1. Executive Summary

Angus Place and Springvale Collieries extract coal by longwall mining from the Lithgow Seam beneath the Newnes Plateau, which is known to support sensitive surface features. Groundwater Dependent Ecosystems, known as Newnes Plateau Hanging Swamps and Newnes Plateau Shrub Swamps under the NSW Threatened Species Conservation Act 1995 and collectively as ‘Temperate Highland Peat Swamps on Sandstone’ (THPSS) under the Commonwealth Environment Protection and Biodiversity Conservation Act 1999 occur on the Newnes Plateau.

Centennial Coal has been proactive in avoiding or minimising, and if relevant managing, any potential subsidence impacts to the geodiversity and biodiversity of the mining area using a comprehensive multi-disciplinary risk-based approach to mine planning and mine design in conjunction with a rigorous monitoring program. The monitoring techniques employed are wide-ranging and complementary and the combined results provide insights into roles which factors such as geology, hydrogeology, topography play in THPSS formation and the effects of mine subsidence on THPSS. The findings of these investigations have been used to enable a socially and environmentally responsible approach to mine planning and mine design.

2. The Issue

An extensive environmental monitoring program (incorporating subsidence, groundwater, surface water, photographic, vegetation and flora monitoring) was implemented at the mine in 2005.

In 2008 and 2009, monitoring at Angus Place and Springvale Collieries detected impacts attributable to mining-related activities at two THPSSs.

Based on the data gathered from the monitoring program, it was also evident that there were no measurable effects from longwall mining under a number of THPSSs on the Newnes Plateau.

Thus it was clear that mining had caused impacts in some THPSS, but not in others. At the time when the impacts were detected, it was not clear why they had occurred where they had occurred. Without understanding the reasons for the impacts, it was not possible to determine the level of risk of impacts to THPSS in future mining areas.
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It was also not possible to provide stakeholders (including regulators and community groups) with a level of confidence that future mining operations would not cause impacts to the THPSS on the Newnes Plateau.

3. The Solution

Centennial Coal has since then launched an extensive investigative program to determine the factors causing these impacts. In addition, investigations were targeted to determine the hydrogeological characteristics of THPSSs. The purpose of these investigations was to ascertain the coincident characteristics which lead to THPSS formation and hence understand the sensitivity of those characteristics to mine subsidence behaviour.

The investigations relied on the data gathered from the environmental monitoring program implemented in 2005, which included:

- Subsidence monitoring (ground based and LiDAR)
- Groundwater monitoring using piezometers installed in swamps and associated aquifers and multi-level vibrating wire piezometers which extended from the surface to the coal seam
- Surface water flows (including the discharge of mine water)
- Groundwater and surface water quality
- Flora monitoring (ground based and Unmanned Aerial Vehicle (UAV))
- Fauna Monitoring

In addition, specialised investigations were conducted to investigate the behaviour of the overlying strata behaviour in response to mine subsidence including:

- Installation of extensometers to monitor ground movement between the surface and the seam
- Use of microseismic monitoring to assist with defining the height of fracturing
- Coring of numerous exploration holes to enable detailed definition of aquifer and aquitard systems in the overlying strata and their relationship to the THPSS
- Use of geophysical techniques (aeromagnetic and transient electromagnetic) to define major geological structure zones
- Use of geophysical and geotechnical techniques (including Ground Penetrating Radar and Resistivity Surveys) to assist with defining the extent of the cavity which formed in one of the swamps where impacts were detected.
- Case studies of THPSS which have been undermined in the past.

These studies were instigated by Centennial Coal and all associated costs were paid by Centennial Coal.

4. Results and significance

The investigations enabled the preparation of a 3 dimensional model of the topography, geology and hydrogeology of historical and future mining areas and also the predicted heights of fracturing of planned mining activities. Figure 1 is an annotated 3D Block Model showing the relationship of topography, geology and mining activities. This enabled the comparison of historical and future mining areas to allow understanding of the reasons why impacts to THPSS had occurred at certain locations and not at others. It was identified that multiple co-incident factors were required for an impact to occur. Table 1 shows the identified causal factors
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contributing to the risk of impact to THPSS and Centennial Coal management response to mitigate risk of future impacts to THPSS.

Trending of data collected was crucial in understanding the reasons for THPSS formation and also the risk of mining impacts to those THPSS. It also enabled validation of modelling of future mining areas to assess subsidence impacts to groundwater systems. Figure 2 shows the relationship of geology, topography and THPSS in the headwaters of Carne Creek.

