THE CHALLENGE TO IMPROVE THE PREDICTION OF SUBSIDENCE IMPACTS

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ABSTRACT: Over the last twenty-five years, due largely to direct monitoring and industry funded research the understanding of mining induced subsidence has been greatly enhanced. A high level of correlation between predicted subsidence and actual ground movement has been achieved, especially where the terrain is fairly uniform. The more critical component is determining the nature of impacts specific levels of subsidence will have on surface features, both natural (cliffs, gorges and rivers) and man made structures (roads, pipelines, houses and commercial buildings). With proposed changes to the approval mechanism for longwall mining operations there will be a greater need to improve the accuracy of subsidence predictions and estimating the resulting impacts upon all surface features. This will require further fine-tuning of the mechanisms used to measure and predict subsidence.

INTRODUCTION

Subsidence and resulting impacts are a direct consequence of mining. Changes in longwall equipment and improved ground stability management techniques have allowed longwall block to become longer and wider. This has resulted in changes to the nature of subsidence related impacts. Along with the variations in longwall layouts the prediction of subsidence parameters is now expected to achieve a higher level of accuracy than was the case in the past.

To some extent improvements in subsidence prediction has been driven by a wide range of subsidence monitoring requirements imposed via the current approval process under section 138 of the Coal Mines Regulation Act 1982 (CMRA) (NSW Govt 1982) and the need for subsidence predictions as part of any environmental impact statement for an underground coal mine. There is generally a growing requirement for the wider community to have an understanding of subsidence and how it will impact upon their amenity, residences, public utilities, and natural surface features.

It logically follows that the challenge for all future longwall operations is to be able to predict the levels of subsidence resulting from longwall extraction (primarily its location and magnitude) and the potential impacts of this subsidence upon a wide range of surface features, both natural and man made. The credibility of these predictions are hence linked to the ongoing acceptance by the wider community of these subsidence impacts and the ability of each mining operation to obtain future approvals to either extract pillars and/or use the longwall method of mining.

EXPLAINING SUBSIDENCE

Subsidence predictions have historically been linked with and directly follow from the measurement of surface ground movement as longwall extraction progressed. For this reason they have traditionally had an empirical focus, with the monitoring of results for a wide range of pillar and longwall extraction areas being used to develop indicative subsidence curves. The work of the late Dr Holla has been fundamental in developing both early and current prediction profiles with the various characteristics for each coalfield being taken into consideration. The characteristics of trough subsidence as illustrated by Holla and Barclay (2000) are shown in Figure 1. In more recent times the development of enhanced surveying techniques has provided an improved monitoring and measurement framework to underpin these predictions. Recently the monitoring technique to provide higher accuracy in subsidence prediction has been three-dimensional monitoring so that the full range of movement of a particular point can be plotted over time and in relation to the underlying extraction of coal.

This empirical approach has been responsible for subsidence prediction being viewed more as an art, rather than a science, which resulted in a certain level of suspicion by people outside of the coal mining industry. It follows

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that any reporting on subsidence and subsidence related issues must have regard for the target audience. The level of detail, the style of reporting and documentation used for a mine manager and other industry related people is significantly different from what should be used in an environmental impact statement and different again from that used in a public news letter.

