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OUTCOMES OF THE INDEPENDENT INQUIRY INTO IMPACTS OF UNDERGROUND COAL MINING ON NATURAL FEATURES IN THE SOUTHERN COALFIELD – AN OVERVIEW

Bruce Hebblewhite[1]

ABSTRACT: An independent panel of experts was appointed in December 2006, jointly by the NSW Minister for Planning and the Minister for Primary Industries & Energy to review the current status and future implications for underground coal mining in the Southern Coalfield of NSW, with respect to its impact on natural features, particularly emphasizing risks to water flows, water quality and ecosystems; and to provide advice on best practice in regard to assessment of subsidence impacts; avoiding or minimizing adverse impacts; and management, monitoring and remediation of subsidence and subsidence-related impacts. The Panel received extensive submissions and presentations in September, 2007 before developing its findings which were reported to the Ministers and released in June 2008. A summary of the process followed by the Panel, and a discussion of the outcomes and recommendations from the Independent Inquiry, and their relevance and application across the underground coal industry in the Southern Coalfield are presented.

INTRODUCTION

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.[2] 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)).

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*
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*

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[2] *Tower Colliery is now known as 'Appin West Coal Mine'. Appin West also includes the Douglas mining area.*

   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 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 did not consider that its terms of reference extended to advising on the 'acceptability' of particular subsidence impacts. The Panel was not assigned 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 & 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 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.

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).

PROCESS

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.

The Panel, through the Department of Planning, then 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 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.

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

During the period of the public hearings (and subsequently), the Panel made a number of very informative field inspections covering areas of Waratah Rivulet, various smaller creeks and swamp locations, plus sections of the Cataract, Nepean, Georges and Bargo Rivers. The Panel was accompanied by representatives of both the mining industry and local community groups on each of these inspections.

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.

KEY FINDINGS

This paper does not attempt to address all the elements considered by the Panel. Rather, it is focused on a selection of the key findings directly related to subsidence behaviour and related prediction capabilities and future needs. The full report of the Panel is available from the Department of Planning website at www.planning.gov.nsw.au. The Appendix to this paper contains a direct extract from the Panel Report, containing the 22 Recommendations of the Panel Report.

Terminology

Within the Panel Inquiry submissions and presentations, there were a number of often contradictory, inconsistent or ambiguous uses of subsidence terminology encountered. The Panel felt the need to clarify this terminology and has attempted to provide a future standard for adoption by all parties. Particular terms of interest were: subsidence *effects*, *impacts* and *consequences*; together with the concepts of *conventional* and *non-conventional* subsidence behaviour.

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* are 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 *conventional* or general model of surface subsidence, which finds worldwide acceptance, is based on assuming the following generalised 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.

Where these conditions are not met, surface subsidence effects vary from those that would be predicted using the conventional model. Such subsidence behaviour and resultant effects are generally known as '*non-conventional'*. The following are the more common site specific variations to the conventional model of surface subsidence behaviour:

- massive overburden strata units
- pillar foundation (floor) settlement
- steep topography
- valleys and gorges (incl. steep slopes)
- regional far-field horizontal movement
- large scale geological features (dykes, faults etc)

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.

Non-Conventional Subsidence

Valley Closure

The mechanism(s) involved when the surface topography contains valleys, gorges or significant slope changes is one which is not fully understood, although there are a number of clearly significant contributing factors. The first of these relates to the role of a dominant pre-mining horizontal stress field. 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. 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.

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. (This second behaviour is a direct and logical consequence of the first, in that if valley sides close, then at the base of the valley, the valley floor must be compressed, leading to buckling; which then gives rise to uplift).

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. 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.

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 200m past it. Closure was effectively completed by the time that the face was 500m 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 influence 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 direction of horizontal displacements associated with valley closures are understood to be associated with a combination of valley orientation (i.e. movement towards the valley centre); horizontal stress orientation; and also movement towards the direction of the triggering mining goaf region. These three directional factors can all play a part in both the mechanism and the direction of horizontal displacement and valley closure.

Upsidence

As indicated above, valley floor buckling then leads to uplift in the floor region. This introduces the concept of upsidence. 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. 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. It is in this sense that the term is used in relation to the Southern Coalfield Panel Report.

