community consultation*** – the process for obtaining development consent or planning approval includes extensive provisions for public consultation and input into the development of specific projects.

Illawarra Coal submitted that it similarly funds a large range of community groups, activities and projects which contribute to the economic and social fabric of the region. During 2004-05, Illawarra Coal reported that it directly contributed over $0.5 m to the local community through donations and sponsorships, while more than $0.8 m was contributed during 2005-06.

Gujarat NRE also reported that it provides direct sponsorship and financial support to local schools, sporting clubs and other community based organisations. It is understood that Centennial Coal, when it was the owner of the Tahmoor Coal Mine, also made community contributions.

3.5 OTHER SOCIAL AND ECONOMIC IMPACTS OF MINING

The Panel notes that there are other social and economic impacts of coal mining which do not fall within its terms of reference. Most particularly, these include impacts associated with surface disturbance from mining activities – such as pit-top facilities, the West Cliff Coal Wash Emplacement Area, ventilation shafts and exploration activities. These cause impacts on surface water. They may be of particular significance within the Special Areas.

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4 Subsidence Impacts on Natural Features

As noted in the Introduction, the Panel has drawn a distinction between *subsidence effects*, *subsidence impacts* and the environmental *consequences* of those impacts.

The Panel has used the term *subsidence effects* to describe subsidence itself – ie deformation of the ground mass caused by mining, including all mining-induced ground movements such as vertical and horizontal displacements and curvature as measured by tilts and strains.

The term *subsidence impacts* is then used to describe the physical changes to the ground and its surface caused by these subsidence effects. These impacts are principally tensile and shear cracking of the rock mass and localised buckling of strata caused by valley closure and upsidence but also include subsidence depressions or troughs. The environmental *consequences* of these impacts include loss of surface flows to the subsurface, loss of standing pools, adverse water quality impacts, development of iron bacterial mats, cliff falls and rock falls, damage to Aboriginal heritage sites, impacts on aquatic ecology, ponding, etc. Before examining 'subsidence impacts' in the Southern Coalfield, it is best to first describe the various 'subsidence effects'.

4.1 SUBSIDENCE EFFECTS

4.1.1 Subsurface Subsidence Effects

When a roof fall occurs above an extracted coal seam, the strata do not shear off vertically at the edges of the excavation but continue to extend out over the excavation as shown in Figure 11. In a narrow excavation, this behaviour causes the roof fall to 'dome out' within a few metres, with a cavity remaining between the top of the fallen material and the base of the overlying bridging strata. The disturbance to the overlying strata is negligible at this stage. As the excavation is made wider, the roof has to cave to a greater height in order to dome out and arrest the fall, although sometimes caving may be arrested by the presence of a particularly competent bed in the roof. The thickness of the overlying strata is reduced as the fall extends higher into the roof, leading to an increase in the sag of these strata.

Figure 11: Example of Caving Developing Underground

The caved material bulks and occupies a greater volume when it falls (see Figure 11). A point is reached where, with increasing excavation width (W), the roof fall will choke itself off and act as a cushion to the overlying strata (see Figure 12). It is known from theoretical calculations and field measurements that this *caving height* typically ranges from 3 to 10 times the mining height, depending on the nature of the roof strata. Highly-laminated strata tend to fall like a deck of cards and so have a low bulking factor, resulting in the caved zone extending to a considerable height. Falls comprising blocky material, such as sandstone, tend to bulk up and choke off quickly. The caving height defines the limit of the *caved zone* shown on Figure 12.

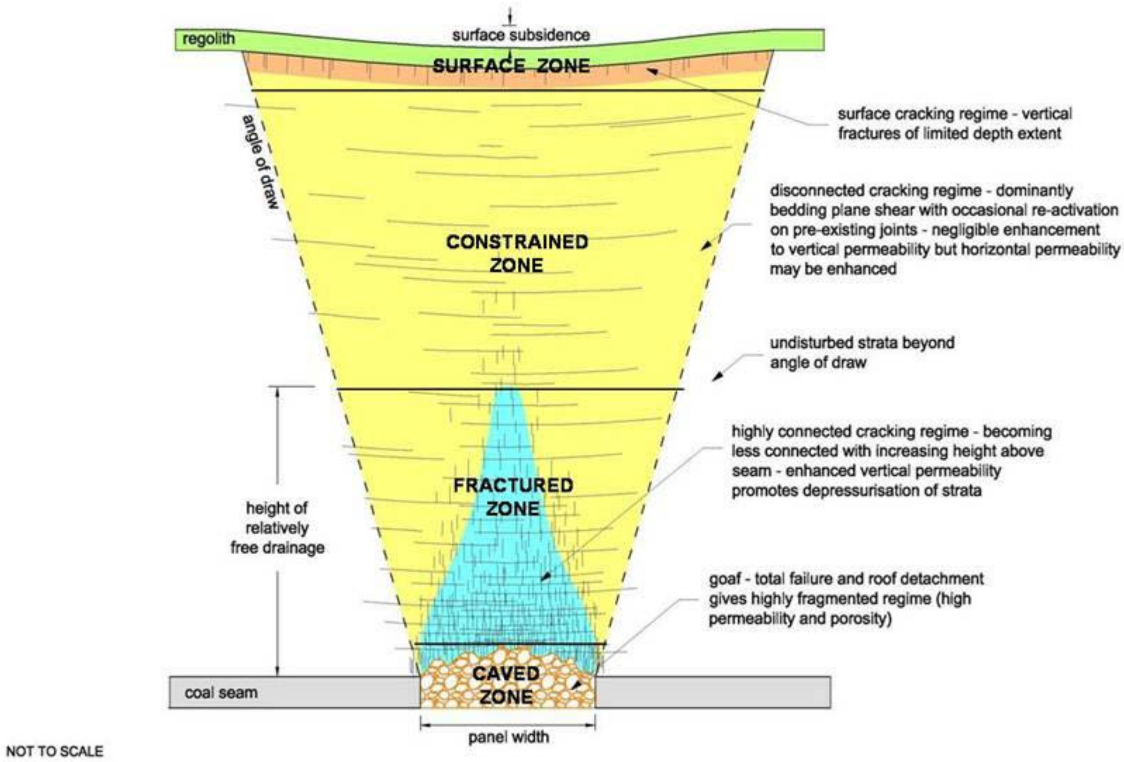


Figure 12: Conceptual Model of Caving and the Nature of Fracturing above a Mine Excavation

Source: Adapted from Wyong Areas Coal Joint Venture

Sag of the overlying strata continues to increase as the excavation is made wider. Mining excavations which result in this situation are referred to as being of *sub-critical span* or *sub-critical width*. Ultimately a point is reached where the full dead weight of the overburden rests on the compacted caved material and a point of maximum sag (ie vertical subsidence) is reached. This excavation width is referred to as the *critical span* or *critical width*. Further increases in excavation width cause negligible additional sag of the overburden towards the excavation, with the excavation width then being referred to as s*uper-critical width* or *super-critical span*.

The overburden is usually comprised of near-horizontally bedded strata. Sag results in each stratum being 'stretched' and placed into tension. Because rock is very weak when under tension, this is conducive to the opening up of existing geological joints and the formation of fresh near-vertical fractures. In the process of sagging, shearing also occurs along the bedding planes between and within the various strata. Fresh near-horizontal fractures may also be formed. These sliding surfaces can develop into open cracks, which may become quite wide if the lower bed of rock sags more than the adjacent upper bed. Hence, a well developed and connected vertical and horizontal fracture network is likely to exist in the rock mass immediately overlying the caved material in a goaf. This network defines the *fractured zone* (see Figure 12).

The lateral extent of sag increases with distance above the excavation. This results in a decreasing rate of deflection, or *curvature,* in the upper strata and a corresponding reduction in shear and tensile stresses. Given sufficient depth, a point is reached where the tensile stresses become too low in the upper strata to cause joints to open or new vertical fractures to develop on a regular or continuous basis. Horizontal fracture planes may still be activated as a result of sagging strata sliding past each other but the magnitude of these displacements also reduces as curvature decreases. The zone in which this behaviour occurs is referred to as the *constrained zone* (see Figure 12). It is characterised by strata which have not suffered significant alteration of their physical properties, and therefore there is negligible change in vertical permeability and only a slight increase in horizontal permeability. The *surface zone* lies above the constrained zone.

This conceptual model of caving and rock mass behaviour, illustrated in Figure 12, has been developed over many decades on the basis of a range of field instrumentation, testing and monitoring and computer based modelling. Most studies have recognised the four separate zones of behaviour although there are variations in terminology. Whilst the model provides the basis for understanding how the subsurface responds to mining, it is not a complete or universally applicable model as it is based on rock mass behaviour above only one isolated excavation and it does not take account of how rock mass response is modified when very competent or massive strata units are present in the roof strata.

4.1.2 Conventional Surface Subsidence Effects

The conventional or general model of surface subsidence, which finds worldwide acceptance, is based on assuming the following site conditions:

- the surface topography is relatively flat;
- the seam is level;
- the surrounding rock mass is relatively uniform and free of major geological disturbances or dissimilarities;
- the surrounding rock mass does not contain any extremely strong or extremely weak strata; and
- the mine workings are laid out on a regular pattern.

As all of these conditions may not be present in practice and as such, the conventional model needs to be refined and adapted to site specific conditions.

The behaviour of a single, or isolated, excavation provides the basis for the conventional model of subsidence behaviour. When a stable excavation is formed in a rock mass, the weight of the undermined strata is transferred to the abutments of the excavation. This extra load results in compression of the coal seam and the immediate roof and floor strata of the coal seam around the perimeter of the excavation. The abutments continue to be subjected to increased load and, therefore, compression, when caving is initiated because a portion of the undermined strata cantilevers off the abutments, out over the goaf (see Figure 11). Therefore, surface movement results from a combination of sag of the roof strata into an excavation and compression of the strata that comprises the abutments of the excavation. This results in surface movement extending beyond the footprint of the excavation. In practice, coal mine workings effectively comprise a series of excavations separated by pillars, and so surface movement is determined by both excavation behaviour and the behaviour of the coal pillars and the strata above and below them.

In flat topography, the surface above coal mine workings usually subsides in the form of a subsidence trough, taking on a saucer-shaped appearance. The *angle of draw* is a subsidence engineering term used to define the limits of the subsidence trough. It is the angle between two lines drawn from the edge of the mine workings, one a vertical line and the other a line to the limit of vertical displacement on the surface as indicated in Figures 12, 13 and 14. Because surface movements can also be caused by natural effects such as seasonal variations or drought leading to swelling or shrinkage of near-surface soil and sediment, it can be very difficult to identify where vertical movement due to mining ceases. Therefore, it is standard practice to specify a limiting value for vertical displacement which might be attributable to mining. In New South Wales, this value is usually 20 mm of vertical subsidence. It should be noted that, in some environments, up to 50 mm or more of vertical movement may occur due to seasonal climatic changes.

When the surface subsides in the shape of a trough, it curves outwards near the perimeter of the trough and inwards towards the centre of the trough, as shown in a grossly exaggerated manner in Figures 13 and 14. This behaviour is referred to as *curvature***.** Curvature is expressed in terms of the radius of a circle that would result in the given curvature, which is usually of the order of kilometres.

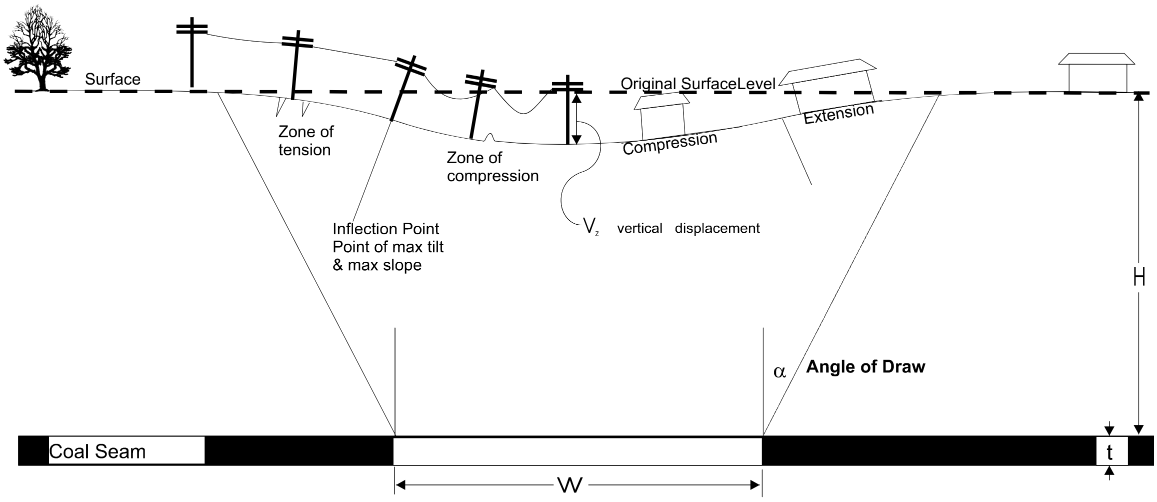


Figure 13: Diagrammatic Representation of Surface Subsidence Components in Flat Topography

Note: Vertical scale grossly exaggerated.

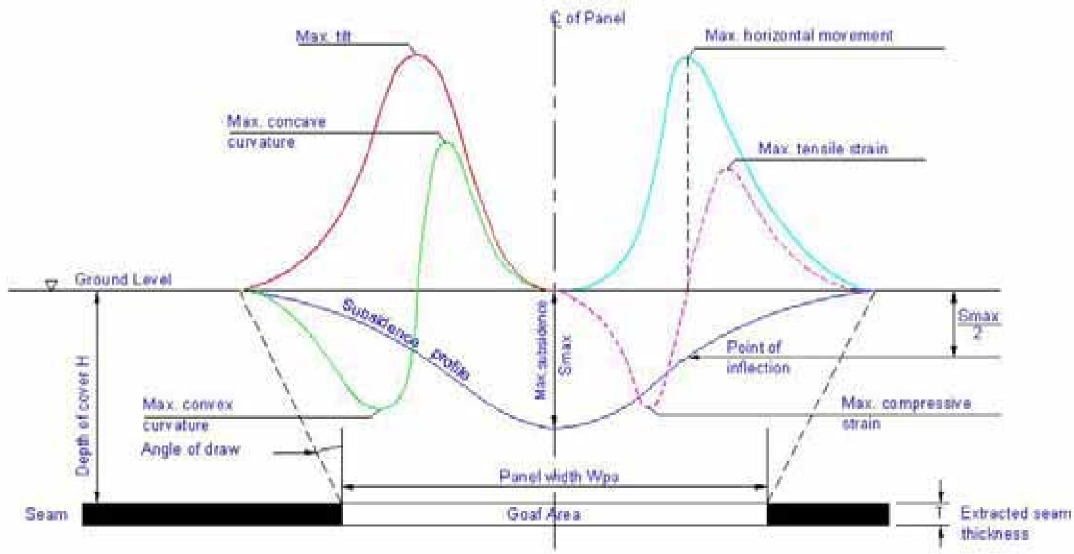


Figure 14: Graphical Representation of Behaviour of Surface Subsidence Components in Flat Topography

Note: Vertical scale grossly exaggerated.

Curvature in an outwards direction results in the ground 'stretching' or 'hogging' and is referred to as *convex curvature***.** Curvature in an inwards direction causes the ground to sag and move closer together and is referred to as *concave curvature***.** Hence:

- curvature results in points on the surface moving in both a vertical direction and a horizontal direction as they subside into a subsidence trough;

- curvature changes the slope, or horizontal level, of the surface which, in turn, changes the tilt, or vertical level, of surface features;
- convex curvature induces tension on the surface;
- concave curvature induces compression on the surface;
- bending is induced in long features located on curvature surfaces; and
- near-surface strata may shear along bedding planes and fresh fracture surfaces as they bend and subside into the subsidence trough.

Figures 13 and 14 illustrate the subsidence profile in only two dimensions. In reality, this type of profile extends longitudinally down the length of a mining panel and also transversely across the width of the panel. Therefore, points on the surface can be subjected to displacement in three dimensions within a subsidence trough. The *vertical component of displacement,* V_z, is also referred to loosely as 'subsidence'. The horizontal component of displacement across the width of the panel is referred to as the *transverse component of horizontal displacement,* V_x; the horizontal component of displacement in the direction that panel is running (extraction is retreating) is referred to as the *longitudinal component of horizontal displacement,* V_y.

When two adjacent points undergo a different amount of vertical displacement, the slope of the ground surface between them changes, which then induces tilt in features located on this surface. Both induced slope and induced tilt are expressed in terms of millimetres/metre. In the case of slope, this represents millimetres of change in ground level per metre of distance. In the case of tilt, it represents millimetres of change from vertical orientation per metre of height above the ground. As mining approaches a site, the site will begin to tilt towards the excavation (see Figures 13 and 14). Maximum tilt occurs at the *point of inflection* between concave and convex curvature. If the zone of concave curvature then passes beneath the site, the site will start to tilt back in the opposite direction and, if the mining area is sufficiently large, it will in theory ultimately return to its original vertical inclination (see Figures 13 and 14).

The amount of horizontal extension or compression induced over a given distance on the surface is expressed in terms of *strain*. Strain is also expressed in terms of mm/m; that is, millimetres of stretch or millimetres of shortening per metre of distance. As the edge of an excavation is approached from the solid side, tensile strain begins to increase and builds up to a maximum value which usually occurs over the excavation. From that point, there is a gradation from the point of maximum tensile strain, through a point of zero strain, to a point of maximum compressive strain, Figures 13 and 14. Surface strain changes from tensile to compressive at the *point of inflection*.

Two points which need to be appreciated when dealing with differential movements are:

- although slope and strain are expressed in terms of mm/m, the differential ground movements may not be uniformly distributed in this manner. In particular, tensile strain may accumulate at specific cracks or natural joints. Typically, the width of these cracks ranges from several hundred millimetres at depths less than 250 m to the order of 20 to 30 mm at depths approaching 500 m; and
- buckling of near surface strata under the effects of high compressive strains can cause cracking which has the appearance of being tensile in origin. This is a localised and superficial effect associated with failure of a thin surface layer of the rock mass, with the deeper rock mass continuing to be subjected to compression.

The simplest case of a single, or isolated, excavation surrounded by solid abutments provides a basis for understanding the manner in which subsidence develops. The overburden above the excavation can be conceptualised as behaving as a beam. For a constant excavation width (ie beam span or 'W'), overburden sag will increase as depth (beam thickness or 'H') decreases. Conversely, for a constant depth of mining ('H'), overburden sag will increase with increase in excavation width ('W'). Hence, in both instances, overburden sag can be expected to increase with increasing W/H ratio. As already noted, compression of the panel abutments results in additional vertical displacement. In subsidence engineering, it is standard practice to express maximum vertical displacement, V_z, as a fraction of the mining height, h. This relationship (V_z/h) is known as the *subsidence factor.* Figure 15 shows subsidence factor plotted against W/H ratio for longwall operations in a number of coalfields throughout the world. Bord and pillar mining, in which the roadways are very narrow compared to depth, would fall at the extreme left of the curve, where subsidence is negligible. The different curves reflect the different geology of the various coalfields.

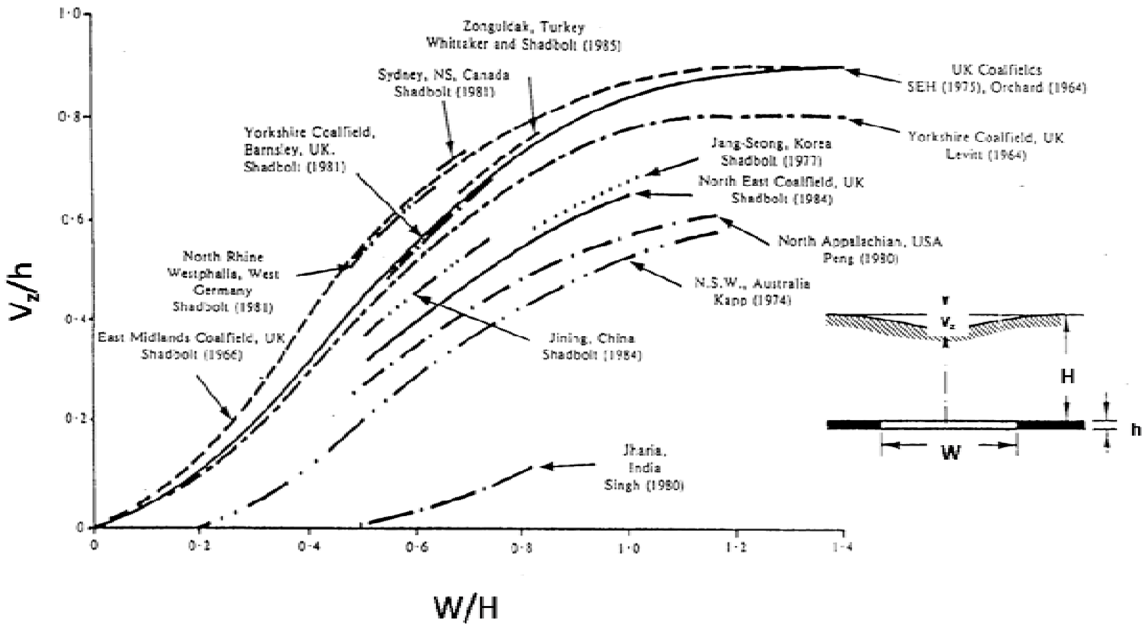


Figure 15: Effect of Panel Width (W) and Depth of Mining (V_z) on Extent of Surface Subsidence in Various International Coalfields

Source: adapted from Whittaker and Reddish, 1989

When the depth of cover is low (typically H less than 150 m) and the excavation width to depth ratio is high (typically W/H greater than 1.6), subsidence over each excavation may develop independently of that over the adjacent panels. The additional abutment load on the interpanel pillars is restricted because the strata over the excavations collapse to surface and because the overburden load acting on the pillars is low. This results in near symmetrical subsidence profiles like those shown in Figure 16 for a longwall operation at shallow depth in the Newcastle Coalfield of NSW, with compression of the pillars between the panels (the *chain pillars*) making only a minor contribution to vertical displacement. In these circumstances, over 90% of the final vertical displacement, tilt and strain at a surface point is usually reached within weeks of the completion of mining beneath. In such circumstances, there is usually a high degree of predictability for subsidence profiles, and the close correlation between predicted and observed outcomes can also be seen in Figure 16.

As depth of cover increases, a greater proportion of the weight of the overburden above an excavation is transferred onto the panel abutments. The stiffness of the overburden also increases as it becomes thicker. Hence, a number of adjacent panels may need to be extracted before the overall mining span is sufficiently large to result in the full deadweight load of the overburden acting on the mine workings. When this occurs, the interpanel pillars are subjected to very high loads. In such circumstances, compression of these pillars and the surrounding roof and floor strata makes a significant and, often, the major contribution to vertical displacement. This behaviour is illustrated in Figure 17 for a longwall mine in the Southern Coalfield of NSW. It should be noted that predictability of both incremental and final subsidence profiles is also quite high.

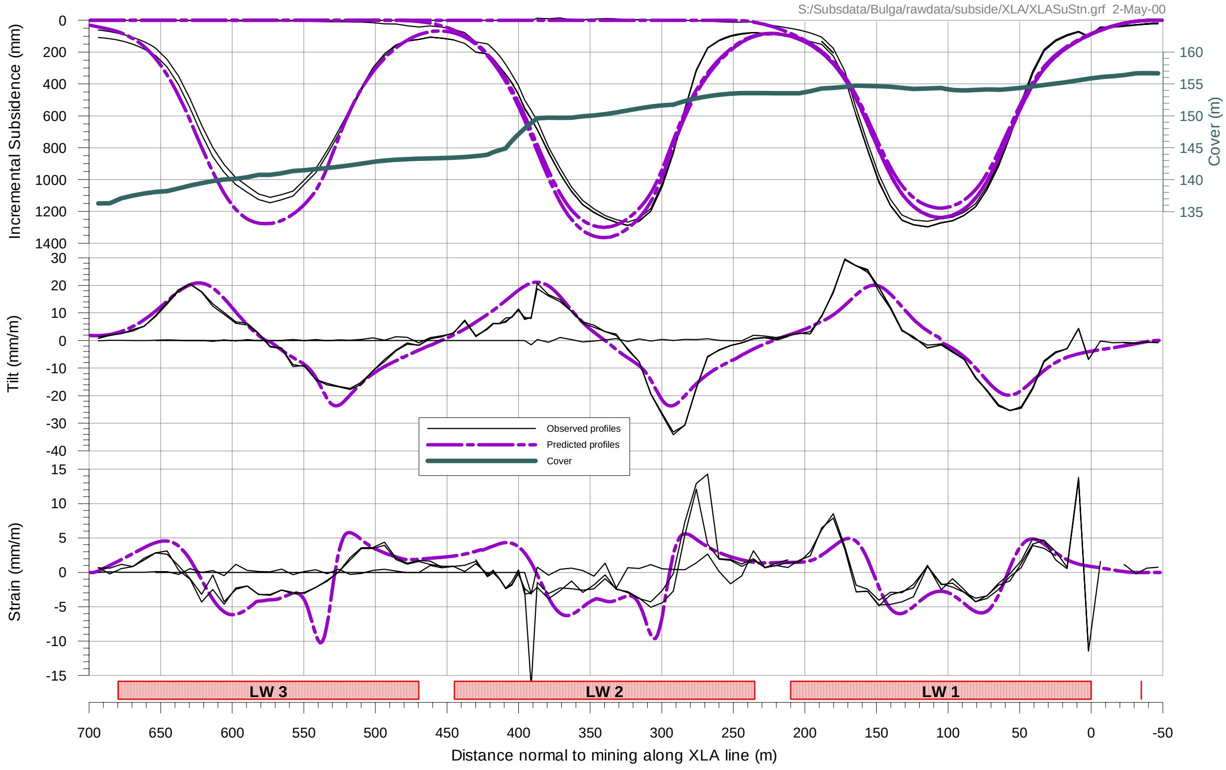


Figure 16: Predicted and Observed Vertical Displacement, Tilt and Strain Profiles at Shallow Depth

Note: The 3 panels are located in the Newcastle Coalfield and are around 210 m wide with a depth of cover of 80 m. Source: MSEC.

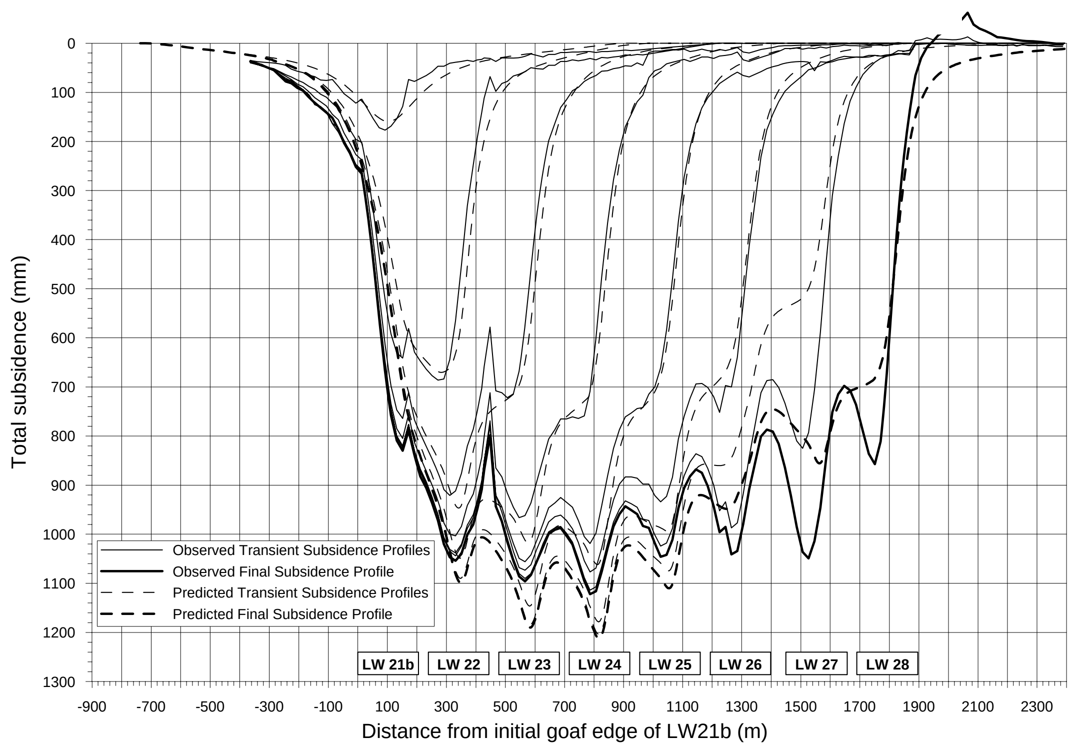


Figure 17: Successional Development of Vertical Displacement

Note: The 8 panels are located in the Southern Coalfield and are around 210 m wide with a depth of cover around 500 m.

Figure 17 shows that limited vertical displacement occurred over the first longwall panel extracted, being longwall 21b. Extraction of longwall 22 resulted in a large step increase (in fact, a five fold increase) in vertical displacement over longwall 21b. The additional vertical displacement that occurred when longwall 22 was extracted is referred to as *incremental* displacement. The overall vertical displacement profile at any point in time is found by summing the incremental profiles up to that point in time. Figure 17 also shows that vertical displacement over longwall 21b continued to increase in increments during extraction of the next four longwall panels, albeit at a diminishing rate after longwall 22. Hence, it might be several years after initial undermining before final vertical displacement, tilt and strain are reached at a point on the surface in this kind of mining environment.

All points on the surface do not experience the full range of subsidence effects. Depending on their location in the subsidence trough, some points may return to a state of near zero strain, tilt and slope after subsiding into the trough. Others on the flanks of a trough may be left in a state of induced tilt, induced slope and tensile or compressive strain. This state may or may not be permanent, depending on whether an adjacent panel is subsequently extracted. If the effect is permanent, the consequences can range from negligible to severe, depending on the magnitude of the subsidence parameters, the nature and position of affected surface and surface features, and the extent and effectiveness of mitigation and remediation measures.

The various subsidence parameters associated with this conventional, or general, model of subsidence behaviour are sometimes referred to as the *systematic* components of subsidence, whist those associated with site-specific behaviours are referred to as *non-systematic*. This distinction in subsidence behaviour can be misleading since most site specific features also respond to undermining in a systematic manner. This Inquiry has maintained the convention of treating subsidence outcomes based on the conventional model of subsidence behaviour as being the standard or norm, and then adapting these to take account of variations created by the effects of the presence of specific natural features.

4.1.3 Non-Conventional Surface Subsidence Effects

As indicated in section 4.1.2, the conventional or general model of surface subsidence is based on the presence of straightforward and uniform site conditions, including:

- the surface topography is relatively flat;
- the surrounding rock mass is relatively uniform and free of major geological disturbances or dissimilarities; and
- the surrounding rock mass does not contain any extremely strong or extremely weak strata.

Where these conditions are not met, surface subsidence effects vary from those that would be predicted using the conventional model. Such subsidence effects are generally known as 'non-conventional', although this is somewhat of a misnomer. The subsidence effects remain conventional; what have varied are the site conditions in which they take place. However, for the sake of simplicity, the general terminology is again applied in this report.

The following are the more common site specific variations to the conventional model of surface subsidence. They may be associated with all types of underground mining method; although the type of mining method may affect the extent and magnitude of the variation (ie pillar extraction or longwall mining will generally increase the effects).

4.1.3.1 Massive Overburden Strata

Massive, strong strata in the overburden can be capable of spanning many tens to hundreds of metres without failing. Therefore, these strata retard the development of subsidence and modify the respective contributions to subsidence of overburden sag and abutment compression. Steps may occur in the subsidence trough as a result of the strata breaking in a periodic manner as a series of plates, rather than caving in a regular, smooth manner. These steps in vertical displacement give rise to irregular magnitudes and distributions of tilt and strain. Surface uplift of the order of tens of millimetres can also occur around the edges of excavations due to the 'seesaw' effect of the competent strata cantilevering out over the goaf. If the massive unit is well defined, such as the dolerite sills that overlie South African coal mine workings, the situation can be controlled by either making mining panels sufficiently narrow that the massive strata will not fail, or sufficiently wide that the strata breaks soon after the commencement of mining and at regular and frequent intervals thereafter (Galvin, 1982).

4.1.3.2 Pillar Foundation Settlement or Failure

One of the most common means of restricting surface subsidence to a designated level is to limit the width of the mining excavations. This approach depends on the system of coal pillars between the mining excavations being strong enough to support the combined weight of the overburden immediately above the pillars, the undermined roof strata that cantilevers off the pillars and the strata that bridge across the goaves. Four interrelated factors by which subsidence may come to exceed pillar design strength in these situations are:

- direct pillar failure due to the pillar load exceeding the pillar strength;
- compaction (settlement) of the roof or floor strata under the effects of pillar load;
- punching of the coal pillars into the roof or floor strata; and
- indirect pillar failure caused by soft and weak strata roof or floor being extruded and pulling the pillars apart in tension.

Pillar system failure may take a considerable period of time to develop, especially where it is associated with soft or weak roof or floor strata. Mining may have been completed in the area many years earlier and that area, or even the mine, abandoned before instability becomes apparent. This behaviour is mainly confined to bord and pillar based systems.

4.1.3.3 Steep Topography

In steep topographic environments, gravity can result in high levels of ground movement in a downhill direction. One effect of this behaviour is that tensile strain accumulates towards the top of hill sides rather than being distributed down the hill sides. This can give rise to one or more wide, open surface cracks on the topographical high sides of the mine workings and compression humps in topographical lows, in locations that do not correspond to those depicted in Figure 14.

4.1.3.4 Valleys and Gorges

It is often the case that coal seams were once buried at significantly greater depth than where they are found today. As erosion has taken place over geologic time, the vertical (loading) stresses have been relieved but a component of the horizontal stress remains locked in the seams and surrounding strata. Tectonic processes associated with the movement of continental plates may have imprinted additional horizontal stresses, which are often strongly directional. Therefore, it is not uncommon in coalfield strata for the horizontal stress in at least one direction to be up to three times greater than the vertical stress. These circumstances exist in the Southern Coalfield.

Steep, incised topography interrupts the transmission of horizontal stress, causing it to be re-directed from the hills and into the floor of the valleys or gorges. This can lead to overstressing of valley floors, with the near-surface rock strata uplifting under the effects of bending and buckling. The valley is deepened which, in turn, causes an increase in the horizontal stress redirected into the floor of the valley. This very slow, self perpetuating natural process is referred to as *valley bulging*. Field investigations have revealed that it can result in the creation of voids beneath water courses, often in the form of open bedding planes which may act as underground flow paths for groundwater and stream water (Patton and Hendren, 1972, Fell et al, 1992, Everett et al, 1998, Waddington Kay, 2002). This natural underground flow of a stream is referred to as underflow. It can occur independently of the surface flow or the two flow paths may intermittently connect.

Mining causes further disruptions to this natural regional horizontal stress system because:

- it creates a void which then redirects horizontal stress into the roof and floor of the void. The effective height of the void is increased if fracturing and/or caving of the undermined strata occur. If a constrained zone exists above the mine workings, some of the horizontal stress will be redistributed through this zone (see Figure 18). This increases the horizontal stress acting across the valley floor; and

- it removes or reduces the resistance to horizontal movement in the zone comprised of caved and fractured material, thereby permitting the surrounding rock mass to relax and to move towards the excavation.

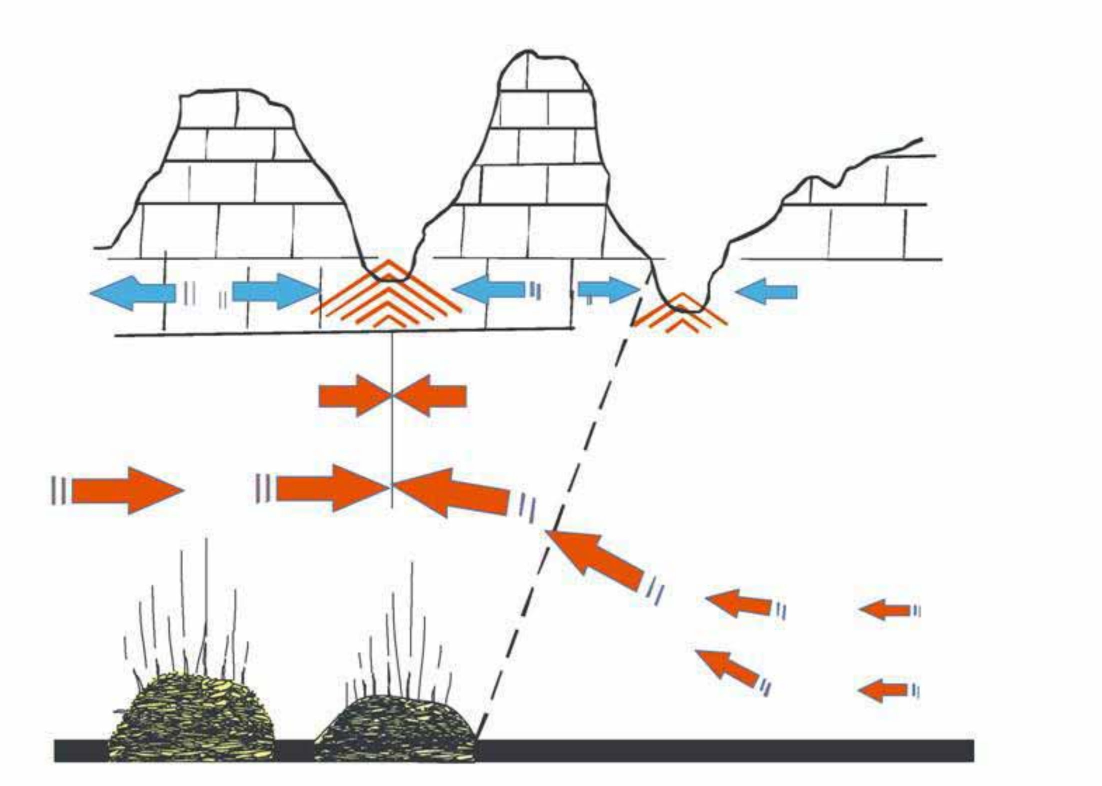


Figure 18: Conceptual Distribution of Horizontal Stress above Mine Workings in Deeply Incised Topography

Note: Natural, regional stress shown in blue; mining induced stress shown in red.
Source: Adapted from Galvin, 2005

Two responses arising from these mining-related stress behaviours are:

- *valley closure*, whereby the two sides of a valley move horizontally towards the valley centreline; and
- *uplift* of the valley floor, as a result of valley bulging and buckling and shearing of the valley floor and near surface strata.

The ground movements that occur around excavations in steeply incised terrain in a high horizontal stress environment are complex and it is difficult to identify the individual contribution of the various components to these movements, which include:

- conventional subsidence movements;
- elastic ground movements associated with redistribution of horizontal stress on a regional basis;
- movements associated with localised buckling and shear failure; and
- gravity-induced downhill slippage.

Some of these components may operate simultaneously in opposite senses. For example, an area may be subject to downwards vertical displacement at the same time that it is being subjected to upwards valley bulging.

Valley closure is not significantly influenced by the orientation of the valley relative to the mining layout or to the goaf (see Figure 19). In the steep-sided Cataract and Nepean River Gorges, it has been found that the closures in the sides of the gorges were almost mass movements with little differential shear displacement between different horizons in the strata. Closure at the base of the

Cataract Gorge was some 86% of that at the top of the gorge. It is reported that in V-shaped valleys, a large proportion of the closure also occurs in the bases of the valleys but in some cases closure is noted to occur at horizons above the bases of the valleys. This observation from measured data was supported by numerical modelling work by CSIRO, which indicates that in V-shaped valleys, some of the shearing occurs along weaker horizons in the valley sides.