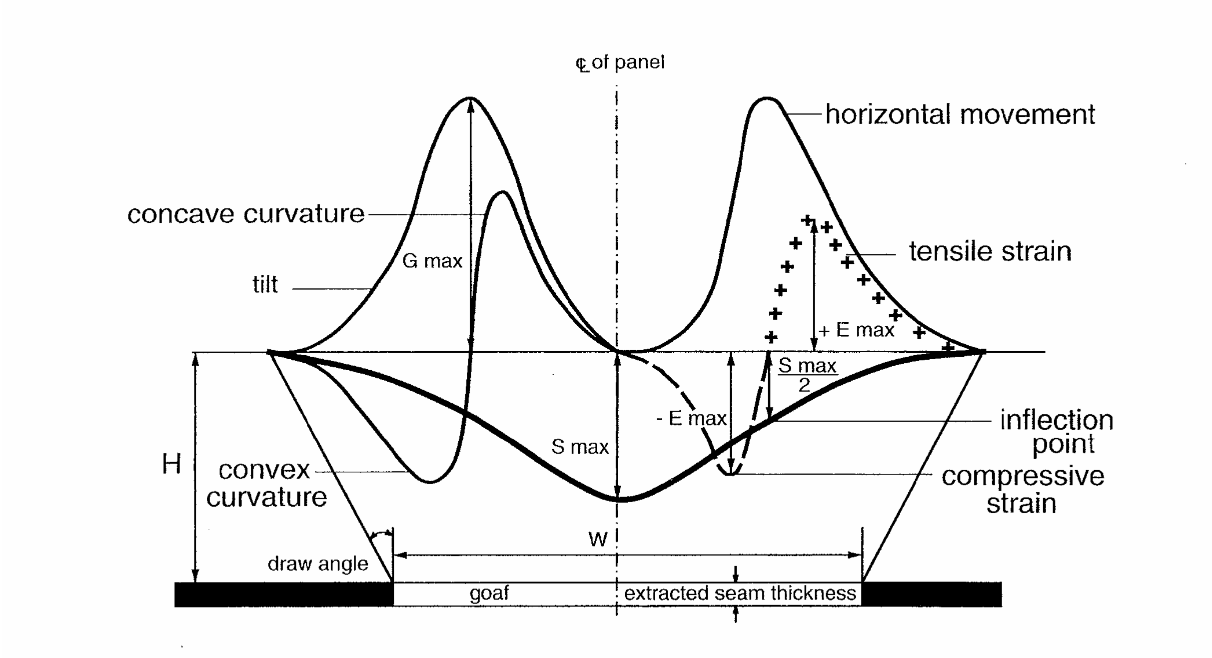

FIG. 1 - Characteristics of trough subsidence (Holla & Barclay, 2000)

Understanding subsidence can be seen as only the first step in a somewhat complicated process of determining subsidence impacts. While predictive models outlining the extent and nature of subsidence can be refined by monitoring, the actual impact of that level of subsidence upon a specific surface feature requires further consideration and understanding by specialists external to the mining and subsidence review process. In this regard a higher level of understanding as to the engineering characteristics and specifications of each surface feature must be understood so that the scale and nature of the impacts can be predicted.

The manner by which the predicted level of subsidence is correlated to specific impacts on a surface feature and the way that this is explained to the general public is potentially just as important as predicting the amount of subsidence. Explaining to home owners that the ground beneath their houses will subside by 800 mm to 1 m, but not to worry as it is within the design limits of the building and in any case the Mine Subsidence Board will rectify any damage, can be very difficult. This also applies to a wide range of infrastructure owners, such as councils, water and sewerage authorities, road, rail and owners of large commercial or industrial buildings. However the real challenge is to develop the same level of skill, expertise and understanding in respect of subsidence impacts on natural features.

Knowing the Surface Features

Current requirements for the granting of a lease (ie. an Environmental Impact Statement (EIS) followed by Development Consent) ensures that at some stage during the life of an underground mine, all the key surface features, land improvements and structures likely to be impacted by mining are identified. For obvious reasons this is considered to be more relevant and highly desirable for longwall extraction, as the direct impacts upon surface features must at some stage be identified as part of the current approval mechanism under Section 138 of the CMRA.

Throughout the life of an underground mine it is not unreasonable for the scale, nature and relative significance of surface features to change. This is true for both man made structures including residential dwellings, public utilities, historical or heritage buildings as well as natural surface features such as cliff lines, streams rivers, swamps, local and or endangered fauna and flora. The rate and degree to which land development for residential, commercial and industrial uses are promoted and undertaken could mean that an entire range of land use issues and or potential constraints can be imposed upon a mining operation some considerable time after the lease was first granted. In respect of natural surface features it is not uncommon for communities and conservation groups to be more vocal as mining progresses towards a particular feature and the potential mining impacts became visible and known. Examples of this include cliff lines in the Lithgow area and rivers in the Appin/Douglas Park area.

The guidelines developed by the Department of Mineral Resources to support any application under section 138 of the CMRA, do detail the range of surface features that need to be identified and considered in respect of the potential subsidence impacts. Following on from this has been the development of specific management programs to mitigate and where necessary remediate the potential impacts of subsidence on surface features. This is more common for man made structures such as buildings, bridges and pipelines, especially where the engineering characteristics are documented and fully understood. It follows that to obtain optimum understanding of what man made features both existing and proposed are likely to effect a particular mine layout, an informed and mutually supportive relationship with the local planning authorities is important. The aim being to solve as many issues during the planning phase as is possible.