Specific outcomes of the investigation process to minimise the risk of subsidence impacts to groundwater systems included:

• Redesign of all future mine workings in the vicinity of THPSS. This included the reduction in longwall mining void width from 315m to 261, and increase of chain pillar width from 43m to 58m.
• Understanding the impacts of mine water discharge to THPSS and commitment to redesign infrastructure to divert any emergency discharges away from THPSS. There have been no discharges of mine water to swamps since 2010.

As a result of the measures implemented, there have been no additional recorded impacts to swamp since 2010.

The outcomes of the investigations conducted and new control measures implemented by Centennial have given stakeholders a level of confidence that future mining activities will not impact THPSS on the Newnes Plateau.

As a direct result, the Federal Department of Environment granted approval for Centennial Coal to conduct longwall mining activities beneath THPSS on the Newnes Plateau in October 2013 and approved the associated THPSS Monitoring and Management Plan.

5. Leading practice

The effects of longwall mining to groundwater systems and related groundwater dependent ecosystems are not generally well understood and their modelling and assessment remains contentious. Centennial Coal has sought to improve the understanding of these effects through extensive targeted direct measurement of parameters such as height of fracturing and aquifer groundwater levels.

Through using the results of the extensive environmental monitoring network and other targeted studies, understanding has been gained of the environmental factors which lead to the formation of THPSS on the Newnes Plateau and also the multiple factors which contribute to mining related impacts to THPSS.

The results of investigations have allowed Centennial Coal to understand the multiple co-incident factors that have led to historical mining-related impacts and implement management practices to ensure mining impacts will be avoided in the future or can be managed appropriately. The findings of these investigations have been used to enable adaptive management resulting in a socially and environmentally responsible approach to mine planning and mine design.
6. Transferability to other organisations and/or industries

Groundwater Dependent Ecosystems (GDEs) are present throughout Australia in areas where underground mining activities are conducted. The monitoring techniques and investigative process which were used by Centennial Coal to determine the causes of mining impacts to THPSS on the Newnes Plateau enabled changes to mine design and mine water management practice to be made which mitigate the risk of future impacts to THPSS. The same monitoring techniques and investigative process could be used by others to assess the risks posed by mining activities to GDEs and mitigate identified risks. Similar investigations could enable similar adaptive management outcomes and a more socially and environmentally responsible approach to mine planning and mine design at other mine sites.

Figure 1 Annotated 3D Block Model showing the relationship of topography, geology and mining activities.
<table>
<thead>
<tr>
<th>Causal Factors</th>
<th>Centennial Coal Management Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mine water discharge</td>
<td>Cease mine water discharge to Newnes Plateau (including proposed underground water storage for future emergency mine water discharges). NB. No Newnes Plateau discharges since April 2010</td>
</tr>
<tr>
<td>Intersection of major geological fault structures</td>
<td>Major geological structure zones identified through detailed topographic, geological and geophysical analysis. The relationship between mine subsidence, geological faulting and groundwater response is well understood from historical monitoring data (based on piezometers, extensometers, subsidence monitoring (terrestrial and LiDAR), exploration borehole data). This understanding is used in the mine planning and design process to ensure that combinations of risk factors do not occur in future mining areas.</td>
</tr>
<tr>
<td>Orientation of longwall panels sub-parallel to major structures</td>
<td>Angle of orientation increased for longwall panels located under swamps in future mining areas e.g increase to 24° for Carne West and 51° for Sunnyside East.</td>
</tr>
<tr>
<td>Steepness and depth valley containing swamps</td>
<td>Surface topography is well understood from Digital Terrain Model. Analysis of topographic and subsidence data identified no measured impacts at slope angles &lt;18 degrees.</td>
</tr>
<tr>
<td>In situ stress direction and magnitude</td>
<td>Horizontal stress orientation mapped through exploration borehole geophysical testing / analysis. Horizontal stress magnitude measured through installation of instrumentation in surface to seam boreholes and in the roof at seam level.</td>
</tr>
<tr>
<td>Critical width longwall panel design</td>
<td>Future longwalls in the vicinity of swamps are based on Subcritical panel design</td>
</tr>
<tr>
<td>Location and orientation of geological structure adjacent to the permanent barrier pillar</td>
<td>Future Mine workings designed to avoid alignment of major geological structure zones sub-parallel with edge of permanent barrier pillar subject to multiple panel subsidence effects</td>
</tr>
<tr>
<td>Subsidence interaction of adjacent Angus Place and Springvale workings</td>
<td>Springvale Mine and Angus Place Colliery future mining areas are not adjacent to each other (separated by over 500 m) thus interaction will be avoided.</td>
</tr>
</tbody>
</table>

Table 1: Causal Factors contributing to the risk of impact to THPSS and Centennial Coal management response to mitigate risk of future impacts to THPSS
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