Potential cumulative impacts of mining on the Outstanding Universal Value of the Greater Blue Mountains Area

Department of Agriculture, Water and the Environment



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Cover photo: Jamison Valley, Greater Blue Mountains World Heritage Area. © Department of Agriculture, Water and the Environment

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Executive summary

This report responds to the 2019 World Heritage Committee (WHC) decision (43 COM 7B.2) that Australia undertake 'an assessment of potential cumulative impacts of all existing and planned mining projects in the vicinity of the [Greater Blue Mountains Area] property'.

The Australian Government commissioned CSIRO, Australia's national science agency, to undertake a cumulative impact assessment of risks from mining near the Greater Blue Mountains Area (GBMA). To do this, CSIRO used a spatial causal network analysis to evaluate how stressors of nearby mines may impact on eight high-level components of the GBMA's Outstanding Universal Value (OUV) chosen to represent the natural values and integrity of the property.

Fifteen existing and planned open-cut and underground coal mines and three sand mines within 20 km of the GBMA were identified as potential threats to its OUV. CSIRO's analysis identified the mining-related stressors that may threaten one or more components of the OUV and rated the risk of each stressor pathway in terms of *likelihood* of occurrence and *consequence* of the impacts (i.e. risk).

The CSIRO analysis identified a potential cumulative impact area (PCIA) of 1984 km² within the 10,438-km² GBMA, distributed across six discrete areas, where cumulative impacts from mining could occur in the absence of protection and management measures. Highly conservative assumptions were made in defining the PCIA which means that the *actual area* of potential cumulative impacts from mining is likely to be considerably smaller. Within the PCIA, the risk of significant impacts to components of the property's OUV is assumed to generally decrease with increasing distance from the mining areas.

The greatest mining-associated risk to the OUV is potentially to the 'water systems' of the GBMA via water table lowering and changes in streamflow, water quality and channel condition. Water systems of the GBMA include streams, riparian areas and many groundwater-dependent ecosystems (GDEs), occupying about 400 km² (c. 20%) of the PCIA.

Collective impacts from multiple stressors are most likely closest to the mining areas, potentially affecting the boundary integrity near the six mines within 1 km of the GBMA.

The Department of Agriculture, Water and the Environment used the independent CSIRO analysis to determine *residual risk* (that risk remaining after legislated protection and management measures have been applied) to the eight high-level components of the OUV. Given the scope of the WHC's request, residual risk was assigned at the scale of the GBMA. However, this does not preclude localised areas of higher risk to components of OUV within the PCIA.

Overall, the residual risk to the OUV of the GBMA was assessed as 'Low' because most potential impacts are currently effectively mitigated by strict environmental conditions imposed on mine operators. Key messages from the residual risk assessment include:

• The residual risk to iconic Gondwanan flora, such as the Wollemi Pine and the Blue Mountains Pine, is rated as 'Very low' due to their likely distance from mining areas.

- The residual risk to Scleromorphic flora is collectively rated as 'Very low'. Their physiological adaptations to harsh environments mean that most of this component's flora can tolerate many mining-related stressors. However, some scleromorphic flora in riparian and wetland habitats that are hydrologically connected to mining areas could be more vulnerable.
- Conservation-significant flora and fauna are considered to be at 'Low' residual risk because they are well protected under existing Australian and New South Wales government legislation which requires mine proponents to determine whether there is potential for significant impacts and provide acceptable avoidance, mitigation and offset options to minimise impacts.
- The residual risk to Geodiversity is 'Very low'. Subsidence and blasting management practices are well established and the impacts from ground movements can be contained close to the mine site by appropriate mine layout and blast control.
- Overall, there is a 'Low' residual risk to Water systems. Most stressors can be managed to avoid and minimise off-site impacts but groundwater drawdown is an inevitable consequence of mining and may have far-field impacts on GDEs. The residual risk to streams, riparian areas and swamp habitats is 'Low' whereas incomplete knowledge of other GDEs and wetlands such as the Thirlmere Lakes system meant that their residual risk from mining could not be determined.
- The Boundary integrity of the GBMA has a 'Low' residual risk of being impacted by subsidence damaging escarpments and cliffs, by clearing or accidental burning of vegetation buffers on mine lease areas that adjoin the GBMA, and incursion of weeds and other invasive species.
- Indigenous custodial relationships within the GBMA, which are important to the integrity of the property, are underpinned by other components of its OUV. Therefore, it is reasonable to assume that mining-related stressors that impact one or more components of OUV may also impact Indigenous cultural connections with the land and custodial relationships. However, consultation with all relevant Indigenous custodians was not sufficient to enable a reliable rating of residual risk to this high-level component of OUV, so it was rated as 'Indeterminate'.