In respect of natural surface features the situation is not as well defined and understood. It is exceedingly difficult and virtually impossible to determine how much ground movement a cliff line or rock formation can withstand before it fails. Similarly the ability of a stream to accommodate local changes in permeability and surface cracking associated with strain induced by valley closure is difficult to quantify. While some generic guiding principals can be developed a more detailed understanding can only come about through extensive baseline research, which could be unobtainable on a wider scale. Hence a formal rating system is seen as the only mechanism, which can be used to identify where the baseline research should be undertaken and an acceptance that some features may be damaged. This involves a structured and systematic means of rating a natural surface feature so that the most significant and least significant features are categorised. Following on from this, further work and research can be applied to specific features, which are less significant but may have a local or related significance to other more prominent features. This allows for detailed fine-tuning of a mine plan where extending or reducing a longwall or pillar extraction panel could greatly alter the potential subsidence impact on that particular feature.

This approach has been successfully developed and implemented for cliff line and rock formations in the Western Coalfields. Work by Harvey (1989), Radloff & Mills (2001), and Waddington Kay & Associates (2002), has led to the fine-tuning of mine layouts at a number of collieries. A similar approach could be taken for other natural surface features such as streams.

MATCHING MINE DEVELOPMENT TO PREDICTED SURFACE IMPACTS

The development of a mine has traditionally been dominated or controlled by mining and economic considerations. That is to say key factors such as stress orientation, geological structures, coal quality and ventilation, get prominent consideration in combination with speed of development and a quick return on invested capital. Potential constraints imposed by surface developments, features (both natural and man made) and the possible impacts of subsidence receive little to no consideration, especially for initial mine planning.

The legacy left by earlier decisions and the extraction of coal from specific locations figure largely in the final layout adopted for a mine. The nature of mining means that if a particular layout proves to be less than appropriate the whole process cannot start again with a clean slate. It is not feasible to "put the coal back" and start again. Hence mine development must contend with circumstances as they present themselves, as well as being flexible enough to accommodate as wide a range of options as is possible.

Surface constraints and environmental considerations have been growing in prominence over the last twenty years. This is directly reflected in the range of issues covered in EIS's for new underground mining operations, the conditions attached to the development consent and the overall cost associated with gaining all necessary approvals. A key component in recent development consent conditions is the requirement for community consultation or liaison committees, as well as undertaking specific documentation and reporting requirements. Also included are the Department of Mineral Resources' Mining Operations Plan (MOP) and Annual Environmental Management Report (AEMR) requirements, which focus on each mine managing the environmental and rehabilitation aspects of its mining activities, especially mining related subsidence impacts.

A direct consequence of these trends, especially the heightened focus on EIS and supporting documentation, is that a higher level of accuracy and predicability is required for the preferred mine plan. This in effect determines the overall footprint of any proposed mining operation and hence the surface impacts. There is a need to develop the most suitable mine plan which can then be justified and defended. However if surface impacts associated with mine subsidence are not accurately determined and receive secondary or superficial consideration, the ability to defend a particular preferred option in a Commission of Inquiry and to the community in general is greatly impaired.

To overcome this particular problem, it would appear that the mine planning process must go through a number of separate iterations, resulting in an optimum plan. The focus of these separate planning steps being:

- Mining and geological considerations; including key components such as stress orientation, geological structures, neighbouring mine workings and ventilation;
- Economic considerations; including development/extraction rates, utilisation of existing mine developments and optimising the return on capital;
- Minimisation of subsidence impacts; including dams, pipelines, large buildings, public services, bridges, future developments, cliff lines, rivers, specific flora and fauna communities.

The resulting mine plan is then a compromise of each separate plan and can reflect a structured ranking and assessment process, which can in turn be defended at subsequent reviews or inquires.

It follows that just as certain mining limitations and constraints must be understood, there is an absolute requirement to define all surface features and the predicted subsidence related impacts that may occur for each mine plan options. Base line data and improved subsidence predictions become fundamental components in mine planning and ultimately matching mine development to predicted impacts.

MINE SUBSIDENCE PLANNING

The concept that subsidence is primarily related to second workings and the distinction between 1st and 2nd workings is fundamental to all industry people. The general community however does not have the same level of understanding. Similarly the distinction between assessing any 2nd working proposal in respect of mine safety aspects versus surface impacts is not clearly understood by the wider community. In this regard the current approval process under section 138 of the CMRA has been criticised at a number of levels, by community groups, conservation interests and other government agencies.