Upsidence is therefore defined as 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 nett 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.

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 1). In general, the extent and intensity of the fracture network increases with upsidence which, in turn, increases with subsidence. Figure 2 typifies the buckling, bed separation, extensive vertical fracturing and 'popping up' of slabs of rock observed by the Panel in Waratah Rivulet.

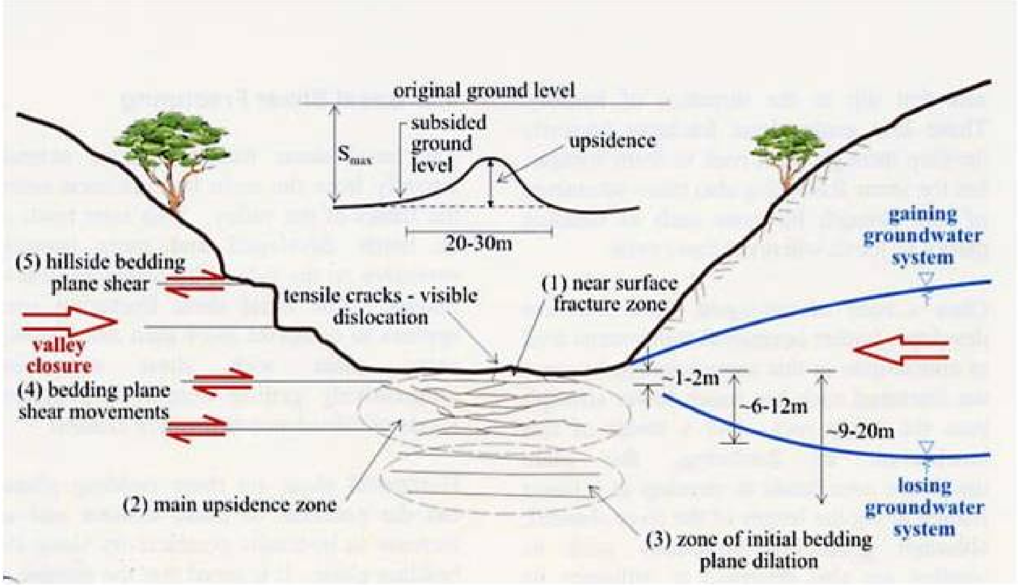

Figure1 - Upsidence fracture network determined from surface and subsurface monitoring, Waratah Rivulet at Metropolitan Colliery *(source Mills, 2008)*

Figure 2 - Buckling of near-surface, Waratah Rivulet, late 2004

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 (including locations where the valley centres are not directly above the mining goaf);
- 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 gently sloping 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 conceptual 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.

Regional Far-Field Horizontal Displacements

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 kilometers 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 1.5 km from the workings. Most of the horizontal movement takes place toward the gorges and active mining areas, although some has been recorded towards old goaf areas.

This behaviour is also 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 to date, 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 protective buffer of 1 km between mining and rivers and significant streams.

Status of Prediction Capabilities (effects and impacts)

In consideration of the non-conventional subsidence effects and impacts discussed above, several points are worth discussing, arising from the review undertaken by the Panel. These include and relate to the following:

- the status of subsidence effects prediction capability;
- the status of subsidence impacts prediction capability;
- caution with the use of upsidence as a prediction parameter.

Prediction of subsidence effects

The Panel found that the status of subsidence effects prediction was well developed with respect to conventional subsidence behaviour, but less so in the case of some of the non-conventional behaviour discussed above. Having said that, there was a clear acknowledgement that there have been very significant gains in this type of prediction capacity over the last 10 to 15 years, particularly as a result of an extensive campaign of subsidence monitoring and related research by the mining industry – both collectively (through ACARP research programs) and by individual mining and consulting companies. This rapidly growing database of monitoring data has particularly encouraged the development of empirical prediction techniques. However, it is important to recognise the need for further development in quantitative prediction capability, which will only occur with parallel development and research into a deeper understanding of the mechanism(s) involved in such forms of non-conventional subsidence.