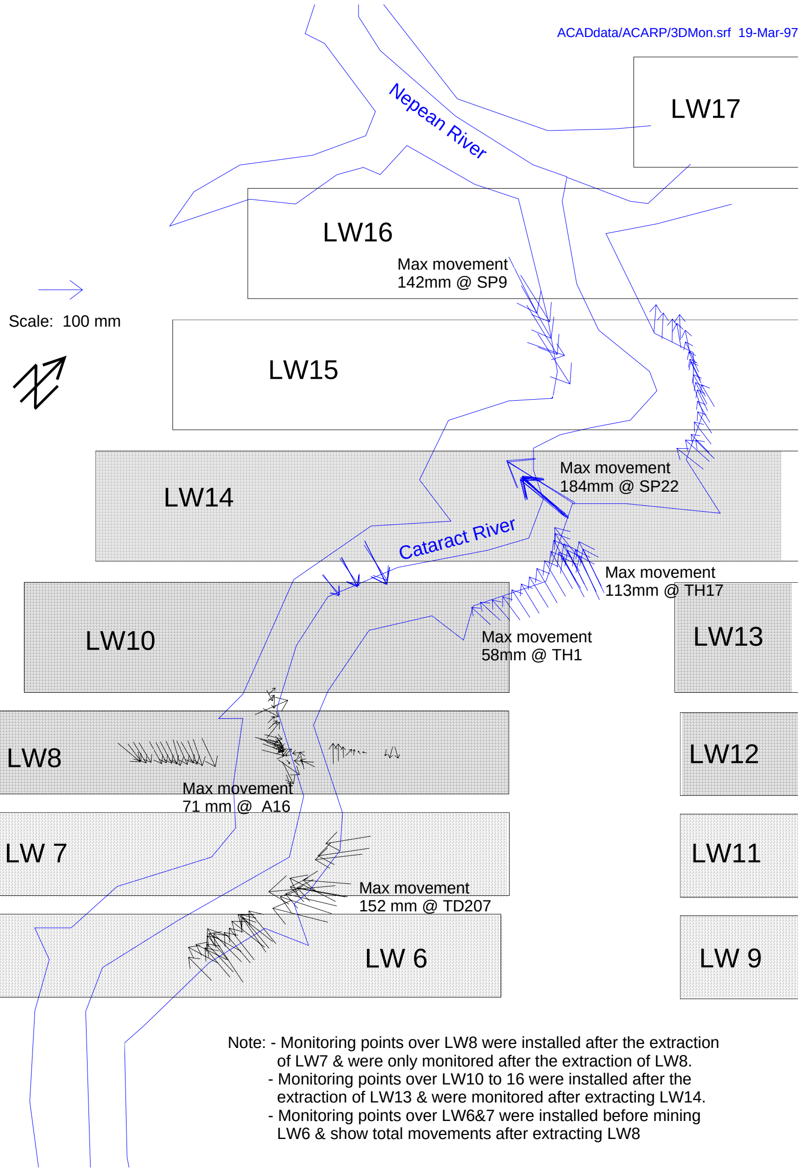


Figure 19: Valley Closure Measurements across Cataract Gorge, Appin Colliery

Source: MSEC

Valley closure in excess of 460 mm has been measured at one site in the Cataract Gorge, with the maximum rate of closure occurring in that time between when the traveling longwall face passed beneath the gorge until the face was 200 m past it. Closure was effectively completed by the time that the face was 500 m past the gorge (Hebblewhite et al, 2000). Significant relative uplift also occurred at the site. Higher closures have been measured in steep valleys in the Western Coalfield but associated uplift levels have been considerably less. Valley shape has an effect on both closure and uplift. Whilst closure is also known to occur in wide flat valleys, such as exist in the Newcastle Coalfield, the magnitude of the closures is smaller, by comparison. Geology can also impact on closure, with higher closures typically occurring in shale strata. In some instances, valley closure can be followed by a degree of valley opening as the valley is then impacted upon by conventional subsidence displacements.

The term *upsidence* has been used by subsidence engineers for some time to describe different types of upward vertical movement or uplift. In some instances it describes the absolute upward vertical movement of the surface at the edges of a region of subsidence influence, associated with massive strata cantilevering, such as described earlier. However, the more common, and widely accepted current use of the term, is associated with the types of valley effect described above, where there is a component of relative upward movement, or uplift, created by the horizontal compression and buckling behaviour of the rock strata in the vicinity of the valley floor. This is the sense in which the term upsidence is used in this report. Upsidence is therefore the relative upward displacement that occurs due to mining subsidence effects specifically associated with irregular surface topography such as valleys and gorges. Whereas mining subsidence of flat-lying surface topography normally produces net downward vertical displacements over a region above and adjacent to mining, in the case of valleys, valley closure and valley floor buckling lead to a certain amount of uplift of the valley floor, superimposed on the conventional downward subsidence displacement. Upsidence is a measure of this relative uplift, compared to the conventional downwards displacement that would have been expected, had the terrain been relatively flat. Depending on the relative magnitudes of upsidence and conventional downward subsidence displacements, the absolute amount of vertical displacement in valley floor regions is normally still downward, but at a reduced level due to upsidence. However in some circumstances, the value of upsidence can exceed the conventional downward movement, leading to an absolute uplift of the valley floor. It is a phenomenon that is not confined to underground mining situations. Similar behaviour has been observed in civil and mining surface excavations when slots are excavated in material subjected to elevated horizontal stress.

Figure 20 shows an example of an idealised upsidence profile constructed on the basis of measurements in the Cataract Gorge over the centreline and the side abutments of Longwall 8 at Tower Colliery. Upsidence extended over a lateral distance of some 300 m either side of the centre of the 150 m wide gorge. It peaked at 350 mm in the centre of the gorge, dropping off to about 100 mm at the cliff lines. Upsidence was projected to drop to 35 mm some 100 m over the solid. Upward buckling of the near surface rock occurred in the central portion of the gorge. A further 300 mm of upsidence occurred when the adjacent longwall panel was extracted, resulting in the base of the gorge ending up higher than its original pre-mining ground level.

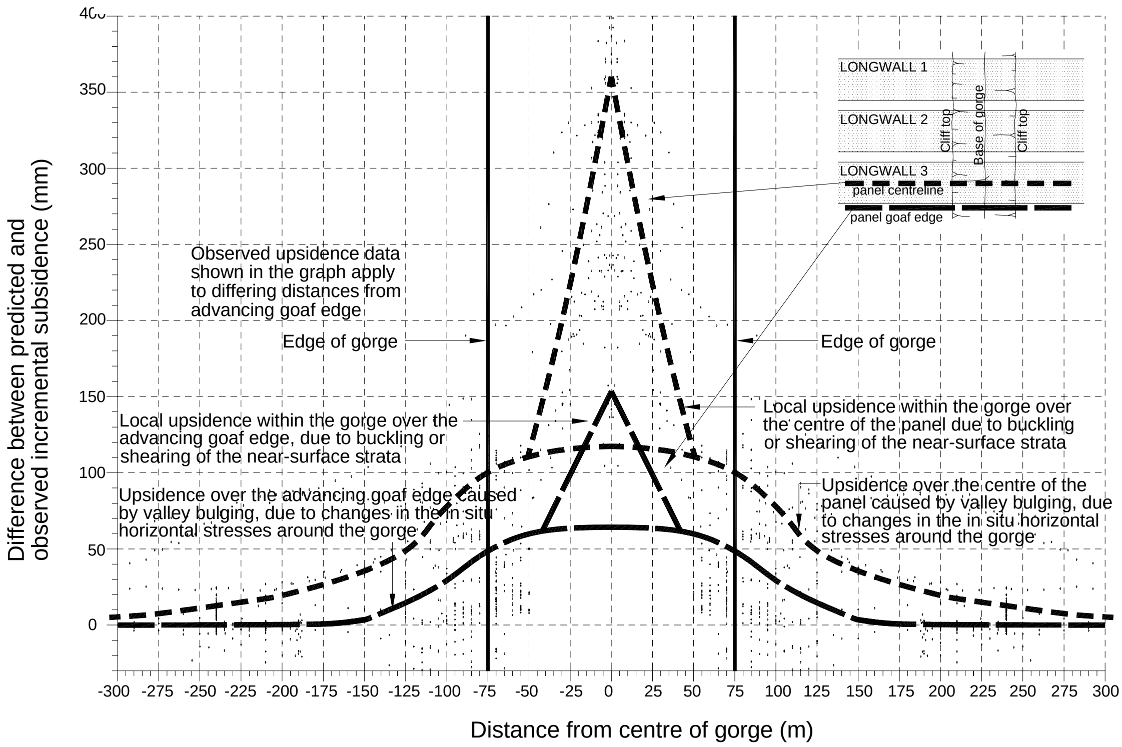


Figure 20: Idealised Upsidence Profile at Tower Colliery in the Cataract Gorge

Source: MSEC

Buckling and shear in the near-surface strata, which leads to upsidence, can also generate an extensive network of fractures and voids in the valley floor. Ground movements due to conventional subsidence can also contribute to the formation of this network if the upsidence occurs within the angle of draw of the mine workings. The formation of an upsidence fracture network has been monitored in detail at Waratah Rivulet (overlying longwall panels at Metropolitan Colliery) for a number of years using an array of surface and subsurface instrumentation (Mills, 2003; Mills and Huuskes, 2004; Mills, 2008). This has revealed that the network becomes deeper with the passage of each longwall in its vicinity. The main fracture network extends to a depth of about 12 m and bed separation extends to a depth of some 20 m (see Figure 21). In general, the extent and intensity of the fracture network increases with upsidence which, in turn, increases with subsidence.

Figure 22 typifies the buckling, bed separation, extensive vertical fracturing and 'popping up' of slabs of rock observed by the Panel in Waratah Rivulet. Figure 23 shows shearing along bedding planes at the surface, resulting in the overriding of slabs or beds of rock.

Figure 24 is a down-hole photograph taken in a shallow drillhole at a remediation site in the Waratah Rivulet. The photograph clearly shows evidence of horizontal shearing which has taken place after the drilling. The rock displaced into the previously-circular drillhole also shows evidence of iron staining. This late stage horizontal shearing may have been associated with reactivation of an existing shear following passage of an additional longwall near the site.

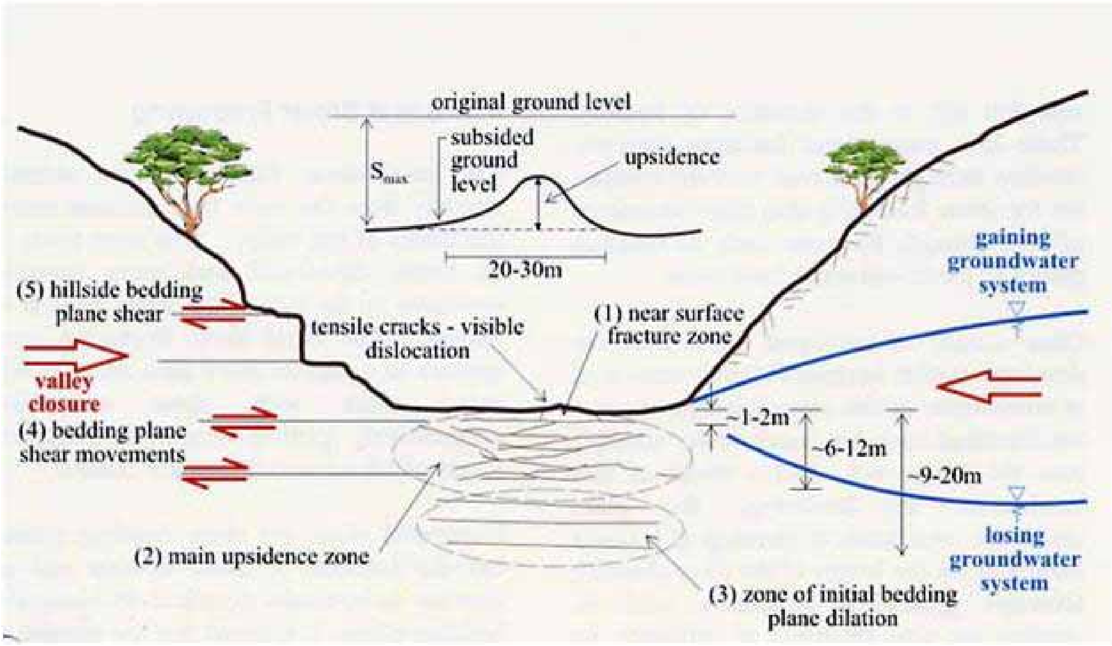


Figure 21: Upsidence Fracture Network Determined from Surface and Subsurface Monitoring, Waratah Rivulet at Metropolitan Colliery

Source Mills, 2008

Figure 22: Buckling of Near-Surface Strata due to Upsidence, Waratah Rivulet, late 2004

Note: Iron staining within the water course.

Figure 23: Shearing along Bedding Planes, Causing Override of Bedding Slabs, Waratah Rivulet, September 2007

Note: Iron staining within the water course.

Figure 24: Incremental Subsurface Horizontal Shearing in a Vertical Borehole, Waratah Rivulet, 2007

Some significant observations regarding valley closure and upsidence are:

- both types of behaviour have been observed to occur up to several hundred metres beyond the conventional angle of draw, but at greatly reduced magnitude;
- the movements develop incrementally with each panel extracted;
- incremental vertical subsidence leads to incremental upsidence and valley closure;
- both valley closure and upsidence are often greater in the presence of a headland; and
- the behaviours can also be associated with gentle valley systems and creek beds, albeit that the magnitudes of the closure and upsidence movements are less.

It is only in the last 15 to 20 years that the effects of underground mining on valley closure and upsidence, on a regional scale, have come to be widely recognised, particularly in the Southern Coalfield where the nature of the surface topography leads to such effects. Whilst a fundamental understanding of the mechanisms which cause this type of behaviour has been developed, the detailed mechanism(s) and hence full extent of this type of behaviour requires further research.

4.1.3.5 Regional Far-Field Horizontal Displacement

In the last 20 years, mining induced, en-masse horizontal displacement of the surface has been detected in the Southern Coalfield for up to several kilometres from the limits of mining. These regional-scale movements are generally greatest at the goaf edge and decrease with increasing distance from the goaf. One of the first publications on the issue was by Reid (1998), who noted horizontal movements of some 25 mm up to 1.5 km from mine workings. Hebblewhite et al (2000) reported horizontal displacements in excess of 65 mm towards mine workings that were 680 m away (where mining was at a depth of approximately 450 m). These movements reduced to 60 mm at a distance of 1.5km from the workings, see Figure 19. Most of the horizontal movement takes place toward the gorges and active mining areas, although some has been recorded towards old goaf areas.

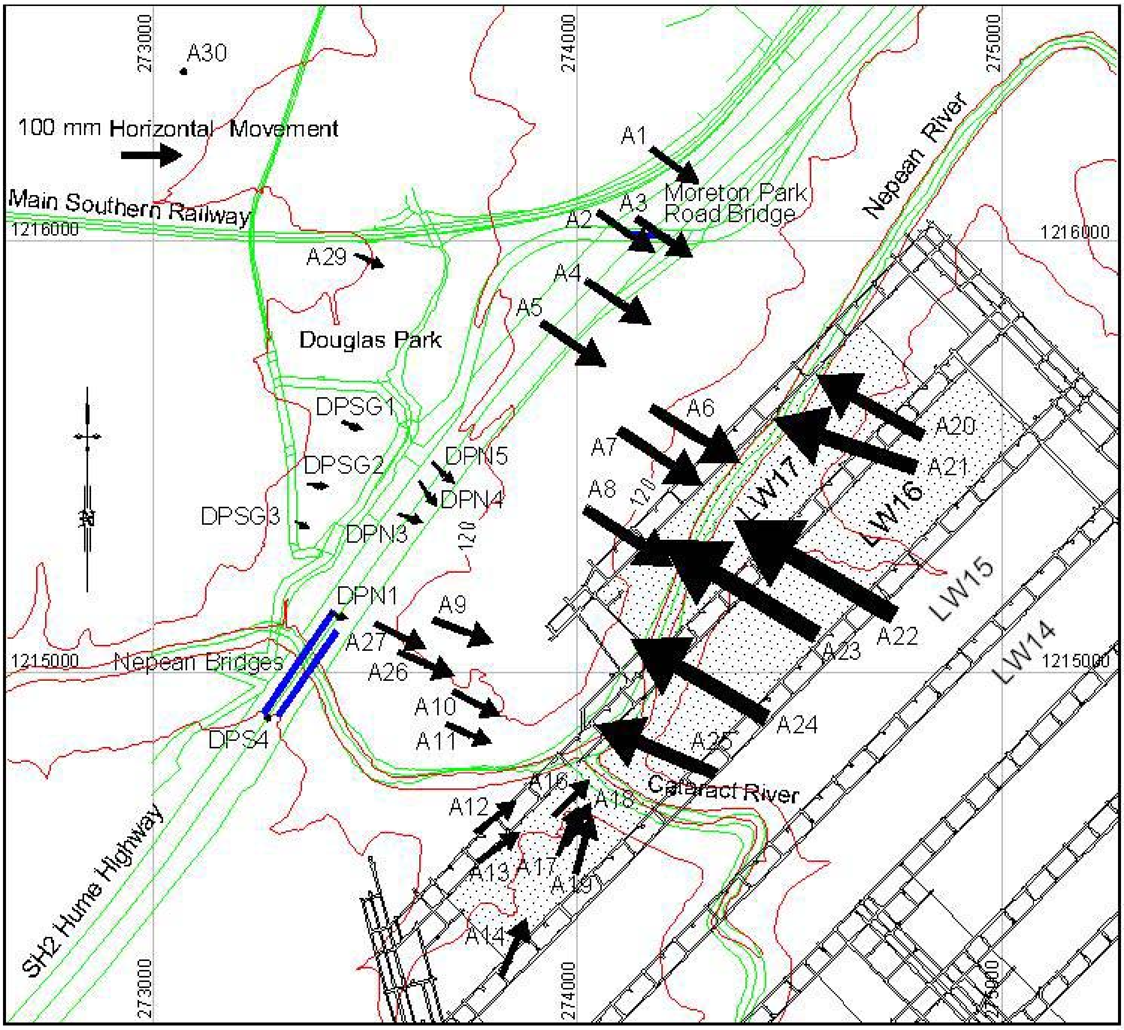


Figure 25: Valley Closure and Far-field Horizontal Movements near Cataract and Nepean Gorges

Source: Hebblewhite et al, 2000

This behaviour is not fully understood by subsidence engineers. A range of possible causes of valley closure, upsidence and far-field horizontal movements are under review. These causes include one or a combination of:

- simple elastic horizontal deformation of the strata within the exponential 'tail' of the subsidence profile that applies in conventional circumstances;
- influence of valleys and other topographical features which remove constraints to lateral movement and permit the overburden to move 'en masse' towards the goaf area, possibly sliding on underlying weak strata layers;
- unclamping of near-surface horizontal shear planes;
- influence of unusual geological strata which exhibit elasto-plastic or time dependent deformation;
- stress relaxation towards mining excavations;
- horizontal movements aligned with the principal *in-situ* compressive stress direction;
- valley notch stress concentrations;
- movements along regional joint sets and faults; and
- unclamping of regional geological plates.

It is important to note that where this type of far-field horizontal displacement has been detected, the levels of horizontal strain are very low. In other words, the differential horizontal movements over a particular length of surface are minimal. Consequently, there has been no evidence to date, of any significant adverse impacts on any natural features from this far-field behaviour. Nonetheless, the recognition of far-field horizontal movements is understood to have been the basis on which some community groups sought a buffer of 1 km between mining and rivers and significant streams.

4.1.3.6 Large Scale Geological Features

Faults and igneous dykes constitute most of the large scale geological features that affect the development of subsidence in the Southern Coalfield, although subsidence can also be affected by other geological features such as igneous sills, synclines, ancient river channels, stone rolls and seam washouts. Faults and dykes can disrupt the transmission of stress within the rock mass and give rise to localised and highly directional stress concentrations which can change the spanning and caving behaviour of undermined strata.

The Panel recognised what it understands to be a significant low angle geological discontinuity in both walls of the Bargo River Gorge, within the major pool known as Mermaid Pool. While no offset of bedding was apparent, the strongly-linear fracture feature was associated with enhanced weathering and erosion and the gully on the eastern side of the pool (see Figure 26) and. Iron hydroxide deposits on bedding planes, forming what are thought to be slickensides, were also identified on rocks exposed in the river bed immediately above the waterfall at Mermaid Pool. Slickensides form during slow, frictional movements along fault planes, joint surfaces or other planes of weakness.

Figure 26: Low Angle Geological Discontinuity in the Walls of Mermaid Pool, Bargo River Gorge

Notes: The geological discontinuity is the strong linear feature running upwards at about 30^o from left to right in the photo. The discontinuity is further represented by the gully which extends upwards at the same angle. Natural iron-stained groundwater is also seeping from bedding planes near the waterfall.

A small, highly weathered dyke (around 1 m thick) was also identified in the gorge wall some hundreds of metres downstream of Mermaid Pool (see Figure 27). Because faults and dykes constitute pre-existing planes of weakness, rock mass failure and displacement are more likely to be associated with slippage along these features. They can therefore induce step changes in the surface profile above mine workings, and shear and horizontal movement for some distance beyond the angle of draw. The unclamping effect of the development of extensive areas of goaf has been known to result in the reactivation of (ie renewed slippage along) fault planes.

Fault and major joint systems have also been associated with subsidence effects in some valleys in the Southern Coalfield. These can give rise to a component of differential lateral displacement along the valley axis.

Figure 27: Weathered Dyke Exposed in the Wall of Bargo River Gorge, Downstream of Mermaid Pool

4.2 SUBSIDENCE IMPACTS AND CONSEQUENCES FOR THE NATURAL ENVIRONMENT

As indicated previously, the Panel has adopted the terminology of referring to subsidence ‘effects’ and subsequent subsidence ‘impacts’. The term ‘subsidence impacts’ is used to describe the physical response of various natural features (for example tensile and shear cracking) due to subsidence ‘effects’. These impacts in turn lead to consequences which may include redirected stream flow, groundwater losses, water discoloration, cliff and rock falls, vegetation die-back, etc.

A number of behaviour mechanisms associated with the development of subsurface and surface subsidence effects may be active simultaneously. Subsidence impacts from these various mechanisms are determined primarily by:

- site specific and regional subsidence-induced changes in the ground that might include displacement, tilt, strain, curvature and changes in rock mass permeability (ie the subsidence effects themselves);
- the nature of the coupling between the ground and the natural feature of interest;
- the nature and condition of the feature of interest; and
- the type and effectiveness of mitigation and remediation measures undertaken.

Given the variable and interactive nature of these factors, it is not possible to consider subsidence impacts only in terms of the subsidence effects in play or only in terms of the nature of the subsurface or surface feature likely to be affected by them. Rather, the interrelationships between these factors have to be assessed on a site specific basis. The following section addresses the general range of subsidence impacts on the range of significant natural features. It incorporates the observations of the Panel, made during its field inspections from August to October 2007. These impacts are summarised in Table 9.

4.2.1 Watercourses

Direct impacts of subsidence on watercourses can include changes to stream bed and bank profiles, cracking of a watercourse bed and the creation or destruction of ponds. These impacts have been observed by the Panel at a number of locations throughout the Southern Coalfield. In turn, these effects have the potential to impact on the flow regime, leakage losses via subsurface cracking, stream water quality, fauna and flora, archaeological features, and amenity. The generation, extent and severity of these impacts are governed very much by site specific features that include the composition of the stream bed and banks and the physical orientation of the watercourse relative to a mine layout. Key areas of impact and considerations by the Panel are summarised below.

Stream water quantity

- ***Once-only losses to fill the shallow non draining subsurface fracture network associated with both tensile and shear failure:*** The Panel considers these losses to have negligible impact on stream flows after initial filling of the storage created by the new fracture network;
- ***Losses into a shear fracture network along shear planes commonly associated with bedding planes in the surficial zone:*** The Panel has observed that these losses can lead to draining of rock pools behind rock bars and consequent partial or complete disconnection of these key components of a healthy stream habitat, particularly during low stream flows (see Figure 29). The shear fracture network extends to around 15 m in depth, or perhaps some greater depth depending upon local conditions (see section 4.1.3.4 and Figure 21). Increasing confinement at depth would be expected to reduce flow pathway apertures and the transmission potential of re-directed surface waters. Similarly, increasing confinement beneath valley sides would be expected to impede transmission along lateral pathways although there is little if any direct evidence to confirm this hypothesis. If these conditions of confinement prevail, then loss of flow from a surface drainage is likely to return to the system at some point downstream. Inspections conducted by the Panel suggest this distance can vary from as little as 20 m for specific rock bars to more than 200 m;

Table 9. Subsidence Impacts and Consequences for Significant Natural Features in the Southern Coalfield, Summary

Natural Feature	Physical Subsidence Impacts	Primary Consequences for Natural Features	Secondary Consequences
Watercourses	• Tensile cracking of stream rock bars; tensile/shear movement of joint and bedding planes in the stream bed (see Figures 23 and 28)	• Loss of surface water flow into subsurface flow path (see Figure 28) • Loss of standing pools/connectivity (see Figure 29) • Additional groundwater inflows, commonly carrying ferrous iron from freshly broken rock (see Figure 30) • Adverse water quality, impacts eg iron bacterial mats (see Figure 36) • Localised adverse visual impacts	• Aquatic ecology loss (connectivity) • Loss of recreational amenity • No evidence of regional loss of water supply
	• Localised uplift and buckling of strata in the stream bed (eg lifting/ mobilising of stream bed rock plates – see Figure 22)	• Loss of surface water flow into subsurface flow path • Loss of standing pools/connectivity • Additional groundwater inflows, commonly carrying ferrous iron from freshly broken rock • Adverse water quality, impacts eg iron bacterial mats • Localised adverse visual impact	
	• Tilting of stream beds (both dynamic/incremental and final outcome)	• Stream bank and bed erosion • Changes in flow rates • Migration of flow channels	
	• Gas releases from near surface strata (see Figure 31)	• Temporary gas releases to the water column, with water quality impacts • (Rarely) riparian vegetation dieback	• Appears to have no significant long term impact
Cliffs	• Tensile surface cracking - close behind and (sub)parallel to cliffs, or within cliff faces (see Figure 33)	• Cliff falls • Instability of cliffs and overhangs, etc	• Adverse visual impact • Public safety implications • Loss of recreational amenity and public access • Potential damage or destruction of Aboriginal heritage sites • Loss of habitat for cliff-dependant species and damage to GDEs or riparian vegetation
Swamps	• ***Valley infill swamps***: Tensile cracking, tensile/ shear movement of joint and bedding planes, and buckling and localised upsidence in the stream bed below the swamp	• Draining of swamps, leading to: ➢ Drying and potential erosion and scouring of dry swamps (see Figures 34 and 35) ➢ Loss of standing pools within swamps ➢ Vulnerability to fire damage of dry swamps ➢ Change to swamp vegetation communities ➢ Adverse water quality impacts, eg iron bacterial matting • Loss of stream base flow	• Loss of swamp ecology (terrestrial and aquatic) • Loss of flow leads to the full range of downstream consequences
	• ***Headwater swamps***: Tensile cracking and tensile/ shear movement of joint and bedding planes in the rocks below the swamp	• Potential drop in perched water tables, leading to draining of swamps • Impacts are likely to be similar in character but less extensive and significant than for valley infill swamps	
Groundwater reservoirs	• Tensile cracking and tensile/ shear movement of strata • Bending of strata and horizontal separation of bedding planes • Depressurisation of groundwater from the coal seam	• Re-direction of subsurface flows • Mixing of aquifers or groundwater with surface water • Change in aquifer storage characteristics • Depressurisation of strata overlying extracted coal seam	• Failure of GDEs • Cross-aquifer contamination • Minewater inflows, and consequent water management issues • Loss of available aquifer resource

- ***Losses into a shear fracture network associated with the constrained zone at intermediate depths:*** Dilation occurs on shear surfaces on bedding planes in the constrained zone (see Figure 12), creating voids that can be filled by water as a once-only event. However, given the right combination of circumstances, shear surfaces could form a conduit for lateral water flow which may or may not report to the same catchment;
- ***Sustained leakage losses into a mine:*** While this is known to have occurred in the Southern Coalfield on isolated occasions it has generally been associated with a shallow depth of cover and/or the presence of anomalous conduits like fractured rock associated with igneous intrusions (Byrnes, 1999). More commonly, mining is conducted at a sufficient depth to support the long term presence of a constrained zone. Permeabilities of the overburden strata within this constrained zone are normally low enough to reduce vertical leakage to negligible rates. However this does not discount the possibility that sustained losses could be invoked by the presence of deep structural conduits. The Kangaloon Aquifer is a good example of such a conduit with quite high fracture permeability to depths of 70 to 100 m.

Figure 28: Severely Cracked Rock Bar Showing Evidence of Water Loss and Iron Staining, Waratah Rivulet, September 2007

Stream water quality

- ***Localised changes in stream water chemistry brought about by water-rock interactions along new flow pathways***: When a new fracture network forms beneath streams beds and their valleys, fresh rock faces are exposed to the groundwater which flows preferentially through available void space rather than through the rock itself. The fresh rock faces are then subject to a variety of chemical interactions with the groundwater, until a new equilibrium is established (ie until the fresh rock faces behave chemically the same as the pre-existing joint and other fracture networks). The chemistry of these groundwater interactions is complex. However, the Panel considers that this process targets any available carbonate or sulphide minerals in the sandstones and other strata.

Candidate carbonate minerals include siderite, witherite, strontianite and less frequently calcite, which respectively contribute the cations iron, barium, strontium and calcium together with the bicarbonate anion to the groundwater and eventually to the surface stream flow. SCA also notes that dissolution of iron oxy-hydroxides like limonite, goethite and haematite provides a mechanism for increasing the presence of iron in surface waters and groundwaters. Marcasite (iron sulphide) may also contribute to elevated iron, sulphate and increased acidity through oxidative dissolution. These iron minerals are common to the Hawkesbury Sandstone and their influence on water quality is reflected in the characteristic bright orange discolouration of groundwater emanating from some cracked stream beds and rock bars (see Figures 28 and 30). This discolouration is often accompanied by the downstream growth of bacterially-mediated iron mats and blooms in rock pools (see Figure 36) which in turn leads to a reduction in dissolved oxygen in the stream flow and related eco toxic impacts (University of Wollongong, 2007).

- ***Regional scale groundwater quality changes***: Subsidence may enhance groundwater storage and transmission characteristics of the Bringelly Shale and the underlying interface with the Hawkesbury Sandstone. The Panel notes that exposure of shale to new water/rock chemical interactions could lead to elevated iron and manganese probably resulting from reductive dissolution. Unlike oxidative dissolution of marcasite, there appears to be an absence of sulphates and acidity. Migration of these groundwaters from elevated areas to the fractured regime associated with valley sides and floors (see Figure 30) is believed to have initiated several ferruginous springs associated with the Cataract and Georges Rivers (Ecoengineers, 2007).

Figure 29: Drained Sandy Bottomed Pool, above WRS3 at Waratah Rivulet, September 2007

Figure 30: Iron Stained Groundwater Seep, Waratah Rivulet, September 2007

Gaseous emissions

- ***Anomalous methane concentrations:***[5] Emissions of methane and other natural gas components have been observed and reported at numerous stream locations affected by mining subsidence including the Cataract, Georges and Nepean Rivers (see Figure 31). Some of these occurrences have been of sufficient magnitude to support ignition at the stream surface. Much less commonly, gaseous emissions through the soil profile close to the river bank and associated heating have induced localised dieback of vegetation communities (eg Cataract River gorge above Tower Colliery). In respect of the Cataract Gorge, Illawarra Coal commissioned CSIRO to undertake studies to consider the source of methane since it occurs in high concentrations in the Bulli Seam and other coal seams. Results of those studies found that the mined Bulli Seam was not the source. Rather, the methane originated from an intermediate depth some 200 m to 350 m below the surface but above the seam. In addition it was determined that the gas release was temporary with a life span of 6 to 12 months (BHPB submission). The Panel observed that the principal dieback area has since partly regenerated. The only obvious evidence of the dieback episode is a number of dead standing and fallen trees.
- The Panel accepts that methane is naturally present in many natural shallow surface water and groundwater systems as a result of organic fermentation and redox-methanogenesis reactions. Methane is produced in measurable quantities in still and slow flowing waters by the rotting of fallen leaves and other vegetation. However the generative fluxes and concentrations are likely to be low and as such, methane derived in this manner and then released more rapidly through disturbance of sediments through shallow subsidence related cracking is likely to be inconsequential.

[5] While it has become common practice to refer to the gaseous emissions noted in the Nepean, Cataract and Georges River as ‘methane’, a variety of higher hydrocarbons (such as ethane) and also carbon dioxide are also present.

- The Panel accepts that the presence of methane in streams and rivers is commonplace and that it may derive from a number of sources. However, it is concerned that insufficient study has been conducted to discount the possibility of sustained upward leakage of methane from the coal seam(s). While small occurrences in the form of bubble trains in rock pools and waterways appear to be largely harmless (and have been so reported), the higher volume occurrences such as those reported for the Lower Cataract River where flaring was possible, are considered to be hazardous.

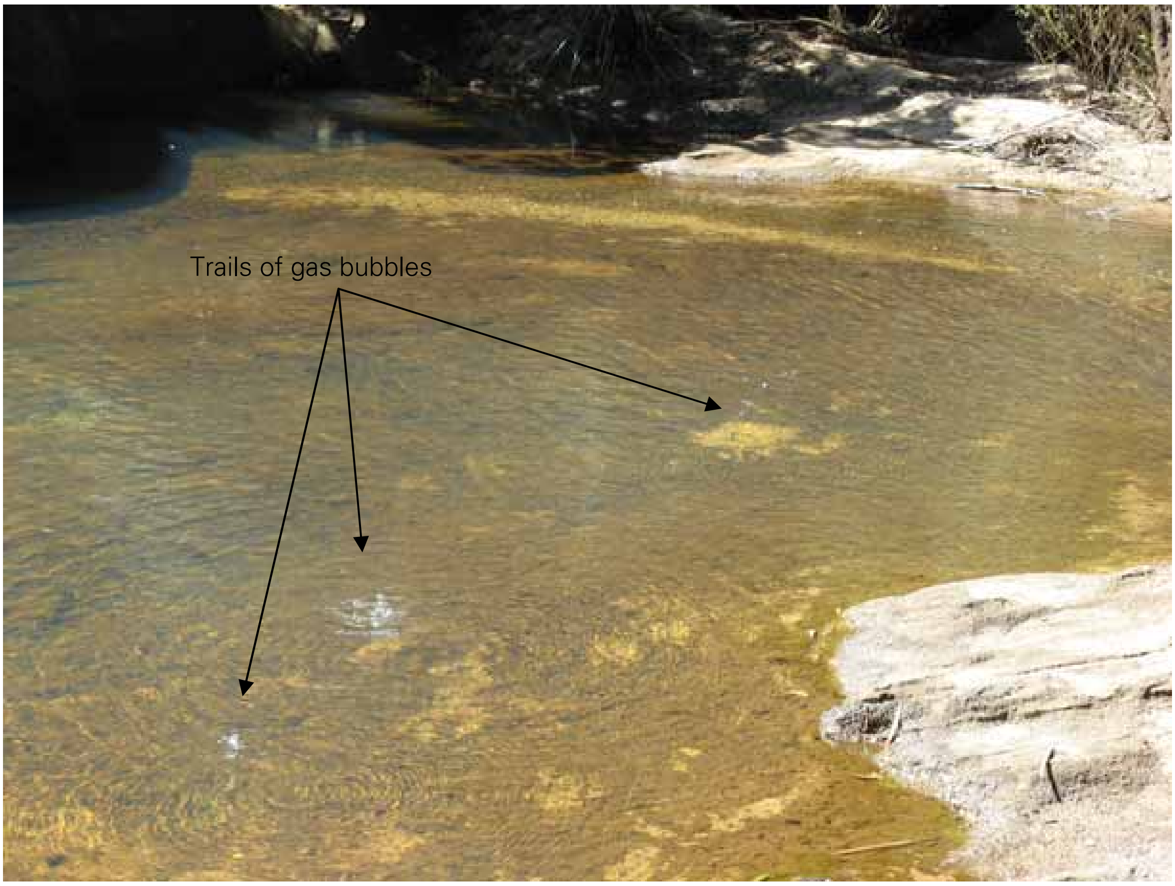


Figure 31: Small Scale Gas Release in the Cataract River

Note light green discolouration to the water column, possibly algal in nature.
Source: Julie Sheppard

4.2.1.1 Subsidence Impacts and Consequences at Waratah Rivulet

The Waratah Rivulet provides examples of most stream related impacts (see Figures 22 – 24 and 28 – 30) and a case study of the impacts at two key rock bars on that stream follows.

The most detailed information available relating to the impacts of upsidence has been collected from two rock bars on the Waratah Rivulet identified as WRS 1 and WRS 3 (Galvin, 2005). The locations of these rock bars are indicated on Figure 32. Because upsidence impacts are very site specific, behaviour at Waratah Rivulet cannot be assumed to be representative of all sites. However, the Panel believes it provides significant insight into the mechanics of buckling and upsidence and serves as a point of reference against which potential impacts at other sites might be evaluated in the future. Key events and observations at WRS1 include:

- borehole drilling detected weathered voids beneath the rock bar that predated mining;
- when Longwall 9 passed 130 m to the side of the rock bar, a step change occurred in measured groundwater levels. This was followed by valley closure of 100 mm, horizontal displacement of 200 mm, subsidence of 10 to 25 mm and upsidence of 60 mm. Surface fracturing was observed to extend to a depth between 6.5 m and 7.5 m and resulted in 37 mm of bed separation;

- undermining of the site by the following Longwall 10 resulted in almost 150 mm of upsidence and 180 mm of valley closure over a 30 m interval. Groundwater levels remained unchanged from when the previous longwall had passed by the site;
- at the completion of a further three longwall panels, upsidence and valley closure had increased further; and
- by all accounts, the rock pool behind WRS1 continues to maintain its pre-mining water level.