Following on from this criticism and a number of reviews of the section 138 approval process, changes have been developed for all underground coal mining operations, which have the potential for surface subsidence. It is proposed for all potential impacts, other than mine safety to be dealt with via an approval under the Mining Act 1992. This will require the preparation of a Subsidence Management Plan (SMP) and its subsequent approval wherever underground coal extraction will result in surface subsidence. Consequently an approval under section 138 of the CMRA will not be granted until an approved SMP is in place.

SUBSIDENCE MANAGEMENT PLANS

Mining which results in surface subsidence impacts must only be undertaken in accordance with an approved SMP. Hence SMP's are required to be prepared and approved prior to the development of first workings associated with secondary extraction either as longwall, mini wall or pillar extraction. Also if first workings have the potential to result in surface subsidence e.g. due to geological conditions such as weak claystone floor, then an SMP must be prepared and approved prior to the first workings being undertaken.
These SMP's must include:

- A full description of the area proposed to be impacted by mining activity, including areas of environmental, heritage or archaeological sensitivity;
- An outline of existing mine workings within the application area, the proposed development plan and a schedule of the proposed extraction for the period to be covered by the SMP;
- Predictions of the expected extent of subsidence for each longwall panel or other sequence of extraction;
- A full assessment of the potential environmental, land use and other impacts associated with the predicted subsidence;
- An assessment of the economic and social benefits and impacts of the proposed mine development;

- Extracts of relevant conditions of any development consent held, relevant conditions of other licences held and relevant policies of other agencies (including the Mine Subsidence Board and the Dams Safety Committee);
- Description of subsidence projections and impact assessment associated with any previous development applications;
- Proposals to minimize impacts of surface subsidence, particularly in areas of environmental, heritage and archaeological sensitivity or important man-made surface features;
- Proposed risk management plans for all areas of environmental, heritage or archaeological sensitivity or important man-made surface features, addressing both the planning and operational phases of mining. In the case of major surface infrastructure, risk management plans are required to be endorsed by the infrastructure owner prior to the operational phases of mining;
- Proposals for ground and surface water management;
- Proposals for any necessary rehabilitation of subsidence impacts;
- Results of consultation with affected landowners, state and local government agencies and the general community and;
- Details of any proposed Community Consultation Process.

An SMP can be approved to cover up to seven years of projected mining operations. When approved the SMP will form part of the Mining Operations Plan required under the mining lease conditions and therefore be subject to the requirement for lodgement and review of an Annual Environmental Management Report. Annual Environmental Management Reports, including the report into the SMP will be provided to all agencies with an identified interest. Details of the method for preparation of SMP's are set out in Appendix A.

THE APPROVAL PROCESS

The SMP will be subject to the approval of the Director General of the Department of Mineral Resources. Draft SMP's and applications should be submitted to the Assistant Director, Environment. The draft SMP's will be assessed by a Departmental SMP Review Committee comprising of the Assistant Director, Environment (chair), Chief Inspector of Coal Mines, the Principal Subsidence Engineer, Manager Policy and Legislative Review and Chief Geologist Coal and Petroleum.

The SMP approval Process will address:

- Development of conditions for the Director General's approval;
- Advice on any additional security deposit needed to reflect possible subsidence related impacts;
- Consultation with and/or participation by other potentially affected agencies (including Department of Land and Water Conservation, Sydney Catchment Authority, National Parks and Wildlife Service and Dams Safety Committee;
- Consideration of the need to consult outside expertise as appropriate, in considering and preparing conditions for subsidence related environmental impacts;
- Review of the results of previous on-site monitoring during and after extraction;
- Requirements for the title holder to obtain an independent audit or assessment where circumstances warrant and;
- Appropriate amendments to existing SMP's and their conditions of approval

A flow chart outlining the process for SMP approval is shown in Figure 2.