In 2019-20, bushfires burnt 71% of the GBMA with varying severity and changed the landscape context in which other stressor activities are occurring. For example, there is emerging evidence from swamp habitats outside the GBMA of irreversible damage or lowered recovery potential in burnt swamps that have been impacted by mining compared to similar burnt swamps that have not been impacted by mining. Future protection and management measures may need to account for an increasing frequency and severity of fires and to ensure that GBMA habitats are not allowed to degrade, even for short periods.

This desktop risk assessment implies that there is a 'Low' residual risk of impacts on some of the high-level components of the OUV of the GBMA, especially in areas that were recently burnt. Future work building on systematically collected field data from the GBMA is needed to confirm these estimates of residual risk, document poorly known elements of the OUV (e.g. subsurface GDEs) and investigate specific areas within the PCIA near multiple mines to monitor potential cumulative impacts on, for example, water systems and flora.

Limitations of the assessment are acknowledged and further work to address these is described. This assessment and its focus on mining-related impacts should be seen as a first step towards a more comprehensive understanding of cumulative risks to the OUV of the GBMA from other past, present and planned human activities within and near the area in the context of a changing climate.

1 Introduction

1.1 Purpose of this report

This report presents the findings of a desktop assessment of the potential cumulative impacts of existing and planned mining projects in the vicinity of the Greater Blue Mountains Area (GBMA). The GBMA was inscribed on the World Heritage List in 2000 because its value is of such exceptional significance 'as to transcend national boundaries and to be of common importance for present and future generations of all humanity' (UNESCO 2019a) - its Outstanding Universal Value (OUV). Mining is prohibited in national parks under New South Wales (NSW) legislation and there is no mining within the GBMA.

The work reported here was done in response to the request of the World Heritage Committee (WHC) at its 43rd session in 2019 for Australia

"to undertake an assessment of potential cumulative impacts of all existing and planned mining projects in the vicinity of the property through a Strategic Environmental Assessment (SEA) or a similar mechanism" (Decision 43 COM 7B.2, UNESCO 2019b).

The WHC made this request after noting "with concern that several mining projects exist in the vicinity of or adjacent to the property, and that some mining activities have resulted in impacts on the property, as evidenced by the incident at the Clarence Colliery".

To address this concern, the Australian Government Department of Agriculture, Water and the Environment (DAWE) engaged the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to prepare a cumulative impact assessment. DAWE works to protect and strengthen Australia's agriculture, water resources, environment and heritage, and is responsible for delivering the Australian Government's response to the WHC. The CSIRO is Australia's national scientific research agency and has expertise in bioregional assessments and analysis of cumulative impacts.

Details of the analyses undertaken by CSIRO are presented in the Technical Report by Holland et al. (2021). The purpose of the current report is to build on these analyses and extend their results by evaluating the current measures for mitigating potential cumulative impacts of mining on the OUV of the GBMA, and using these to estimate residual risk remaining after implementation of these measures.

The authors sought input from relevant experts throughout the process. CSIRO undertook internal and external peer reviews in accordance with their business requirements. DAWE sought reviews from relevant experts internally and in the NSW Department of Planning, Industry and Environment.

1.2 Scope and objectives

The investigative scope of this assessment is the potential cumulative impacts of existing and planned mines within 20 km (justified in Section 2.4) of the property's boundary on the GBMA's Outstanding Universal Value (OUV).

The assessment focuses on the residual risk of cumulative impacts at the scale of the entire GBMA. Where information is used from environmental impact statements of individual mines, it is primarily for illustrating potential impacts and mitigation measures operating at more local scales that may collectively affect the OUV of the GBMA.

Climate change and human activities such as tourism, agriculture and urbanisation may also contribute to cumulative impacts. Given the specific wording of the WHC's request, the potential impacts of these drivers were not in scope. However, in the spring and summer of 2019-20 (after this assessment had commenced), severe bushfires associated with climatic extremes burnt 71% of the property. As these fires led to a change in its 'Conservation Outlook' rating in the 2020 IUCN Outlook Report to 'Significant Concern', the scope of the assessment was broadened to include discussion of their likely influences (e.g. reduced ecological resilience, modified landscape) on the potential cumulative mining-related impacts on the property's OUV.