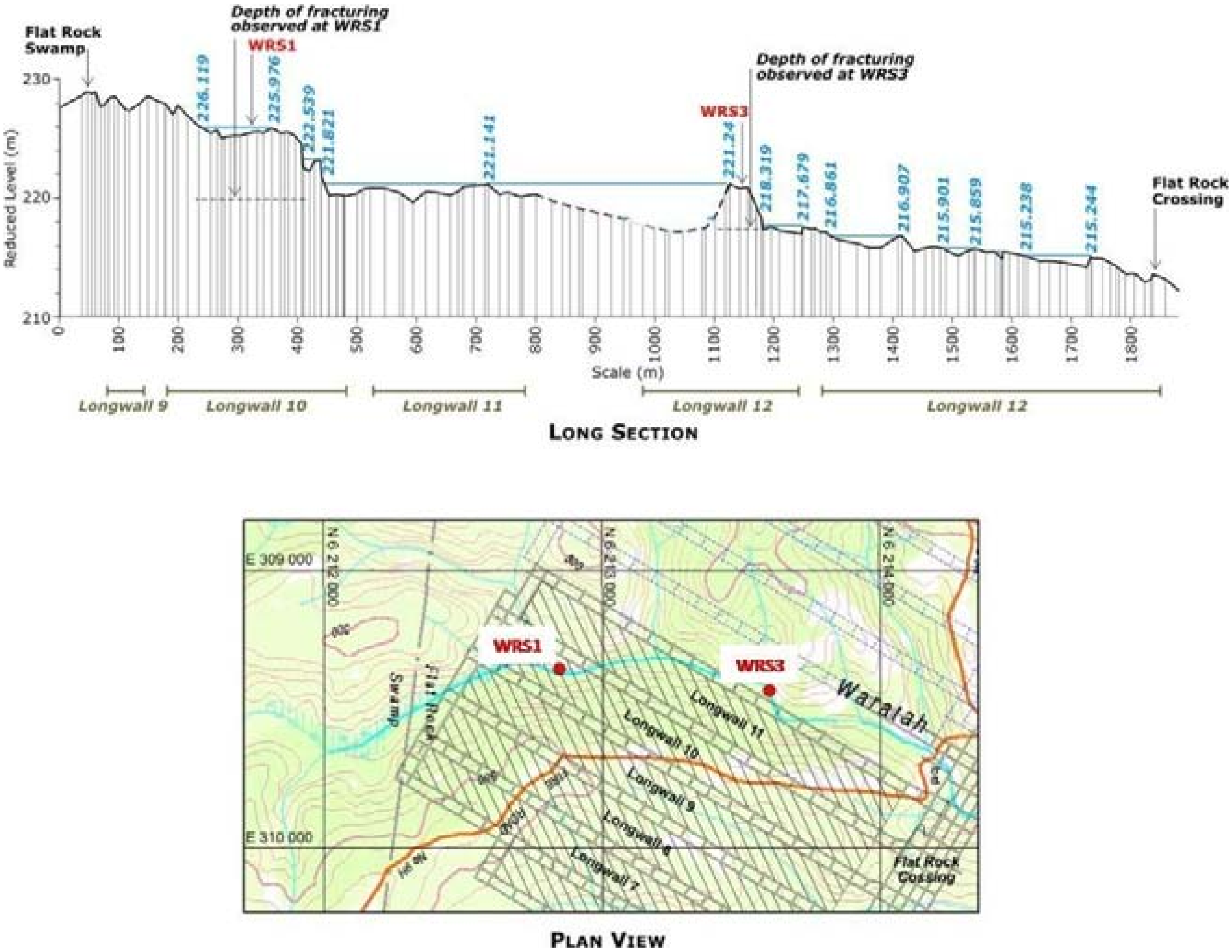


Figure 32: Cross-Section and Plan View of the Waratah Rivulet

Source: Galvin, 2005

In contrast, at WRS3:

- surface cracking, comprising predominately over-ride shearing, was observed after Longwall 10 (at a depth of approximately 350 m) had passed within 270 m to the side of the rock bar. This resulted in valley closure of some 60 mm over a 40 m interval. Little change was recorded by any of the instrumentation, whilst vertical displacement was effectively zero and there were no perceptible impacts on water levels;
- by the time that Longwall 11, which was 50 m to one side of the rock bar, had retreated 50 m past the rock bar, upsidence of 60 mm had occurred and the rock bar was extensively fractured. This fracturing resulted in diversion of about 4.5 ML/day of flow from the perched pond behind the WRS3 rock bar into the subsurface fracture network below. Groundwater levels dropped noticeably in five of the six monitored holes and subsurface water emerged from a rock lip at the base of the bar for a period of time before drying up and emerging further downstream; and
- the pond behind this bar had not recovered at the time of the Panel's inspection and continues to empty in the absence of regular rainfall, potentially disconnecting the aquatic

system and influencing streamflow water quality. Figure 21 shows that the upsidence-related fracturing network now extends to a depth of about 12 m with bedding plane dilation extending down to a depth of about 20 m.

The site investigations also revealed that;

- upsidence did not always follow bends in the watercourse but sometimes cut a straight line through the valley. This response clearly has implications for mitigation and remediation measures;
- upsidence affected a zone up to 100 m in width and was concentrated in a 60 m wide zone, peaking over a 20 m wide zone in the centre of the valley. Within this 20 m wide zone, fracturing extended to a depth of up to 10 m with upsidence values of less than 150 mm; and
- although an extensive fracture network may develop for some metres below the surface, this does not always result in the loss of water from overlying perched ponds.

The Panel adopts the view from its site inspections that the manner in which upsidence has developed at the Waratah Rivulet is not unique. However the extent of subsurface fracturing at this location does tend towards one extreme. In contrast, the Upper Bargo River tends towards the other extreme. Centennial Tahmoor reported that it has experienced upsidence of some 400 mm, resulting in sporadic cracking of the river bed and the drying out of some ponds at the time of mining. Subsequently, the fracture network in the Upper Bargo River appears to have largely self healed, surface water levels have returned to their pre-mining steady state, and there are no obvious impacts on ecology.

It is not clear why the observed impacts differ so significantly between these two sites. However, the Panel suggests that a combination of near-surface geology and the actual valley shape/profile may have had some influence. These factors are likely to have altered the subsidence effects with respect to valley closure, buckling, upsidence, and development of voids and fracture networks. This marked difference in response confirms the importance of detailed site-specific investigations in order to determine, firstly, the subsidence effects, and then the likely impacts on the natural features.

The Panel also considers that it is important to note that documentary material provided by Helensburgh Coal Pty Ltd (the operating company for Metropolitan Colliery) confirmed that the type and location of damage to Waratah Rivulet - in terms of fractured rock bars and impacts to water flows and losses - had been predicted by it in a Longwall Subsidence Management Plan for Longwalls 8 – 13 submitted to, and approved by the then Department of Mineral Resources in 2002.

4.2.2 Valleys and Cliff Lines

Apart from the actual watercourses discussed above, the other aspect of subsidence impact on valleys relates primarily to the impact on valley sides, especially where significant cliffs are present, and also on valley vegetation.

In relation to valley sides and cliff lines, the potential exists for damage to vertical or near-vertical cliff faces and overhangs, resulting in collapse and potential landslides. Furthermore, there is potential for damage to some Aboriginal heritage sites which may be contained on or within these cliff faces.

Several types of falls or mechanical failures may occur when a cliff is mined beneath. Toppling type failures may occur when cliff lines are subject to tilts. Compressive and tensile strains may cause fracturing of sandstone which in turn may affect the stability of cliffs. These impacts have led to rock falls and, in some cases, overhang collapse, eg in the Cataract River where eight rock falls were recorded when Tower Colliery's longwalls mined directly under the deeply incised Cataract Gorge (see Figure 33). Illawarra Coal has submitted that very few rock falls have been observed in the Southern Coalfield unless the longwalls passed directly under the cliff.

Illawarra Coal's Supplementary Submission provides a summary of cliff fall statistics, in terms of fall frequency and location. It indicates that rock falls have taken place at Dendrobium Areas 1 and 2, Appin Area 3, West Cliff Area 5 and Tower Colliery. At Tower Colliery, the company surveyed around 5.57 km of cliff line along the Cataract River. Cliff instabilities and rock falls were observed at 10 sites, totalling around 200 linear metres in length. All instability was associated with significant rock overhangs in the cliff face. Characteristic vertical joint planes or vertical tensile fractures are visible on the cliff side of most instability. The north-south joint set is also an integral control on the general drainage trend of the Cataract River (Illawarra Coal, 2007). There are now 8 known rock falls in Dendrobium Area 1, totalling some 200 linear metres of a total cliff line of around 2 km.

Cliff falls and other rock falls usually take place within the footprint of the underlying goaf. It is unusual for cliff falls to take place other than immediately above the longwall extraction operation. The only exception of which the Panel was made aware occurred with the mining of three small longwalls within Illawarra Coal's Appin Area 3. This mining was associated with 5 small rock falls in the Cataract River Gorge outside of the direct mining footprint. However, these falls were relatively minor (each less than 30 m^3) and evidence exists that they were associated with existing zones of weakness caused by jacking of natural joints by tree roots and a period of heavy rain. Further, rock falls of similar geometry and magnitude but not related to coal mining are visible along the entire length of the Cataract River (Illawarra Coal, 2007).

A number of steep slopes have also experienced cracking and others forms of mass movement. For example, cracking has occurred at the commencing end of Dendrobium Longwall 3. This cracking in the soil profile is a result of tension at the margins of the goaf area from Longwall 3. Illawarra Coal contends that, despite prolonged and extensive rainfall, there has been no evidence of erosion or sedimentation leaving this area.

Figure 33: Small Rock Fall in the Cataract River Gorge

Source: Julie Sheppard

Cliff falls, impacts to overhangs, rock outcrops and steep slopes resulting from subsidence have been monitored from a geomorphological perspective for a number of years by Illawarra Coal. More recently, ecological monitoring associated with rock falls and other morphological changes for the Dendrobium area has only identified very minor terrestrial or aquatic ecological impacts (Biosis, 2006).

There is little to no evidence that vegetation or fauna habitats have been significantly altered as a result of cliff falls associated with subsidence. The existence of the cliff with a rocky talus slope below is a demonstration that these are dynamic environments, where rock falls are not uncommon over significant periods of time. However, there is potential for large cracks at the surface to act as temporary pitfalls for small ground fauna such as reptiles or small mammals

The Panel inspected valley sides at a number of sites which have been affected by subsidence, including Waratah Rivulet, Upper and Lower Cataract River, Nepean River and Bargo River. It was the opinion of the Panel that whilst a number of small cliff and overhang collapses were observed, these were relatively isolated incidents. It was the general observation of the Panel that the cliff lines and valley sides in many of the areas inspected were remarkably robust, when considering the amount of valley closure that has occurred in places (eg Nepean Gorge valley closure in excess of 460 mm, see Figures 19 and 25).

4.2.3 Swamps

Some research has been undertaken in an endeavour to determine whether mining subsidence has contributed to the impacts which have occurred at a number of valley infill swamps in the Southern Coalfield. Probably the most detailed work was undertaken in 2005 by Macquarie University in conjunction with the SCA (Tomkins and Humphreys 2006). The swamps investigated in detail were Drillhole Swamp on Flying Fox Creek in the Avon catchment, Swamp 18 on Native Dog Creek in the Avon Catchment, and Flatrock Swamp on Waratah Rivulet in the Woronora catchment (see Figures 34 and 35). All three swamps have been subject to gully erosion. Gully erosion exposes swamp sediments which presents a unique opportunity to examine the internal stratigraphy and assess the type of erosion events that have taken place over the length of time over which the swamp developed. The methods used included an assessment of the history of disturbance to each swamp (mining and wildfires), analysis of previous work, air photo interpretation commencing with the oldest photos available (late 1940s – early 1950s), a detailed analysis of swamp stratigraphy and dating, and an analysis of rainfall records (Tomkins and Humphreys 2006).

Tomkins and Humphreys concluded that:

- published radiocarbon dating showed that upland swamps on the Woronora Plateau formed during the Late Pleistocene – Holocene (between 17,000 and 2,000 years ago);
- these upland swamps are resilient sediment storage features despite extensive disturbance through drought, wildfires, mine related subsidence and severe rainfall events (> 700 mm over several days);
- both headwater/drainage divide swamps and valley infill swamps are filled with predominantly sandy sediments, tending to peat during conditions of high water tables and low sediment supply;
- it is valley infill swamps which are currently eroding, except for Drillhole Swamp, which is a headwater swamp which was found to have eroded in 1978 as a direct response to extensive mine-related surface disturbance coupled with extreme rainfall;
- erosion of the valley infilling swamps takes place by knickpoint retreat between pre-existing scour pools resulting in a gully cutting through the swamp;
- the stratigraphy of Drillhole Swamp and Flatrock Swamp however, reveals older cut and fill channels indicating prior erosion events and suggesting that episodic erosion is an important natural process in the evolution of all swamps on the Woronora Plateau;
- the formation of scour pools appears to be a critical indicator of likely future gully erosion;
- extreme rainfall events are thought to be a likely trigger in forming these pools although thresholds could not be identified;
- wildfires were found to increase erosion in swamps where erosion was already underway, but fires alone do not appear to trigger erosion in upland swamps; and

- dewatering of swamps through mine subsidence may play a role in increasing the sensitivity of swamps to external forces such as fires and extreme rainfall events.

Drillhole Swamp was undermined from 1965 to 1969 and again between 1971 and 1974. Surface cracking was first identified in 1971 (Tomkins and Humphreys, 2006). However, it is quite possible that the 1978 gully erosion was not directly caused by mining subsidence, *per se*. Significant site disturbance took place as a result of site clearing, soil disturbance and erosion associated with the drilling of a stratigraphic drillhole in 1976 for the Reynolds Inquiry. Tomkins and Humphreys conclude that the cause of the gully erosion was this site disturbance, coupled with an extreme rainfall event.

The air photo analysis undertaken by Tomkins and Humphreys indicated that, for Swamp 18, there were scour pools present at least as early as 1951, and in the case of and Flatrock Swamp at least as early as 1947. Further, there was an eroding knickpoint within Swamp 18 in 1951, which continued to actively erode upstream through the swamp until 1990 and beyond. There has been other recent research, review or predictive work undertaken on swamps, primarily by mining companies and their consultants (eg Earth Tech, 2003 and 2005; Illawarra Coal, 2004; Biosis, 2007 and Ecoengineers, 2006 and 2007).

Different swamp types, geometries and locations are also likely to affect the extent of any adverse impacts, in relation to issues such as swamp drainage and resultant vegetation changes due to water losses and changes to water storage characteristics. For example, it seems reasonable to infer that valley infill swamps are simply organic/sandy sediment-draped stream valleys with a rocky substrate, if those streams are located in upland environments. A number of such swamps are known to have rock bars, and the swamps themselves may therefore fill pre-existing pools. It seems likely that these rock bars and pools in the rocky substrate will respond to subsidence effects in a manner similar to those in streams which are filled with water, rather than sediment. Thus tensile and shear cracking, together with localised upsidence and buckling of the surface strata would be anticipated beneath at least some valley infill swamps. In turn, it is reasonable to infer that such cracking is likely to lead to drainage of water from the swamp into the fracture network in the stream bed below. Thus, it is possible that water tables may drop within valley infill swamps, leading to the potential for damage by fire, surface vegetation changes or scouring erosion by high flow events. It can be suggested that scouring may also be caused or increased by slope changes in the swamp as the result of subsidence.

However, there is as yet no scientific consensus over the role that mining subsidence may play in impacting swamps. Consequently, the impact of subsidence on swamps is a matter where the Panel is not able to make any conclusive determinations. What is clear to the Panel is that the interactions between subsidence effects and impacts such as vertical displacement, strata fracturing, buckling and uplift (possibly leading to water loss) do have potential consequences for swamps. In many of the swamp sites visited by the Panel, there had also been a range of other factors in play at the time, including drought, severe bushfires and heavy rain events. The actual sequence of events was not at all clear, in relation to the subsequent swamp impact.

What was also noted was the fact that no unaffected or ‘healthy’ valley infill swamps were observed where longwall extraction had taken place beneath them. In most cases, where swamps appeared largely unaffected by mining beneath, it was where the mining had been restricted to either narrow panels, or some form of partial extraction only (ie bord and pillar operations) which restricted surface subsidence.

It is therefore the Panel’s view that the issue of, and mechanisms associated with swamp impacts from mining-induced subsidence is an extremely complex one, for which there is no simple generic explanation at the present time. On the evidence available, it would appear that there is a distinct possibility that undermining of valley infill swamps has or will cause drainage, water table drop and consequent degradation to swamp water quality and associated vegetation. But without additional research, this remains only a possibility, which is complicated by a number of other non-mining factors in most instances.

Figure 34: Eroded Valley Infill Swamp, Showing Rocky Substrate and Confining Valley Side, Flatrock Swamp, Waratah Rivulet, September 2007

Figure 35: Deeply Gullied Peat in a Valley Infill Swamp, Flatrock Swamp, Waratah Rivulet, September 2007

The consideration of potential impacts then becomes one of site specific characterisation, together with site specific determination of the significance of each individual swamp. This characterisation is addressed further in section 4.3.4.2.

4.2.4 Groundwater

The impacts of subsidence on groundwater systems is best considered in two parts – shallow groundwater systems which are connected with the upland surface stream network and the upland swamps, and deep aquifer systems.

Subsidence impacts on shallow aquifer networks are intimately related to those which affect watercourses and swamps (see Table 9). These surface impacts include cracking of rock bars, draining of rock pools and diversion of creek flows. Tensile cracking and tensile/shear movement of near-surface strata, bending of strata and horizontal separation of bedding planes may lead to changed groundwater flow pathways. Surface flows may be redirected to the subsurface, while pre-existing subsurface flows may be redirected to the surface drainage network. One of the key impacts is the chemical interaction between freshly broken rock faces and percolating groundwater (discussed in section 4.2.1 above). Groundwater dependent ecosystems, including both valley infill and headwater swamps, may also be impacted by changes in the water table and water chemistry.

Deep aquifer impacts are less easily characterised. Aquifers within the fractured zone (see Figure 12) are likely to drain to the mine workings, as will any aquifer in the caved zone. This is probably what has recently happened at Dendrobium Area 2. Dendrobium Coal Mine had two major water inflow events in June 2007 and February 2008. Chemical testing has indicated that each inflow event was sourced from separate aquifers which had been breached by subsurface cracking. The water from the first of these inflow events appears to have been sourced from the Scarborough Sandstone. The second inflow event appears to have derived from groundwater found in strata immediately above the Wongawilli Seam. Such disruptions to aquifers may lead to long term changes in their storage capacity. This depressurisation of aquifers in strata overlying the coal seam may be of little long term significance, providing that the aquifer is isolated from the surface drainage network of the water supply catchments and that there is no current or prospective use for the groundwater otherwise contained in the aquifer. It may also lead to cross contamination between fresh and saline aquifers.

Most underground coal mines have to deal with substantial quantities of groundwater which flows into the workings. Much of this is not sourced from overlying aquifers, but from the coal seam itself, since most coal seams have the permeability necessary to qualify as an aquifer. Consequently, most mines are able to handle the additional groundwater inflows that may result from disruption of overlying aquifers. Nonetheless, substantial inflows, such as those which have occurred at Dendrobium Area 2, are significant mine management issues. Further, the increased rate of pumping represents an additional water management or disposal problem once the mine water is brought to the surface. This may have implications for natural features such as watercourses, for example if the water is saline.

4.2.5 Aquatic Flora and Fauna

A large number of submissions to the Panel identified the various possible subsidence-related impacts of longwall mining on aquatic ecosystems. Submissions from SCA, DECC and many individuals outlined both the possible impacts from subsidence, as well as providing specific examples of impacts in the Southern Coalfield. The vast majority of impacts relate to surface cracking in the bed of the watercourses. A summary of possible impacts was put forward by DECC

> '*Surface cracking as a result of longwall mining subsidence can have the following impacts on riverine features or attributes:*
> - *Loss of surface flows or water levels (increased frequency, duration and magnitude of drying aquatic habitats)*
> - *Loss of aquatic or instream habitats (complete drying of river pools, instream macrophyte beds and wetlands has occurred which may in some cases be irreversible)*

- *Loss of longitudinal connectivity (connectivity between pools and riffles may reduce migration opportunities)*
- *Changes to water quality (increased iron oxides, manganese, sulphides and electrical conductivity, and lower dissolved oxygen)*
- *Reduced diversity of instream habitat due to the growth of iron-oxidising bacteria which can also be seen as a rusty-coloured mass in the water (*see Figure 36)
- *Release of gas into the water column (oxidation of gas may lead to death of riparian vegetation and instream fauna)*'

Where streambeds are damaged from mining activities, such that flow and pool water holding ability is temporarily lost or water quality chemically changed, the ecological processes are altered and biological 'corridors' or linkages broken. In these situations damage to the aquatic ecology is not confined to the immediate site, but may be quite widespread. Upstream habitats may no longer be accessible and movement of animals for feeding and spawning purposes may be restricted or halted completely. The flora and fauna that return to such sites after remediation and return of water flows are likely to be quite different (eg, perhaps less diverse) than the original communities.

Figure 36: Extreme Example of Bacterially-Mediated Iron Matting on Aquatic Macrophytes and Iron Flocculant in the Water Column, Below Flatrock Swamp, Waratah Rivulet, September 2007

4.2.6 *Aboriginal Heritage*

Several types of subsidence impact are relevant to Aboriginal archaeological sites, namely:

- rock falls and cliff collapses;
- surface cracking and exfoliation; and
- water table and/or seepage changes.

Rock shelter and painted art sites may be located in areas subject to cliff falls or rock falls. Axe grinding grooves and engraved art sites are the sites most exposed to cracking of creek bed or creek side strata.

If mining or exploration activities are likely to destroy, damage or deface an Aboriginal object or site, the mining company must first obtain consent under section 90 of the *National Parks and Wildlife Act 1974* (NPW Act), or else risk prosecution for an offence. To avoid the risk of prosecution for inadvertently damaging an Aboriginal site or object, miners and explorers must also first conduct site surveys, including surface and occasionally subsurface investigations. Before disturbing or excavating land to look for an Aboriginal object, or disturb or move an Aboriginal object, they must obtain a permit under section 87 of the NPW Act.

In the Southern Coalfield, Caryll Sefton has conducted a monitoring program reviewing the effects of longwall mining on sandstone overhang Aboriginal archaeological sites for Illawarra Coal over a 10 year period (Sefton 2000). This review covered Illawarra Coal's Appin, Tower, West Cliff, Elouera, Cordeaux and other mines. At the time of the review 52 sandstone overhang sites had been monitored by Sefton prior to, during and after longwall mining in the vicinity of the sites. Of the 52 sites, only five had evidence of impact from longwall mining. The impacts can be grouped into four effect categories: cracking; movement along existing joints / bedding planes; block fall; and change of water seepage. No art panels in the monitoring program have been directly impacted by subsidence effects noted by Sefton. No site had collapsed or been destroyed.

The Panel was shown two rock shelters in creeks which had been impacted by subsidence cracking. The first of these shelters, located on Ousedale Creek, showed evidence of minor recent cracking of some 1 – 3 mm in width (see Figure 37). The second shelter, on Simpsons Creek, showed no evidence of damage, although the creek itself had been impacted by upsidence, bedding plane separation, tensile cracking and consequent drainage of its small pools.

Much more substantial damage was caused in 1979-80 at Whale Cave, on the Illawarra Escarpment near Bulli. Whale Cave suffered significant and permanent damage following underground mining, with impacts including cracks in the roof of the shelter, water seeping into the back of the cave and the need for 26 posts to be installed in 1984 to support the cave roof from further collapse.

4.2.7 *Far-Field Subsidence Effects*

The far-field effects discussed in section 4.1.3.5 have primarily been associated with horizontal displacement – usually towards the mining excavation, but more often dominated by movement towards any major valleys or gorges. There is very little evidence of significant far-field vertical subsidence effects, although the possibility of this cannot be totally ruled out.

The rate of decay of the horizontal movements (where measured), has been so low that average induced tensile strains are less than 0.01 mm/m and, therefore, of no significance in relation to any form of adverse impact. As discussed previously, the horizontal displacements have been recorded at large distances from any mining boundary and well beyond that defined by any traditional angle of draw calculation. Given the low strain levels, it is not appropriate to consider far-field effects in the context of any significant mining impacts on natural features.

Figure 37: Minor Cracking (Exfoliation) in Rock Shelter Wall, Ousedale Creek, October 2007

In the case of the monitoring program conducted around Tower Colliery Longwalls 16 and 17, and the potential impact on the Douglas Park Twin Bridges, one of the more likely scenarios postulated by Hebblewhite et al (2000) was that shear along bedding planes may have contributed to the entire landmass bounded by the Nepean and Harris Creek gorges moving as a block towards the Nepean Gorge and the mining excavation.

4.3 PREDICTION OF SUBSIDENCE EFFECTS, IMPACTS AND CONSEQUENCES

4.3.1 Prediction of Conventional Surface Subsidence Effects

The prediction of surface subsidence impacts first requires the various subsidence effects to be predicted – for a given mining, geological, topographic and geotechnical environment. Whilst the practice and science of subsidence prediction has in the past been primarily focused on *subsidence effects* (displacement, strain, tilt etc), it is the view of the Panel that the prediction process needs to be extended further, so as to provide greater insight and understanding into the anticipated *subsidence impacts* on particular surface features of interest. In other words, subsidence prediction should use the prediction of effects to then proceed to accurately predict what impact these effects will have on features of interest.

In the Southern Coalfield, it has come to be accepted that in most practical circumstances, the effects of conventional subsidence are negligible outside an angle of draw of 35°. Irrespective of the technique employed to predict mine subsidence, *vertical displacement* and *horizontal displacement* are the only components that can be predicted directly. *Tilt* is the rate of change of vertical displacement and so is calculated by either differentiating the vertical displacement profile or multiplying the vertical displacement profile by a calibration profile. Similarly, *curvature* is the rate of change of tilt and is calculated by differentiating the tilt profile or by multiplying the vertical displacement profile by a separate calibration profile. Therefore, any error in the prediction of vertical displacement can carry over to the predictions of tilt and curvature.

There are a variety of ways for calculating *strain* but these are also derived directly or indirectly from the prediction of vertical displacement. This introduces an additional source of error, being the strain calibration factor. Potential for error also arises if tilt or strain is concentrated at specific locations rather than being uniformly distributed. The net effect of these factors is that whilst strain distribution profiles usually reflect field outcomes on a regional scale, either or both strain distributions and strain magnitudes can vary on a local scale from predictions.

Like many other engineering disciplines involving geologic materials, uncertainties are an inherent part of subsidence engineering and management. Management of subsidence must therefore be risk-based, flexible, responsive and capable of dealing with unexpected changes or uncertainties. In the context of uncertainty and variability, it is also important to recognise that subsidence prediction is never going to predict every detail of localised variation in ground behaviour. Many very localised subsidence effects are a product of variation in rock types, local structures such as jointing, bedding planes, weathering etc. The subsidence prediction approaches discussed below relate to the prediction of overall subsidence effects, rather than these very local variations.

Techniques for predicting surface subsidence *effects* can be classified under three categories, namely empirical, analytical/numerical and hybrid methods. *Empirical* techniques are based on the back analysis of previous field outcomes. Reliability of outcomes is dependent, therefore, on the overall size and representativeness of the database and considerable care is required if the techniques are applied to conditions that are outside of this database. The more common *empirical* prediction methods are:

1. ***Graphical***, which involves plotting suites of curves showing relationships between various parameters and subsidence outcomes;
2. ***Upper Bound***, which involves constructing an envelope over measured maximum or worse case outcomes and predicting on the basis of that envelop;
3. ***Profile Function***, which attempts to define the shape of the vertical displacement curve by a mathematical equation and is confined in general to single (isolated) excavations; and
4. ***Incremental Profile Method***, which involves constructing the overall vertical displacement profile by summing the incremental vertical displacement that occurs each time a panel is extracted.

Analytical techniques are based on applying mathematical solutions derived from first principles to calculate how the rock mass will behave when an excavation is made within it. Most of the mathematical formulae have been known for decades; however, until the advent of computers, they could only be solved for very simple, two dimensional mining layouts. Advances in computational power now enables more complex mathematical equations to be solved, thereby enabling more detailed mining layouts, geological and geotechnical conditions and ground behaviour mechanisms to be analysed. Such analysis has now come to be known as mathematical modelling, *numerical analysis* or computer modelling. No one mathematical model is currently capable of fully describing rock behaviour and so numerical models still require a database for calibration purposes. Modelled outcomes need to be accepted with caution, especially at greenfields sites.

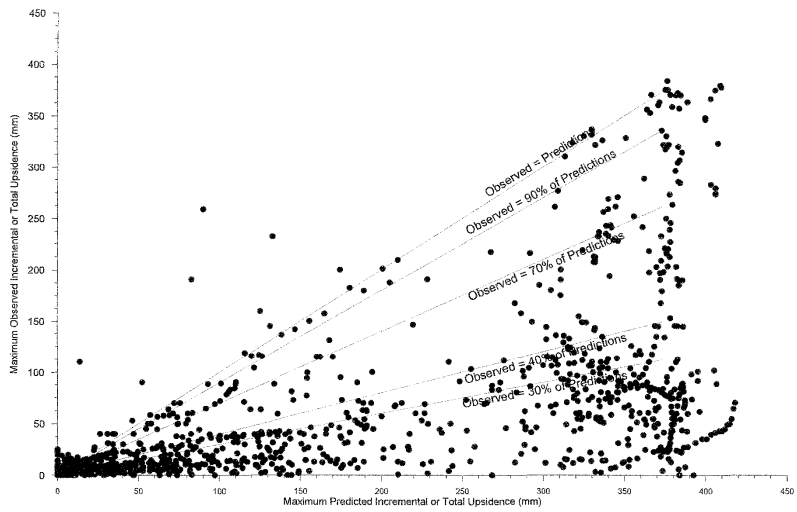
Hybrid subsidence prediction techniques involve various mixtures of back-analysis of field data and the application of analytical and numerical techniques. Further information on these prediction techniques is contained in Appendix B.

A number of techniques are capable of producing reasonably accurate predictions of vertical displacement, typically within ±150 mm. The more noteworthy of these are the incremental subsidence prediction technique, the influence function technique and a number of numerical modelling codes. However, the accuracy of any subsidence prediction technique should never be taken for granted. All depend to some extent on input parameters being representative of the specific site conditions. Particular care has to be taken when predicting subsidence for a greenfields site due to a lack of site specific data. A number of panels need to be extracted before subsidence prediction models can be properly calibrated and validated.

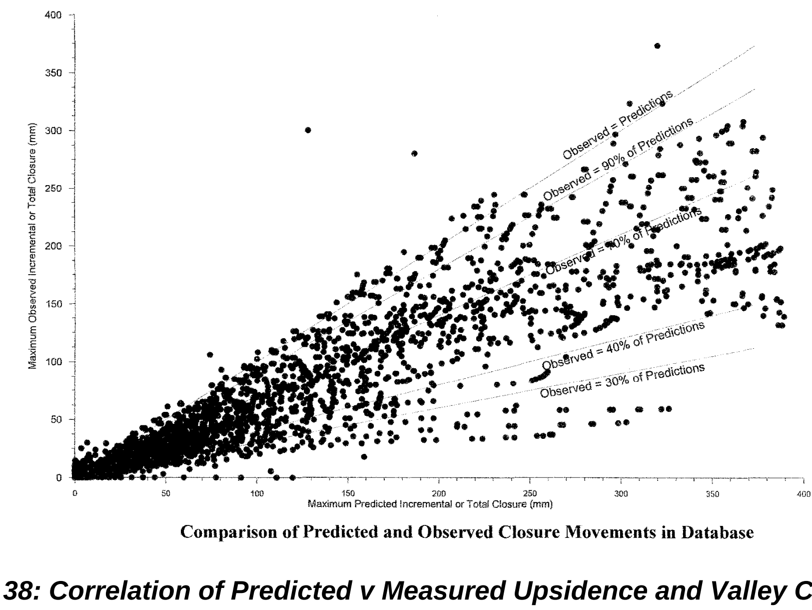
4.3.2 Prediction of Non-Conventional Surface Subsidence Effects

Prediction of some of the subsidence effects on specific features, such as valley closure, uplift and upsidence and far-field horizontal displacements, is being carried out by a number of specialist consultants and research institutions in New South Wales, although the science of such prediction, and hence its reliability, is at a far earlier stage than the prediction of conventional subsidence effects. This type of prediction is currently being carried out by using both empirical and numerical techniques.

Figure 38 shows two graphs of data prepared by the NSW subsidence consultant MSEC (or Mine Subsidence Engineering Consultants) using its database of actual and predicted upsidence and valley closure. These graphs show a reasonable degree of confidence in predicting upper bounds for both valley closure and upsidence. The graphs indicate that both observed upsidence and observed valley closure are generally conservative with respect to predictions by MSEC, and often are substantially less. It should be noted that the level of scatter for measured upsidence as a percentage of the predicted value is greater than for valley closure, indicating that the prediction of upsidence is less reliable. Because of the problems with measuring upsidence, and hence difficulty with validating upsidence prediction, the Panel considers it more appropriate for the industry to focus prediction of valley effects on valley closure, rather than on upsidence. Further, industry should use an upper bound, or conservative, approach in predicting valley closure.



Comparison of Predicted and Observed Upsidence Movements in Database



Comparison of Predicted and Observed Closure Movements in Database

Figure 38: Correlation of Predicted v Measured Upsidence and Valley Closure (MSEC)

Source: NSW Minerals Council Supplementary Submission – MSEC data

Recent research conducted for Illawarra Coal and the Australian Coal Association Research Program (Waddington and Kay, 1999 and 2001) has provided a first pass methodology for predicting cliff damage. However the impacts are very site specific and the Panel does not accept that a generally applicable technique for predicting cliff damage is currently available.

4.3.3 Prediction of Subsurface Subsidence Effects

Subsurface effects and impacts are important in respect of the potential for water loss from significant aquifers located above the mine workings. They are also important in respect of potential water loss (either surface water or from aquifers) directly into mine workings.

A considerable amount of mining, including longwall mining, has been undertaken over the last two hundred years beneath the sea, lakes, lagoons, dams and rivers in both the Newcastle Coalfield and the Southern Coalfield. The issue of hydraulic connections between the surface water bodies and the mine workings has also been the subject of two major inquiries commissioned by the State Government in the 1970s (Wardell, 1975 and Reynolds, 1977). The Wardell Inquiry was concerned with the potential for mine safety to be jeopardised by a direct connection between mine workings and overlying lakes and ocean in the Newcastle, Lake Macquarie and Wyong LGAs. The Reynolds Inquiry was primarily concerned with potential water loss from reservoirs into mine workings in the Southern Coalfield of NSW.

A number of criteria have evolved over the years for assessing the likelihood of a hydraulic connection between the surface and mine workings, the principal ones being:

1. ***Presence of an aquiclude***: an aquiclude is an impermeable layer such as shale, clay or some claystones. International experience indicates that if the right type and thickness of material is present, unrestricted extraction may take place beneath water bodies without surface water finding its way into the mine workings.
2. ***Maximum tensile strain on the surface***: for many years, it was believed that water could be prevented from entering the mine if cracking of the surface was restricted by limiting the maximum tensile strain on the surface to between 5 – 10 mm/m, depending on the nature of the strata. The Wardell Guidelines for mining beneath the tidal waters of Lake Macquarie, Lake Munmorah and Budgewoi Lake in the Wyong LGA were premised on this criterion (Wardell, 1975). It is recognised today that it fails to adequately consider the behaviour of the strata in the constrained zone and has fallen into disuse.
3. ***Development of a constrained zone***: the recommendations of the Reynolds Inquiry into mining under stored waters in the Southern Coalfield of NSW (Reynolds, 1977) were based on this principle and have been applied without incident at a number of sites. Mine planning has progressively deviated from them in the Southern Coalfield in the light of field monitoring, field experience and advances in numerical modelling.

Put simply, aquifers located within either the caved zone or the fractured zone will locally drain into the mine workings. If the fractured zone extends to the surface, then aquifers located within the surface zone will also drain to the mine workings because no constrained zone exists. It follows that the successful prediction of drainage from aquifers to the mine workings is dependent on two factors:

- adequate local and vicinity mapping of the presence and nature of aquifers and aquicludes; and
- adequate prediction of the local height of the fractured zone;

Byrnes (1999) reported on detailed investigations into groundwater hydrology undertaken in the Southern Coalfield for longwall mining under Cataract Reservoir. His report included case studies from around the world of successful and unsuccessful experiences in mining under water bodies. Byrnes concluded that higher than 185 m above the seam (equivalent to 1.7 times panel width) there was no evidence that there was any change in the hydraulic connectivity of water from reservoirs to mine workings. A number of other measurements and studies have produced outcomes consistent with this conclusion. However, the studies also highlight that mine design recommendations should not be applied blindly and that careful consideration must always be given to site specific geology and geological features.

An extensive groundwater testing program conducted by Forster and Enever (1992) in the Lake Macquarie region of NSW resulted in the model of subsurface behaviour zones not dissimilar to those shown in Figure 12. This model has since been applied to the successful extraction of three longwall panels beneath Lake Macquarie in NSW.

4.3.4 Prediction of Impacts and Consequences

The Panel notes that, unlike the prediction of subsidence effects, the science of predicting subsidence impacts and consequences is at a relatively early stage of development. For example, it is understood that the impacts on the Cataract River between 1993 and 1997 and their consequences were not predicted in the preceding application for approval under section 138 of the *Coal Mines Regulation Act 1982* (MSEC, 2008, pers comm.). This was also the case with the impacts on the Upper Bargo River which took place in 2002. These failures to predict significant impacts and consequences led to some mining companies and their subsidence consultants reviewing the ways in which they attempted to deal with these matters. Evidence is now emerging that recent predictions of impacts and consequences in SMP applications (eg for West Cliff longwalls 30-32, Appin longwall 301 and Appin West longwall 701) have significantly improved accuracy. To not only make predictions but for them to be generally accurate is a substantial advance on the situation that prevailed just a few years ago. However, it must be said that these predictions have been largely qualitative in nature (‘minor’, ‘moderate’, ‘possible’, etc). The challenge for the mining industry and its consultants over the next few years will be to move to a new generation of predictive capacity which is essentially quantitative in nature.

One of the weaknesses in the current system of impact assessment and subsidence management appears to be the lack of integration between the various scientific studies carried out for mining proposals. A large number of scientific disciplines are involved in most such impact assessment and environmental management studies. Studies are carried out on subsidence predictions, water quality and flows, landscape, terrestrial flora and fauna, aquatic flora and fauna, and so on. These various studies are often produced as compartmentalised, stand alone documents, which are then brought together into a final summary document. The outputs from the various disciplines are often not well integrated into a final report form, and there may be a poor integration of the assessment of subsidence *effects* and *impacts* (within a subsidence impact assessment) with the environmental *consequences* of those impacts. The process of predicting subsidence impacts and then the consequences on the natural features requires an integration of the information produced in the various scientific disciplines, not just a summary of compartmentalised studies. This lack of integration has led to situations where there may be an incomplete overall understanding and appreciation by both the community and government agencies, of the predicted impacts and consequences of a mining activity.

For example, if cliff falls are predicted in a particular area, this information needs to be integrated into the studies of the water flows and distribution of flora and fauna so that specific consequences might also be considered in detail. Currently the level of information provided by these impact studies is usually generic (eg ‘minor rock falls’, ‘minor impacts on water flows’, etc) and provides little specific detail about the predicted extent and high risk locations of the subsidence impact, and, the possible consequences for natural features. Best practice might, for example, involve producing risk maps indicating ‘high risk/medium risk/low risk/poor prediction’ of cliff falls (or other impacts or consequences) overlaid with information about ecological communities (or other natural features). This would allow a better appreciation by both the public and by government of the expected impacts and consequences, compared to the generic methods currently adopted in many impact assessment and environment management studies.

4.3.4.1 Watercourses, Valleys and Cliff Lines

The Panel has accepted that subsidence impacts within valleys and their contained watercourses should be seen primarily as ‘non-conventional’. Consequently, it follows that prediction of conventional subsidence parameters (vertical or horizontal displacement, strain, tilt and curvature) will be incomplete in predicting potential impacts on watercourses and their confining valleys. Therefore, it is the measurement of predicted valley closure and upsidence that have the most value for predicting subsidence impacts on stream beds.

Of these two factors, it has already been noted that upsidence is a derived parameter, and reflects a measurement compared with a prediction. It is also highly variable over short distances, owing to preferential dilation and delamination of horizontal bedding planes or cross bedding, with local uplift of rock plates. The Panel is therefore of the view that predicted valley closure is currently the most useful subsidence parameter for predicting subsidence impacts on rocky stream beds, rock bars, pool drainage.