Prediction of subsidence impacts
The Panel was critical of the current status of subsidence impact prediction capacity. This criticism was not because of a total lack of any such prediction, but because the current prediction in this regard lacked the quantitative rigour that might be expected in relation to particularly sensitive natural features such as particular valley floor rock bars, cliff lines, etc. Whilst current subsidence planning and management documents have again made great strides in this regard over the last decade, they remain more subjective or generic in regard to predicting subsidence impacts on significant natural features. There is of course good reason for this, since it is an extremely complex problem to deal with in any form of predictive model, where the number of variables and the actual variability of particular critical parameters can be extreme. However this should not detract from setting an objective to improve both the prediction capabilities in this regard, and the subsequent documentation of such predictions in any future mine planning submissions.

Caution in use of upsidence
A word of caution is required in the use of "upsidence" as a prediction or control parameter, relating to valley topography scenarios – for two reasons. Firstly, as defined above, upsidence is actually a relative parameter, rather than an absolute one. It relies on the measurement of absolute vertical displacement, but it then relies on the reduction of this figure by subtraction of the expected level of downward "conventional" vertical subsidence at the point in question. This immediately introduces an element of interpretation into the determination of upsidence – either in field monitoring, or in prediction. The second reason to express caution in the use of upsidence (at least in isolation) is that the actual manifestation of this phenomenon can vary enormously over short distances, depending on the individual layers of rock on the surface of the valley floor where it is measured. A far more reliable parameter to work with in relation to valley contributions to non-conventional subsidence is the actual horizontal valley closure. That is not to say that upsidence should be disregarded, but since it is a secondary effect of valley closure, then it should be used in this context, and not in isolation. Data presented to the Panel by the NSW Minerals Council (from MSEC) supported the view that there was a better correlation between actual and predicted behaviour for valley closure, than for valley floor upsidence.

Risk Management Zones

One of the key findings of the Panel was the fact that there was no scientific evidence or argument to support the view that an absolute "one size fits all" protective buffer region should be applied for protection of significant natural features from adverse subsidence impacts from underground mining. A number of community groups argued that a 1 km wide buffer, below which no mining was permitted, should be applied to all rivers in the Southern Coalfield. However the basis for either the 1 km figure, or the universal application of a single measure was not substantiated. For example, simple variations in depth, not to mention mining widths, seam thicknesses, and structural geology features all contribute to some degree of variability in the surface extent of any adverse subsidence impacts.

Furthermore, there was a clear misconception in the minds of some, in relation to the widely reported far-field horizontal displacement effects associated with the monitoring of the Lower Cataract and Nepean Gorges above Tower Colliery. The fact that horizontal displacements occurred at least 1 km away from the edge of mining (a subsidence effect) did not equate to an adverse subsidence impact (of which there was no evidence of any). In fact the greatest distance away from the edge of mining where any adverse impacts had been observed and reported across the Southern Coalfield was less than 400m.

Therefore, the approach taken by the Panel was to define a concept of Risk Management Zones (RMZs) in relation to a specific range and categories of natural features – not to prevent mining within such zones, but to require an increased level of prediction confidence and level of proof of such confidence (through previous case history back-analysis etc). The RMZ definition included an "angle from vertical" component, to recognise the role of depth, as well as a default minimum figure of 400m. It is expected that the definition and application of the RMZ will be the subject of ongoing review as the relevant databases and prediction techniques improve.

KEY RESEARCH RECOMMENDATIONS

The Southern Coalfield Panel Report made a number of recommendations for future research, including the following ones specifically relating to mine subsidence behaviour; prediction techniques; monitoring and remediation:

- 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.
- 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.
- 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.

ACKNOWLEDGEMENTS

This paper has made use of selected sections of the content of the Report prepared by the Southern Coalfield Panel. In so doing, the author acknowledges the significant contribution made by all Panel members to the preparation of the Panel Report, and the findings, conclusions and recommendations contained therein.

In drawing out and discussing some specific findings and issues in this paper, the views expressed (beyond the direct wording of the Panel Report) are solely those of the author of this paper and not necessarily of other Panel members, or the government Departments involved in commissioning the Panel of Inquiry.

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APPENDIX

Recommendations of Southern Coalfield Report

(The following is a direct extract from the published report of the Southern Coalfield Panel of Inquiry)

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 two 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 & 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 & Assessment Act 1979* or for approval of a Subsidence Management Plan.