The objective of this assessment is to evaluate the present residual risk (i.e. assuming current levels of protection and management) of potential cumulative mining-related impacts on the GBMA's OUV. To achieve this objective, the following eight questions (Qi-Qviii) were addressed:

- i) What are the main components of the GBMA's OUV, and how might these be summarised to efficiently assess potential cumulative mining-related impacts?
- ii) What and where are the existing and planned mining operations in the vicinity of the GBMA that could impact components of its OUV?
- iii) What are the key mining-related stressors, processes and causal pathways (terms defined in Table 3.1) that could impact components of the GBMA's OUV?
- iv) In which areas of the GBMA might these key mining-related stressors individually and cumulatively impact components of the GBMA's OUV?
- v) To what extent and where do these areas of potential impact overlap with the distributions of components of the GBMA's OUV, and with areas burnt in 2019/20?
- vi) Which components of the GBMA's OUV are potentially most at risk of cumulative mining-related impacts, and where?
- vii) What measures (e.g. protection and management) are in place to protect and manage components of the GBMA's OUV from potential cumulative mining-related impacts, and are they likely to be adequate in how and where they are currently applied?
- viii) What is the residual risk to the components of the GBMA's OUV from cumulative impacts of mining?

The assessment does not review the effectiveness of existing protection and management arrangements in delivering environmental outcomes, or evaluate the level of compliance and environmental performance of the mine operations.

1.3 Approach

The approach was a desktop-based risk assessment drawing on scientific literature, existing data and expertise within the CSIRO and relevant government agencies. Although no biophysical modelling was done for this assessment, previous modelling for nearby Bioregional Assessments (Herron et al. 2018a) was used to support some of the inferences.

Details of the approach are given in Chapter 3. Briefly, the main components of the GBMA's OUV were summarised (Qi), and existing and planned mines within 20 km of the property were mapped and assessed for their potential to impact on the OUV components (Qii). After identifying key mining-related stressors and processes, the links along their causal pathways to the OUV components were evaluated for risk (likelihood and consequence) to underpin a causal network (Qiii). The likely maximum spatial extent of each mining-related stressor was mapped (Qiv) and superimposed on maps of the OUV components and the areas burnt during the 2019/2020 bushfires (Qv). Spatial analysis of the causal networks and the maps indicated which components were potentially most at risk of cumulative mining-related impacts and where they were located (Qvi). Protection and management measures were reviewed for each OUV component to identify which ones are applied at specific mines and in the GBMA, and their likely effectiveness was evaluated (Qvii). Integrating and mapping the information from Qi-Qvii enabled assessment of residual risk (Qviii), the main objective.

1.4 Structure of this report

Following this introduction (Chapter 1), the context of the assessment is presented in Chapter 2 which describes the GBMA, the components of its OUV, the existing and planned mines within 20 km of the property, and the main protection and management measures currently in place in the GBMA. Chapter 3 defines technical terms used in this report, briefly reviews relevant literature on cumulative impact assessment, outlines the risk assessment approach and the methods used to address Qiii-Qviii, and lists the assumptions and limitations of the approach.

Key findings and their supporting evidence are presented in Chapter 4 and its appendix, focusing on the components of OUV of the GBMA that are threatened by mining near the property, threats and their likely pathways for each component, current protection and management measures, and what residual risk remains after implementing these measures. Finally, Chapter 5 reiterates the main findings and their implications, broadly reviews protection and management measures and their effectiveness, discusses limitations of the current assessment and suggests future work to address knowledge gaps in our understanding of the potential cumulative mining-related impacts to the OUV of the GBMA.

There is also a list spelling out the initialisms used in this report, and a glossary defining various words and terms. As these words and terms are used in a particular context here, some of the definitions may differ from those used conventionally, in common language or in other reports.

2 The Greater Blue Mountains Area

2.1 Overview of the property

The Greater Blue Mountains Area (GBMA) consists of 1.04 million hectares of sandstone plateaus, escarpments and gorges dominated by temperate eucalypt forest contained within seven national parks and one conservation area (Figure 2-1). It forms part of the Great Australian Dividing Range to the west of the major coastal cities of Sydney, Wollongong and Newcastle, providing large areas of accessible wilderness close to more than five million people.