Successful prediction of impacts on water flows and water quality within watercourses is essentially a matter of understanding a limited number of key parameters:

- current surface flow dynamics and current water quality;
- proportion of surface flow likely to be lost to the subsurface after mining, for different percentile stream flows;
- amount of any increased flow from near-surface aquifers or groundwater conduits to the stream and their water quality; and
- associated water quality impacts on the stream in terms of increased mineral concentrations, pH, oxygen, iron flocculation, etc.

The SCA has noted a number of baseline water flow and water quality parameters that should be adequately measured in order to support successful impact prediction. These are discussed in respect of monitoring of impacts, under section 4.4.2.5.

4.3.4.2 Swamps

Prediction of subsidence related impacts on swamps, streams and aquifer systems has historically been limited. The Dendrobium EIS and subsequent Commission of Inquiry during 2001 appears to have triggered a more comprehensive monitoring and analytical approach both to the understanding of natural processes, and the prediction of impacts that might arise from longwall mining. As previously noted, there is no current scientific consensus over the potential impacts that mining subsidence may have on either valley infill or headwater swamps. Further, there is currently no generally accepted technique for prediction of subsidence impacts on swamps. Nonetheless, the Panel is of the view that mining subsidence has the potential to impact on swamps, particularly valley infill swamps where significant valley closure and upsidence is anticipated.

The consideration of potential impacts therefore becomes one of site specific characterisation, together with site specific determination of the significance of each individual swamp. The key individual features of swamps that as a minimum should be determined in order to improve the prediction of potential impacts are:

- whether the swamp (or a section of a broader expanse of swamp) is a valley infill swamp;
- existing swamp characteristics (longitudinal slope, water table characteristics, floristics, depth of sediment, etc);
- observed or inferred presence of rock bars (either at surface or below the soil);
- existing disturbances or potential disturbances (eg scour pools, other erosional features);
- predicted subsidence effects (including conventional subsidence effects but focusing on valley closure and upsidence values);
- overall values and significance of the swamp.

The Panel encourages the research efforts currently underway by SCA, Illawarra Coal and other mining companies towards improved understanding of swamp impacts.

4.3.4.3 Groundwater

The Panel acknowledges that prediction of impacts within the shallow groundwater systems of the region is difficult since these impacts are governed in turn by predictions of subsidence effects. As noted, resulting impacts on streams include cracking of rock bars, draining of rock pools, diversion of creek flows and associated water/rock hydrochemical interactions and the development of ferruginous springs. The establishment of a measurement and monitoring regime aimed at increasing predictive accuracy (ie additional monitoring bores and associated surface infrastructure) might result in greater impact on the natural environment (at the surface) than may result from subsidence alone. A precautionary approach is therefore advocated with increased emphasis on subsidence prediction, geological mapping, mineralogical assessments (for water-rock interactions) and predictive modelling.

In respect of regional deep strata depressurisation and potential impacts on surface drainages and other water bodies arising from mining operations, the Panel recommends the use of 3D groundwater numerical modelling which surprisingly, has hitherto not been utilised in the Southern Coalfield even though this type of predictive analysis has been employed in the Hunter and Western Coalfields for many years. 3D groundwater modelling promotes an understanding of natural recharge processes, the role of creeks and rivers in constraining the water table, base flow estimations (including swamp contributions), and rates and directions of groundwater movement throughout a system for pre-mining, mining and post mining conditions. The Panel notes that it is especially important to ensure that a groundwater numerical model code is adopted that can adequately address high contrasts in hydraulic properties and steep hydraulic gradients that are typically associated with underground mining operations.

The Panel observes that during recent years there has been a significant increase in groundwater related data gathering throughout the Southern Coalfield. However the density and duration of observations appear to be limited, especially with respect to redirected surface flows and regional strata depressurisation. This may be attributed in part to the technical difficulties and costs associated with monitoring both the water table and deeper strata pressures in SCA Special Areas.

4.3.4.4 Flora and Fauna

Prediction of impacts on biological systems is always difficult, and this is particularly true when the linkages between and within the habitats, populations, species and communities are not obvious or are poorly studied. Despite the Southern Coalfield being located relatively close to major population centres, surprisingly little basic biological research on aquatic ecology has been carried out in this region, and this is particularly true for the aquatic communities.

Consequently, while some data are available for the distribution of particular species at local sites, the data provides little insight into the abundances of species across the region, the life history of these species or the inter-relationships between habitats and individual species. This is critical information when assessing regional significance and impacts on populations. The lack of an adequate regional assessment of many aspects of biodiversity means that any consideration of the significance of individual sites cannot be based within a framework of relevant scientific data, and may be little more than an opinion based on anecdotal information. A general indication of the consequences of subsidence impacts on biological systems comes instead from observations of previously documented subsidence impacts and consequences on natural features (see Table 9).

Best practice prediction of the consequences of subsidence impacts on biological systems will require a concerted effort on the part of both government and industry to improve the level of biological information available for the terrestrial and aquatic ecosystems in the Southern Coalfields region. It also requires well designed monitoring studies and an experimental approach to the assessment of possible impacts on the biological systems (eg impact/control experiments, see section 4.4.2.4). These monitoring and experimental studies need to be of a time frame that takes into account the seasonality and inter-annual variability of the systems under study. The minimum baseline periods for most ecologically-based studies would likely be between 18 and 24 months.

4.3.4.5 Aboriginal Heritage

The prediction of impacts on features of Aboriginal heritage significance is determined, first, by adequate surveys to determine the existence and significance of archaeological or cultural significance. Survey methodologies for both archaeological and cultural significance are well-developed and do not need to be further discussed or addressed by the Panel.

As indicated above, the archaeological sites which are most susceptible to subsidence-induced damage are rock shelters in caves or overhangs, generally associated with cliff lines. Consequently, the prediction of impacts on cliff lines is of key relevance (see section 4.3.4.1).

4.3.4.6 Anomalous Subsidence Impacts

As discussed in section 4.1.3, anomalous surface impacts (not relating to valley closure and upsidence) can arise from a variety of geological factors, especially the presence of faults (whether high angle or low angle), dykes and other geological intrusions, or massive overburden strata. Whilst anomalous movements can occur gradually, the actual failure and fracturing of surface rocks often develops suddenly but in limited locations. Inadequate baseline geological information, particularly regarding low angle and other faults, may mean that such movements are not predicted, and are only recognised post-subsidence. It is for this reason that such un-predicted movements are often termed 'anomalies'.

It is well-known in the Southern Coalfield that anomalous impacts may arise in respect of man-made structures. While no evidence was provided to the Panel that geological disturbances or dissimilarities can cause anomalous impacts on significant natural features, the Panel is of the opinion that there is no reason why this should not be the case. The Panel is therefore of the view that increased attention should be paid to geological and geophysical mapping of geological disturbances or dissimilarities which may cause anomalous subsidence movements at the surface, particularly where such discontinuities may be located close to significant natural features.

However, the Panel accepts that, at times, not all such features will be able to be mapped before the approval stage of mines. Consequently, it is very important to have contingency plans in place to manage unexpected impacts on significant natural features which are judged to be of high value. In addition, mines should have adaptive management strategies which can be activated where geological disturbances or dissimilarities are recognised after the approval stage but prior to extraction. In this respect, it is important that clear lines of communication exist between those mine personnel in change of subsurface mapping and those charged with managing subsidence impacts at the surface.

4.4 SUBSIDENCE MONITORING

4.4.1 Monitoring of Subsidence Effects

This section refers specifically to the monitoring of direct, mechanistic subsidence effects. As discussed in section 4.1, the main subsidence effects parameters are:

- displacement (vertical);
- displacement (horizontal);
- strain (tensile and compressive);
- tilt; and
- curvature

A number of these parameters can be derived from other primary field measurements such as absolute displacements. The Panel has focussed considerable attention on the phenomenon known as upsidence. It is important to again note that, as previously discussed, upsidence is also a derived, relative displacement parameter.

In terms of best practice subsidence management; prediction, monitoring, analysis and subsequent back-analysis of observed versus predicted subsidence parameters all form an essential part of a sound Subsidence Management Plan (SMP). One of the most crucial parts of a robust SMP is the last step of back-analysis, to provide a feed-back loop in the management system to assess the accuracy and effectiveness of the original subsidence predictions.

Traditional forms of surveying continue to provide a valuable means of subsidence monitoring. These consist primarily of precise leveling for vertical displacement, but should also include direct or derived measurement of horizontal displacement between each survey point. By processing this raw displacement data, the values of strain and tilt can also be determined for each bay or segment between adjacent survey points. Conventional subsidence surveys rely on the design of appropriate subsidence survey lines – generally along the centreline of the extraction panel being monitored (longitudinal survey lines), as well as one or more cross lines at right angles across the panel (transverse survey lines). The centreline and cross lines should extend well beyond the anticipated angle of draw to ensure that the extent of subsidence due to mining is reliably determined. Clearly, issues of access and surface terrain often dictate and limit the placement of surface line survey pegs and some compromises are inevitable.

Once survey points are installed it is critical to establish a set of baseline data well before undermining commences. Ideally an initial survey plus at least two subsequent surveys should be carried out prior to mining – not only to determine that the survey stations are stable, but also to determine any variation that may be present in near-surface ground movement that is not attributable to mining. Such movement can be due to weathering effects on surface soil and rock material, swelling and shrinkage of clay, slippage on sloping ground etc.

Surveying of the subsidence lines should be carried out on a regular basis during mining, with mining face location recorded accurately for the time of each subsidence survey. Surveys should then be continued on a less regular basis after mining has ceased until the data confirms that the ground surface has once again stabilised.

There have also been considerable advances in alternative and/or remote measurement techniques in recent years. Mining companies, consultants and research organisations in Australia have been at the forefront of these developments, many of which are now used routinely within a comprehensive subsidence monitoring and analysis program.

These alternate techniques include the use of EDM (electronic distance measurement) scanning devices for measuring line of sight distance between two survey points. This is extremely valuable for measuring closure (horizontal displacement) between two survey stations on opposite sides of a gorge or opposing cliff lines. Use of the GPS (Global Positioning System) is rapidly finding application for measuring absolute displacement at particular monitoring stations which may be inaccessible for line of sight surveying, but can be scanned by satellite surveying. The levels of accuracy achievable for both EDM and GPS systems continues to improve, with results in many cases equal to or better than that which can be achieved by conventional surveying.

A more recent development has been the use of satellite based radar scanning of surface terrain. The advantage of this technique is that it measures absolute displacement (primarily vertical) of the entire ground surface, without the need for placement or sighting onto specific survey stations. As a result, complete surface contour plans can be produced for different time intervals, to follow the progression of subsidence across the land surface. It is also capable of accurately monitoring deformation of the ground surface, even when it is masked by relatively thick vegetation. There is little doubt that in the future this form of subsidence monitoring will gain wide acceptance as the technique and the available satellite coverage improve.

One difficulty with remote scanning subsidence monitoring systems is the ambiguity in the data in the vicinity of rapid terrain changes, such as steep slopes and cliffs. The satellite imagery has difficulty resolving the changes in surface profile, especially where the ground has also undergone significant horizontal displacement. This issue requires further research to enable improved monitoring accuracy around these critical locations.

4.4.2 Monitoring of Subsidence Impacts and Consequences

4.4.2.1 Watercourses, Valleys and Cliff Lines

Whilst the level of monitoring across the industry is improving at a steady rate, and databases of the results of monitoring are now being developed, best practice monitoring of subsidence impacts on watercourses, valleys and cliff lines is still in a developmental stage. As indicated when discussing prediction techniques, there is a priority need to extend the focus of prediction further into prediction of subsidence impacts on specific types of natural features such as rock bars and rock structures in watercourses, valley slopes and cliff lines. In order to achieve sound ‘best practice’ subsidence management, the further requirement is then to use monitored actual impacts for back analysis, to compare and refine impact prediction techniques.

Subsidence impact monitoring, like subsidence effect monitoring, needs to follow similar principles:

- accurate and comprehensive baseline data records, prior to mining, for each of the identified significant natural features. This should include obvious parameters such as exact location and spatial extent; pre-mining condition; and any evidence of natural variability in that condition or extent. Factors such as unstable cliff lines (due to natural weathering/erosional effects or human influence) should be recorded;
- during and immediately after mining, data should be gathered in both visual format and quantitative parameters, whenever possible. This may include crack widths, extents, propagation rates, depths (where assessable), cliff fall locations, magnitudes and secondary consequences (such as flora/habitat damage);
- it is essential that the exact dates of all surveys/records are recorded and linked directly to the location of mining activity at the time; and
- any apparent non-mining impacts on the same natural features should also be recorded during the period of the mining/post-mining surveys. These may include impacts due to flooding, erosional events, bushfires, non-mining human activity, and in rare circumstances, earthquake or seismic activity.

In terms of technology available for such subsidence impact monitoring, some of the systems discussed under the previous section on subsidence effect monitoring may also find application here, such as conventional survey methods, as well as some of the newer scanning systems; conventional photography, aerial photography etc. In any close-up photography, it is essential to have a numeric scale device, such as a calibrated ruler or tape visible in the photographs to provide accurate and irrefutable evidence of magnitude, in the case of crack dimensions, for example.

All of the above monitoring data, plus the associated mining records, should be stored in such a way that they are readily available across the industry and regulatory agencies to facilitate analysis, interpretation and back-analysis against prediction. Whilst it is acknowledged by the Panel that it is not possible to predict every individual impact, prediction of impacts should identify areas of expected impacts and likely extent of impacts, which can then be compared to comprehensive and quantitative impact monitoring data.

4.4.2.2 Swamps

Monitoring of subsidence impacts on swamps is at an even-earlier stage of development than for watercourses, valleys and cliff lines. However, monitoring of swamps needs to follow the same principles as those set out above for the other natural features.

Emphasis needs to be given to the regular recording of the water table within the swamp, and any deviations in the water table from longterm or seasonal expectations or which do not reflect recent rainfall events. Surveying techniques should be used to monitor any changes in slopes of the swamp (particularly longitudinal or downstream slope). Pre-existing scour pools and other erosional features should be closely monitored for any evidence of increased erosion. Evidence of fresh erosion (especially knick points) should be closely monitored, with a view to incorporating mitigatory features should the need be apparent. If the water table has changed significantly (either in association with erosion or otherwise) increased flora and fauna monitoring may be necessary to determine whether the existing swamp floral community and ecosystem remains stable or has entered a state of change.

4.4.2.3 Groundwater

In areas where natural conditions could change as a result of mining, specific monitoring regimes need to be tailored to mine plans and to address aquifer definition(s) and interactions, strata hydraulic properties, pore pressure distributions, and groundwater qualities. Monitoring regimes should be based on:

- ***shallow piezometer installations*** for the monitoring of groundwater levels/pressures within significant upland swamps, drainages and any connected alluvium. Piezometers should have a sufficient distribution so as to be able to characterise the aquifer system with a high level of confidence in potentially affected areas. Water level measurements should be automated with daily or more frequent recording;

- ***groundwater quality classification*** through regular sampling and analyses at installed piezometers. Candidate analytes must facilitate the discrimination of mining related impacts and in particular, any ionic species that might be attributed to new water/rock interactions;
- ***deep piezometer installations*** for the monitoring of pore pressures within the natural rock strata. Piezometers should have a sufficient distribution so as to be able to describe the distribution of deep aquifer pressures with a high level of confidence. Pore pressure measurements should be automated with daily or more frequent recording;
- ***strata hydraulic property measurements*** to facilitate calculation of subsurface flows. While such properties (porosity and permeability) are unlikely to change naturally over time and hence regular monitoring is not required, a properties database is required for impacts assessment and in this context, such measurement is considered to constitute baseline data. Techniques for the measurement of hydraulic properties are well established and include packer testing, variable head testing, test pumping, core analyses (matrix properties and defects inspections) and geophysical logging where appropriate; and
- ***mine water balance for existing and extended operations*** is considered by the Panel to be an especially important part of baseline data measurements. It provides a means of confirming the groundwater transmission characteristics of the coal seam, overburden, and the drainage characteristics of goaves and the overlying failure regimes. It also provides a first indication of potentially anomalous mine water seepage that might be initiated by faulting or fractured igneous intrusions and increased connectivity to surface drainage systems. The water balance should take into account all water imported to an underground operation or part thereof, and all water exported from that same operation including pumped water, coal moisture increases (allowing for inherent moisture), ventilation moisture and any other exports.

4.4.2.4 Flora and Fauna

The importance of establishing well designed baseline studies of flora and fauna and on-going monitoring programs is demonstrated well in the Southern Coalfields where, at least historically, very little pre-mining data on the flora and fauna were collected with some data having questionable value. As a result, in many cases it is difficult to accurately assess the impacts of past underground mining activities or to set biological targets for remediation, when it has become necessary. This situation is at least partly a consequence of increased public expectation and the considerable advances made in recent years in the design of monitoring studies and analyses of data. The Panel noted that in several recent cases, subsidence management programs in the Southern Coalfields have included environmental monitoring programs with improved experimental designs that should prove more useful in assessing impacts and setting targets and standards for remediation activities, if required in the future.

The Panel noted in particular the lack of baseline information concerning the aquatic ecosystems in the Southern Coalfields region, which in several cases has led to the situation where outcomes of rehabilitation projects cannot be assessed adequately. For example, Illawarra Coal stated in its Submission to the Inquiry that, in relation to its rehabilitation of the Cataract River, 'the degree of success of this rehabilitation grouting is the subject of ongoing speculation due to the lack of pre-mining data.'

One of the key issues in establishing best practice in environmental monitoring programs is to ensure adequacy of the baseline studies. These studies need to be of a sufficient time period and of sufficient intensity to provide an understanding of the variability and seasonality in distribution of flora and fauna, prior to any mining activity. This is especially true for species, populations and communities that have been listed as threatened within NSW, under the relevant legislation. In most cases, this requires that a well coordinated sampling program be established many months, and more likely years before the mining activity is undertaken. As a general guide, the minimum time period for baseline studies is often 18 - 24 months, although even this period is insufficient to understand inter-annual variability in distribution and abundance that many animals exhibit.

Selection of study sites is another key aspect of any monitoring program. As well as sampling at sites directly within the impact zone of the proposed activity (eg directly above the mine), comparative sampling sites must be chosen at control locations (ie outside the direct impact zone), so that changes and fluctuations due to non-impact effects are considered. In both the impact and control sites, the research design also needs to replicated so that natural variability can be determined.

These sampling programs need to be established within an experimental design that allows advanced statistical analyses techniques to be employed. The most appropriate design for many impact studies is known as the Before, After, Control, Impact (BACI) study. BACI designed ecological studies require an understanding of this statistical approach and the requirements in the sampling design, as well as the limitations in analyses.

While a well designed monitoring program is essential to any environmental management program, it is also important to understand that many natural systems (eg populations of macro-invertebrates) are highly variable and often it is difficult to measure impacts, as variability within the system may be greater than, or simply mask, the impact. Well executed baseline studies and environmental monitoring programs need to be combined with an adaptive approach to managing unexpected change in the system. Data collected from BACI sampling programs may also contribute to establishing biological targets for remediation projects that may be attempted in the future.

Several texts and scientific publications are available outlining best practice in impact monitoring and assessment of remediation efforts (eg Green, 1979; Underwood, 1991 and 1997).

4.4.2.5 Water Quality and Water Supply

Water quality is a key determinant not only of aquatic ecosystem health but also for the quality and reliability of the water supply for both Sydney and the Illawarra region.

In its submission, SCA states that it has a need for 'good scientific data to be in a position to clearly identify the degree of risk a longwall mining project might pose to the sustainability of water supply operations and catchments.' SCA's draft water monitoring guidelines point to a need for monitoring in respect of:

- pre-mining hydrological (including hydrogeological) conditions and their behaviour under natural climate variability;
- changes in the hydrological system and impact on surface and groundwater resources during mining including water quality and quantity;
- post mining recovery from impacts; and
- effectiveness of rehabilitation options to repair the hydrological system.

The Panel agrees with these monitoring goals and strongly encourages rigorous collection of data and the implementation of new technologies where appropriate. An appropriate monitoring program might include;

- rainfall measurement at a sufficient number of locations so as to permit assessment of runoff contributions (quick flow and base flow) and aquifer recharge characteristics in potentially affected areas;
- stream flow gauging with automated daily or more frequent recording of flows at strategic gauging stations, distributed in such a manner so as to accurately characterise the flow regime and to reflect mining-related impacts within 3rd and higher order stream channels; and
- stream water quality characterisation through regular sampling and analyses. Candidate analysts must facilitate the discrimination of mining-related impacts and address appropriate water quality guidelines (eg ANZECC 2000) and any other regulatory requirements.

4.5 MITIGATION, REHABILITATION AND REMEDIATION

Mitigation refers to measures undertaken to reduce or prevent the impacts of mining-induced subsidence on natural and man-made features. *Rehabilitation* or *remediation* refers to the activities associated with partially or fully repairing and rehabilitating natural and man-made features impacted upon by subsidence.

The following natural and other features may require preventive and/or remedial measures during mining or on completion of mining:

- cliffs and overhangs;
- upland swamps, wetlands, water bodies and floodplains;
- rivers, creeks and drainage lines;
- vegetation and ecosystems; and
- Aboriginal sites.

The response of these features to subsidence and the rehabilitation or remediation of these features can be substantially different to that associated with man-made structures. Usually, man-made structures are decoupled to some extent from the ground and have a degree of built-in flexibility, both of which improve tolerance to subsidence. They are geographically accessible, small scale and can often be relocated or decommissioned whilst subsidence is occurring. After mining has been completed they can be repaired or, if necessary, replaced to the same form and appearance as they were before being impacted by mining. Natural features on the other hand, are usually rigidly coupled to the ground and can suffer a permanent change to their structure or fabric. Some, such as cliffs, may not be able to be rehabilitated if they are damaged.

4.5.1 Mitigation

Mitigation measures for natural features can be classified under the following headings:

1. ***Avoidance of ground movement:*** This encompasses measures which result in no mining within a zone of influence of the structure. These measures usually involve leaving a protective pillar beneath the feature or modifying the mine layout so that no mining occurs within a predicted zone of influence of the feature.
2. ***Restriction of ground movement:*** The magnitude of surface ground movements can be controlled by restricting mining height and/or restricting excavation width and/or increasing pillar width. Mining layouts in which panel width is restricted for the purpose of controlling subsidence are referred to in general as ‘partial extraction’ mining systems. The number of partial extraction panels required to protect a surface feature depends on the width of the excavations and the width of the intervening pillars relative to the depth below surface. At depth, a number of adjacent partial extraction panels may be required in order to afford a specific level of protection to a feature. Ground movement at the site of a feature may also be restricted by designing the mine layout so as to position the feature in a specific part of the subsidence trough. This measure is not usually feasible where the natural feature extends over a considerable distance or meanders.
3. ***Isolation of ground movement:*** This involves isolating a feature from ground strains and shear displacements by constructing slots at strategic locations adjacent to the feature, with the intention that ground strain will concentrate at the slots. The success of this measure is dependent on a number of factors including selecting the correct locations and directions for the slots, having access to these sites, and constructing the slots a sufficient time in advance of mining. The slots may be cut mechanically or formed by drilling a pattern of closely spaced, large diameter drill holes. This control measure is still in a development stage. The usefulness of this technique depends on a number of factors, including timing (the ability to fully construct a slot prior to the approaching longwall face), access to the appropriate location and the environmental impacts associated with access and construction. However, it has shown promising results in the limited number of cases where it has been employed (eg at Marnhyes Hole on the Georges River).
4. ***Maintenance responses:*** This involves measures which aim to maintain the physical state and function of a feature, albeit that it may be impacted by subsidence during the mining process. Examples include increasing flow volume in a fractured section of a watercourse in order to maintain surface flow at pre-mining levels, and installing support in overhangs and cliff faces prior to undermining.
5. ***Preservation responses:*** Archaeological artefacts which may be at risk from mine subsidence may be removed on a temporary or permanent basis prior to undermining, or logged and recorded in a visual format for posterity.

4.5.2 Rehabilitation

There are a number of rehabilitation (or remediation) techniques which are available for the remediation of significant natural features impacted by mining subsidence. These include backfilling and/or grouting of cracks and fracture networks at strategic locations, stabilisation of slopes and drainage and erosion control measures.

Fractures may infill naturally in watercourses that have a moderate to high sediment load; otherwise they may have to be grouted. Grout can be either cement-based or composed of various plastics or resins (eg polyurethane). Grout is commonly injected under pressure into the fracture network beneath both rock bars and pools but the degree of success is dependent on the accessibility of the site, on the type of grouting materials which are used and on timing.

In the case of watercourses, subsidence related cracking and upsidence related fracture networks can extend over hundreds of metres and it is not feasible to remediate the entire fracture network. Hence, remediation efforts in the Southern Coalfield have to date focused on sealing the fracture network at strategic locations, such as rock bars. At these sites, the fracture network can extend some distance laterally under the toe of valleys and be overlain by talus. It can also be covered by boulder beds within watercourses. These types of settings restrict access for grout injection equipment. If the site of fracturing is affected by a number of mining panels, several episodes of grouting may be required over a number of years. In the interim, mitigation measures are required to sustain surface water flows if the local ecology is not to be impacted.

The Panel inspected four sites where remediation of fracture networks had been undertaken (Cataract River, Waratah Rivulet and at Marnhyes Hole and Jutts Crossing on the Georges River). The program on the Georges River involved:

- shallow drilled pattern grouting within Pools 8, 9, 14, 16B and 17;
- deep angle drilled grouting of fractures 5-10 m below stream bed level in Pool 15; and
- installation of a grout curtain beneath the rock bar at Jutts Crossing, between Pools 9 and 10.

This program was described in detail in a report by Illawarra Coal in November 2006. The report concludes that these techniques significantly increased surface flow over the remediated zone during periods of low flow (when previous reductions in flow had been most apparent). Figure 39, from that report, compares flow conditions in the river when 1.5 ML/day was flowing over the Georges River Weir after mining and rehabilitation. Prior to the rehabilitation works, a net loss of 1.23 ML/day was estimated between the Georges River Weir and Rockbar 40 where the flow entering the system was 1.5ML/day. These flow losses principally occurred in the section of river containing Pools 7 to 14. After the remediation works, the flow improved significantly with the system experiencing a net gain of 0.1ML/day over the 6.4 km length of the River between the weir and Rockbar 40. The Panel accepts that this program has been generally successful and that stream flow, pool depth and pool water holding capacity have largely returned to pre-mining levels.

Sealing was most effective at the three sites that had utilised a cementing agent in the grout. Nevertheless, a 100 per cent seal was not achieved, although the effectiveness of grouting appeared to be improving with experience. The Panel also noted deterioration of the cosmetic covering of surface crack expressions and of holes used to inject grout.

Some types of grouting agents used for sealing similar types of fracture networks in other civil and mining environments (eg polyurethane resin or PUR which is used extensively to seal tunnels and shafts) have not been permitted in the Southern Coalfield until recently because of concerns regarding pollution of water supplies. In fact, until recently, the SCA has not permitted any form of grout to be used within its Special Areas. Consequently, in sections of the Waratah Rivulet, unconsolidated sand has been used to fill cracks within the river bed. This unconsolidated sediment soon washed out of the cracks during high flow events and now can be found downstream within various pools in the watercourse. SCA has now allowed, on a trial basis, PUR to be used in grouting and sealing stream bed cracks within the Special Areas and Helensburgh Coal has recently completed remediation of one rock bar (WRS4) on Waratah Rivulet using this type of grout. Helensburgh Coal has claimed a high measure of success for this operation, but this view has not yet been independently verified.

The Panel is not aware of any attempts to remediate fracture networks beneath swamps. However, further research is taking place in this area and Illawarra Coal has recently commissioned a consultant to examine potential remediation techniques for impacted wetlands and swamps. The Panel is also not aware of any remediation having been undertaken of mining induced cracks in cliffs and overhangs.

The Panel noted that little (if any) work has been done in the Southern Coalfield to re-establish biological communities, particularly aquatic flora and fauna, following subsidence-related impacts to habitats. Further, there has been little work done to successfully demonstrate re-establishment of ecosystems either after remediation of habitat features (such as rock bars or pools) or in the absence of any such remediation.

The Panel recognises that there are a number of limitations on the successful implementation of rehabilitation techniques in the Southern Coalfield. These include:

- weaknesses in baseline data against which rehabilitation outcomes should be measured;
- lack of agreed completion criteria for the measurement of rehabilitation outcomes;
- lack of research and experience in applied rehabilitation techniques for these types of mining-related impacts;
- lack of research comparing the outcomes of interventionist remediation with natural processes of remediation;
- difficulties in accessing impacted sites due to remoteness, terrain and/or high water levels;
- environmental impacts of remediation and related access in pristine natural areas (particularly restricted-access water catchments); and
- approvals processes for remediation activities.

However, the Panel observes that most of these limitations are within the power of both industry and government agencies to address.

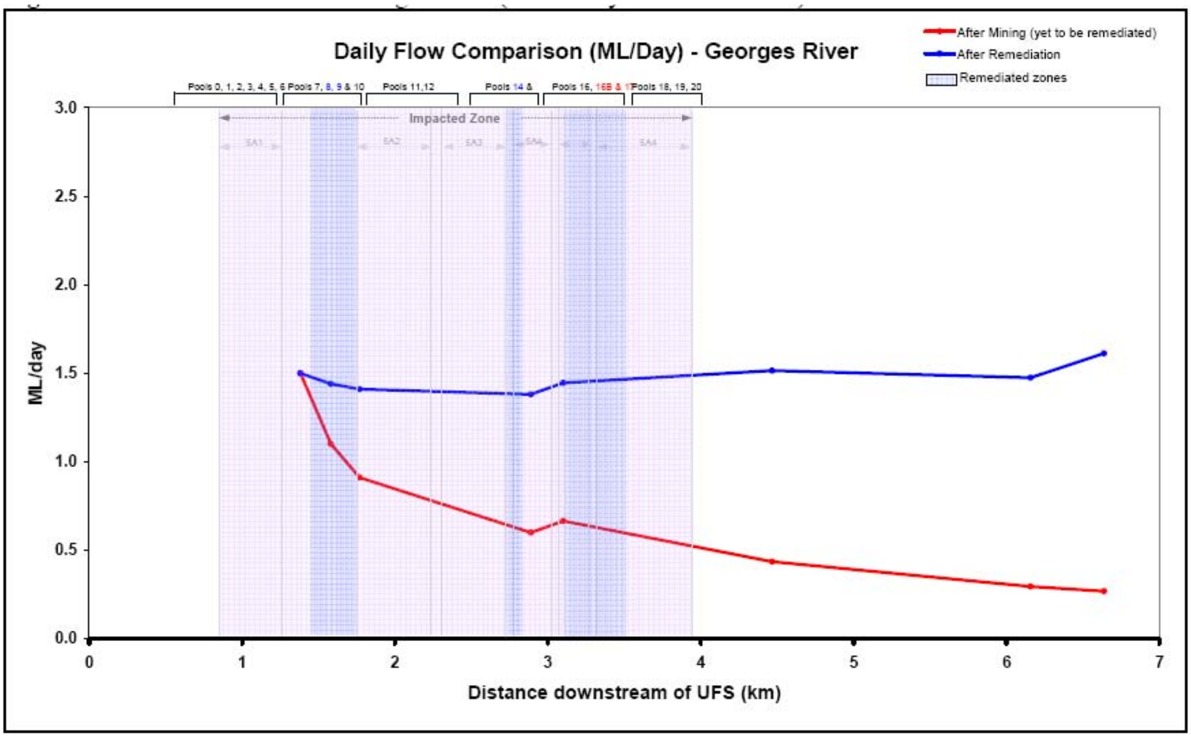


Figure 39: Post-Mining and Post-Rehabilitation Flow Balance for the Georges River

Note: Balance determined with 1.5ML/day flow at Georges River Weir. Source: Illawarra Coal

The Panel is of the opinion that the remediation of subsidence impacts on natural features is in its infancy and, consequently, the level of risk currently associated with the successful remediation of natural features ranks as medium to high. A number of aspects warrant more detailed consideration and research in order to reduce this level of risk. These include:

- all technical aspects of remediation, including matters relating to environmental impacts of grouting operations and grout injection products, life spans of grouts, grouting beneath surfaces which cannot be accessed or disturbed, techniques for the remote placement of grout, achievement of a leak-proof seal and cosmetic treatments of surface expressions of cracks and grouting boreholes; and
- administrative aspects of remediation, in particular, procedures for ensuring the maintenance and security of grout seals in the long term.

4.5.3 Natural Processes of Remediation

There has been substantial discussion over recent years, and statements were provided to the Panel, which noted the ability of some natural systems to 'self heal' following subsidence impacts. These issues deserve some discussion.

In regard to watercourses, the Panel is of the opinion that the measure and rate of natural processes of remediation depend on the extent of damage and the type of watercourse. For example, the Nepean River is heavily regulated by weirs and can be considered as a long, shallow, generally low stream-energy impoundment in the area where mining has and will take place. Rate of flow is therefore interrupted and the river contains a substantial and semi-constant water column and a significant bed load of fine sediment and decomposing vegetation. Cracking of the stream bed beneath this sediment load is unlikely to lead to any long term consequences, and the short term impact of gas release generally dissipates over a number of months. On the other hand, a high energy stream environment with a low natural sediment load such as the Waratah Rivulet which has been impacted by upsidence, rock bar cracking and pool drainage, may be expected to show a much slower rate of natural remediation. The Cataract River might be considered to fall mid way between these two cases.

The Panel observed a number of examples of natural processes of remediation of subsidence impacts. Stream bed cracking, surface water drainage to the subsurface and ferruginous springs which occurred in the Upper Bargo River in 2002 were barely evident. In the lower Cataract River, where subsidence caused stream bed cracking between 1993 and 1997 and a simultaneous period of historically low water flows led collectively to loss of surface flow, drainage of pools and significant water quality and aquatic ecosystem changes, exposed stream bed cracks had been colonised by lichens and/or mosses, reducing the visual impact (see Figure 40). Cracks are also being colonised by other flora and fauna such as saplings and ants (see Figure 41). Water quality was sufficient to support aquatic macrophytes and small fish, and a large fish-eating bird was observed.

These examples of natural processes of remediation of watercourses over time are considered to be both significant and encouraging, but it is not possible for the Panel to quantify the extent or effectiveness. While stream bed impacts in these rivers have self healed to varying degrees, the Panel notes that some impacts like redirected stream flows and degraded water quality have been sustained in other locations for long periods of time.

Rock falls from cliff faces may have substantial aesthetic impacts when the freshly-broken rock is first exposed. However, rock falls are not unusual events for cliff faces over geologic time, and in fact the very reason for the existence of those cliff faces is rock falls associated with jointing, root penetration and soil and root swelling during heavy rainfall events.

The extent of self healing of fracture networks beneath swamps and the degree to which the ecological functioning of deeply scoured swamps can be restored through natural processes is unknown.

Figure 40: Colonisation of Subsidence Crack by Lichens, Lower Cataract River, September 2007

Figure 41: Colonisation of Subsidence Crack by Sapling and an Ant Nest, Lower Cataract River, September 2007

4.6 NON-MINING IMPACTS ON SIGNIFICANT NATURAL FEATURES

In addressing the terms of reference for the Inquiry, it is important to make some passing note of the large scale and significant impacts on significant natural features from non-mining activities. In particular, the Panel considers that there are three very significant non-mining impacts that are recurring themes in the Southern Coalfield region. These are:

- construction of in-stream structures (eg dams and weirs) and diversions that alter natural water flows and quality;
- disposal of sewage and other contaminated waste water and storm water that impacts on water quality and aquatic ecosystems; and
- introduction of pest and alien (ie non-native) species into the waterways.

4.6.1 Watercourses

The construction of large dams and weirs within the water catchments has had obvious and major implications for the watercourses of the region. These include the direct impacts of the construction of the dams and weirs and also related access roads and pipelines, especially vegetation clearing, erosion and sedimentation.

In addition, there are the impacts associated with long-term impoundment within the water storages. Disruption of natural water flows; drowning of ecosystems; unnatural flooding and draining of shoreline and creek habitats; eutrophication or deoxygenation at depth within the water storages; release of cold and deoxygenated water from dams and a variety of other related issues are well documented impacts for water storages that have affected most catchments in this region. While most of these impacts may be seen as unavoidable consequences of supplying water to a major city, much more could probably be done to manage the consequences.

A number of examples of substantial ongoing impact deserve mention. The Lower Cataract River carries a much reduced volume of water when compared with the 1980s and early 1990s (see Figure 42). Some members of the community considered that these reduced flows were the result of riverbed cracking. However, the SCA increased pumping capacity at Broughtons Pass Weir in the mid 1990s leading to a significant capture of high-flow events within the river. For this reason and also because of sustained drought conditions, average flow reduced from around 40,000 MLpa in the late 1980s to less than 10,000 MLpa from 1993 to 2003. Further, in response to Sydney's recent water shortage, SCA reduced environmental flows to the Cataract River to less than 1.0 ML per day, which appeared to be roughly the daily rate of flow when the Panel visited the lower Cataract River in September 2007. The impacts on the river include a substantial reduction in long-term river depth and stagnation in some pools leading to the development of pale-green algal blooms and green algal mats (see Figure 43).

The Panel also visited several sites that were obviously contaminated from either storm water or agricultural runoff or, more seriously, from subsurface migration of wastes from septic tank and/or sewage overflows. These resultant impacts on water quality were also often falsely attributed to mining activities by concerned locals. Sites included gullies which drained into the Lower Cataract River, and the Georges River downstream of Appin. The Panel notes that Appin is currently on Sydney Water's Priority Sewage Program (see section 2.3.2.4).

4.6.2 Swamps

The Panel notes that there is an unresolved debate about the significance of non-mining impacts on valley infill swamps. In particular, some mining companies maintain that the roles of erosion (where not induced by mining) and bushfire in damaging swamps within the Southern Coalfield is very substantial. Researchers have produced air photo evidence that suggests that some erosive events in swamps which are now severely impacted by scouring may have been initiated many decades before any likely impact by mining. Equally, there is evidence that scouring, erosion and consequent burning of vegetation and soil-based peat within dry swamps (as has occurred at Swamp 18 on Native Dog Creek) may be a natural and periodic event, related to climatic cycles and natural drying events (see Tomkins and Humphreys, 2006). The Panel considers that these issues should be subject to further research, as a priority for both industry and Government.

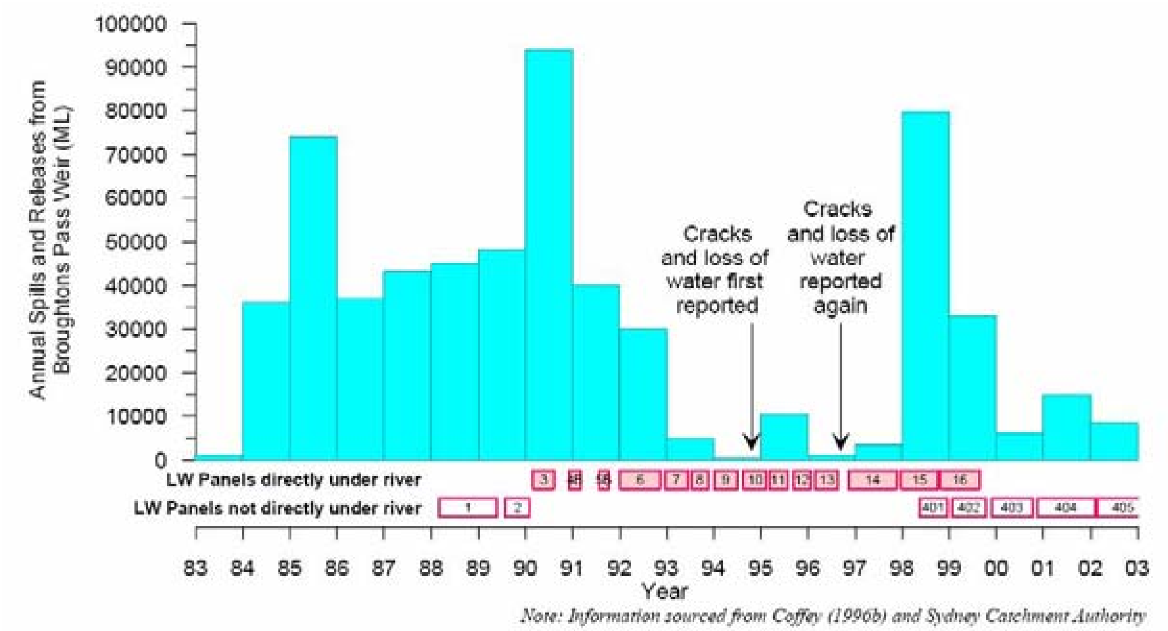


Figure 42: Annual Spills and Releases from Broughtons Pass Weir, 1983-2003, Showing Timing of Longwall Extraction and Major Riverbed Cracking

Figure 43: Lower Cataract River Showing Evidence of Changed Long Term Flow Patterns, September 2007

Note: Light green discolouration, probably algal in nature.