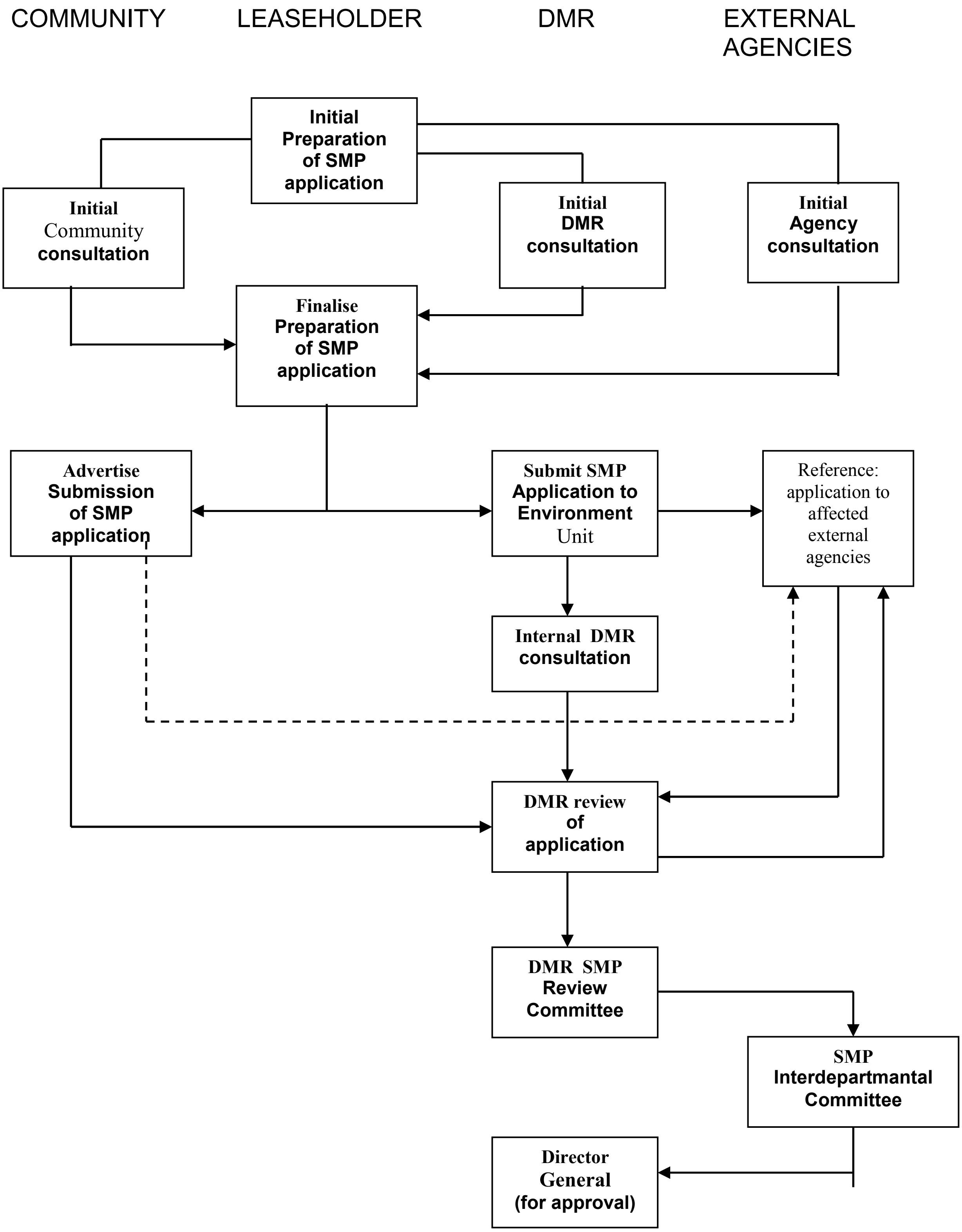

FIG. 2 - Process for Approval of SMP's

CONSULTATION AND PARTICIPATION BY THE COMMUNITY

As indicated previously the desire to involve the local community and potentially affected land owners is a fundamental component of the new approval process. This is also reflected with a number of the recent development consents grant for underground coal mining operations in the State.

During the development of the draft SMP each applicant must:

- Advertise in local and state newspapers their intention to submit an SMP and application for approval for the identified area.
- Identify all land holders and local councils directly effected by their proposals
- Consult with all such land holders and councils
- Take into account the views expressed in responses received

Throughout the process of community consultation, applicants for SMP approvals are encouraged to apply the *"Guidelines for Best Practice Community Consultation in the NSW Mining and Extractive Industries"*, as developed by the NSW Minerals Council. Consultation with landholders is to include discussions on integrating any proposed mitigation works with the management of the property as a whole.

CONCLUSIONS

It is evident that the controls and restrictions on longwall extraction have been extended over the last ten years. This is largely evidenced by the conditions of development consents and the conditions attached to approvals issued under section 138 of the CMRA. With this growing awareness of subsidence has come a greater understanding of predicting the amount of subsidence and more importantly being able to identify the impacts, which subsidence will have on specific surface features. In the case of specific man made features the development of subsidence management plans has enabled coal to be recovered, which previously may have been sterilised. The obvious challenge is to develop the same style of approach and understanding for natural surface features. The requirement to develop SMP's with an enhanced level of community and government agency liaison further supports the need for a total management approach.