The GBMA was inscribed on the World Heritage List in 2000 based on natural heritage values meeting World Heritage criteria (ix) and (x) (Box 2-1). The GBMA is noted for its representation of the evolutionary adaptation and diversification of eucalypt ecosystems and associated communities of plants and animals that occurred on the Australian continent after the break-up of Gondwana 180 million years ago. It is especially biodiverse, harbouring some 10% of Australia's vascular flora (including almost 100 eucalypt taxa) and numerous rare or threatened species. These species include endemic and evolutionary relict species such as the Wollemi Pine (*Wollemia nobilis*) and the Blue Mountains Pine (*Pherosphaera fitzgeraldii*) that persist in highly restricted microsites.

The GBMA also meets conditions of integrity, as provided in its statement of integrity (Box 2-2). The combination of its huge area and the extensive legislative mechanisms (e.g. the NSW statutory wilderness designation of 65% of the property) that protect the 'wholeness and intactness' of its natural heritage values are critical to its integrity. Parts of the property adjoin National Parks and conservation reserves that further buffer the biota and ecosystem processes of the area from human activities outside the GBMA. This connectivity with other protected areas also means that the area will continue to provide opportunities for adaptation and range-shifts for its native plant and animal species, allowing essential ecological and evolutionary processes to continue. The area's integrity also depends upon the complexity of its geological structure, geomorphology and water systems which have created the conditions for the evolution of the GBMA's outstanding biodiversity and require the same level of protection.

When it was inscribed as a World Heritage property in 2000, there was insufficient evidence to support a listing based on the area's geodiversity, scenic value and cultural heritage values. However, these three values are now also identified as important components of its integrity. Aboriginal people from six language groups continue to have a custodial relationship with the area through ongoing practices that reflect traditional and contemporary presence.

Box 2-1 The two natural heritage criteria underpinning the inscription of the GBMA on the World Heritage List, as included in the Statement of Outstanding Universal Value

The GBMA was inscribed on the World Heritage list in 2000 based on two criteria:

(ix) be outstanding examples representing significant on-going ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals.

The Greater Blue Mountains include outstanding and representative examples in a relatively small area of the evolution and adaptation of the genus *Eucalyptus* and eucalypt-dominated vegetation on the Australian continent. The site contains a wide and balanced representation of eucalypt habitats including wet and dry sclerophyll forests and mallee heathlands, as well as localised swamps, wetlands and grassland. It is a centre of diversification for the Australian scleromorphic flora, including significant aspects of eucalypt evolution and radiation. Representative examples of the dynamic processes in its eucalypt-dominated ecosystems cover the full range of interactions between eucalypts, understorey, fauna, environment and fire. The site includes primitive species of outstanding significance to the evolution of the Earth's plant life, such as the highly restricted Wollemi Pine (*Wollemia nobilis*) and the Blue Mountains Pine (*Pherosphaera fitzgeraldii*). These are examples of ancient, relict species with Gondwanan affinities that have survived past climatic changes and demonstrate the highly unusual juxtaposition of Gondwanan taxa with the diverse scleromorphic flora.

(x) contain the most important and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of Outstanding Universal Value from the point of view of science or conservation.

The site includes an outstanding diversity of habitats and plant communities that support its globally significant species and ecosystem diversity (152 plant families, 484 genera and c. 1,500 species). A significant proportion of the Australian continent's biodiversity, especially its scleromorphic flora, occurs in the area. Plant families represented by exceptionally high levels of species diversity here include Myrtaceae (150 species), Fabaceae (149 species), and Proteaeceae (77 species). Eucalypts (*Eucalyptus, Angophora* and *Corymbia*, all in the family Myrtaceae) which dominate the Australian continent are well represented by more than 90 species (13% of the global total). The genus *Acacia* (in the family Fabaceae) is represented by 64 species. The site includes primitive and relictual species with Gondwanan affinities (*Wollemia, Pherosphaera, Lomatia, Dracophyllum, Acrophyllum, Podocarpus* and *Atkinsonia*) and supports many plants of conservation significance including 114 endemic species and 177 threatened species.