4.6.3 Non-Mining Impacts on Aquatic Ecosystems

Losses to natural water flows and changes to water quality (eg temperature) from the construction and the previous and continuing management practices for water supply dams for Sydney and the Illawarra has had a major impact on the distribution of aquatic flora and fauna in the Southern Coalfield region.

Historically, the distribution and abundance of fishes across freshwater rivers and streams in the Southern Coalfield region, like most parts of NSW, have been heavily impacted through the construction and operation of in-stream structures, such as dams and weirs, and water extraction for irrigation purposes. The *'installation and operation of instream structures and other mechanisms that alter natural flow regimes of rivers and streams'* is listed as a key threatening process under Schedule 6 of the *Fisheries Management Act 1994* (analogous to the listing of '*alteration of habitat following subsidence due to longwall mining*' as a key threatening process under Schedule 3 of the *Threatened Species Conservation Act 1995*). In particular, the Panel notes that the construction and operation of large dams in the Upper Nepean and Woronora Catchments is considered to be the primary factor leading to the loss of many fish populations in this region. The existence of these dams remains the main impact on the threatened species, Macquarie Perch (*Macquaria australasica*). The listing of Macquarie Perch as a vulnerable species under the FMA Act has led to a more concentrated effort to understand the distribution and life history requirements of this species.

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5 Decision Making and Regulatory Processes

5.1 CURRENT REGULATORY ENVIRONMENT

There are two key pieces of legislation that are central to the mining approvals process. These are the *Environment Planning and Assessment Act 1979* (EP&A Act) and the *Mining Act 1992*. The application of these two key Acts is outlined below and addressed in detail in Appendix A.

In addition, there are numerous Acts and Regulations that do or may apply to underground coal mining in the Southern Coalfield. These are outlined in Appendix A and include the:

- *Sydney Water Catchment Management Act 1998*
- *National Parks and Wildlife Act 1974*
- *Threatened Species Conservation Act 1995*
- *Fisheries Management Act 1994*
- *Dams Safety Act 1978*
- *Heritage Act 1977*
- *Native Vegetation Act 2003*
- *Water Management Act 2000*
- *Water Act 1912*
- *Protection of the Environment Operations Act 1997*

The interaction of this legislation can be complex but has been simplified substantially by the introduction of Part 3A EP&A Act in August 2005. One of the major effects of Part 3A is to integrate a number of licensing requirements under much of this legislation into the up-front project application process.

5.1.1 Environmental Planning and Assessment Act 1979

5.1.1.1 Historical Background

Until recently, most coal mines in the Southern Coalfield operated without a development consent. This is because the long history of coal mining in the area meant that most coal mines have been operating since before development consent was required due to the introduction of the EP&A Act, or, in some cases, before Part XIIIA of the *Local Government Act 1919*, the planning scheme which preceded the EP&A Act. Mines which have been operating under development consent include the:

- Dendrobium Coal Mine (consent granted by the Minister for Urban Affairs and Planning on 20 November 2001);
- Tahmoor Coal Mine (a 3-part consent granted by Wollondilly Shire Council in 1975, the Land and Environment Court in 1994 and the Minister for Planning in 1999); and
- West Cliff Coal Mine (a 2-part consent granted by Wollondilly Shire Council in April 1975 and the Minister for Planning in December 1988).

Transitional provisions associated with the introduction of the EP&A Act have meant that existing mines did not need development consent, provided that those provisions were adopted in the relevant local environmental plan (LEP). The relevant provisions (or similar) were adopted in the Wollongong, Wollondilly and Wingecarribee LEPs (ie throughout the Southern Coalfield).

This longstanding separation between existing coal mines in the Southern Coalfield and the EP&A Act came to an end with the passage of the *State Environmental Planning Policy (Major Projects) 2005* in May 2005. This SEPP established that all development which in the opinion of the Minister for Planning is 'development for the purpose of …. coal mining' is declared to be a project to which the new Part 3A of the EP&A Act applies – ie, it is a 'major project'. The SEPP established a five year transitional period during which mines which did not have an existing development consent were required to obtain a project approval under Part 3A.

When Part 3A of the EP&A Act was passed in August 2005, it included amendments to the *Mining Act 1992*, which removed a related exemption under section 74(1) of that Act whereby existing mines operating under a mining lease did not require a new or amended development consent for new or expanded mining operations within the area of the lease. Transitional provisions also provided a five-year timeframe for the implementation of this change in the case of an existing mining lease where underground mining operations are carried out. This period expires on 16 December 2010.

5.1.1.2 Part 3A Approval Regime

Part 3A of the EP&A Act was introduced in August 2005 specifically to deal with the complexities of major projects, such as coal mines. The key steps are the preparation of a short, 'preliminary environmental assessment' (PEA),[6] which leads to an assessment and determination by the DoP of the 'key issues' for environmental impact assessment for the project. This leads to the development of 'Director-General's requirements' (DGRs) issued to the proponent which form the basis for the preparation of the required environmental assessment (EA). The EA is first assessed by the DoP and other key agencies to determine whether it adequately addresses the DGRs, and, if considered adequate, the EA is then publicly exhibited for a period of at least 30 days. Public and agency submissions received by DoP are forwarded to the proponent, which must prepare a 'response to submissions' and, potentially, a 'preferred project report'. DoP then assesses the EA and considers all submissions and the proponent's response. This leads to the preparation of a Director-General's assessment report which enables the Minister to determine the project (ie approve it or disapprove it) and to decide under what conditions it may proceed.

A key outcome of Part 3A is to simplify the approvals process for major projects. The legislation exempts approved major projects from requiring a significant number of other statutory approvals. Further, other statutory approvals cannot be refused for an approved project, and those approvals must be 'substantially consistent with' the project approval.

Mines in the Southern Coalfield which do not currently have development consents and which are therefore required to obtain project approvals under Part 3A by December 2010 in order to continue their current operations include:

- Peabody Coal's Metropolitan Coal Mine;
- Illawarra Coal's Appin, Appin West and West Cliff Coal Mines; and
- Gujarat NRE's No 1, Avondale and Wongawilli Coal Mines.

All these mine are expected to lodge project applications under Part 3A over the next 2 years. The key process steps for mining related approvals in the Southern Coalfield are set out in Figure 44.

5.1.1.3 Conditions of Project Approval under Part 3A

The Department of Planning's (DoP's) current standard conditions of project approval for underground coal mines under Part 3A include requirements to prepare and implement a number of management plans and strategies to the satisfaction of DoP's Director-General. These include a Subsidence Management Plan (SMP), which must also be prepared and implemented to the satisfaction of DPI's Director-General (see section 5.1.2.1 below).

Apart from requiring independent environmental audits (generally every 3 years) under conditions of project approval, DoP also has a Compliance Unit which undertakes site audits and inspections of mine sites, generally on a targeted basis.

[6] 'Environmental assessment' is the name given under Part 3A to what is otherwise known as an environmental impact statement or EIS.

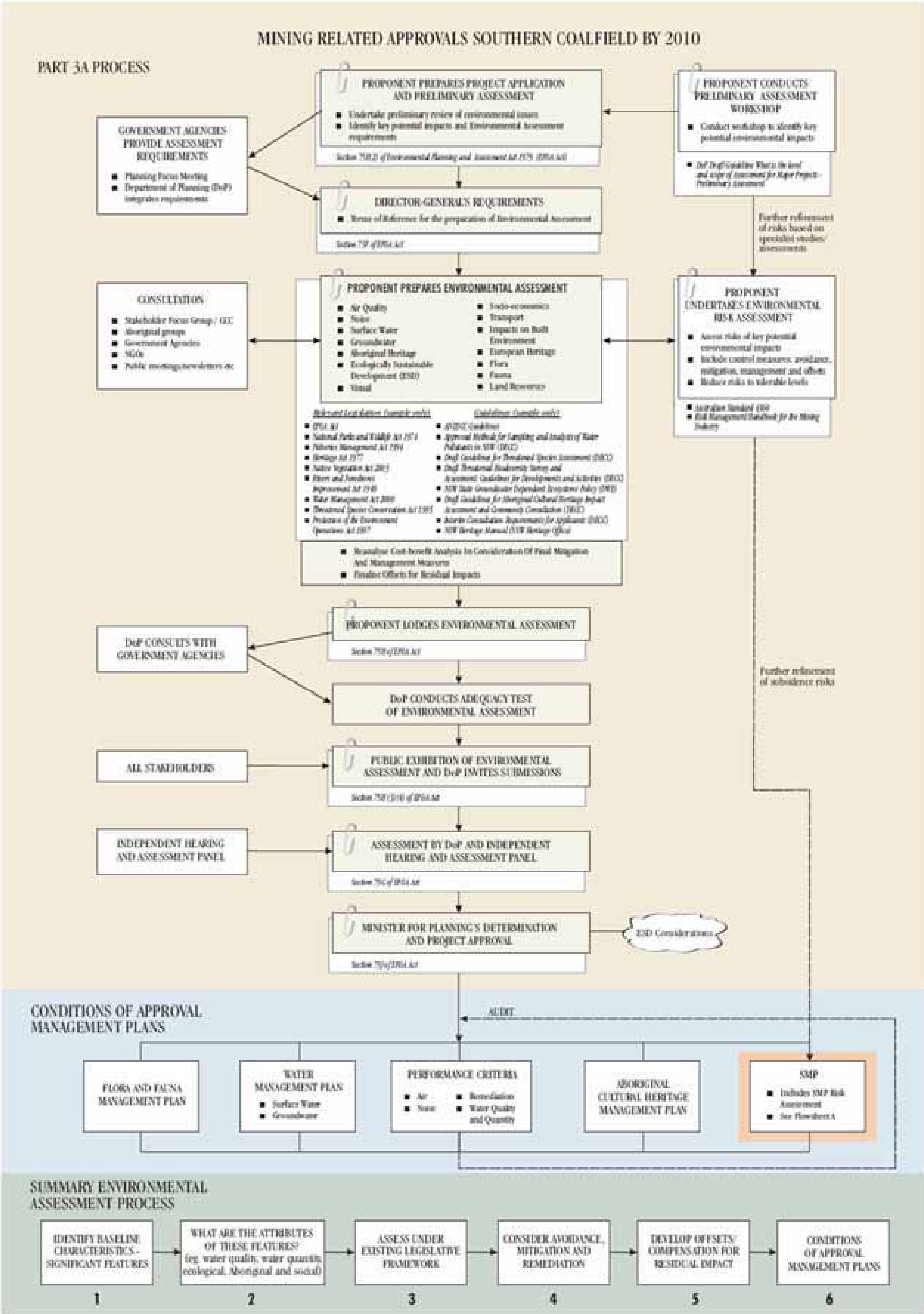

Figure 44: Part 3A Approvals Process for Southern Coalfield Coal Mines, Showing Relationship with Subsidence Management Plan

Source: DoP

5.1.2 *Mining Act 1992*

Under the *Mining Act 1992*, coal cannot be mined without a mining lease. Under Part 3A of the EP&A Act, any mining lease granted must be 'substantially consistent with' any project approval granted by the Minister for Planning. It follows that any mining lease application may only be granted following the giving of any necessary project approval by the Minister for Planning.

5.1.2.1 *Subsidence Management Plans*

Since early 2004, all new and existing leases permitting underground coal mining have included a condition requiring the leaseholder to prepare a Subsidence Management Plan (SMP) prior to commencing any 'underground mining operations which will potentially lead to subsidence of the land surface'.

SMPs are prepared by leaseholders to predict potential impacts of underground operations and identify how significant natural and built features are to be managed. Management may involve the avoidance of damage to particularly significant features, the mitigation of damage, or rehabilitation. The expressed policy intent of the SMP is to provide for the adequate protection of important natural and built features.

SMPs and their supporting information are first reviewed by DPI, and a recommendation prepared for its Director-General. Before approval by the Director-General, the SMP and DPI's assessment are reviewed by an interagency committee (the SMP Inter-Agency Committee or SMPIAC). This whole-of-Government approach was established by DPI to ensure a thorough assessment of each SMP. The committee includes representatives from each of the following agencies:

- Department of Planning;
- Department of Water and Energy;
- Department of Environment and Climate Change;
- Department of Primary Industries – Fisheries;
- Dam Safety Committee;
- Sydney Catchment Authority; and
- Mine Subsidence Board.

Other agencies, such as the Heritage Office, the Roads and Traffic Authority or Railcorp, may be invited to attend specific meetings where they have an identified interest.

5.1.2.2 *Rehabilitation and Security Deposits*

All mining leases contain conditions requiring the leaseholder to maintain security (either a cash deposit or a bank guarantee) for the fulfilment of all obligations arising under the *Mining Act 1992* in respect of the lease.

DPI policy requires that the security deposit be sufficient to cover the full rehabilitation costs of all activity on the lease. This requirement ensures the State does not incur financial liabilities if the leaseholder defaults on their rehabilitation obligations. The leaseholder is required to provide an estimate of rehabilitation costs for DPI to consider when determining the security deposit amount.

When mining has been completed, DPI assesses and determines whether rehabilitation obligations have been fully met so that the security deposit can be released. Partial release of the security deposit may occur when successful rehabilitation has been demonstrated for part of the site.

Amendments to the *Mining Act 1992* assented to in May 2008 provide *inter alia* that a security deposit may now be held in respect of mining-related damage which occurs *outside* (including above) the lease area. These amendments will also strengthen DPI's enforcement powers outside of mining leases and other titles.

5.1.3 Stakeholder Consultation

There are substantial opportunities for agency and community consultation under both the Part 3A and SMP processes. DoP guidelines encourage proponents to undertake community consultation at an early stage, and this is almost universally the case for large mining projects.[7]

Major projects are also usually subject to a requirement to hold a 'planning focus' meeting, where representatives of all affected Government agencies meet with the proponent and their consultants to identify any key issues of concern over a project at an early date. This meeting usually discusses a draft PEA, and its outcomes are reflected in the final PEA and, in turn, the EA.

After the EA is received by DoP and found to adequately address the DGRs, it must be publicly exhibited for at least 30 days. Public and agency submissions received by DoP are forwarded to the proponent, which must prepare a 'response to submissions'. The public exhibition is advertised, as is the receipt of the project application and any approval or disapproval by the Minister. All key documents relating to a project application (including the EA and any ultimate project approval) are publicly available at all times via DoP's website.

Under DPI's SMP process, the applicant must publicly advertise that its intention to submit an SMP application, and ask for community submissions. Any such submissions must be reflected in its SMP application. It must then readvertise that it has made its application, and make that application publicly available. DPI considers community and agency submissions received in its consideration of SMP applications, and makes those submissions available to the SMPIAC. The SMP approval must also be publicly advertised by the applicant, and the terms of the approval are available on DPI's website.

5.1.4 Current Review of the SMP Process

The Panel accepts that the introduction of the SMP process focused attention and improved the management and understanding of subsidence impacts. However, experience with the process has identified a number of improvements which DPI can make. DPI is currently undertaking a review of the SMP process, the aim of which is to.

- improve transparency and streamlining in the approval process;
- remove duplication in approval requirements;
- provide certainty for industry and government; and
- ensure environmental and infrastructure impacts are appropriately identified and addressed.

DPI has reported that the SMP review will be informed by the outcomes of the Southern Coalfield Inquiry report and will therefore not be finalised until after the report is presented to government. DPI has indicated that the draft review is underpinned by the fact that the application of the Part 3A approval process to existing coal mines clearly establishes the planning legislation as the prime approval mechanism for the operation of all underground coal mines, including for the identification and approval of subsidence impacts. Consequently, the expansive environmental impact assessment role that the SMP application process has taken to date, in the absence of either current development consent or Part 3A approval for many mines, is no longer required.

DPI therefore anticipates that the SMP process will in future focus on management plans that define how subsidence impacts on specific natural and built features will be managed, including contingency plans to be invoked in the event that subsidence predictions are exceeded. Management plans should stipulate how subsidence impacts on specific surface features are to be managed within the limits of the Part 3A approval and how effective rehabilitation will be achieved.

The SMP review has also identified a need to consider how rehabilitation security bonds can be more effectively used to ensure adequate and effective rehabilitation. Further SMP guidelines need to be developed to provide clarity about the requirements of the application process and the contents of the management plans.

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[7] *Guidelines for Major Project Community Consultation*, Department of Planning, October 2007.

5.2 RISK-BASED DECISION MAKING

Successful subsidence management is essentially an exercise in risk management – collecting data, making predictions and establishing and implementing management plans (which include monitoring programs and contingency plans and which facilitate adaptive management) so as to realise coalmining opportunities whilst managing environmental effects.

Environmental risk management faces a range of difficulties due to complexity in the natural environment, positive and negative impacts from decisions involving long time spans with potential for irreversible outcomes, and assumptions about projected impacts needing to be made when there is significant scientific uncertainty.

Such difficulties are present in the case of coal mining in the Southern Coalfield. Despite improvements in the ability to predict most subsidence effects, there remains considerable uncertainty as to the extent and nature of subsidence impacts on natural features, the environmental consequences of these impacts, the significance of these consequences and the importance that the community places on these features.

In this section of the report, risk management, as it applies to mining subsidence, is examined. This is done by:

- establishing a rationale for the use of risk-based decision-making;
- reviewing best practice approaches to risk-based decision making;
- reviewing how risk management is currently incorporated into subsidence approval processes; and
- discussing the proposals for improvements to risk management processes proposed by various stakeholder groups.

The Glossary contains definitions of key terms used in risk assessments, grouped together in boxed text.

5.2.1 Rationale for Risk-Based Decision Making

Risk management is a standard aspect of mine planning and operations. The International Council on Mining and Minerals lists the implementation of risk management strategies as a core sustainable development principle, and this has been endorsed by the Minerals Council of Australia (MCA, 2005).

Practical guidance on risk management has been provided by Standards Australia (Standards Australia, 2006). The key risk management steps identified by Standards Australia and widely adopted by coal mining companies in the Southern Coalfield are shown in Figure 45.

The key steps are intuitive – identify potential risks; analyse these risks in terms of their likelihood and consequences given existing or standard management controls; evaluate these risks against established risk criteria; develop, assess, consult and implement risk management responses and then monitor and review the outcomes.

5.2.2 Best Practice Risk Management

5.2.2.1 Qualitative Risk Assessment

Qualitative risk assessments are used where full quantitative analysis is not possible. In the case of subsidence, this arises for several reasons. First is the complexity of the physical, hydrological and ecological systems of concern, the difficulty of predicting interactions between these systems and management actions, the long time-frames that are involved and disparate views on the importance of alternative management consequences. Second, numerical data for many key attributes are simply inadequate, such as where there is an absence or inadequacy in baseline data on ecological systems and the presence of threatened species. Third, time and resourcing limitations in approval processes can prevent the comprehensive collection and interpretation of information.

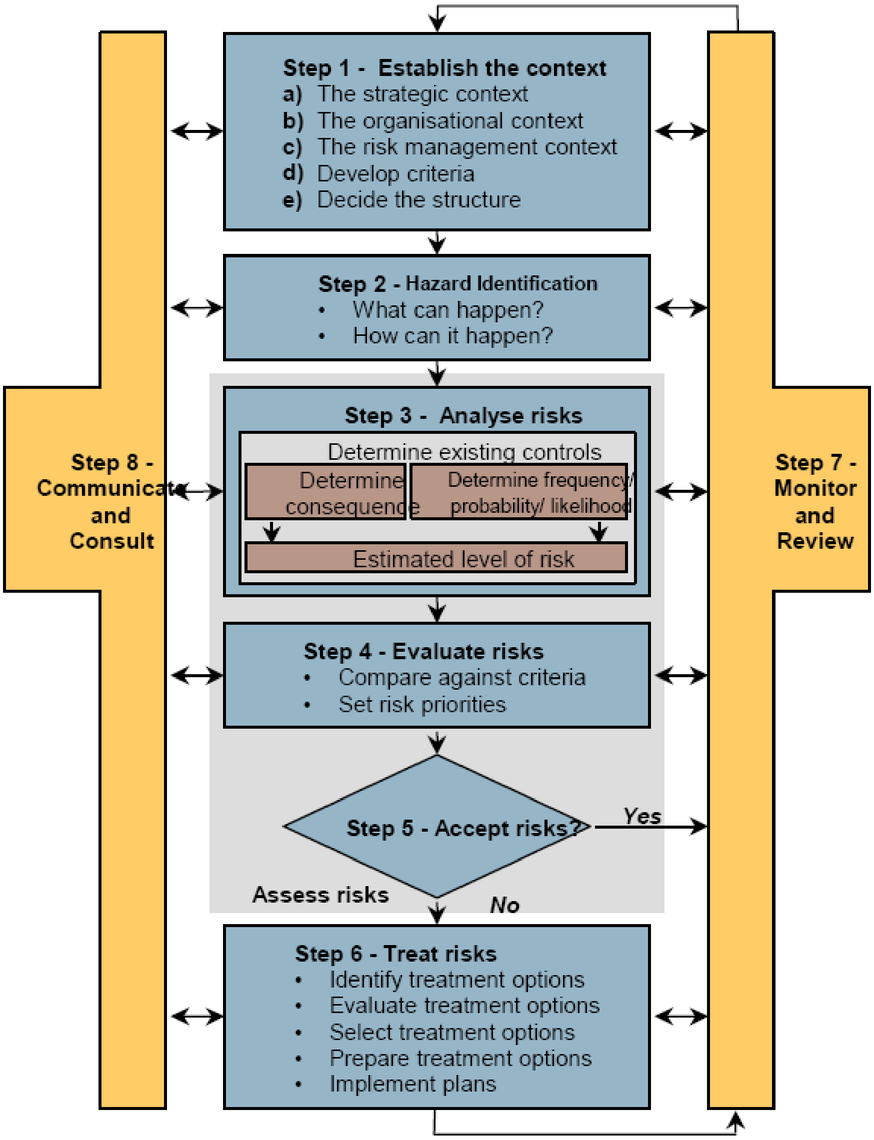

Figure 45: Standards Australia Risk Management Process

Source: AXYS Consulting, 2008

Qualitative analysis uses a scale of words or descriptions to examine the impacts of each event arising and its likelihood. A risk matrix based on these qualitative measures of consequences and likelihood may then be used as a means of combining this information to give a measure of risk (Standards Australia, 2006). An example of a qualitative risk matrix used to assess coalmining subsidence risk is shown in Figure 46.

Likelihood or Frequency / Probability	Consequence Severity				
	Low	Minor	Moderate	Major	Critical
Almost Certain	High 100	High 300	Extreme 1,000	Extreme 3,000	Extreme 10,000
Likely	Moderate 30	High 90	High 300	Extreme 900	Extreme 3,000
Possible	Low 10	Moderate 30	High 100	Extreme 300	Extreme 1,000
Unlikely	Low 3	Low 9	Moderate 30	High 90	Extreme 300
Rare	Low 1	Low 3	Moderate 10	High 30	High 100

Figure 46: Standard Risk Rating Matrix

Notes: 'ALARP' stands for Reduce to 'As Low As Reasonably Practicable'
Source: AXYS Consulting, 2008

The point should be made that consequence ratings, as shown by the colour codings in the risk rating matrix above, are not fixed and immutable. Rather, they reflect limitations which are inherent to risk management; ie they reflect the subjective valuations of those undertaking the assessment that may not align with valuations of other stakeholder interests, Government or the broad community.

5.2.2.2 Choice of Risk Criteria

Apart from the difficulties in establishing risk ratings, whether or not by qualitative or quantitative means, there is the problem of identifying what risks are tolerable to Government or the community. Lack of clear guidance in this regard has almost certainly led to inconsistencies in approvals and outcomes, unnecessary costs to business and avoidable harm to the environment.

The key issues are:

- who should decide acceptable or tolerable risk; and
- what evaluation framework should underpin the risk criteria used by decision makers?

Risk criteria that specify what is tolerable can be established either by:

- *case by case evaluation*: in principle, this is currently done in the Part 3A and SMP processes, where acceptability of each mining project or part of a project is determined through consideration of likely benefits and costs – an approach to a net benefit test; or
- *policy*: where management practices, a risk standard (eg acceptable level of risk), or performance outcomes are established by Government policy or regulation, or are adopted at the mining company or industry level. Examples of regulatory-based risk criteria for environmental exposures in Australia include acceptable ambient pollutant concentrations

established under the National Environment Protection Measure for Air Quality and the ANZECC water quality guidelines.

One approach to overcome the lack of information on the importance of potential environmental and water supply amenities would be for Government to develop valuation datasets that could be used in case-by-case assessments and assist ‘net-benefit’ risk assessments.

Precedents for such an exercise exist. For example, a study by Bennett and Morrison (2001) was prepared for the NSW Environment Protection Authority to provide information on the values held by the people of NSW for environmental and recreational attributes of rivers. The study estimated environmental values for a number of representative rivers across the State so as to provide a database of environmental values that could be drawn on by Water Management Committees when assessing alternative river management options. The study provided value estimates for changes in riverine vegetation, the presence of native fish and waterbirds, as well as values for improved recreational amenities (such as swimming and fishing) associated with water quality improvements. The Panel considers that such studies could play an important role in assisting communities and the Government in their consideration of economic trade-offs.

However, valuations based solely on economic efficiency are not sufficient by themselves to inform decision-making on proposals that may impact ecological sustainability and social values. Therefore, consideration of broader environmental and social impacts will continue to be undertaken through Government-established compliance requirements and through qualitative assessment in approvals processes. The critical requirements are then to ensure objectivity and transparency in these processes, and that they incorporate a workable whole-of-Government mechanism where competing economic, environmental and social outcomes can be appropriately balanced.

5.2.2.3 Other Key Considerations

Other key considerations arise in the assessment and management of risk. Perhaps foremost among these is the recognition that not all natural features are truly ‘significant.’ Indeed, not all significant natural features are ‘equally significant’. Further, different stakeholders hold different views on the significance of any particular natural feature. Since management of risk is partly the management of consequences, it must also be recognised that the consequences of subsidence impacts on one natural feature are not necessarily the same or as great as consequences on another.

Considerable material was presented to the Panel indicating that disparate views exist across the community as to what constitutes a ‘significant’ impact on natural features and the ‘value’ of potential consequences. Panel members themselves had considerable discussion as to the specific meaning of the term ‘significant natural feature’. Clearly, significance is in the eye of the beholder and no universally-agreed definition is possible.

The Panel is of the view that the ranking (or scaling) of significance of the natural features of the Southern Coalfield is not within its terms of reference. This is primarily a matter for Government to determine, as informed by specialist opinion, and the views of the community. Nonetheless, the Panel’s conclusions and recommendations are based on the recognition that the significance of a natural feature is a variable. This variability arises both when a feature is compared with other features of the same type and also when compared to features of a different type.

Given the impossibility of a simple consensus view as to significance of various natural features, and the ongoing risks of what is a values-driven debate being skewed by those with the most active interest in the outcomes, the Panel considers that it should be a priority for Government to provide improved guidance on significance to inform company risk management processes, community expectations and Government approvals.

The other key consideration is the appropriate application of the Precautionary Principle. The Precautionary Principle is defined under Australia’s 1992 Inter Governmental Agreement on the Environment as: ‘

Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation. In the application of the precautionary principle, private and public decisions should be guided by:

(i) careful evaluation to avoid, wherever practical, serious or irreversible damage to the environment: and

(ii) an assessment of the risk weighted consequences of various options.

The Precautionary Principle should not be seen as advocating a nil risk position. The precautionary principle clearly requires risks associated with other options and socio-economic factors to be taken into account (Standards Australia, 2006).

As a precautionary approach, a 'reverse onus of proof' may be applied to shift the burden of proof on to a specified party to *disprove* a pre-held position. This approach has been used within a number of environmental statutes in relation to criminal offences, as well as in relation to acceptable pollution monitoring and load assessment practices under the *Protection of the Environment Operations Act 1997*.

5.2.3 Nature of Risk Management under the Current Approvals Process

Risk assessment, in the broader sense, is a significant element of the current approvals processes. For Part 3A project applications, the whole intent of preparing a Preliminary Environmental Assessment is to scope all potential environmental issues associated with a project, subject them to a risk analysis, and identify any 'key environmental issues' which will require detailed assessment by the proponent within the environmental assessment and careful attention by DoP and other key agencies when the environmental impact assessment is conducted.

The essential nature of the environmental impact assessment process (whether under Part 3A or more generally) is to assess and balance loss (or risk of loss) against potential reward. The losses, or risks of losses, are generally environmental and/or social in nature. Commonly, most of the benefits are economic and social. Guidance as to key risks (and their tolerability) is provided to the proponent through the planning focus process, direct liaison with DoP and other key Government agencies, the DGRs (which have input from other agencies and which identify key issues), public exhibition of applications and community and Government agency responses. If key risks requiring expert assessment are identified by DoP in assessing any project application, the Minister for Planning may appoint a panel of experts (an 'independent hearing and assessment panel' or IHAP under Part 3A) to assess and advise on the application or else DoP may employ an external expert to advise it in its assessment. Identification of unacceptable environmental losses or risks during any stage of the assessment process may lead to the requirement to produce a varied project outline (a 'preferred project report' under Part 3A). Thus, in the general sense, the Part 3A approval process is a risk management process incorporating assessment, avoidance and mitigation.

The SMP application process guidelines are less specific, but applicants are also required to undertake site-specific subsidence risk assessments and to develop management plans that 'produce outcomes that are consistent with Government policies, taking into account community expectations' (DMR 2003, p 17). The guideline also specifically addresses the issue of risk assessment, and states that:

'In the case of subsidence, fixed criteria are either impossible or inappropriate to specify due to the high degree of variations in site conditions and community expectations between different mining leases and the complexities / variations of the site-specific assessments likely to be involved' (DMR 2003, p 14)

In the current absence of Part 3A approvals for mines in the Southern Coalfield, SMPs have tended to take on the broader role of establishing, on a case by case basis, what risks are acceptable. However, of the 14 issues that must be detailed in the SMP, none relate to the value that might be ascribed to environmental impacts nor the costs involved in adopting management measures to prevent them. There is also a lack of clear up-front guidance given to industry on just what risks and impacts are acceptable to Government. The industry's responsibility to interpret both explicit and unstated policy requirements to identify 'tolerable' risks in an operational planning sense is therefore a limitation to more robust subsidence management.

5.2.4 Potential New Risk Management Mechanisms

Many submissions to the Inquiry argued that current subsidence approval processes fail to incorporate robust risk assessments, and called for improved risk-based decision making. Most participants in the Inquiry called for a more robust risk-based decision-making approach being applied in the planning, assessment and management of impacts of mining. A range of risk criteria was proposed, including technology-based standards, thresholds for unacceptable risks and use of an improved net benefits test.

5.2.4.1 Proposals for a 1 Kilometre Buffer Zone

Many environmental groups have called for a 1 km protection zone around all rivers (and in some cases, all streams as well) – a specific management practice designed to deliver what is essentially a 'nil risk' standard (ie risk avoidance). The TEC submission states that the distance of 1 km was determined as a distance that was believed to meet existing legislative, regulatory and policy criteria, as well as being compatible with recommendations of the Hawkesbury-Nepean River Management Forum in 2004 to 'eliminate' all existing impacts by longwall mining on Sydney's water supply catchment. However, TEC also acknowledges that there are a number of alternative ways in which protection zones could be prescribed for rivers, supply catchments, swamps and certain orders of streams, based on significance, flows and other environmental factors.

Rivers SOS's submission states that the call for a 1 km buffer around rivers is not an ambit claim, but rather application of the 'precautionary principle'. It opted for a specific distance (rather than the 35° angle of draw) because damage was considered less predictable in rugged terrain such as river gorges and it holds little confidence in site-specific studies. It states that 'the likelihood of 'anomalies' dogs every prediction' and the 'inability to pinpoint the existence of underground faults and dykes calls out for a reasonably ample safety zone'.

Several submissions to the Inquiry and comments at the public hearings supported the use of a 1 km buffer in expectation that this would essentially eliminate subsidence impacts. Notably, Rivers SOS's submission does not equate a 1 km buffer with nil subsidence, but with nil likely impact. It accepts that subsidence movements may extend beyond 1 km (so called far-field movements) but considers these unlikely to damage gorges and river valleys or crack river beds (Sub 16, p 7). In addition, such a 'safety zone has the added advantage of lending some protection to tributary creeks and streams near their confluence with the rivers'. It thus considers the proposed 1 km buffer to be a 'compromise'.

The Panel understands that the width of the buffer zones proposed by these groups was based on research papers which described far-field horizontal movements in the Southern Coalfield, rather than either conventional subsidence effects or valley closure or upsidence. There appears to be no evidence of these subsidence effects extending anywhere near that distance from rivers or significant streams. There is also no evidence that far field horizontal movements may cause significant impacts or consequences for significant natural features.

The Minerals Council's submission rejects the 1 km buffer zone approach:

> *'A mandated setback distance is illogical. The extent and magnitude of subsidence related movements are related to many factors including depths of cover, seam thicknesses, and longwall and pillar widths. Optimised decisions around impacts and mitigation can only be made with the benefit of a location specific knowledge and assessment. The use of different types of measures and the acceptability of some impacts needs to be considered to provide the greatest net benefit to society.'*

TEC and others argue that impact avoidance should be prioritised over minimisation, rehabilitation and compensation in that order. Reflecting adequate protection zones, minimisation and remediation should only ever take place in extraordinary circumstances. Accordingly, TEC recommends a legislated protection zone around rivers, streams and groundwater aquifers, immediately made mandatory in all mining leases for all longwalls that have not proceeded to second workings. More recent policy proposals by TEC and Rivers SOS no longer mention the proposed 1 km protection zone, advancing only a 'legislated preventative approach that incorporates mandatory protection zones'.[8]

5.2.4.2 Ecological Risk Based Decision Making

In submissions to the Inquiry, DECC proposed using risk-based subsidence decision making that is outcome-based and designed to avoid overly-prescriptive requirements. DECC has instead proposed an ecological risk-based standard that addresses threatened species, Aboriginal heritage, upland swamps and other features, in addition to rivers and streams. This model is based on both risk management and risk avoidance. High risks are to be avoided; lesser risks are to be managed. DECC considers that clear and objective criteria with defined 'acceptable limits of change' are needed.

It proposes that this be made operational via a decision model that identifies limits of risk acceptability for identified ecological features and potential subsidence outcomes. The model is based on an ecological risk assessment approach that identifies risk values of 'High', 'Medium' and 'Low' and stipulates management measures of 'Prevent', 'Minimise' and 'Proceed with Caution'. In essence, the model establishes qualitative risk standards by ensuring impacts do not exceed a qualitative impact rating. DECC argues that mining companies would then have the flexibility to determine solutions to comply with the required outcomes. DECC stresses that its model is still in infancy and remains 'conceptual' until it can be trialled with mining companies and stakeholders.

5.2.4.3 Net Benefit Based Decision Making

While not supporting DECC's proposed model, the mining industry has also argued that subsidence management should be assessed using net expected benefit risk criteria. The NSW Minerals Council states that economic trade-off should be the primary consideration of Government in approving SMPs, and that the optimal level of environmental restriction is where the marginal opportunity costs of foregone coal production are equal to the marginal environmental benefits of restriction. In its submission, a case study of the net expected benefit framework is presented and a recommendation put forward for '*support from Government in sponsoring non-market economic valuation studies of different environmental outcomes to facilitate economic trade-off analysis'*. This proposed net expected benefit framework was broadly supported in individual submissions from Illawarra Coal and Helensburgh Coal. Most submissions from industry also emphasised that site-specific factors have a major bearing on the extent and magnitude of potential impacts on natural features, and therefore meaningful decisions must be made on a case by case basis.

5.3 OTHER STAKEHOLDER PERSPECTIVES ON APPROVAL PROCESSES

5.3.1 Improved Regional Datasets

To support its proposed ecological risk-based decision model (or indeed any quantitative risk assessment model), DECC believes that the quantification of acceptable limits of impact will need to be based on regional mapping of all significant natural features (and, presumably, Aboriginal heritage) through a regional assessment of ecological and heritage attributes. DECC suggests that, while it should manage such a program, it should be funded by the mining industry.

The Panel notes that the process of delineating areas for coal mining is long and expensive. Accordingly, much of the detailed exploration is done in the few years before development of the new mining proposal, in order that the capital costs of the exploration can be more quickly recovered. The areas eventually mined are relatively small on a regional scale and the eventual area mined may not be finalised until after mining actually begins. Illawarra Coal, for example, has changed the planned mine layout for one or another of the three longwall domains at its

[8] *A Preventative Approach to Subsidence Damage in the NSW Southern Coalfield*, Total Environment Centre and Rivers SOS, April 2008.

Dendrobium mine at least a dozen times since 1999, as more information about the most-economically recoverable coal resource became known.

Consequently, a regional assessment of all biodiversity and other heritage values would gather large amounts of data which would not be directly used in individual mining approvals (other than by way of providing a regional context). The Panel considers that there is merit in the argument that environmental impact assessment for coal mine developments in the Southern Coalfield and elsewhere should continue to be focused on examining project-related impacts, and setting this in the context of available regional data, rather than requiring the mining industry to fund 'up front' a regional scale assessment.

5.3.2 Timing of Applications and Approvals

DPI's SMP Guidelines only require the collection of 12 months of baseline data prior to submission of an SMP application. These baseline data are essentially local to the SMP application area. There are strong suggestions that 12 months baseline data are insufficient to properly inform the approvals process. Further, and more importantly, as noted by DECC and SCA, regional baseline data are also not sufficiently available. This limits the capacity of mining companies to place either the environment in which they are mining or the impacts that they are likely to have in a strategic, regional context. It also limits the ability of regulators to identify and contextualise regional impacts.

The Panel also notes that, despite clear provisions to the contrary in the SMP Guidelines, mining companies continue to approach DPI with 'last minute' SMP applications, wherein they seek rapid approval for new longwalls and/or their defining first workings based on the potential for mine continuity to be disrupted. That is, either workers will be standing idle instead of developing new panels, or else a future longwall production stoppage can be envisaged because of delayed longwall development. The Guidelines state that a minimum of 6 months is needed for adequate assessment by DPI and other agencies of SMP applications. However, companies regularly submit applications seeking approvals within 2-3 months, and sometimes within one month. This 'just in time' planning by mining companies poses clear risks for both them and for the environment. Agencies are pressured to provide an approval without adequate opportunity to fully review or understand potential impacts. Companies run the risk of significant economic loss if coal production is disrupted. The risks to the environment are multiple, and arise from potentially-shortened periods for collection of baseline data, hasty preparation of an SMP application and reduced Government assessment and approval timeframes.