Following on from possible limitations and restrictions on the way longwall mining is undertaken, is the need to predict with greater accuracy the level of subsidence resulting from a particular longwall layout. The amount of surface displacement, tensile and compressive strain, tilt and curvature must be predicted to an increasing level of accuracy. It is important to be able to categorically determine the degree of impact a particular amount of subsidence will have on a surface feature. Hence, not only must the measurement and prediction of subsidence be accurate but also the determination of the subsidence impacts must be correct. Failure to meet this challenge has the potential to cause the "right to mine" to be questioned and possibly revoked.

In conjunction with this need for more accurate subsidence prediction is the challenge to make each longwall panel and its related infrastructure more adaptive. Longwalls have traditionally been regarded as large inflexible "monsters" that require considerable planning and mining logistics. This is definitely the case for modern day longwall panels with face lengths of 300 metres or more. To manage the potential subsidence related impacts that arise from such longwalls, the mining operation must be able to provided localised protection to surface features by such means as varying face width, chain pillar sizes and installation and recovery locations. If the flexibility of longwall mining operations cannot be improved the potential resource sterilisation and resulting impacts of mine subsidence could drastically reduce the overall economic advantage the longwall mining method has over other extraction methods.

REFERENCES

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APPENDIX A

SUBSIDENCE MANAGEMENT PLAN REQUIREMENTS

In preparing an SMP and application for approval, the applicant shall:

- Identify properties and update ownership and land use with the area subject to the application;
- Fully describe the physical landforms and environment of the area, including water courses, wetlands, acquifers, water related ecosystems, forests, cliff lines and other sensitive areas, together with areas of potential conservation, heritage or archaeological significance;
- Survey drainage channels within and adjacent to the relevant area and fully describe base line surface and ground water flows and levels and water quality;
- Fully describe the inventory of surface infrastructure and other man made features within or adjacent to the area which is subject to the SMP, including but not limited to:
  - buildings (dwellings, offices, business premises, shed, etc);
  - sealed or gravel roads, access tracks other tracks, etc;
  - dams, bores, tanks, springs, water reticulation systems, etc;
  - on-site waste water systems, swimming pools, tennis courts etc;
  - service infrastructure and utilities (telecommunication lines, transmission lines, water sewage and other pipelines, etc);
- Assess current agricultural utilisation, agricultural improvements and the agricultural suitability of the area;
- Review current utilisation of the land for business purposes (other than agriculture, including the value of improvements and businesses;
- Provide comprehensive subsidence predictions, taking into account the results of any relevant previous subsidence monitoring undertaken and other factors such as topographic variations and geological complexities, with a description of the methodology and assessment of the reliability of the predictions;
- Provide detailed results of pre-mining base line monitoring of environmental values in areas of environmental sensitivity that may be damaged by subsidence (such as ground and surface water flows, water quality and water dependent ecosystems, based on at least a twelve month survey;
- Identify features that will potentially be subject to significant impacts resulting from subsidence and fully describe the expected impacts including:
  - surface water courses and ground water resources (impacts on water quality, river or ground water flows, and areas that will potentially be drained, inundated or affected by cliff falls, etc);
  - lake foreshores and flood prone areas;
  - other significant natural features, particularly cliffs;
  - significant ecological values;
  - major surface infrastructure;
  - other built structures and surface improvements;
  - known proposed surface developments;
  - surface features of community significance;
- Identify dwellings that may be subject to damage beyond safe, serviceable and repairable criteria;
- Identify agriculture or other businesses likely to be adversely affected;
- Identify and quantify the economic and social benefits of the proposed mine development (jobs, continued mine operation, regional economic development, royalties, etc0 such as to provide sufficient information for balanced assessment;
- Investigate feasible mitigation and remediation measures that can be implemented to reduce and or rehabilitate subsidence impacts on significant natural features and ecological values;
- Identify the costs (production forgone, delays, added costs, etc0 associated with various mitigation, remediation or surface feature protection options;
- Investigate other options if subsidence impacts cannot be reduced satisfactorily, such as compensation, acquisition, temporary relocation, or any other form of agreement with landowners and
- Identify all areas of potential compensable loss under the Mining Act 1992 and either reach agreement with landowners in regard to likely compensable loss, or determine suitable mitigation measures to minimise compensable loss