5.3.3 Removal of Duplication

Industry has also stated that it supports the identification and prioritisation of sensitive features during the Part 3A process, and that this should not then be duplicated as part of the SMP process. Rather SMPs should be scaled down to a review of the features identified and conditions imposed at the project approval stage to ensure they remain relevant and consistent.

The NSW Minerals Council argues that project approvals should establish the features to be protected, outcome criteria and impact limits, with concurrent grant of the project approval and SMP approval for the first interrelated group of longwalls (ie a longwall 'domain', commonly covering 3 to 7 years of mining). The NSW Minerals Council then argues that the identified features and outcome criteria should not be revisited for subsequent longwall domains covered by the same project application – subsequent assessment should focus on subsidence prediction, impact assessment and management within the set of outcomes pre-determined by the project approval. Illawarra Coal also indicated to the Panel that the potential for last minute adjustments under the SMP process represented a difficult sovereign risk to manage and that the company's preference was therefore to shift approvals from the SMP stage to the Part 3A process.

5.3.4 Improved Government Guidance to Industry and the Community

The NSW Minerals Council suggested that there has been a lack of communication to interest groups and the public that approved mining is expected to have some environmental impacts. That is, the outcome of a risk-based assessment will at times be to allow mining where risks are deemed 'tolerable' despite the expectations of environmental consequences. The Council also indicated that there has been a lack of communication by Government to interest groups and the general public of these anticipated subsidence impacts of underground mining.

5.3.5 Early Engagement by Industry with Stakeholders

DECC sought involvement in risk assessment by mining companies at an earlier stage of the approvals process, in order to provide for strategic consideration of potential risks. DECC therefore recommends that DoP and DPI stipulate early engagement with key agencies as a requirement, at least 12 months prior to submission of either a Part 3A application or an SMP application. This would facilitate the exchange of information to support risk-based decision making and requirements for baseline monitoring.

5.4 POTENTIAL IMPROVEMENTS TO APPROVALS PROCESSES

5.4.1 Relationships between Part 3A Approvals and SMPs

The Panel is of the opinion that the decision making framework provided by Part 3A of the EP&A Act (see Figure 44), together with the recent amendments to the *Mining Act 1992*, provide a good foundation for the future management of coal mining subsidence in the Southern Coalfield and elsewhere in the State. Part 3A provides a process through which performance standards and environmental outcomes can be developed following scientific studies and stakeholder input and then set within a robust approval document. The project approval process under Part 3A is a case-by-case process that recognises the variability of sites and remains flexible within the growing body of knowledge regarding subsidence effects, impacts and consequences. The Part 3A process already involves risk assessments and it is amenable to using other risk management mechanisms such as those outlined in sections 5.2.4.2 and 5.2.4.3.

Environmental impact assessment, performed at the application stage for project approval under Part 3A of the EP&A Act, should be the primary tool used to set the envelope of all acceptable environmental impacts for mining projects. There are statutes, guidelines and policies which provide some guidance as to what levels of impacts are acceptable. Following the identification of natural features, the acceptability of impacts should be determined using a combination of environmental, economic and social values, risk assessment of potential environmental impacts, consultation with relevant stakeholders and consideration of broader sustainability issues. This should be undertaken within a local, regional and State context. Ultimately it is the Government's responsibility to determine what environmental impacts are acceptable. This envelope of acceptability should be expressed in clear conditions of approval which establish measurable performance standards against which environmental outcomes can be quantified.

Once the expected outcomes are defined and an underground mining project has project approval under Part 3A, the essential role of the SMP should be to ensure that the risk of impacts remains within that which was assessed and approved. The SMP should be a management document - plans should be prepared to demonstrate how the required outcomes will be achieved, what monitoring will occur and how deviations and contingencies will be addressed. In other words, the SMP assessment should be scoped down, and not seek to be a substantial environmental impact assessment, which is repetitive, unnecessary and expensive.

However, in cases where a mining project approval under Part 3A of the EP&A Act does not yet exist, the SMP process should take a greater role in assessing and determining the acceptability of impacts. This will only apply up to December 2010, by which time all mines will be required to have approval under either Part 4 or Part 3A of the EP&A Act. During this transitional period, the approach taken within the SMP process for these mines should be consistent with the process under the EP&A Act to ensure an equivalent level of assessment, giving certainty to both the industry and the community regarding the level of environmental assessment.

5.4.2 Risk Management Zones

Since 1974, mines working in the vicinity of tidal waters in NSW have had to give special consideration to working within a 'High Water Mark Subsidence Control Zone' when seeking approval from DPI to conduct underground coal mining. This zone is defined by two 35° angles of draw. The first is measured from the Mean High Water Mark (MHWM) and extends under the water body. The second is measured from the contour 2.44 m above MHWM and extends landward. A similar concept, based on an angle of draw of 26.5° and the so-called 1 in 100 year flood level contour (1% AEP), has been applied to workings in the Great Northern Seam in the Lake Macquarie district since the early 1990s. A modified concept that also incorporates a restricted zone beneath dam walls has been applied in the Southern Coalfield since the mid 1970s as a result of the Reynolds Inquiry into mining beneath stored waters.

The Panel considers that the extension of this concept to significant natural features in the Southern Coalfields would offer improved identification of features requiring detailed assessment, careful management and appropriate environmental outcomes. To this end the Panel proposes the identification and use of 'natural features Risk Management Zones' or RMZs. The identification of RMZs will lead mine proponents to focus their assessment and consideration of potential impacts on the significant features within them. RMZs are appropriate to manage all subsidence effects on significant natural features, but are particularly appropriate for non-conventional subsidence effects (especially ***valley closure*** and ***upsidence***). Consequently, RMZs should be identified for all significant environmental features which are sensitive to valley closure and upsidence, including rivers, significant streams, significant cliff lines and valley infill swamps.

The Panel proposes that RMZs should be defined from the outside extremity of the surface feature, either by a 40° angle from the vertical down to the coal seam which is proposed to be extracted, or by a surface lateral distance of 400 m, whichever is the greater. RMZs include the footprint of the feature itself and the area within the 40^{o} angle (or the 400 m lateral distance) on each side of the feature. Potential subsidence impacts at the feature relate to the extraction panel within this seam, rather than adjacent bord and pillar gate roads or other first workings. Consequently, the RMZ represents a 40^{o} angle from the extremity of the surface feature, or a surface distance of 400 m, whichever is the greater. Providing that the 400 m minimum is exceeded, the lateral extent of the RMZ would represent a fraction of the depth of mining (0.84). For example, for a depth of cover of 500 m, it would be around 420 m.

In order to satisfactorily address valley closure and upsidence risks in rivers and significant streams, the Panel proposes that RMZs for watercourses are applied to all streams of 3rd order or above, in the Strahler stream classification. Aligning RMZs with the Strahler system provides a simple and pragmatic basis of establishing areas for more rigorous risk assessment. RMZs should also be developed for valley infill swamps not on a 3rd or higher order stream and for areas of irregular or severe topography, such as major cliff lines and overhangs not directly associated with watercourses. In the case of cliffs and gorges, the edge of the feature should be defined as the top of the cliff line when the extraction panel is approaching the cliff line from the high side of the cliff, and from the bottom of the cliff line when extraction is approaching it from the low side.

The identification of RMZs is not intended to represent either a determination of 'significance' or to suggest or require the exclusion of mining. The purpose of identifying an RMZ around a significant natural or other environmental feature is to flag that proposed mining within the zone requires careful assessment, and potentially careful management. Management outcomes may potentially be threefold. If the feature within the RMZ is not highly significant and/or not highly sensitive, then a standard subsidence management regime may apply. If it is highly significant and sensitive, then strict management and performance standards should be applied. If the feature is both highly significant and highly sensitive, then predicted impacts and consequences may be deemed unacceptable by Government and longwall mining may not be permitted to proceed close to the feature. The Panel considers that it will provide for greater focus and emphasis on specific natural features, provide specific parameters where such increased focus is to be applied and promote more rigorous risk assessment taking account of all stakeholder input.

The Panel considered various angles which might be used to define the RMZs. It must be first noted that valley closure and upsidence can extend for up to several hundred metres beyond the footprint of mine workings. The submission from the NSW Minerals Council reported that, in the Southern Coalfield, the furthest known distance from the edge of a longwall panel to a mining-induced fracture in a stream bed is approximately 400 m. The Panel noted a number of instances where visible expressions of upsidence impacts (cracking and shear) fell within an angle of draw of

35 to 40°. Groundwater monitoring data was only available for one of these sites and it indicated that groundwater levels had not been impacted. It was also reported to the Panel that the furthest known examples of noticeable water diversion have occurred when longwalls have been extracted within 100 to 150 m of a major stream. These correspond to an angle of draw of less than 26.5°.

Given the limited baseline and monitoring data currently available, the Panel considers that it would be conservative to initially define the usual width for RMZs by using an angle of 40°. Further, this conservative approach is supported by use of a 400 m minimum distance, which is the maximum distance at which stream bed fracturing has been observed in the Southern Coalfield. Use of a minimum distance is particularly useful where mining is proceeding under a low depth of cover (less than 350 m). At this depth, a 40^{o} angle would equate to only 294 m, whereas at 250 m depth of cover, 40^{o} equates to a distance of only 210 m. The Panel also recommends that both the standard 40^{o} angle and the 400 m minimum should be subject to review when more representative and extensive data becomes available within the Southern Coalfield.

The RMZ concept can be readily incorporated into the Part 3A process. RMZs should initially be identified by mining proponents, subject to additional input from key agencies and other stakeholders via early engagement and the planning focus process. DoP should have the final responsibility for identifying the location and lateral extent of RMZs for all Part 3A project applications. This identification should be in the DGRs issued for preparation of an environmental assessment. The Director-General's report, which is provided by DoP to the Minister for Planning in his consideration of any proposed project approval, should then be structured in such a way as to give clear consideration to the various RMZs which may be associated with any particular project application. Project approvals should then provide clear conditions and performance standards for mining or subsidence within RMZs which should be addressed within the SMP.

5.4.3 Improved Guidance on Significance and Value

The Panel considers that there is a need for improved guidance by Government on the issues of significance and value for natural and other environmental features for the benefit of mining proponents, other stakeholders and the general community. The use of RMZs around features of significance will provide an indication of perceived significance and value, at least in respect of impacts associated with non-conventional subsidence effects. But there remains a need for guidance in respect of natural and other environmental features more generally. For example, which types of Aboriginal sites are considered most important? Which cliff lines have higher values (eg ecosystem function, aesthetic, water quality protection) than others? Which rivers and significant streams are most significant, and why? It is not entirely reasonable that the initial responsibility for identifying features of significance rests solely with the mining proponent. Identification of such significant features should be guided by a clear delineation of the priorities of both Government and the community for their protection and values. This guidance should reflect the recognition that approved mining would be expected to have environmental impacts. That is, the outcome of a risk-based assessment will at times be to allow mining where risks are deemed acceptable despite the environmental consequences.

The DoP's position regarding subsidence impact assessment requirements, both within and outside of RMZs, should be clearly set out in its 'Director General's Requirements' issued to the proponent to guide formal risk assessment and preparation of the environmental assessment;

5.4.4 Earlier Engagement with Stakeholders

The Panel considers that mining proponents should initiate earlier engagement with all key stakeholders and involve all key stakeholders in the identification of significant natural features. DECC has requested that mining companies initiate engagement with itself and other key agencies at least 12 months prior to submission of either a Part 3A application or an SMP application. For key agencies (eg DECC and SCA), this engagement should begin prior to the planning focus stage of a project application. The mining company would need to have already identified RMZs based on 3rd order streams and any other candidate natural features. Agencies and/or the community would then have the opportunity to nominate additional natural features during planning focus and initial public consultation.

5.4.5 Improved Timeliness of Applications and Approvals

Because Part 3A has statutory timeframes, and a well-established statutory process, it is likely that the move to Part 3A approvals will see an end to the practice of mining companies submitting SMP applications only 1 to 3 months prior to needing to start development of new mining panels (ie first workings).

Nonetheless, the Panel considers that mining companies should make every effort to develop and adhere to satisfactory timeframes in the submission of both project applications under Part 3A and applications for SMP approval.

5.4.6 Improved Documentation for Environmental Assessments

The Panel considers that environmental assessments for project applications lodged under Part 3A can be significantly improved in the manner in which they address subsidence effects, impacts and consequences. There is clearly a need for improved baseline data, and a minimum of 2 years of baseline data should be provided for significant natural features, whether located within an RMZ or not. There is also a need to better distinguish between subsidence effects, subsidence impacts and environmental consequences. There should be increased transparency, quantification and focus in describing anticipated subsidence impacts and consequences. In particular, the use of non-quantifiable terms in describing impacts and consequences (eg 'negligible', 'minor', 'moderate', 'significant') should be discouraged, and the use of quantified values required. Key aspects of the subsidence assessment (particularly in respect of predicted impacts on significant natural features and their consequences) should be subject to peer review prior to submission. Cumulative impacts within a region, both by the project under assessment and other mining operations, should be clearly addressed.

The Panel also encourages the use of a net benefit review by both mining proponents and regulatory agencies in assessing applications. Such assessments should include valuation of coal left in the ground, at either the proposal of the company, or the requirement of Government. However, it accepts that, at times, decisions may need to be made by Government based on absolute values (whether environmental, social or economic), rather than the summation of all competing costs and benefits. In such cases, commitment to an absolute value (eg the desire to protect a certain feature no matter the cost) overrides any net benefit assessment of overall costs and benefits.

5.4.7 Reverse Onus of Proof and Contingency Planning

Due to the extent of current knowledge gaps, the Panel considers that a precautionary approach should be applied to mining which might unacceptably impact highly-significant natural features. The Panel considers that the approvals process should require a 'reverse onus of proof' from the mining company before any mining is permitted which might unacceptably impact highly-significant natural features. In other words, the mining company must demonstrate, on the balance of probabilities, that identified highly-significant natural features would not be unacceptably impacted. If insufficient assurance can be provided, then mining which might cause severe impacts should not be permitted to proceed. Any proposed mining that might unacceptably impact those features should require that subsidence effects and impacts are predicted and assessed with a high degree of confidence. Evidence should be provided of both the validity and accuracy of the prediction techniques used. The predicted impacts would have to be 'acceptable' to Government. Alternatively, mitigation and/or remediation strategies (offering sufficient certainty of outcome and effectiveness), could be proposed.

The Panel also considers that mining approved to proceed within an RMZ associated with such highly-significant features should be subject to preparation and approval of a contingency plan to deal with the chance that predicted impacts are exceeded. This plan might include any one or a combination of measures, including a cessation of mining within the subject longwall panel, a pull back of subsequent longwall panels from the feature, undertaking foreshadowed remedial works with predictable and acceptable outcomes, or provision of an environmental offset.

5.4.8 Increased Monitoring and Back Analysis

The Panel considers that approved mining within identified RMZs (and particularly in proximity to highly-significant natural features) should be subject to increased monitoring and assessment requirements which should address subsidence effects, subsidence impacts and environmental consequences. The requirements should also address reporting procedures for back analysis and comparison of actual versus predicted effects and impacts, in order to report on the accuracy and confidence levels of the prediction techniques used.

5.4.9 Increased Security Deposits and Rehabilitation Responsibilities

Rehabilitation plans should be prepared and costed for all damage where rehabilitation is required. The security held by DPI should include these costs. Where rehabilitation is not possible, offsets should be considered to minimise the net impact of the mining activities.

In addition, the Panel considers that mining which could unacceptably impact highly-significant natural features should be subject to a substantially increased security deposit. This deposit should be sufficient to cover both the anticipated rehabilitation costs (as at present), and potential rehabilitation costs in the event of non-approved impacts to the highly significant feature. The higher deposit should be commensurate with the nature and scale of the potential impact. The increased deposits should be attached to the mining lease by DPI under powers available to its Minister under the *Mining Act 1992*.

If non-approved impacts occur as a result of errors in predictions and the feature is not able to be remediated by the mining company, then the deposit should be able to be forfeited as compensation for the loss of environmental amenity. Alternatively, to avoid forfeit, the mining company may be able to provide a sufficient offset for the non-remediable damage. The Panel recognises that these proposals lie outside powers currently available for security deposits, and hence amendments to the *Mining Act 1992* would be required.

Offsets may also be able to be used in the case of predicted damage, in certain cases. Where appropriate, such offsets should be provided for under Part 3A project approvals, rather than within a mining lease or SMP approval.

5.4.10 Improved Regional Data Sets

The Panel also considers that further consideration should be given to other, longer term, management initiatives. Matters that should be considered by regulatory agencies (including DECC, SCA, DoP and DPI) include the development of improved regional data sets.

Opportunities can be taken by both mining companies and Government agencies to develop a more regional assessment of the nature and extent of natural features across the Southern Coalfield, in advance of individual specific mining applications. It is considered that, over time, such a regional approach will provide a more informed judgment of important natural features for assessment under RMZs.

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6 Conclusions

Term of Reference 1

Undertake a strategic review of the impacts of underground mining in the Southern Coalfield on significant natural features (ie rivers and significant streams, swamps and cliff lines), with particular emphasis on risks to water flows, water quality and aquatic ecosystems.

Significant Natural Features of the Southern Coalfield

- The Southern Coalfield contains large areas of natural bushland. Its significant natural features include its rivers and higher order streams; associated sandstone river gorges; major cliff lines and upland swamps. It also contains important flora, fauna and aquatic ecosystems; many listed threatened species, populations and endangered ecological communities and a significant number of Aboriginal heritage sites.
- The upland swamps of the Southern Coalfield fall into two categories – *headwater* swamps (which make up the majority) and *valley infill* swamps.
- The major land use includes water supply catchment for the Sydney and Illawarra Regions and associated major water storage infrastructure.

Subsidence Impacts in the Southern Coalfield

- A number of the site conditions which are associated with non-conventional subsidence effects are present in the Southern Coalfield, in particular, valleys and gorges, locally-steep topography and geological features including faults and dykes. Consequently, a number of non-conventional subsidence effects (including valley closure, upsidence and regional far-field horizontal displacement) regularly occur.
- Since unpredicted impacts of subsidence on rivers and significant streams in the Southern Coalfield first came to public attention, the coal mining industry has made significant advances in its understanding of and ability to predict non-conventional subsidence effects. The level of understanding which has resulted from this work leads this field internationally.

Subsidence Impacts on Significant Natural Features

- The majority of subsidence impacts on significant natural features are associated with valley closure and upsidence effects, leading to impacts on some ***rivers and significant streams*** and in particular the cracking of stream beds and underlying strata. This has the potential, under certain conditions, to result in:
  - loss or redirection of surface water flows;
  - changes in water quality (particularly ferruginous springs and/or development of iron bacterial mats);
  - loss of ecosystem functionality (eg loss of pool integrity and connectivity and changes in water quality); and
  - loss of visual amenity.
- ***Stream bed cracking*** is most evident where the stream bed is comprised of solid rock and is less apparent where the stream bed is covered with sediment (including valley infill swamps) or deep water and sediment (such as the Nepean River). The consequences of stream bed cracking are most severe in streams with significant amounts of exposed bed rock (eg in rock bars).
- The Panel was not made aware of any significant impacts on ***headwater swamps*** caused by mining subsidence. Although it is likely that subsidence impacts observed elsewhere in the landscape are likely to take place beneath such swamps, the Panel is not in a position to draw firm conclusions regarding the potential for subsidence to have adverse consequences on these swamps.
- Most impacted swamps that the Panel was made aware of were ***valley infill swamps*** (eg Flatrock Swamp and Swamps 18 and 19). However, at all sites inspected by the Panel, there

had been a range of other environmental factors in play, including evidence of pre-existing scour pools, previous initiation of erosion, concurrent drought, and subsequent heavy rainfall and/or severe bushfires. The sequence of events was not clear in relation to the swamp impacts (drying, erosion and scouring, water table drop, burning, vegetation succession, etc). Whilst the Panel cannot be certain that subsidence either initiated or contributed to the overall damage at these swamps, the available evidence suggests a significant possibility that undermining of valley infill swamps could cause drainage, water table drop and consequent degradation to swamp water quality and associated vegetation. Further research is required before a definitive conclusion can be reached.

- The Panel observed subsidence impacts and consequences on ***cliff lines***, principally rock falls associated with river gorges or other cliffs. Most such rock falls appeared to be minor, in so far as they seem to affect a relatively small proportion of cliffs close to longwall operations. Secondary extraction can lead to significant valley closure without necessarily inducing cliff falls.
- Subsidence impacts on shallow ***groundwater*** systems (aquifers) are intimately related to those impacts which affect watercourses and swamps and mainly relate to groundwater mixing and new water-rock interactions that affect the system geochemistry.
- Aquifers in close proximity to the mining horizon where strata caving and extensive fracturing occurs are likely to drain into the mine workings. Deep aquifer impacts have recently been noted in Area 2 of the Dendrobium Coal Mine. Such disruptions to aquifers may lead to long term changes in their storage capacity. This is an area where further investigation and research is warranted.
- ***Aboriginal heritage*** sites are most at risk of subsidence impacts where they are located in cliff lines and/or rock overhangs. The Panel was not made aware of any significant impacts having occurred on Aboriginal heritage features in the Southern Coalfield since the 1980s.
- ***Releases of methane*** and other gases to the water column may take place in standing pools or reaches of streams which have suffered stream bed cracking (eg the Nepean River and the Cataract River). These releases appear to be temporary in nature and generally attenuate over a matter of months. Since methane is also naturally generated by decomposing organic material on the stream bed, the releases are likely to be of only short-term environmental significance. However, since methane is a flammable and poisonous gas, substantial releases may represent a potential safety hazard.
- Releases of methane through the soil profile close to river banks (again, likely to result from cracking of the stream bed/valley floor below) have led to some areas of ***dieback of riverbank vegetation***. This rare phenomenon (known only from the Cataract River) has limited areal extent and is temporary. Natural revegetation remediates this impact over a number of years.
- The Panel was not made aware of any adverse impacts on significant natural features likely to have been caused by ***regional far-field horizontal displacement***. There is no evidence requiring closer management of this subsidence effect in relation to its potential to adversely impact significant natural features.

Subsidence Impacts on Water Supply for Sydney and the Illawarra

- The Panel is not aware of any scientific evidence supporting the view that subsidence impacts on rivers and significant streams, valley infill or headwater swamps, or shallow or deep aquifers have resulted in any measurable reduction in runoff to the ***water supply system*** operated by the Sydney Catchment Authority or to otherwise represent a threat to the water supply of Sydney or the Illawarra region. However, this does not discount the possibility that a reduction in runoff may be realised under certain conditions, including downwards leakage to mining operations, especially where a shallow depth of cover prevails or a structural feature provides a conduit for flow.

Non Mining Impacts

- There is clear evidence of other factors also having major environmental impacts on significant natural features in the Southern Coalfield. Some of these impacts are independent of subsidence, and others may act in concert with subsidence impacts. They include:
  - ***poorly controlled runoff from surface land uses*** resulting in adverse water quality impacts. Examples include agricultural runoff from gullies into the Cataract and Georges

Rivers; septic discharges into the Georges River at Appin just above Marnhyes Hole; and discharges from the West Cliff Coal Waste Emplacement Area into Brennans Creek;

- ***abstraction and regulation of stream flows*** by SCA and other water users resulting in impacts on water flow, water quality, ecosystem function and aquatic ecology. The key example is limited spills and environmental flows from Broughtons Pass Weir to the Cataract River;
- ***SCA dams, weirs and other water supply infrastructure*** resulting in habitat loss through impoundment, loss of connectivity, changes to water temperature and dissolved oxygen and impacts on threatened species; and
- ***major climatic and related events***, such as droughts, bushfires, severe rainfall events, changed rainfall patterns, which have the capacity to impact on features such as swamps as well as stream flow and water quality.

State of Knowledge for Environmental Baseline Data

- While substantial improvements in ecological and other baseline data (vegetation mapping, threatened species records, Aboriginal sites register) have been made over the past 15 years, the Panel is of the opinion that regional ecological and other baseline data is insufficient to provide a robust underpinning to localised environmental impact assessments.
- There is a limited knowledge of the aquifers and groundwater resources of the Southern Coalfield, although this has improved substantially in recent years with groundwater exploration in the area of the Kangaloon Aquifer. There is a strong need to provide a more comprehensive assessment of existing data sets on aquatic diversity and to collect targeted information that would be useful for a regional assessment of aquatic diversity and an identification of sites of regional significance. In all fields, there is a lack of regional and cumulative data records, over time, and subsequent review and assessment of cumulative and regional impacts.
- Opportunities can be taken by both mining companies and Government agencies to develop a more regional assessment of the nature and extent of natural features across the Southern Coalfield, in advance of individual specific mining applications. Regulatory agencies (including DECC, SCA, DoP and DPI) should consider the development of improved regional data sets.

Term of Reference 2

Provide advice on best practice in regard to:

a) assessment of subsidence impacts;
b) avoiding and/or minimising adverse impacts on significant natural features; and
c) management, monitoring and remediation of subsidence and subsidence-related impacts.

Prediction of Subsidence Effects and Impacts

- Conventional surface subsidence effects and their impacts are well understood and are readily and reasonably predictable by a variety of established methods.
- The understanding of non-conventional surface subsidence effects (especially far-field horizontal movements, valley closure, upsidence and other topographical effects) is not as advanced. Both valley closure and upsidence are difficult to predict. Upsidence is a highly variable factor, particularly at the local scale, and is less predictable than valley closure. However, there is a rapidly developing database of non-conventional surface subsidence impacts in the Southern Coalfield which is being used to develop improved prediction. It is the Panel’s view that these techniques are less advanced, and less reliable than those used for conventional subsidence.
- Subsidence impact assessments in the Southern Coalfield (and elsewhere in NSW) have in general focused too much on the prediction of subsidence *effects*, and have not paid sufficient attention to the accurate prediction of subsidence *impacts* and their *consequences* and the development and implementation of appropriate management techniques for those impacts and consequences. However, there have been substantial improvements in the industry’s ability to predict impact and consequence in recent years, although these predictions have generally been very qualitative in nature (eg ‘moderate cracking’, ‘a possibility that some pools will drain’). Consequently, it has been difficult for agencies to establish whether impacts were

either greater or less than predicted. The challenge for the mining industry and its consultants over the next few years will be to move to a new generation of predictive capacity which is essentially quantitative in nature.

- It is critical for mining companies and regulatory agencies to establish the presence of, and understand major geological features such as faults and dykes which may lead to non-conventional subsidence effects.
- While significant attention has been paid by mining companies to monitoring and reporting subsidence impacts on natural features, there is still insufficient back analysis of monitoring results against earlier predictions, to validate or challenge prediction methodologies. Future back analysis or audit of the accuracy and effectiveness of subsidence predictions should be based on subsidence *impacts*, rather than subsidence *effects*, in particular the ability to adequately and accurately predict subsidence impacts and the confidence levels associated with these predictions.

Subsidence Impact Management

- Subsidence impacts can be managed by any one or more of the following:
  - tolerance of the resultant impact, coupled with natural processes of remediation;
  - avoidance measures (eg barriers or buffers between panel extraction and significant features, or modification of the mining system or geometry);
  - mitigation measures (eg smaller buffers designed to reduce but not eliminate subsidence impacts; mine layout or system changes (in terms of panel widths, limited extraction); use of slots to isolate ground movement; increasing stream flow volume, etc);
  - remediation or rehabilitation measures (eg grouting or filling of surface and subsurface cracks, drainage of ponded areas, revegetation of eroding areas).
- ***Avoidance measures*** may be impractical unless adopted at an early stage of the mine planning process, since longwall mining is an expensive and relatively inflexible mining system.
- Some ***mitigation measures*** also depend on early planning and adoption. Others may be initiated at a relatively late stage (eg ground isolation through slots or increased environmental flows). However, there is a need for a more precise understanding of subsidence impacts likely to arise from subsidence effects (especially valley closure and upsidence) before mitigation measures can be reliably designed and implemented during mine planning. In addition some mitigation methods may involve serious environmental impacts in themselves and require close environmental cost-benefit scrutiny.
- ***Remediation or rehabilitation measures*** have been applied with mixed success to stream bed cracking in a number of watercourses in the Southern Coalfield; notably at Marnhyes Hole, Jutts Crossing and other locations on the Georges River, in the Lower Cataract River and at Waratah Rivulet. Stream bed cracking is difficult to remediate, particularly when access is restricted and the majority of cracking extends deeper into the valley floor. While increasing success has been demonstrated in re-establishing pool water holding capacity and stream flow at a number of locations, little effort has been directed towards re-establishing aquatic ecosystems or measuring their return. Successful outcomes are largely dependent on the capacity to understand the vertical and horizontal extent, geometry and style of the fracture network resulting from subsidence, as well as the underlying ecological processes.
- The capacity of mining companies to undertake successful remediation of stream bed cracking within the Special Areas has been limited, until recently, by SCA restrictions on materials permitted to be transported into or used within these areas. The Panel supports SCA's recent decision to permit the use of polyurethane resin (PUR) in injection grouting to remediate stream bed cracking within the Special Areas.
- The level of confidence associated with current remediation measures for natural features is low to moderate, which equates to a medium to high risk rating. Therefore, remediation should currently not be relied upon as a forward management strategy for highly-significant features. However, remediation may be a valuable option as a contingency measure, if actual subsidence impacts exceed predictions. Remediation measures should not currently be relied upon as a forward management strategy for highly-significant features. However, remediation may be a valuable option as a contingency measure, if actual subsidence impacts exceed predictions. Mining companies should provide much more detailed information concerning proposed remediation measures and evidence as to their likely effectiveness and their secondary/consequential impacts in project applications and SMP applications.

- There is a need for more research by the industry into techniques for remediating natural features which may allow a greater degree of proactive remediation, as a control strategy in the future.
- There are a number of examples of ***natural processes of remediation*** in the Southern Coalfield. Stream bed cracking, surface water drainage to the subsurface and ferruginous springs which occurred in the Upper Bargo River in 2002 were barely evident five years after mining. In the lower Cataract River (where subsidence caused severe stream bed cracking between 1993 and 1997 and a simultaneous period of historically low water flows led collectively to a loss of flow, drainage of pools, loss of fish life and significant water quality changes), exposed stream bed cracks have subsequently been colonised by lichens, ant nests and small saplings. Water quality was sufficient to support aquatic macrophytes and small fish. While stream bed impacts in these rivers have self healed to varying degrees, some impacts (eg degraded water quality) at other locations have continued over longer periods of time.

Assessment and Regulatory Processes

- Both Part 3A and SMP approval processes take into account the economic, social and environmental costs and benefits of any mining development proposal and involve significant elements of risk assessment. Coal seams in the Southern Coalfield cannot be mined economically by any mining method without causing some degree of surface subsidence. If mining of hard coking coal in the Southern Coalfield is to continue, then a certain level of subsidence impact must be accepted as a necessary outcome of that mining. The question which Government must decide is “How much impact will be permitted, and where?”
- The decision making framework provided by Part 3A of the EP&A Act, together with the recent amendments to the *Mining Act 1992*, provides a good foundation for the future management of coal mining subsidence in the Southern Coalfield and elsewhere in the State. Part 3A provides a process through which performance standards and environmental outcomes can be developed following scientific studies and stakeholder input and then set within a robust approval document. The project approval process under Part 3A is a case-by-case process that recognises the variability of sites and remains flexible within the growing body of knowledge regarding subsidence effects, impacts and consequences.
- The introduction in 2004 of the requirement for mines to obtain approval for a Subsidence Management Plan (SMP) as a requirement of their mining lease was a substantial improvement in the regulatory process for subsidence impacts, which has led to many improved outcomes.
- There are a number of areas where the management of mining subsidence can be strengthened in both the Part 3A and SMP processes, including:
  - clarified relationships between Part 3A and SMP approvals;
  - improved identification of natural features which require detailed assessment and careful management, using the concept of ‘Risk Management Zones’;
  - improved guidance by Government agencies on the significance and value of the natural features of the Southern Coalfield;
  - earlier engagement of all stakeholders by mining proponents and involvement by all key stakeholders in the identification of significant natural features;
  - improved timeliness of applications and approvals;
  - improved documentation for environmental assessments for project applications lodged under Part 3A, involving:
    - improved baseline data (a minimum of 2 years for significant natural features, collected at an appropriate frequency and scale);
    - better distinction and articulation of subsidence effects, impacts and consequences;
    - increased communication between subsidence engineers (subsidence effects) and specialists in ecology, hydrology, geomorphology, etc (impacts and consequences);
    - increased transparency, quantification and focus in describing anticipated subsidence impacts and consequences;
    - increased use of peer reviewed science and expert opinion;
    - the use of a net benefit review;
  - a reverse onus of proof, with contingency planning, for mining where insufficient assurance can be provided that highly-significant natural features would not be unacceptably impacted;
  - increased monitoring and back analysis of predicted subsidence effects, impacts and consequences;

- increased security deposits and rehabilitation responsibilities; and
- improved regional data sets.

- The SMP process is currently being reviewed by DPI, with a view to better integrating it with approvals under Part 3A. The Panel supports the current review of the SMP process and its proposed closer integration with Part 3A approvals. The key role of the Part 3A approval should be to clearly define required environmental outcomes and to set appropriate performance standards. The subsequent role of the SMP should be one of management. SMPs should demonstrate how the required environmental outcomes will be achieved, what monitoring will occur and how deviations and contingencies will be addressed.
- The 'significance' of a natural feature cannot be expressed as a universally agreed and quantified factor. Different interest groups hold different (generally qualitative) valuations of significance. In the absence of consensus, Government has a responsibility to provide improved guidance - on which natural features are of significance and to what extent and what level of environmental risk is acceptable - in order to properly inform company risk management processes, community expectations and the approvals process. Currently, there is a lack of clear guidance regarding which features are of what level of significance, and what level of protection is required for each. Government guidance should reflect the recognition that approved mining would be expected to have environmental impacts.
- Longwall mining is a large scale, high productivity, capital intensive mining process with long lead times to establish extraction panels. Consequently it needs timely approvals to facilitate continued production. The granting of timely approvals needs to be supported by clearer guidance from government, provision of more-focused key data, improved impact assessment and longer assessment timeframes.
- Risk Management Zones (RMZs) should be identified to focus assessment and consideration of potential impacts on significant natural features. RMZs are appropriate to manage all subsidence effects on significant natural features, but are particularly appropriate for non-conventional subsidence effects (especially ***valley closure*** and ***upsidence***). Consequently, RMZs should be identified for all significant environmental features which are sensitive to valley closure and upsidence, including rivers, significant streams, significant cliff lines and valley infill swamps.
- Due to the extent of current knowledge gaps, a precautionary approach should be applied to mining which might unacceptably impact highly-significant natural features. The approvals process should require a 'reverse onus of proof' from the mining company before any mining is permitted which might unacceptably impact highly-significant natural features.
- The security deposit system applied to all mining leases granted under the *Mining Act 1992* is a well-established incentive mechanism which provides capacity for increased management of subsidence impacts on natural features, once forthcoming amendments to the *Mining Act 1992* are commenced.

Term of Reference 3

Report on the social and economic significance to the region and the State of the coal resources in the Southern Coalfield.

- The Southern Coalfield is a major source of high quality hard coking coal used for production of steel, both in Australia and internationally. The unique nature of this hard coking coal resource within NSW makes it a very important contributor to the local, regional and State economy.
- 8 currently operating mines in the Southern Coalfield produce around 11 Mt of coal annually. Five mines use longwall mining methods, and produce the vast majority of this coal (98%).
- Coal mining has high economic and social significance within the communities of the Southern Coalfield and directly employs about 2,500 people. Economic data suggests that indirect employment may be as high as 12,000.
- Coal mining and related industries are significant generators of wealth for the local community, the State and the nation, through expenditure, taxes, receipts and royalties. Coal royalty income from the Southern Coalfield was $58.7 m in 2006-07.
- The Southern Coalfield contains sufficient coal resources to enable coal mining in the region to continue for many decades into the future.

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7 Recommendations

Assessment and Regulatory Processes

1) Risk Management Zones (RMZs) should be identified in order to focus assessment and management of potential impacts on significant natural features. RMZs are appropriate to manage all subsidence effects on significant natural features, but are particularly appropriate for non-conventional subsidence effects (especially ***valley closure*** and ***upsidence***). Consequently, RMZs should be identified for all significant environmental features which are sensitive to valley closure and upsidence, including rivers, significant streams, significant cliff lines and valley infill swamps.

2) RMZs should be defined from the outside extremity of the surface feature, either by a 40° angle from the vertical down to the coal seam which is proposed to be extracted, or by a surface lateral distance of 400 m, whichever is the greater. RMZs should include the footprint of the feature itself and the area within the 40^{o} angle (or the 400 m lateral distance) on each side of the feature.

3) RMZs for watercourses should be applied to all streams of 3rd order or above, in the Strahler stream classification. RMZs should also be developed for valley infill swamps not on a 3rd or higher order stream and for other areas of irregular or severe topography, such as major cliff lines and overhangs not directly associated with watercourses.

4) Environmental assessments for project applications lodged under Part 3A should be subject to the following improvements in the way in which they address subsidence effects, impacts and consequences:

- a minimum of 2 years of baseline data, collected at an appropriate frequency and scale, should be provided for significant natural features, whether located within an RMZ or not;
- identification and assessment of significance for all natural features located within 600 m of the edge of secondary extraction;
- better distinction between subsidence effects, subsidence impacts and environmental consequences;
- increased transparency, quantification and focus in describing anticipated subsidence impacts and consequences;
- increased communication between subsidence engineers and specialists in ecology, hydrology, geomorphology, etc;
- key aspects of the subsidence assessment (particularly in respect of predicted impacts on significant natural features and their consequences) should be subject to independent scientific peer review and/or use of expert opinion in the assessment process; and
- increased use of net benefit reviews by both mining proponents and regulatory agencies in assessing applications.

5) Due to the extent of current knowledge gaps, a precautionary approach should be applied to the approval of mining which might unacceptably impact highly-significant natural features. The approvals process should require a 'reverse onus of proof' from the mining company before any mining is permitted which might unacceptably impact highly-significant natural features. Appropriate evidence should include a sensitivity analysis based on mining additional increments of 50 m towards the feature. If such mining is permitted because the risks are deemed acceptable, it should be subject to preparation and approval of a contingency plan to deal with the chance that predicted impacts are exceeded.

6) Approved mining within identified RMZs (and particularly in proximity to highly-significant natural features) should be subject to increased monitoring and assessment requirements which address subsidence effects, subsidence impacts and environmental consequences. The requirements should also address reporting procedures for back analysis and comparison of actual versus predicted effects and impacts, in order to review the accuracy and confidence levels of the prediction techniques used.

7) Part 3A of the *Environmental Planning and Assessment Act 1979* should be the primary approvals process used to set the envelope of acceptable subsidence impacts for underground coal mining projects. This envelope of acceptability should be expressed in clear conditions of approval which establish measurable performance standards against which environmental outcomes can be quantified. Once a project has approval under Part 3A, the Subsidence Management Plan approval should be restricted to detailed management which ensures that the risk of impacts remains within the envelope assessed and approved under Part 3A. In cases where a mining project approval under Part 3A of the EP&A Act does not yet exist, the SMP process should take a greater role in assessing and determining the acceptability of impacts.

8) The acceptability of impacts under Part 3A (and, in the interim, the SMP process) should be determined within a framework of risk-based decision-making, using a combination of environmental, economic and social values, risk assessment of potential environmental impacts, consultation with relevant stakeholders and consideration of sustainability issues.

9) Mining which might unacceptably impact highly-significant natural features should be subject to an increased security deposit sufficient to cover both anticipated rehabilitation costs (as at present), and potential rehabilitation costs in the event of non-approved impacts to the highly significant feature. The higher deposit should be commensurate with the nature and scale of the potential impact and should be attached to the mining lease by DPI under powers available to its Minister under the *Mining Act 1992*. If non-approved impacts occur and the feature is not able to be remediated by the mining company, then the deposit should be able to be forfeited as compensation for the loss of environmental amenity.

10) Consideration should be given to the increased use within Part 3A project approvals of conditions requiring environmental offsets to compensate for either predicted or non-predicted impacts on significant natural features, where such impacts are non-remediable.

11) Mining companies should ensure that they consult with key affected agencies as early as possible in the mine planning process, and consult with the community in accordance with applicable current industry and Government guidelines (eg NSW Minerals Council's *Community Engagement Handbook* and DoP's *Guidelines for Major Project Community Consultation*). For key agencies (eg DECC and SCA), this engagement should begin prior to the planning focus stage of a project application.

12) Government should provide improved guidance to both the mining industry and the community on significance and value for natural and other environmental features to inform company risk management processes, community expectations and Government approvals. This guidance should reflect the recognition that approved mining would be expected to have environmental impacts.

Subsidence Impact Management

13) The coal mining industry and Government should undertake additional research into the impacts of subsidence on both valley infill and headwater swamps. This research should focus on the resilience of swamps as functioning ecosystems, and the relative importance of mining-induced, climatic and other factors which may lead to swamp instability.

14) The coal mining industry should undertake additional research into means of remediating stream bed cracking, including:

- crack network identification and monitoring techniques;
- all technical aspects of remediation, such as matters relating to environmental impacts of grouting operations and grout injection products, life spans of grouts, grouting beneath surfaces which cannot be accessed or disturbed, techniques for the remote placement of grout, achievement of a leak-proof seal and cosmetic treatments of surface expressions of cracks and grouting boreholes; and
- administrative aspects of remediation, in particular, procedures for ensuring the maintenance and security of grout seals in the long term.

15) Coal mining companies should develop and implement:

- approved contingency plans to manage unpredicted impacts on significant natural features; and
- approved adaptive management strategies where geological disturbances or dissimilarities are recognised after approval but prior to extraction.

16) Government should review current control measures and procedures for approval and management of non-mining related impacts on Southern Coalfield natural features. These include various forms of discharge into rivers and streams, as well as water flow control practices. The impacts of such non-mining factors must be recognized when assessing the value of significant natural features in the region, and the assessment of appropriate control strategies.

Prediction of Subsidence Effects and Impacts

17) The coal mining industry should escalate research into the prediction of non-conventional subsidence effects in the Southern Coalfield and their impacts and consequences for significant natural features, particularly in respect of valley closure, upsidence and other topographic features.

18) Coal mining companies should place more emphasis on identifying local major geological disturbances or discontinuities (especially faults and dykes) which may lead to non-conventional subsidence effects, and on accurately predicting the resultant so-called 'anomalous' subsidence impacts.

19) In understanding and predicting impacts on valleys and their rivers and significant streams, coal mining companies should focus on the prediction of valley closure in addition to local upsidence. Until prediction methodologies for non-conventional subsidence are more precise and reliable, companies should continue to use an upper-bound, or conservative, approach in predicting valley closure.

20) Mining companies should incorporate a more extensive component of subsidence impact prediction with respect to natural features, in any future planning submissions. Such predictions should be accompanied by validation of the prediction methodology by use of back-analysis from previous predictions and monitoring data.

Environmental Baseline Data

21) Regulatory agencies should consider, together with the mining industry and other knowledge holders, opportunities to develop improved regional and cumulative data sets for the natural features of the Southern Coalfield, in particular, for aquatic communities, aquifers and groundwater resources.

22) Coal mining companies should provide a minimum of two years of baseline environmental data, collected at appropriate frequency and scale, to support any application under either Part 3A of the *Environmental Planning and Assessment Act 1979* or for approval of a Subsidence Management Plan.

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Appendix A: Applicable Legislation

A1.1 ENVIRONMENTAL PLANNING AND ASSESSMENT ACT 1979

A1.1.1 Historical Background

Until recently, most coal mines in the Southern Coalfield operated without a development consent. This is because the long history of coal mining in the area meant that most coal mines have been operating since before development consent was required due to the passage of the *Environmental Planning and Assessment Act 1979* (EP&A Act), or even under Part XIIIA of the *Local Government Act 1919*, the planning scheme which preceded the EP&A Act. Mines which have been operating under development consent include the:

- Dendrobium Coal Mine (consent granted by the Minister for Urban Affairs and Planning on 20 November 2001);
- Tahmoor Coal Mine (a 3-part consent granted by Wollondilly Shire Council in 1975, the Land and Environment Court in 1994 and the Minister for Planning in 1999); and
- West Cliff Coal Mine (a 2-part consent granted by Wollondilly Shire Council in April 1975 and the Minister for Planning in December 1988).

Transitional provisions associated with the introduction of the EP&A Act (found in cl. 35 and cl. 7 of Sch. 1 of the *Environmental Planning and Assessment Model Provisions 1980*) meant that existing mines did not need development consent, providing that those provisions were adopted in the relevant local environmental plan (LEP). The relevant provisions (or similar) were adopted in the Wollongong, Wollondilly and Wingecarribee LEPs (ie throughout the Southern Coalfield).

This longstanding separation between existing coal mines in the Southern Coalfield and the EP&A Act came to an end with the passage of the *State Environmental Planning Policy (Major Projects) 2005* in May 2005. This SEPP established that all development which in the opinion of the Minister for Planning is 'development for the purpose of …. coal mining' is declared to be a project to which the new Part 3A of the EP&A Act applies – ie, it is a 'major project'. The SEPP established a five year transitional period during which mines which did not have an existing development consent were required to obtain a project approval under Part 3A.

When Part 3A of the EP&A Act was passed in August 2005, it included amendments to the *Mining Act 1992*, which removed a related exemption under s. 74(1) of that Act whereby existing mines operating under a mining lease did not require a new or amended development consent for new or expanded mining operations within the area of the lease. Transitional provisions also provided a five-year timeframe for the implementation of this change in the case of an existing mining lease where underground mining operations are carried out. This period expires on 16 December 2010.

New underground coal mining proposals in the Southern Coalfield, as with all other new mining developments, are subject to the *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007*. This SEPP provides *inter alia* that underground mining is permissible on all land, with development consent.

A1.1.2 Part 3A Approval Regime

Part 3A of the EP&A Act was introduced in August 2005 specifically to deal with the complexities of major projects, such as coal mines. The key steps are the preparation of a short, 'preliminary environmental assessment' (PEA),[9] which leads to an assessment and determination by the DoP of the 'key issues' for environmental impact assessment for the project. This leads to the development of 'Director-General's requirements' (DGRs) issued to the proponent which form the basis for the preparation of the required environmental assessment (EA). The EA is first assessed by the DoP and other key agencies to determine whether it adequately addresses the DGRs, and, if considered adequate, the EA is then publicly exhibited for a period of at least 30 days. Public

[9] 'Environmental assessment' is the name given under Part 3A to what is otherwise known as an environmental impact statement or EIS.

and agency submissions received by DoP are forwarded to the proponent, which must prepare a 'response to submissions' and, potentially, a 'preferred project report'. DoP then assesses the EA and considers all submissions and the proponent's response. This leads to the preparation of a Director-General's assessment report which enables the Minister to determine the project (ie approve it or disapprove it) and to decide under what conditions it may proceed.

A key outcome of Part 3A is to simplify the approvals process for major projects. The legislation exempts approved major projects from requiring a significant number of other statutory approvals. Further, other statutory approvals cannot be refused for an approved project, and those approvals must be 'substantially consistent with' the project approval.

Importantly, Part 3A also provides for Independent Hearing and Assessment Panels (IHAPs) to strengthen the assessment process. Panel members are appointed by the Minister and may be required to provide advice at any stage of the assessment process. Public hearings may also be undertaken to provide input to the IHAP's assessment and advice

Mines in the Southern Coalfield which do not currently have development consents and which are therefore required to obtain project approvals under Part 3A by December 2010 in order to continue their current operations include:

- Peabody Coal's Metropolitan Coal Mine;
- Illawarra Coal's Appin, Appin West and West Cliff Coal Mines; and
- Gujarat NRE's No 1, Avondale and Wongawilli Coal Mines.

All these mine are expected to lodge project applications under Part 3A over the next 2 years. The key process steps for mining related approvals in the Southern Coalfield are set out in Figure 44.

A1.1.3 Conditions of Project Approval under Part 3A

The Department of Planning's (DoP's) current standard conditions of project approval for underground coal mines under Part 3A include requirements to prepare and implement the following management plans and strategies to the satisfaction of DoP's Director-General:

- Water Management Plan, including a:
  - Site Water Balance;
  - Erosion and Sediment Control Plan;
  - Surface Water Monitoring Plan;
  - Groundwater Monitoring Program; and
  - Surface and Groundwater Response Plan;

- Landscape Management Plan, including a:
  - Rehabilitation Management Plan; and
  - Mine Closure Plan;
- Environmental Management Strategy;
- Environmental Monitoring Program;
- Incident Reporting;
- Annual Environmental Management Reports; and
- Independent Environmental Audits.

In addition, the conditions require preparation and implementation of a Subsidence Management Plan (SMP) to the satisfaction of the Director-General of DPI (see section A1.2.3 below).

Apart from requiring independent environmental audits (generally every 3 years) under conditions of project approval, DoP also has a Compliance Unit which undertakes site audits and inspections of mine sites, generally on a targeted basis.

A1.2 MINING ACT 1992

A1.2.1 Statutory Approvals

Under the *Mining Act 1992*, coal cannot be mined without a mining lease. Under Part 3A of the EP&A Act, any mining lease granted must be 'substantially consistent with' any project approval granted by the Minister for Planning. It follows that any mining lease application may only be granted following the giving of any necessary project approval by the Minister for Planning.

Following changes made to the *Mining Act 1992* in association with the passage of Part 3A of the EP&A Act, project approvals and development consents may now address certain matters which previously could only be covered by conditions of a mining lease. These matters are:

- rehabilitation of land during or after mining;
- preparation of land for mining;
- mining methods;
- safety measures; and
- security deposits regarding performance in these matters.

It is therefore important to note that, since July 2005, the Minister for Planning has had power to include conditions in project approvals relating to rehabilitation of land affected by mining.

The *Mining Act 1992* permits that underground mining may take place under a mining lease which does not extend all the way to the surface of the land. Most underground mining of coal in the Southern Coalfield takes place on subsurface mining leases, which do not extend to the land surface. The usual exception to this rule is the land around the surface facilities associated with the mine, where a surface mining lease is also obtained.

However, coal miners need access to the surface of land for a variety of reasons, the most important of which is prospecting (ie exploration). The *Mining Act 1992* permits prospecting operations (including exploration drilling and seismic surveys) to take place above a subsurface lease with the consent of the landholder, with notice to the Director-General of DPI and subject to any security deposit the Director-General may require.

The other principal means by which a coal mine operator may gain access to the surface to conduct exploration is to obtain an exploration licence under the *Mining Act 1992*. Certain additional rights and responsibilities flow from holding an exploration licence, including the requirement to enter into an access arrangement with any affected landholder. All current exploration licences for coal within the Southern Coalfield are shown on Map 3.

Following the partial expiry in August 2007 of transitional provisions associated with passage of Part 3A of the EP&A Act, mines which need to establish significant new surface works above a subsurface mining lease (eg construction of a new ventilation shaft), will need to seek project approval under Part 3A of the EP&A Act. They may also require the grant of a mining lease for 'mining purposes' under the *Mining Act 1992*.[10]

A1.2.2 Mining Operations Plans and Annual Environmental Management Reports

Conditions of all mining leases require that all mining operations must be carried out in accordance with a Mining Operations Plan (MOP) that has been reviewed by, and is accepted by DPI. The MOP describes site activities and the progress toward environmental and rehabilitation outcomes required under the mining lease, project approval (or development consent) and other approvals. The MOP, together with environmental conditions of other approvals, forms the basis for ongoing adaptive management of mining operations and their environmental impacts.

The MOP must present a schedule of proposed mine development and clearly identify:

- area(s) proposed to be disturbed under the MOP;
- mining and rehabilitation method(s) to be used and their sequence;

[10] The *Mining Act 1992* does not require that all 'mining purposes' take place within a mining lease. Mining purposes are defined under the *Mining Regulation 2003*.

- areas to be used for disposal of tailings/waste;
- existing and proposed surface infrastructure;
- existing flora and fauna on the site;
- progressive rehabilitation schedules;
- areas of particular environmental, ecological and cultural sensitivity and measures to protect these areas;
- water management systems (including erosion and sediment controls);
- proposed resource recovery; and
- where the mine will cease extraction during the term of the MOP, a mine closure plan including final rehabilitation objectives/methods, post mining land uses and revegetation.

Proposed operations must be consistent with any development consent and all other Government agency approvals and licenses, including the mine safety regulations and mine safety plans. The MOP must apply best available practice and technology to all aspects of mine operations and include strategies to control identified environmental risks.

Premature cessation of mining will require either a ‘care and maintenance plan’ or a ‘mine rehabilitation and closure plan’ before the Minister for Mineral Resources will grant approval to suspend mining. The period of a MOP is generally seven years, although this is able to be varied in some instances. MOPs can be varied as required with the approval of DPI.

Conditions of all mining leases also require that within 12 months of the commencement of mining operations and thereafter annually (unless otherwise allowed by the Director-General of DPI), the leaseholder must lodge an Annual Environmental Management Report (AEMR) with DPI. The AEMR must contain a review and forecast of performance for the preceding and ensuing twelve months in terms of:

- the accepted Mining Operations Plan;
- development consent (or project approval) requirements and conditions;
- DECC and DWE licences and approvals;
- any other statutory environmental requirements;
- details of any variations to environmental approvals applicable to the lease area; and
- where relevant, progress towards final rehabilitation objectives.

Collectively, the MOP and AEMR constitute DPI’s Mining, Rehabilitation and Environmental Management Process (MREMP). The MREMP aims to monitor and manage the progress of mining and to ensure that all mining operations are safe, the resources are efficiently extracted, the environment is protected and rehabilitation achieves a stable, satisfactory outcome.[11] The AEMR required by DPI is integrated with that required under the conditions of any development consent or project approval from DoP, such that a single AEMR serves the requirements of all Government agencies.

DPI also monitors mine sites through inspections and audits to ensure compliance with title conditions and MOPs. These may be carried out in conjunction and cooperation with other regulatory agencies.

A1.2.3 Subsidence Management Plans

Since early 2004, all new and existing leases permitting underground coal mining have included a condition requiring the leaseholder to prepare a Subsidence Management Plan (SMP) prior to commencing any ‘underground mining operations which will potentially lead to subsidence of the land surface’. Such operations include:

- secondary extraction panels, such as longwalls;
- associated first workings such as gateroads, installation roads, main development headings, etc; and
- pillar extraction.

[11] *Guidelines to the Mining, Rehabilitation and Environmental Management Process*, Department of Primary Industries, January 2006 (edg03 mremp guide, vsn 3).

SMPs are prepared by leaseholders to predict potential impacts of underground operations and identify how significant natural and built features are to be managed. Management may involve the avoidance of damage to particularly significant features, the mitigation of damage, or rehabilitation. The expressed policy intent of the SMP is to provide for the adequate protection of important natural and built features.

The Panel notes that DPI policy defining the purpose and nature of the SMP states:

> *'The SMP must be appropriate to the nature and scale of the potential subsidence impacts, with the level of investigation and detail of reporting related to the scale of impact and the sensitivity of the features affected.*
>
> *The intent of the SMP is to describe the area that may be affected; the process of subsidence prediction employed; the prediction and assessment of subsidence impacts on the area affected; the consultation process undertaken with Government agencies and the community; the results of that consultation; and the proponent's proposals to prevent, mitigate or rehabilitate subsidence impacts.*
>
> *The draft SMP must include a:*
> - *full description of the area proposed to be impacted by mining activity, including areas of environmental, heritage or archaeological sensitivity,*
> - *outline of existing mine workings within the application area, the proposed mine plan and a schedule of proposed mine development for the period to be covered by the SMP;*
> - *predictions of the expected extent of subsidence for each longwall panel or other stage of mining;*
> - *full assessment of the potential environmental, land use and other impacts of that subsidence;*
> - *assessment of the economic and social benefits and impacts of the proposed mine development;*
> - *extracts of relevant conditions of any associated development consent held, relevant conditions of other licences held, and relevant policies of other agencies (including the Mine Subsidence Board and Dam Safety Committee);*
> - *description of previous subsidence projections and impact assessment associated with any previous development application;*
> - *proposals to minimise impacts of surface subsidence, particularly in areas of environmental, heritage or archaeological sensitivity or important built surface features;*
> - *proposals for ground and surface water management;*
> - *proposals for any necessary rehabilitation of subsidence impacts;*
> - *results of consultation with affected landowners, State and local agencies, and the general community; and*
> - *details of any proposed Community Consultation Process.*
>
> *Applicants are encouraged to submit applications for SMP approval in respect of complete longwall domains. However, an SMP can only be approved to cover up to seven years of projected mining operations. If the full domain or other area subject to the SMP approval has not been mined out within seven years, an application to extend the term of the approval will be required.*
>
> *When approved, the SMP will form part of the MOP required under the mining lease, and therefore be subject to the requirement for lodgement and review of an AEMR. AEMRs, including the report against the SMP, will be provided to all agencies with an identified interest.'*[12]

[12] *New Approval Process for Management of Coal Mining Subsidence – Policy*, Department of Primary Industries, December 2003 (edp08).

SMPs and their supporting information are first reviewed by DPI, and a recommendation prepared for its Director-General. Before approval by the Director-General, the SMP and DPI's assessment are reviewed by an interagency committee (the SMP Inter-Agency Committee or SMPIAC). This whole-of-Government approach was established by DPI to ensure a thorough assessment of each SMP. The committee includes representatives from each of the following agencies:

- Department of Planning;
- Department of Water and Energy;
- Department of Environment and Climate Change;
- Department of Primary Industries – Fisheries;
- Dam Safety Committee;
- Sydney Catchment Authority; and
- Mine Subsidence Board.

Other agencies, eg the Heritage Office, the Roads and Traffic Authority or Railcorp, may be invited to attend specific meetings where they have an identified interest.

A1.2.4 Rehabilitation and Security Deposits

All mining leases contain conditions requiring the leaseholder to maintain security (either a cash deposit or a bank guarantee) for the fulfilment of all obligations arising under the *Mining Act 1992* in respect of the lease.

DPI policy requires that the security deposit be sufficient to cover the full rehabilitation costs of all activity on the lease. This requirement ensures the State does not incur financial liabilities if the leaseholder defaults on their rehabilitation obligations. The leaseholder is required to provide an estimate of rehabilitation costs for DPI to consider when determining the security deposit amount.

When mining has been completed, DPI assesses and determines whether rehabilitation obligations have been fully met so that the security deposit can be released. Partial release of the security deposit may occur when successful rehabilitation has been demonstrated for part of the site.

The Panel notes that subsidence takes place in the rock strata *above* the underground coal seam which is extracted. Consequently, much of this subsidence takes place outside of the mining lease, where that lease does not extend to the surface. Amendments to the *Mining Act 1992* assented to in May 2008 provide *inter alia* that a security deposit may now be held in respect of mining-related damage which occurs *outside* (including above) the lease area. These amendments will also strengthen DPI's enforcement powers outside of mining leases and other titles.

A1.3 OTHER LEGISLATION

A1.3.1 Sydney Water Catchment Management Act 1998

The *Sydney Water Catchment Management Act 1998* (SWCM Act) establishes the Sydney Catchment Authority (SCA) to manage and protect Sydney's water catchment areas. The SWCM Act sets out the principal objectives of the SCA as being:

- to ensure that the catchment areas and the catchment infrastructure works are managed and protected so as to protect water quality, protect public health and safety, and protect the environment;
- to ensure that water supplied by the SCA complies with appropriate standards of quality;
- where SCA activities affect the environment, to conduct its activities in compliance with the principles of ecologically sustainable development; and
- to manage SCA's catchment infrastructure works efficiently and economically and in accordance with sound commercial principles.

The SCA's main functions are therefore to:

- manage and protect the catchment areas, and its dams, storages and pipelines;
- supply bulk water to Sydney Water and other water supply authorities;
- protect and enhance water quality;

- carry out research on catchments generally and on the health of its own catchments in particular; and
- help educate the community about water management and catchment protection.

Under the SWCM Act, public agencies must first give notice to SCA of their intention to exercise their functions within a Special Area, and those agencies may not exercise those functions contrary to any representations that SCA makes except with 28 days notice (see s. 47 SWCMA). The *Sydney Water Catchment Management (General) Regulation 2000* regulates conduct in Special Areas to protect water supply and biodiversity. It categorises Special Area lands as:

- Schedule 1 - No Entry; or
- Schedule 2 - Restricted Access.

Both the Metropolitan and Woronora Special Areas are Schedule 1 lands. The O'Hares Creek Special Area is Schedule 2 land.

Operating underground coal mines within the Metropolitan Special Area are Wongawilli, Dendrobium, Gujarat NRE No 1 and Appin. Mines on care and maintenance are Avondale, Avon and Cordeaux. Metropolitan Coal Mine is largely within the Woronora Special Area and West Cliff is largely within the O'Hares Creek Special Area. The Northcliff Mine, which is not currently operating, straddles the Woronora and O'Hares Creek Special Areas.

The SCA's management approach for the Special Areas is outlined in its *Special Areas Strategic Plan of Management* (SASPoM), which was first adopted by the Government in 2001 and replaced by a fully revised version in February 2007. The SCA and DECC are joint sponsors of the plan. The SASPoM essentially seeks to control impacts on the water supply catchments rather than to control land uses as such. Consequently, it does not seek to control 'underground coal mining' for example, but rather matters such as:

- water quality risks;
- ecosystem management;
- regulation of human activity;
- fire management;
- 3rd party asset construction and maintenance;
- pest and weed management; and
- Aboriginal and historic cultural heritage.

Nevertheless, it contains several actions which particularly relate to mining (ie 'third parties' in the context of the SASPoM), as follows:

- SCA and DECC will formalise access arrangements with utility providers and mining operators, including updating licences and maintenance agreements (Action 3.5);
- SCA and DECC, in collaboration with other agencies as required, will commission and collate monitoring information for mining in Special Areas, to better understand the impacts and to promote the protection of Special Areas to Government decision makers (Action 5.2);
- DECC and SCA will investigate the impact of longwall mining in Special Areas on water quantity, water quality, ecological integrity and cultural heritage, and will analyse results to promote protection of Special Areas (Action 5.4);
- DECC and SCA will require all existing and proposed asset construction and maintenance operations (including access requirements) by the joint sponsors and third parties to meet best practice to protect water quality, ecological integrity and cultural heritage, and will selectively audit compliance (Action 5.5);
- SCA will investigate the impacts of priority derelict mines within the Special Areas and develop appropriate responses and rehabilitation strategies with relevant organisations (Action 5.6);
- DECC and SCA will develop and implement Soil Erosion Prevention Guidelines for natural areas, to be applied to all asset construction and maintenance within Special Areas. These guidelines will aim to minimise soil disturbance and include soil erosion mitigation techniques, control measures and management protocols and will also address priority events identified in SCA's Water Quality Risk Management Framework (Action 5.7); and

- SCA and DECC will audit a selection of activities by the joint sponsors, contractors and third parties, for compliance with licence and environmental impact assessment conditions and water quality protection measures (Action 9.7).

A1.3.2 National Parks and Wildlife Act 1974

The principal approvals under the *National Parks and Wildlife Act 1974* (NPW Act) that affect mining and exploration in the Southern Coalfield are approvals under Part 6 of that Act to conduct Aboriginal archaeological surveys (section 87 permits) or to damage or destroy Aboriginal sites or objects (section 90 consents). These approvals are granted by the Director General of DECC.

If mining or exploration activities are likely to destroy, damage or deface an Aboriginal object or site, the mining company must first obtain consent under section 90, or else risk prosecution for the offence. In considering whether to issue this consent, DECC takes into account the:

- significance of the Aboriginal object(s) or Aboriginal site(s) to be impacted;
- effect of the proposed impact and the mitigation measures proposed;
- justification of the proposed impacts; and
- outcomes of the Aboriginal community consultation regarding the proposed impact and conservation outcomes.

To avoid the risk of prosecution for inadvertently damaging an Aboriginal site or object, miners and explorers must first conduct site surveys, including surface and occasionally subsurface investigations. Before disturbing or excavating land to look for an Aboriginal object, or disturb or move an Aboriginal object, they must obtain a permit under section 87. In considering whether to issue a section 87 permit, DECC takes into account the:

- views of the Aboriginal community about the proposed activity;
- objectives and justification for the proposed activity; and
- appropriateness of the methodology to achieve the objectives of the proposed activity.

Parts of the Southern Coalfield are within the system of conservation parks and reserves reserved under the NPW Act and now managed by DECC. Mining and exploration are not permitted in most types of conservation reserve (eg national parks and nature reserves, see ss. 41 and 54 NPWA). However, mining and exploration are permitted to take place in one form of conservation reserve under the Act under strict oversight and conditions (State conservation areas, see ss. 47H and 47J NPWA). There are seven State conservation areas in the Southern Coalfield (see section 2.3.2.5).

Other permits and approvals may be required under the NPW Act for miners and explorers to undertake activities within State conservation areas.

A1.3.3 *Threatened Species Legislation*

A1.3.3.1 *Threatened Species Conservation Act 1995*

Threatened species, populations and ecological communities are protected by the *Threatened Species Conservation Act 1995* (TSC Act), with the exception of fish and marine plants, which are protected under Part 7A of the *Fisheries Management Act 1994* (see below).

All terrestrial threatened species, populations and ecological communities are listed in Schedules to the TSC Act. DECC administers the TSC Act, but the Schedules are maintained by an independent Scientific Committee. Anyone can make a nomination to the Scientific Committee to add, remove or change the status of a species.

The TSC Act provides for the identification, conservation and recovery of threatened species and their populations and ecological communities, but it does not contain a specific approval regime. Instead, the Act is integrated with regulatory procedures under both the EP&A Act and the NPW Act. This allows for integration of threatened species assessment into the planning system and removes the requirement to obtain a separate threatened species licence in addition to development consent or project approval under the EP&A Act.

Parts 4 and 5 of the EP&A Act require concurrence by the Director-General of DECC to any development which will have significant impact on threatened species. Under Part 4, development consent cannot be granted for development on land that is, or is a part of, critical habitat, or for development that is likely to significantly affect a threatened species, population, or ecological community, or its habitat, without the concurrence of the Director-General of DECC. The Minister for the Environment may also choose to exercise this role.

However, because major projects assessed under Part 3A of the EP&A Act are seen to be of State significance, and the legislation assumes consultation between Ministers, no such concurrence is required in the case of project approvals.

Recent amendments to the TSC Act also provide for developers to provide native vegetation offsets where their activities will lead to impacts on biodiversity values (the ‘Biobanking Scheme’). DECC is currently undertaking a pilot for the Biobanking Scheme. Under the Scheme, developers may be required to purchase and retire sufficient biodiversity credits to ensure that the impact of their development on biodiversity values is fully offset, as well as to take onsite measures to minimise any negative impact on biodiversity values.

Recent amendments to Part 3A EP&A Act provide that the Minister for Planning may approve a project subject to a condition that requires the proponent to acquire and retire (in accordance with the TSC Act) biodiversity credits of a number and class specified by the Minister (see s. 75JA EPAA). The Minister may permit the deferred retirement of some or all of the biodiversity credits, pending completion of rehabilitation or restoration actions to be undertaken on the project site to restore or improve biodiversity values affected by the project.

The TSC Act also is aimed at reducing the threats faced by threatened species. One initial step in doing this is for the Scientific Committee established under the Act to list what are termed ‘key threatening processes’. These are processes that could:

- adversely affect threatened species, populations or ecological communities, or
- cause species, populations or ecological communities that are not threatened to become threatened.

In 2005, the Scientific Committee listed the ‘alteration of habitat following subsidence due to longwall mining’ as a key threatening process under Schedule 3 of the TSC Act.[13] This listing does not change the current laws regulating longwall mining activities. However, it has led to an increased need for both project proponents and agencies to consider the biodiversity impacts of subsidence caused by longwall mining.

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[13] NSW Scientific Committee (2005). See
http://www.nationalparks.nsw.gov.au/npws.nsf/content/longwall_mining_ktp.

In response to the listing, DECC has developed a *Threatened Species Priority Action Statement*[14] that outlines that a whole of Government response is required to ensure that biodiversity implications of subsidence are more thoroughly assessed and monitored where long wall mining is being proposed or carried out.

DECC has also advised that there are a number of threatened flora and fauna species that may be affected by subsidence due to longwall mining in the Southern Coalfield. These species are listed in section 2.1.5 and Appendix C.

A1.3.3.2 Fisheries Management Act 1994

The *Fisheries Management Act 1994* (FM Act) contains provisions for the identification and protection of threatened species, populations and ecological communities of marine and freshwater fish and aquatic plants. These provisions are parallel to those in the TSC Act covering terrestrial species, including the concepts of threatened species, key threatening processes, recovery plans and a Scientific Committee. The FM Act is also integrated with the EP&A Act in a similar way as is the TSC Act.

The definition of 'fish' under the FM Act includes aquatic invertebrates, such as crayfish and other crustacea, and aquatic insects.

A1.3.4 Dams Safety Act 1978

In the 1970s, the NSW Government gave significant consideration to the extent of mining that should be permitted adjacent to, and under Sydney's major dams and water storages. At the time, the then Metropolitan Water Sewerage and Drainage Board (now Sydney Water) did not support the underground extraction of coal in the vicinity of its major storages due to concerns about the potential for loss of stored water into the mine workings. The Wran Government instigated an inquiry in 1977, known as the Reynolds Inquiry, to investigate this issue.

The inquiry developed guidelines for coal mining beneath stored waters. The inquiry resulted in a legislated framework for ensuring that dams are managed safely and protected from, among other things, the impacts of mining. The *Dams Safety Act 1978* gave effect to the findings of the inquiry and established the NSW Dams Safety Committee (DSC), which continues to play an integral role in managing this issue.

The DSC plays a role in determining the type and extent of coal mining allowed in the vicinity of prescribed dams and their storages. This role is pursuant to statutory, mining-related functions under its Act, as well as under the *Mining Act 1992*. However, its regulatory powers extend only to the safety of dam structures and their stored waters, and not to catchment water resources and water quality.

The DSC prescribes 'notification areas' around all significant dams and stored waters which might be affected by underground coal mining (or other mining). These areas are gazetted under powers provided to the DSC in s. 369 of the *Mining Act 1992*. The notification area sets the limit of the DSC's interest in mining around the dam and includes the 'storage restricted zone' and the 'structure restricted zone', with mining outside of the notification area considered far enough away to pose negligible risk to the dam and stored waters. The storage restricted zone comprises the areas of the reservoir and a marginal zone (defined by an angle of draw of 35° from full storage level plus half the depth to the base of the coal seam). The structure restricted zone generally extends 1.2 times the depth from full storage level to the base of the coal seam, but is 1.7 times this distance for rigid dams (Holla et al, 1993). All SCA dams within the Southern Coalfield and the Broughtons Pass Weir are subject to DSC notification areas.

Before granting a coal mining lease within a DSC notification area, the Minister for Mineral Resources seeks the DSC's advice, which normally recommends that the lease contain a condition requiring the leaseholder to seek an additional approval from the Minister to mine within the

[14] DECC (2006). *Threatened Species Priority Action Statement.* See http://www3.environment.nsw.gov.au/PDFs/pas0610.pdf.

notification area. The Minister then again seeks the DSC's recommendations before granting any such approval. The DSC recommends to the Minister the extent of mining which should be allowed and the monitoring and surveillance requirements for the mining operations and the dam.

The extent of mining permitted by the DSC near a dam depends on the mining geometry (ie coal pillar dimensions, size of headings and other voids, etc), proximity to the dams or stored water, and local geology. In general, substantial mining near a major dam structure is not permitted. Monitoring requirements normally include the preparation of geological plans and reports, the establishment and monitoring of subsidence and strain survey lines and the measurement of water inflows and outflows. As part of this monitoring and surveillance requirement, DSC members and staff regularly inspect underground workings of coal mines under or near dams, including in the Southern Coalfield.

A1.3.5 Other Approvals

Mining activities generally require approvals under other legislation. In particular, these include:

- a water access licence under the *Water Management Act 2000*; or groundwater and surface water access licences and other approvals under the *Water Act 1912* (in the areas of the State where this Act still operates); and
- an environment protection licence under the *Protection of the Environment Operations Act 1997*.

The *Water Management Act 2000* has not yet commenced across large parts of the State, including the Southern Coalfield, and so the provisions of the *Water Act 1912* still apply. While this has not always been the case, DWE currently considers that an underground mine falls within the definition of a groundwater 'bore' under Part 5 of that Act. Consequently, underground coal mines must obtain a licence to interfere with the saline groundwater within coal seams.

Mines require an environment protection licence under the *Protection of the Environment Operations Act 1997* (PEO Act) if they are discharging any polluted waters from the area of the mining lease or emitting any air pollution or noise pollution. In the case of underground coal mines, these emissions are generally associated with the surface facilities of the mine (eg coal stockpiles, coal preparation and handling plants, coal loading facilities, coal wash emplacements) rather than the underground mining activity itself. Underground mining therefore does not require a licence under the PEO Act, only the discharge of pollutants to the environment.

Mines and other projects which obtain project approval under Part 3A of the EP&A Act become exempt from requiring a significant number of other statutory approvals (see s. 75U EPAA). These are:

- concurrences under Part 3 of the *Coastal Protection Act 1979* of the Minister administering that Part of the Act;
- permits under section 201, 205 or 219 of the *Fisheries Management Act 1994*;
- approvals under Part 4, or excavation permits under section 139, of the *Heritage Act 1977*;
- permits under section 87 or consents under section 90 of the *National Parks and Wildlife Act 1974*;
- authorisations under section 12 of the *Native Vegetation Act 2003* to clear native vegetation or State protected land;
- permits under Part 3A of the *Rivers and Foreshores Improvement Act 1948*;
- bush fire safety authorities under section 100B of the *Rural Fires Act 1997*;
- water use approvals under section 89, water management work approvals under section 90 or activity approvals under section 91 of the *Water Management Act 2000*.

The purpose of these exemptions is not to avoid the consideration of these issues in the approval process, but merely to avoid duplication and overlapping processes. The legislative intent is that these issues are addressed in the Part 3A approval process.

Where a Part 3A project approval has been obtained, then many other statutory approvals have to be granted so as to be 'substantially consistent' with the project approval (see s. 75V EPAA). These are:

- aquaculture permits under section 144 of the *Fisheries Management Act 1994*;

- approvals under section 15 of the *Mine Subsidence Compensation Act 1961*;
- mining leases under the *Mining Act 1992*;
- production leases under the *Petroleum (Onshore) Act 1991*;
- environment protection licences under Chapter 3 of the *Protection of the Environment Operations Act 1997*;
- consents under section 138 of the *Roads Act 1993*; and
- licences under the *Pipelines Act 1967*.

Again, the purpose of these limitations on licence content is to ensure consistency between approvals. The legislative intent is that the Part 3A approval clearly be the primary and dominant approval process.

Appendix B: Subsidence Prediction Techniques

Surface subsidence prediction techniques can be classified under three headings:

- empirical methods;
- analytical – numerical methods; and
- hybrid methods.

The various techniques and methods are briefly described below.

B1.1 EMPIRICAL METHODS

Empirical subsidence prediction techniques are premised on the back-analysis of field performance. Reliability of outcomes is dependent, therefore, on the size and representativeness of the database and considerable care is required if the techniques are applied to conditions that are outside of this database. The more common methods are:

1. ***Graphical***: This involves plotting suites of curves showing relationships between various parameters and subsidence outcomes. There may be no engineering basis for some of the relationships, but purely a statistical correlation. This is added reason for exercising caution when applying the relationships to mining conditions or regions which fall outside of the database. The *Subsidence Engineers Handbook* produced by the National Coal Board (NCB) of Britain in 1965 is a well known example of a graphical prediction approach. Whilst it proved quite reliable in the UK, the method met with limited success when introduced into Australia and South Africa in the 1970s because the geological conditions of these countries were substantially different to those of the UK.

2. ***Upper Bound***: This approach was brought to prominence in NSW in the early 1980s by Dr Lax Holla, then Principal Subsidence Engineer with the NSW Department of Mineral Resources. This method still finds application. Basically, Dr Holla modified the NCB approach to subsidence prediction so that the maximum values of vertical displacement, tilt and strain could be predicted in the Newcastle, Southern and Western Coalfields of NSW. Predictions are based on an envelope that has been constructed over the majority of the maximum vertical displacement outcomes recorded over single panels across a range of W/H ratios in a coalfield, Figure 47. As such, the envelope encapsulates variations in site specific conditions, such as geology and stress field.

   The subsidence factor defined by the upper bound vertical displacement envelope is then multiplied by various calibration factors to predict the maximum values of tilt, compressive strain and tensile strain. Predicted maximum curvatures are derived from predicted maximum strains. Further calibration factors are applied in making predictions over multiple panel layouts. Effectively, the methodology is not concerned with accurately predicting subsidence outcomes at specific locations or with producing profiles of the various subsidence parameters across the subsidence trough, but only with restricting subsidence at all sites under all circumstances to less than some maximum value. When sufficient data are available, a site specific version of Figure 47 can be developed.

3. ***Profile Function***: This technique attempts to define the shape of the vertical displacement curve by a mathematical equation. This equation is then mathematically differentiated to produce a profile of tilt. In turn, the tilt profile is differentiated to produce a profile of curvature. Calibration factors derived from back analysis of field data are then applied to the curvature profile to produce predictions of strain. The methodology is confined in general to single (isolated) excavations as it cannot replicate non-symmetrical subsidence profiles.

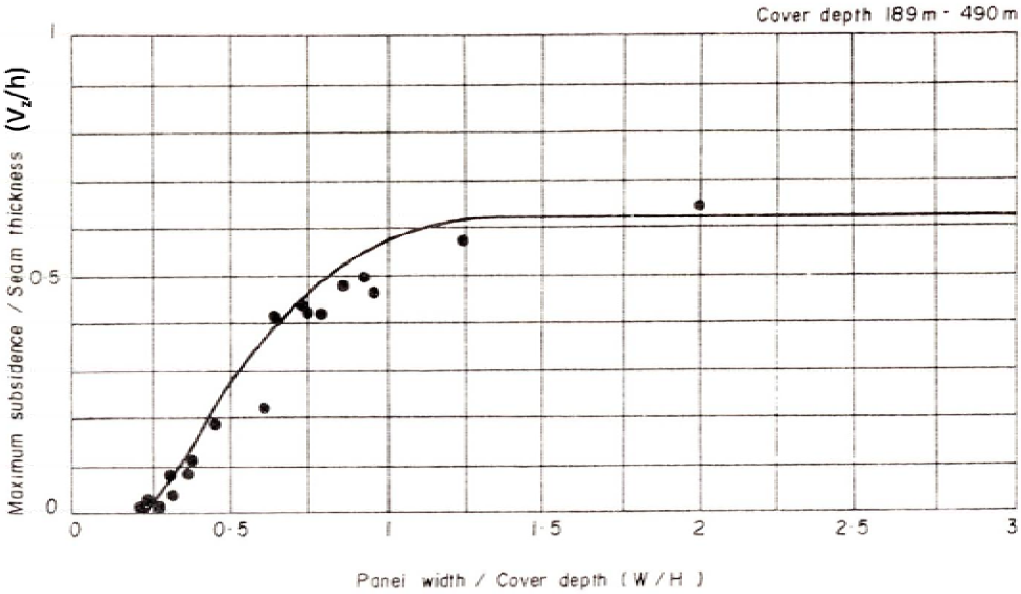

Figure 47: Maximum Vertical Displacement Prediction Curve for the Southern Coalfield

Source: Adapted from Holla, 1985

4. ***Incremental Profile Method***: It has been known for decades that, in theory, the vertical surface displacement profile over mine workings at any point in time can be constructed by summing the increments of vertical displacement arising from the mining of each panel making up those workings. The Australian coal mining industry has provided considerable research funding over the last decade to effectively 'reverse engineer' the subsidence prediction process by utilising the large databases of subsidence information relating to the Southern Coalfield and the Newcastle Coalfield in NSW to define the characteristic shape for each increment of vertical displacement resulting from a mining operation. Once the vertical displacement profile has been created, it can used to calculate tilt, curvature and strain in the same manner as that described for the profile function technique. This prediction technique offers a number of benefits over other empirical techniques because variations in depth, seam thickness and seam dip can be taken into account, as well as the influence of multiple mining panels - and subsidence predictions can be produced at any nominated point on the surface.

B1.2 ANALYTICAL – NUMERICAL METHODS

Analytical techniques are based on applying physical and engineering principles to calculate how the rock mass will behave when an excavation is made in it. Most of the mathematical formulae that describe these responses have been known for decades; however, until the advent of computers, they could only be solved for very simple two dimensional mining layouts. Each advance in computational power enables more complex mathematical equations to be solved, thereby enabling more detailed mining layouts, geological and geotechnical conditions and ground behaviour mechanisms to be analysed. Such analysis has now come to be referred to as *mathematical modelling, numerical analysis* or *computer modelling.*

Nevertheless, limitations are also associated with numerical models. No one mathematical model is capable of fully describing rock behaviour and so the modelled behaviour is not always representative of that acting in the field. Representative models still require a database for calibration purposes and, therefore, outcomes need to be accepted with caution at greenfields sites.

B1.3 HYBRID METHODS

Hybrid techniques involve various mixtures of back-analysis of field data and the application of analytical/numerical techniques. The Influence Function technique is one of the more popular hybrid techniques, although it is sometimes classified as an empirical technique and sometimes as an analytical technique. It is based on engineering theory which defines the area impacted upon, or influenced, by the formation of a void at a specific point. The displacements arising from the formation of a void at this point and at neighbouring points are summed to produce a profile of the total displacement at any nominated distance on the surface from the void. The principle is applied in subsidence engineering to calculate total vertical displacement at the surface. Tilt and strain are then calculated by mathematically differentiating this profile. The technique can be applied to a wide range of mining layouts but the selection of the appropriate influence function is dependent on the availability of appropriate field data.

Appendix C: Subsurface Subsidence Prediction

C.1.1 PREDICTION METHODOLOGY

A considerable amount of mining, including longwall mining, has been undertaken over the last two centuries beneath the sea, lakes, lagoons, dams and rivers of the Newcastle Coalfield and the Southern Coalfield. The issue of hydraulic connections between the surface water bodies and the mine workings was a subject of interest in two earlier inquiries commissioned by the NSW Government (Wardell 1975, Reynolds 1977). The Wardell Inquiry was concerned with the potential for safety to be jeopardised by a direct connection between mine workings and overlying water bodies in the Newcastle, Lake Macquarie and Wyong LGAs. The Reynolds Inquiry was primarily concerned with potential for water loss from water supply storages into mine workings in the Southern Coalfield.

A number of criteria have evolved over the years for assessing the likelihood of a hydraulic connection between the surface and mine workings, the principal ones being:

- ***Presence of an aquiclude***: an aquiclude is an impermeable layer such as shale, clay or some claystones. International experience indicates that if the right type and thickness of material is present, unrestricted extraction may take place beneath water bodies without surface water finding its way into the mine workings.
- ***Maximum tensile strain on the surface***: for many years, it was believed that water could be prevented from entering the mine if cracking of the surface was restricted by limiting the maximum tensile strain on the surface to between 5 – 10 mm/m, depending on the nature of the strata. The Wardell Guidelines for mining beneath the tidal waters of Lake Macquarie, Lake Munmorah and Budgewoi Lake in the Wyong LGA were premised on this criterion (Wardell 1975). It is recognised today that it fails to adequately consider the behaviour of the strata in the constrained zone and has fallen into disuse.
- ***Development of a constrained zone***: the recommendations of the Reynolds Inquiry into mining under stored waters in the Southern Coalfield of NSW (Reynolds 1977) were based on this principle and have been applied without incident at a number of sites. Mine planning has progressively deviated from them in the Southern Coalfield in the light of field monitoring, field experience and advances in numerical modelling.

An extensive groundwater water testing program conducted by Forster and Enever (1992) in the Lake Macquarie region of NSW resulted in the model of subsurface behaviour zones shown in Figure 48 (see also Figure 12). This model has since been applied to the successful extraction of three longwall panels beneath Lake Macquarie.

C.1.2 PREDICTION ACCURACY

Byrnes (1999) reported on detailed investigations into groundwater hydrology undertaken by South Bulli Colliery in the Southern Coalfield for longwall mining under Cataract Reservoir in the mid to late 1990s. He included a number of case studies of successful and unsuccessful experiences in mining under water bodies, the following being noteworthy:

i) At Wongawilli Mine in the Southern Coalfield, a 3 m thickness of the Wongawilli Seam was extracted by bord and pillar mining (first workings) under the Avon Reservoir. Depth of cover varied from 90 m to 160 m. Strata were predominantly well jointed massive sandstones containing frequent igneous intrusives. Mining induced a water inflow which increased from 7.8 to 28 litres/second (l/s). The flow was stabilised to around 19 l/s.

ii) Extensive longwall mining at Rend Lake, USA, at a depth of 200 m has been undertaken below a freshwater lake with no reported water inflows or loss of water from the overlying reservoir, despite the presence of a number of fault zones continuous between the surface and the mine workings. Importantly, there were many metres of clay and silt sediment at the floor of the lake. The rock cover was mostly shale.

iii) At Rufford Lake in the UK, mining 420 m beneath a shallow lake caused fracturing in the bed of the reservoir and significant loss of water. Cracking was suspected to be due to the reopening of a fault plane beneath the lake.

iv) a number of studies were undertaken when conducting pillar extraction beneath Cataract Reservoir at Bulli Colliery in the Southern Coalfield of NSW. Piezometers situated in the Hawkesbury sandstone (320-300 m above the extracted Bulli Seam) showed a response to the changing perched aquifer water table which was responding to climatic and topographic controls, but no response to mining was evident. In the Bulgo Sandstone, piezometers at 150 m above the seam showed a response to mining.

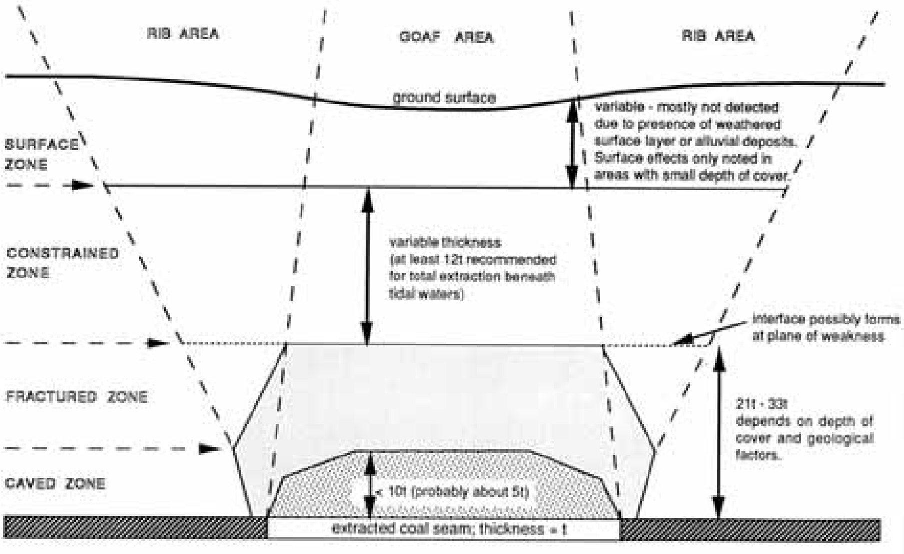

Figure 48: Behaviour Zones above an Excavation in the Lake Macquarie Region of NSW

Source: Forster and Enever 1992

Byrnes concluded that, higher than 185 m above the extracted seam (equivalent to 1.7 times panel width) there was no evidence that there was any change in the hydraulic connectivity of water from the reservoir to the mine workings. Water balances based on the pumping system at South Bulli Colliery supported this conclusion as did precise *in-situ* strain measurements undertaken in conjunction with the University of Queensland and CSIRO. The outcomes are not inconsistent with the outcomes of research in the Western Coalfield of NSW by Mills and O'Grady (1998), who concluded that the height of disturbance above an individual longwall is limited to within 1 to 1.6 times panel width.

Everett et al (1998), Barclay and Holla (2000) and Waddington Kay (2002) also make note of a number of case histories of mining under watercourses and water bodies in the Southern Coalfield. Some successful cases are attributed to the significant depth of mining (~500 m) or the presence of the Bald Hill claystone acting as an undisturbed aquiclude. Galvin (2005) undertook an independent review of the impacts of longwall mining on the Waratah Rivulet as at March 2005. The review noted that whilst chain pillar size was considerably smaller than that used at South Bulli Colliery, resulting in greater vertical surface displacement, there was no evidence of any direct hydraulic connection to the Waratah Rivulet.

MSEC (2007) undertook a review of literature regarding the likely heights of the caved, fractured and constrained zones and found that:

- generally, the height of the caved zone has been indicated to fall within the range of 1.5 to 14 times the extraction height, with the majority of cases in the range of 5 to 10 times the extraction height;
- the height of the fractured zone has been reported to lie within the range of 10 to 105 times the extracted height; and
- the height to the base of the constrained zone has also been reported in terms of extraction width and found to vary between 0.16 and 1.4 times this width.

MSEC noted some instances of higher reported values than those quoted above but attributed these to imprecise definitions of the fractured and constrained zone and differing interpretations of extensometer results.

The studies by Forster and Enever (1992), Byrnes (1999) and Galvin (2005) highlight that mine design recommendations should not be applied blindly and that careful consideration must always be given to site specific geology and geological features. Forster and Enever flagged that it is not sufficient to create a constrained zone above mine workings but that this zone must also have a low natural permeability and/or contain beds of low permeable strata for it to function as a hydraulic barrier between the surface and the mine workings. Exploration and instrumentation boreholes have revealed that some of the claystones in the Newcastle and Southern Coalfields have a high propensity to swell and that the floor sediments of the coastal lakes can include clay rich material. The role that these materials may have played in producing successful outcomes also needs to be borne in mind.

In the last decade there have been significant advances in computer modelling which not only provide more detailed insight into ground responses to mining but also enable this behaviour to be integrated with groundwater behaviour. Irrespective of which prediction methodology is utilised, consideration still needs to be given to the potential for a geological feature or disturbance to provide a direct connection between a water body and the mine workings.

Appendix D: Flora and fauna of the Southern Coalfield

D1.1 TERRESTRIAL VEGETATION

The biological diversity of the Upper Nepean and Woronora catchments is influenced by relatively infertile, acidic soils which have been developed from the Hawkesbury Sandstone. As a result, vegetation is generally a composite of dry sclerophyllous woodlands, forests and heaths, with some rainforest and upland swamps. A survey of the Upper Nepean and Woronora catchments by the NPWS in 2003 identified 48 different vegetation communities (see Map 4). Of these communities, DECC reports that 26 have less than 15% of their remaining area conserved within NPWS reserves in the Sydney Basin Bioregion. It should be noted that occurrences within the non-reserved sections of the Special Areas are in addition to this.

In 2005, the alteration of habitat following subsidence due to longwall mining was listed by the NSW Scientific Committee as a 'Key Threatening Process' under Schedule 3 of the *Threatened Species Conservation Act 1995*.[15] Key Threatening Processes are processes that could:

- adversely affect threatened species, populations or ecological communities, or
- cause species, populations or ecological communities that are not threatened to become threatened.

In response to the listing, DECC developed a *Threatened Species Priority Action Statement*, which outlines that a whole-of-Government response is required to ensure that biodiversity implications are more thoroughly assessed and monitored where long wall mining is proposed or undertaken.

Several vegetation communities have been recognised as endangered ecological communities (EECs) under the *Threatened Species Conservation Act 1995* due to a combination of factors which include their naturally restricted distribution, levels of historical clearing and low levels of protection in conservation reserves (see Table 10 below).

Table 10. Endangered Ecological Communities in the Upper Nepean and Woronora Catchments

Endangered Ecological Community – as listed under the TSC Act 1995	**Vegetation Community – as named in NPWS 2003 Vegetation Survey**
O'Hares Creek Shale Forest	O'Hares Creek Shale Forest
Cumberland Plain Woodland	Cumberland Shale Plains Woodland
	Cumberland Shale Hills Woodland
Shale/Sandstone Transition Forest	Transition Shale Dry Ironbark Forest
	Transition Shale Stringybark Forest
	Transition Shale Open Blue Gum Forest
Southern Highlands Shale Woodlands	Highlands Alluvial Red Gum Woodland
	Highlands Ribbon Gum Gully Forest
	Highlands Shale Tall Open Forest
Robertson Basalt Tall Open-forest	Robertson Basalt Brown Barrel Forest
	Moist Shale Messmate Forest
Robertson Rainforest	Robertson Cool-Warm Temperate Rainforest

Source: DECC

[15] NSW Scientific Committee (2005); *Alteration of Habitat Following Subsidence due to Longwall Mining - Key Threatening Process Listing, see:* *http://www.threatenedspecies.environment.nsw.gov.au/tsprofile/threat_profile.aspx?id=20001*.

The shale communities are largely confined to the southern and western sections of the catchments, particularly in O'Hares Creek Catchment, while the Robertson Basalt Tall Open Forest and Robertson Rainforest are found in pockets of rich volcanic soils around Robertson and have been largely cleared on private land.

There are a number of threatened flora that may be affected by subsidence due to longwall mining in the Southern Coalfields and which are dependent on either stream and swamp habitats. DECC has identified more than 20 species of threatened plants in the region associated with habitats such as upland swamps, creeks, cliffs and rock overhangs that may face impacts from longwall mining (see Table 11).

Upland swamps on the Woronora Plateau are considered by DECC as perhaps the most significant floristic community which may be potentially significantly impacted by subsidence-related impacts, despite the fact that they are not listed as such as an EEC.16 Upland swamps are characterised by ti-tree thicket, cyperoid heath, sedgeland, restioid heath and Banksia thicket with the primary floristic variation being related to soil moisture and fertility (Young, 1986, Keith and Myerscough, 1993). Swamps and wetlands contain 'hydrophytic vegetation', plants which tolerate oxygen-poor, wet substrate conditions (Schmid and Kunz, 2000). Swamps and wetlands also have 'hydric soil' which is soil that was formed when oxygen was lacking as a result of prolonged inundation or saturation (Schmid and Kunz, 2000). The specialised hydrological and edaphic conditions within upland swamps provide habitats for a unique array of native plants and animals and often these comprise unique ecological communities (Kodela et al, 1992, Keith and Myerscough, 1993). The swamps are exceptionally species rich with up to 70 plant species in 15 m^2 (Keith and Myerscough, 1993) and are habitats of particular conservation significance for their biota.

Riparian vegetation occurs close to stream banks and is considered to comprise a distinct vegetation assemblage of plants that prefer high levels of moisture. However, it is not recognised as a distinct community in the NPWS survey[17] due to the difficulty of mapping at a small scale.

D1.2 TERRESTRIAL FAUNA

In 2005, DECC completed a major study titled the Terrestrial Vertebrate Fauna of the Greater Southern Sydney Region. This region covers the Southern Blue Mountains to the Illawarra coast, including south-western Sydney and Royal NP. The project aimed to comprehensively survey the region's drinking water catchments for terrestrial vertebrate fauna and provide a regional conservation assessment and habitat maps for species of conservation concern. This extensive fauna survey and research project was jointly undertaken with the SCA in the Warragamba, Metropolitan, Woronora, O'Hares Creek, Blackheath, Katoomba and Woodford Special Areas. It also integrates the results of other biodiversity surveys undertaken by DECC and other organisations and individuals across the region.

Upland swamps support a wide variety of fauna, many of which are unique to the swamps. Threatened fauna species known to occur in the region's upland swamps include the:

- Giant Burrowing Frog *(Heleioporus australiacus)* – vulnerable;
- Red-crowned Toadlet *(Pseudophryne australis)* – vulnerable, but also known from sandstone habitats;
- Eastern Bristlebird *(Dasyornis brachypterus)* – endangered (possibly locally extinct);
- Littlejohn's Tree Frog *(Litoria littlejohni)* – vulnerable; and
- Turquoise Parrot *(Neophema pulchella)* – vulnerable, but also known from grassy woodlands.

Further tables are provided by DECC in its submission, which list additional protected and/or regionally significant species which DECC considers to be dependent on either swamps, water in streams or pools, or cliffs and rock overhangs

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[16] While the upland swamps of the Woronora Plateau are not listed as an EEC under the NSW *Threatened Species Conservation Act 1995*, DECC has reported in its submission to the Inquiry that they appear to be encompassed by the definition of 'Temperate Highland Peat Swamps on Sandstone' (Commonwealth Department of Environment and Heritage, 2005), an ecological community listed as endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (Keith et al. 2006).
[17] Op cit, Note 4.

Table 11. Threatened Flora Species Recorded in DECC and SCA Estate in the Southern Coalfield

Sensitive flora species	Listings			Habitat		
	TSC Act	*EPBC Act*	ROTAP status	upland swamps	creeks and rivers	cliffs, rock benches or overhangs
Acacia baueri subsp. aspera	V	-	2RC-	no	no	yes
Blandfordia cunninghamii	-	-	3RCi	yes	no	yes
Burnettia cuneata	-	-	3RC-	yes	no	no
Darwinia grandiflora	-	-	2RCi	yes	no	no
Epacris coriacea	-	-	3RC-	no	no	yes
Epacris purpurascens var. purpurascens	V	-	2KC-	yes	yes	no
Eucalyptus luehmanniana	-	-	2RCa	no	no	yes
Gonocarpus salsoloides	-	-	3RCa	yes	no	no
Grevillea longifolia	-	-	2RC-	no	yes	yes
Grevillea parviflora subsp. parviflora	V	V	-	yes	no	no
Hibbertia hermanniifolia	-	-	3RCa	no	no	yes
Hibbertia nitida	-	-	2RC-	no	yes	no
Leucopogon exalasius	V	V	2VC-	no	yes	no
Lissanthe sapida	-	-	3RCa	no	no	yes
Lomandra fluviatilis	-	-	3RCa	no	yes	No
Lysimachia vulgaris var. davurica	E	-	-	yes	yes	No
Melaleuca deanei	V	V	3RC-	yes	no	No
Monotoca ledifolia	-	-	3RCa	no	yes	Yes
Pomaderris brunnea	V	V	2VC-	no	yes	No
Pultenaea aristata	V	V	2V	yes	no	No

Notes: Source: DECC
ROTAP status: ROTAP is the database of Rare or Threatened Australian Plants developed by Briggs and Leigh for the CSIRO in 1995. ROTAP status is a coding which quickly lists plant distribution, conservation status and reservation status.
V = vulnerable; E = endangered; R = rare; C = occurs within a conservation reserve; a = adequately reserved (>1000 specimens); i = inadequately reserved (<1000 specimens); 2 = occurs over <100km; 3 = occurs over >100km.

Table 12. Threatened Fauna of the Greater Southern Sydney Region

Sensitive fauna species	**Listings**		**Habitat**			**Conservation priority (assigned by DECC, in press)**
	TSC Act	***EPBC Act***	**upland swamps**	**creeks and rivers**	**cliffs, rock benches or overhangs**	
Beautiful Firetail	-	-	Yes	No	No	Moderately High
Black Bittern	V	-	No	Yes	No	High
Broad-headed Snake	E	V	No	No	Yes	High
*Brush-tailed Rock Wallaby**	E	V	No	No	Yes	Highest
Eastern Bentwing-bat	V	-	No	No	Yes	Low**
*Eastern Bristlebird**	E	E	Yes	No	No	Highest
Eastern Pygmy Possum	V	-	Yes	No	No	Moderate
Giant Burrowing Frog	V	V	Yes	Yes	No	Moderate
*Green and Golden Bell Frog**	E	V	No	Yes	No	Highest
*Ground Parrot**	V	-	Yes	No	No	Highest
Large-eared Pied Bat	V	V	No	No	Yes	High
Large-footed Myotis	V	-	No	Yes	No	High
Littlejohn's Tree Frog	V	V	Yes	Yes	No	High
*Long-nosed Potoroo **	V	V	Yes	No	No	Highest
Platypus	-	-	No	Yes	No	Low***
Red-crowned Toadlet	V	-	Yes	Yes	Yes	Moderate
Rosenberg's Goanna	V	-	Yes	No	No	Moderate
Southern Emu Wren	-	-	Yes	No	No	Moderate
Spotted-tailed Quoll	V	V	No	No	Yes	High
Stuttering Frog	V	V	No	Yes	No	Highest
Tawny-crowned Honeyeater	-	-	Yes	No	No	Moderate
Turquoise Parrot	V	-	Yes	No	No	Moderately High

Notes: Source: Terrestrial Vertebrate Fauna of the Greater Southern Sydney Region (DECC, 2005)
** Species may be locally extinct (K. Madden, pers comm).*
*** Maternity sites in caves and disused mines are a very high conservation priority.*
**** Species has a low conservation priority but is of high interest to the community.*

Cliffs and overhangs provide shelter and nesting sites for a number of species. In particular, snakes and geckos commonly shelter under rocks while overhangs may contain the nests of insectivorous bats, brown antechinus and rockwarblers. The superb lyrebird is known to nest on elevated sandstone ledges. Six threatened fauna species commonly use cliffs and overhangs (see Table 13).

Table 13. Threatened, Protected and Regionally Significant Fauna Commonly Using Cliffs and Rock Overhangs

Scientific name	Common name	Conservation status
Oedura lesueurii	Lesueur's Velvet Gecko	Protected
Phyllurus platurus	Broad-tailed Gecko	Regionally significant
Diplodactylus vittatus	Eastern Stone Gecko	Regionally significant
Underwoodisaurus milii	Thick-tailed Gecko	Regionally significant
Ctenotus taeniolatus	Copper-tailed Skink	Protected
Egernia whitii	White's Rock Skink	Protected
Egernia cunninghami	Cunningham's Spiny-tailed Skink	Regionally significant
Egernia saxatilis	Black Crevice-Skink	Regionally significant
Holocephalus bungaroides	Broad-headed Snake	Threatened (E)
Demansia psammophis	Yellow-faced Whip Snake	Protected
Drysdalia rhodogaster	Mustard-bellied Snake	Regionally significant
Rhinoplocephalus nigrescens	Small-eyed Snake	Protected
Origma solitaria	Rockwarbler	Regionally significant
Menura novaehollandiae	Superb Lyrebird	Protected
Tyto tenebricosa	Sooty Owl	Threatened (V)
Tyto novaehollandiae	Masked Owl	Threatened (V)
Antechinus stuartii	Brown Antechinus	Protected
Chalinolobus dwyeri	Large-eared Pied Bat	Threatened (V)
Miniopterus schreibersii	Eastern Bent-wing Bat	Threatened (V)
Rhinolophus megaphyllus	Eastern Horseshoe-bat	Protected

Source: DECC

A further 7 fauna species that are protected or are regionally significant may be affected if swamps are impacted by longwall coal mining (see Table 14 below).

Table 14. Protected and Regionally Significant Fauna Species Commonly Using Swamps

Scientific name	Common name	Conservation status
Paracinia haswelli	Haswell's Froglet	Protected
Litoria freycineti	Freycinet's Frog	Regionally significant
Litoria jervisiensis	Jervis Bay Tree Frog	Regionally significant
Acritoscincus platynota	Red-throated Cool-skink	Protected
Cyclodomorphus michaeli	She-oak Skink	Protected
Gallinago hardwickii	Latham's Snipe	Protected
Coturnix ypsilophora	Brown Quail	Protected
Calamanthus pyrrhopygius	Chestnut-rumped Heathwren	Regionally significant
Stipiturus malachurus	Southern Emu-wren	Regionally significant
Gliciphila melanops	Tawny-crowned Honeyeater	Regionally significant
Stagonopleura bella	Beautiful Firetail	Regionally significant
Centropus phasianinus	Pheasant Coucal	Regionally significant
Antechinus swainsonii	Dusky Antechinus	Regionally significant
Sminthopsis murina	Common Dunnart	Regionally significant
Rattus lutreolus	Swamp Rat	Regionally significant

Table 15 below lists seven threatened terrestrial fauna species and one protected and regionally significant terrestrial fauna species that DECC considers as dependent on flow in streams.

Table 15. Protected and Regionally Significant Terrestrial Fauna Dependent on Water in Streams and Pools

Scientific name	Common name	Conservation status
Litoria citropa	Blue Mountains Tree Frog	Protected
Litoria lesueuri / wilcoxii	Lesueur's Frogs	Protected
Litoria phyllochroa	Green Stream Frog	Protected
Chelodina longicollis	Eastern Snake-necked Turtle	Protected
Ornithorhynchus anatinus	Platypus	Regionally significant
Hydromys chrysogaster	Water Rat	Regionally significant
Myotis adversus	Large-footed Myotis	Threatened (V)

D1.3 AQUATIC FLORA AND FAUNA

Various submissions and consultants reports are available that provide site specific information on the occurrence of large aquatic plants, macroinvertebrates and fishes within particular watercourses across the Southern Coalfield region. The general situation across the region was summarised in one submission as:

> *'In the Southern Coalfield there is a broad range in the extent of habitats and ecological attributes present, indicating that the nature and extent of impacts may vary greatly depending upon the location of mining. For example, larger watercourses in lowland areas (eg Nepean River near Wilton) may be relatively broad, deep and have gentle gradient. This in turn, can favour sedimentation and the growth of large macrophyte beds (ie water plants such as Valissneria). In some of the more elevated catchments, watercourses are often dominated by bedrock, with very limited growth of macrophytes (eg catchments above Cordeaux Dam). Sedimentary processes can be greatly affected by local runoff and the presence of impoundments.*
>
> *Aquatic invertebrates include several species of freshwater crayfish and a diverse range of smaller taxa, including freshwater shrimp, molluscs, worms and numerous aquatic insects. The geographical ranges of two species of dragonflies that are scheduled as threatened extend into the Southern Coalfield, but these are very rarely collected in the area. There are about a dozen species of native freshwater fish and four to six alien species of fish that occur in the area. One of these, the Macquarie Perch (Macquaria australasica) is listed as a threatened species. Macquarie Perch are considered sensitive to disturbance due to their breeding requirements. This species is increasingly observed in the area, mainly due to increased monitoring being done in relation to coal mining and water supply issues.'*[18]

There is an obvious and urgent need to provide a more comprehensive assessment of existing data sets on the aquatic diversity in this region and to collect targeted information that would be useful for a regional assessment of aquatic diversity and an identification of sites of regional significance.

[18] NSW Minerals Council (2007); *Mining and the Natural and Cultural Environment in the Southern Coalfield – Submission to the Independent Expert Panel Inquiry into Southern Coalfield*, p 10, prepared by Biosis Research; July 2007.

D1.3.1 Aquatic Habitats

Many submissions to the Inquiry used the general term of 'aquatic habitats' when describing significant natural areas or areas that had been impacted by mining activities. In general, the geomorphology of particular locations has a strong influence on the waterway characteristics and hence the availability and structural characteristics of habitats for aquatic fauna and flora. Thus the nature of 'aquatic habitats' varies greatly across the Southern Coalfields, from large riverine waterways to small streams and waterlogged upland swamps. Some of the features that may be included as 'aquatic habitats', such as the various swamp communities, are well documented and mapped for most of the region, but there is less information available for distribution and abundance of submerged communities (eg aquatic plants, macroinvertebrates and fishes). Species commonly associated with the upland swamps have been considered in more detail under Section 2.1.5.

D1.3.2 Aquatic Plants

The definition of what constitutes an aquatic plant is not clear and there is obviously overlap in describing plants whose habitat is in various 'wetland' environments (eg swamps) as against riparian communities and plants which actually live in water. For example, riparian areas are often defined as 'lands adjacent to waterways, necessary to protect the health of that waterway', whereas aquatic plants could be considered to be species occupying a pool of water, either completely submerged (eg *Vallisneria spp*.) or emergent (eg *Juncus spp*.). Obviously many of the swamp areas also contain standing waters. Depending on depth and flow, the same species may come under several general definitions. Overall, aquatic plants are poorly studied in Australia and often lack detailed taxonomic information.

Large-scale mapping of major aquatic macrophyte beds (eg *Vallisneria* beds in the lower Hawkesbury-Nepean system) has been undertaken by DPI-Fisheries, however little, if any, information is available on the general distribution of aquatic plants across the smaller creeks and streams of the Southern Coalfield. There is also a lack of taxonomic and biological information for key aquatic plant species. This can be easily demonstrated by considering the situation with regard to one of the key species in the region, *Vallisneria* (ie ribbonweed or river grass). *Vallisneria* often forms large meadows of dense plants, with characteristic grass-like leaves. These meadows are important as habitats for a diverse range of fauna, including many fish species, but the taxonomy of *Vallisneria* is poorly understood and it is unclear how many species actually occur in the region.

Information available to the Panel regarding the aquatic plants in the Southern Coalfield region as a whole was generally poor and mainly derived from various consultant's' reports. While such reports are often quite adequate for ongoing localised impact assessment and environmental monitoring programs, they usually contain very general information and lack precise taxonomic identifications required for useful biodiversity assessments.

The following example from a recent report demonstrates this situation with respect to the aquatic flora in the Dendrobium Coal Mine's Area 1, in that the exact species remain unknown as they are only generically described:

> *'Thirteen aquatic macrophytes were recorded at the 18 sites (Table 2). Of these, 9 taxa were found in Kembla Creek, all 13 were in Goondarrin Creek and 9 taxa were in Kentish Creek. The majority of macrophytes (10 taxa) had emergent growth, growing along the creek banks, but were mostly absent from the wetted area of the creeks. Six of these taxa - Specimen X/Z, Isolepis sp., Carex sp. (Tussock Sedge), Juncus sp., Ranunculus sp. (Buttercup) and Lomandra longifolia - were recorded in all three creeks. The remaining three taxa were defined as either floating attached or submerged growth forms. Only one of these, the Common Starwort (Callitriche stagnalis), was found in Kembla Creek. The Common Starwort has a growth form defined as floating attached and was also recorded in Goondarrin Creek and Kentish Creek (Table 2). Overall, slightly fewer taxa were found in the current survey than in the Autumn Baseline Surveys 7 and 8 (14 taxa*

found), however general distribution of emergent, floating attached and submerged macrophytes was similar in all three creeks.' [19]

More detailed information would be required across the whole of the Southern Coalfield area if any regional assessment of significant areas of aquatic plants was to be made.

D1.3.3 Aquatic Macroinvertebrates

Aquatic macroinvertebrates have received a great deal of attention in recent years as they have been adopted as a means of assessing the health of Australian rivers and streams (eg see http://ausrivas.canberra.edu.au/). The AUSRIVAS methodology has been adopted in many monitoring programs that deal with fresh water watercourses, including many within the Southern Coalfield. For example, recent assessments of the Bargo River used the AUSRIVAS methodology described as follows:

> *'Animals were collected using techniques described in the AUSRIVAS Rapid Assessment Method developed by the NSW EPA (Turak et al. 2004). The method involves collection of samples from two habitats and with two sampling techniques: slow flowing river edges (dip-net technique) and fast flowing riffles (kick-net technique). Macroinvertebrates were live picked from the samples while in the field. Results were analysed using the AUSRIVAS software package, which contains predictive models that assess the ecological health of a site by comparing its macroinvertebrate community with those of similar 'reference' sites within the model. Reference sites are selected from rivers of similar physical characteristics to the study site, but without any known human impacts. The macroinvertebrates recorded for these sites are considered to be a list of what would be expected to occur at a study site if it is in a 'reference' or undisturbed condition.'* [20]

The AUSRIVAS methodology is one of the more commonly adopted standard methods for assessing river health and is based on measurement of expected families and genera of maco-invertbrates in both impacted and control sites. However, it places sites into very broad bands of 'health' and the usefulness of this method in assessing environmental impacts has not been well investigated. For example, it failed to detect impacts at Waratah Creek, despite significant losses in flows and habitats:

> *'The reduction and modification of habitats in Waratah Rivulet are likely to have resulted in localised changes to the macroinvertebrate assemblage. However, the results of AUSRIVAS band classifications for autumn 2007 are consistent with historical AUSRIVAS band classifications recorded at similar locations within the Waratah Rivulet and within reference creeks not impacted by subsidence.'*[21]

Also, the AUSRIVAS methodology is limited in its applicability and cannot be used in many areas in the Southern Coalfield, due to the small intermittent nature of the watercourses, and/or the lack of suitable sampling sites. Another disadvantage of the AUSRIVAS methodology is that it does not provide detailed taxonomic information, as explained in this passage from a submission to the Panel:

> *'Macroinvertebrates were identified in accordance with the NSW AUSRIVAS Sampling and Processing Manual (Turak et al, 2004), which takes most identifications to taxonomic family level. Exceptions to this were as follows: nematodes and nemerteans (threadworms) were identified to phylum, oligochaetes and polychaetes (freshwater worms) were identified to class, ostracods (pea shrimps) to subclass, Acarina (water mites) to order and Chironomids (midge larvae) to sub family.'* [22]

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[19] The Ecology Lab (2007); *Dendrobium Coal Mine Area 1 Aquatic Ecology Monitoring Program, Progress Report 4 Final*; August 2007.
[20] Biosis Research (2007); *Aquatic Ecology Assessment of the Bargo River Downstream of Mermaids Pool, Tahmoor*; March 2007.
[21] Helensburgh Coal Pty Ltd (2007); *Submission to Independent Expert Panel Inquiry into Southern Coalfield*, p 22; July 2007.
[22] Op cit; Note 7, Page 11.

Despite its shortcomings, the AUSRIVAS method of stream assessment remains one of the most appropriate tools for assessment of impacts at this stage. However, it is clear that it should only be used in combination with other biological assessments.

There are very few studies of the waterways in the Southern Coalfield that have identified macroinvertebrates to a taxonomic level that would be useful for an assessment of biodiversity. One of the iconic macroinvertebrates in the Southern Coalfield region is the crayfish, the main species being *Euastacus spinifer* although, even for this group, there is some doubt about the number of species present and the genetic diversity of across the area:

> *'Baker et al (2004) investigated the genetic diversity of macroinvertebrates in the Metropolitan and Woronora Special Areas. They found several taxa to be particularly associated with unregulated headwater streams with conservation efforts needing to focus on preserving the rich diversity of fauna in these areas. In particular, they found high genetic diversity in the spiny crayfish (Euastacus spp.), with mitochondrial data suggesting very limited gene flow within and among subcatchments for all species of Euastacus occurring in Sydney's drinking water catchments.'*[23]

Freshwater crayfish are not currently listed as a threatened species in NSW, but many species are listed on threatened species schedules throughout Australia, and the group as a whole is vulnerable to impacts such as changes in water flows and water quality. There are a number of recent genetic studies that have demonstrated that freshwater crayfish throughout eastern Australia have very limited dispersal of eggs and juveniles across watercourses, leading to genetic differences between populations within the same catchments.

Several dragonfly species are also often considered within the surveys for aquatic macroinvertebrates, as they can spend extended periods as larvae in aquatic habitats. There are currently two species of dragonfly listed as threatened species within NSW that may occur within the Southern Coalfield region, namely the Sydney Hawk Dragonfly (*Austrocordulia leonardi*), which is listed under the *Fisheries Management Act 1994* as endangered, and the Adams Emerald Dragonfly (*Archaeophya adamsi*), which is listed under that Act as vulnerable. Both species are quite rare and, to date, neither has been reported in the current monitoring programs in the region.

D1.3.4 Fish

While there are about a dozen species of native freshwater fish and several introduced (or alien) species of fish in the general Southern Coalfield region, the distribution and abundance of fishes, like the other aquatic flora and fauna, are poorly documented. Numbers of fish species and abundances at particular sites depend on a wide range of local environmental factors, as well as the connectedness between habitats that support the life history stages of particular species. The large rivers have the majority of the fish species and generally the larger sized species. However, small streams are also often important habitats for smaller sized species (eg Australian Smelt (*Retropinna semoni*) and Mountain Galaxias (*Galaxias olidus*)) which can have limited ranges within particular sub-catchments.

Most fish species have very particular life history requirements in terms of habitats, water flows and other environmental cues. Particular habitats, such as gravel beds, meadows of aquatic plants and deep pools are often critical as spawning sites, egg-laying habitats and/or feeding areas. In addition, several of the species in this region are considered to be diadromous, in that they migrate significant distances along rivers, streams and watercourses, often to complete part of their life cycle, such as spawning and reproduction. Consequently, integrity and connectivity between such habitats are critical to the survival of populations within sub-catchments.

In summary, the bulk of available information on the distribution of fishes in the Southern Coalfield region, particularly for the smaller watercourses, comes from consultant reports. Again these data are not suited for a regional assessment of the significance of the sites and habitats.

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[23] DECC (2007), *Submission on the Strategic Review of the Impacts of Underground Mining in the Southern Coalfield, Attachment 1 - DECC Scientific Services Report – Ecological Impacts of Longwall Mining in the Southern Coalfield of NSW – A Review*; p 9.

D1.3.5 Significance of Aquatic Flora and Fauna

Currently there is very limited information available that would be useful in an assessment of the regional significance of any particular local occurrence of aquatic habitat or aquatic flora or fauna. The type of information that could be used to make such a regional assessment is similar to those developed for assessment of other biological resources, such as during the regional forest resource assessments (eg *Criteria and Indicators in the Eden RFA region*, report undertaken for the NSW CRA/RFA Steering Committee, April 1998).

Examples of indicators that could be used in assessing the regional significance at particular locations might include: the extent of (aquatic) vegetation type and integrity; the extent of connectivity within the catchment, particularly in relation to threatened species habitat, retained habitat and conservation reserves; the management measures in place to maintain species and abundance; lists of representative species by extent and abundance (representative protected areas to include threatened species, key functional groups and indicator species); and lists of biological factors influencing health and vitality.

Unfortunately little if any of these data are currently available for the aquatic communities in the Southern Coalfield region. In summary:

- there has been no independent regional assessment of aquatic biodiversity in the Southern Coalfield which could form the basis of a consideration of sites of regional significance;
- existing information suggests that there are several aquatic plant species, about a dozen species of native fish, several species of large freshwater crayfish and hundreds of other aquatic invertebrates in the region's waterways;
- the area of the Southern Coalfield includes the geographic range of at least one threatened fish species and two threatened dragonfly species;
- the genetics, life history and ecology of even the iconic species, such as the aquatic plants, the fishes and the crayfishes, are poorly, if at all, studied;
- non-mining impacts on water flows, water quality, system-connectivity and through the introduction of non-native species of both plants and animals, are critical factors affecting the sustainability of aquatic organisms throughout the Southern Coalfield, particularly in the lower catchments; and
- the network of watercourses in the region are habitat corridors for aquatic flora and fauna. As a result, local impacts can resonate through entire catchments and threaten populations, species and communities with local and more widespread extinctions.