<u>Greater Blue Mountains - New South Wales - World Heritage Places (environment.gov.au)</u>

Box 2-2 The statement of integrity underpinning the inscription of the GBMA on the World Heritage List as included in the Statement of Outstanding Universal Value

Statement of integrity

The seven adjacent national parks and single karst conservation reserve that comprise the GBMA are of sufficient size to protect the biota and ecosystem processes, although the boundary has several anomalies that reduce the effectiveness of its 1 million hectare size. This is explained by historical patterns of clearing and private land ownership that preceded establishment of the parks. However, parts of the convoluted boundary reflect topography, such as escarpments that act as barriers to potential adverse impacts from adjoining land. In addition, much of the property is largely protected by adjoining public lands of State Forests and State Conservation Areas. Additional regulatory mechanisms, such as the statutory wilderness designation of 65% of the property, the closed and protected catchment for the Warragamba Dam and additions to the conservation reserves that comprise the area further protect the integrity of the GBMA. Since listing, proposals for a second Sydney airport at Badgerys Creek, adjacent to the GBMA, have been abandoned.

Most of the natural bushland of the GBMA is of high wilderness quality and remains close to pristine. The plant communities and habitats occur almost entirely as an extensive, largely undisturbed matrix almost entirely free of structures, earthworks and other human intervention. Because of its size and connectivity with other protected areas, the area will continue to play a vital role in providing opportunities for adaptation and shifts in range for all native plant and animal species within it, allowing essential ecological processes to continue. The area's integrity depends upon the complexity of its geological structure, geomorphology and water systems, which have created the conditions for the evolution of its outstanding biodiversity and which require the same level of protection.

An understanding of the cultural context of the GBMA is fundamental to the protection of its integrity. Aboriginal people from six language groups, through ongoing practices that reflect both traditional and contemporary presence, continue to have a custodial relationship with the area. Occupation sites and rock art provide physical evidence of the longevity of the strong Aboriginal cultural connections with the land. The conservation of these associations, together with the elements of the property's natural beauty, contributes to its integrity.

Greater Blue Mountains - New South Wales - World Heritage Places (environment.gov.au)



Figure 2-1 The Greater Blue Mountains Area and nearby NSW conservation reserves.

2.2 Components of Outstanding Universal Value

As mentioned in Chapter 1, the GBMA is considered to be of Outstanding Universal Value (OUV) because the property is of such exceptional significance 'as to transcend national boundaries and to be of common importance for present and future generations of all humanity' (UNESCO 2019a). This OUV is composed of multiple and inter-related components that, together, constitute the GBMA's exceptional significance.

For this assessment of the potential cumulative impacts of existing and planned mining projects in the vicinity of the GBMA, eight high-level components of OUV were selected that represent the two criteria of natural heritage value as presented in the Statement of OUV for the property (Box 2-1) and key aspects of the integrity of the GBMA (Box 2-2). There is considerable overlap among these high-level components, reflecting the interconnectedness of the component values contributing to its OUV.

Although attention in this report focuses on these eight high-level components, examples and evidence are also drawn from mid-level components such as Threatened Ecological Communities (e.g. Temperate Highland Peat Swamps on Sandstone) and valued ecosystems (Thirlmere Lakes) and from species-level components (e.g. Wollemi Pine, Blue Mountains Pine). This broad hierarchical classification (Figure 2-2) seeks to represent important components of the OUV of the GBMA as a focus for assessing the potential cumulative impacts of existing and planned mining projects in its vicinity.





High-level components were used as Assessment Endpoints in the spatial causal network analysis (Section 3.6) whereas mid- and species-level components were assessed spatially, drawing on narratives and the conceptual model underpinning the causal network.

2.2.1 Natural heritage value

Six high-level components represent the two natural heritage values used to justify inclusion of the GBMA on the World Heritage List (Figure 2-3). There is an intentional bias towards the floral components of OUV, reflecting the specific values presented in the Statement of OUV for the property (Box 2-1). Note that when referring to specific high-level components as proper nouns in this report, the first word of the component is capitalised (e.g. Scleromorphic flora).

Four of the components were assessed in detail (as described in Chapter 3):

- 1) **Gondwanan flora** Primitive rainforest species with Gondwanan affinities that have survived in isolated pockets of the GBMA (e.g. Wollemi Pine, Blue Mountains Pine, species of *Lomatia, Dracophyllum, Acrophyllum, Podocarpus* and *Atkinsonia*).
- 2) Scleromorphic flora Plants having hard, short and often spiky leaves that have evolved in response to conditions of low soil fertility and limited water (e.g. Myrtaceae eucalypts, Fabaceae acacias, Proteaceae banksias, grevilleas and hakeas). Scleromorphic flora cover more than 98% of the GBMA.
- 3) Conservation-significant flora Plant species and ecological communities that are identified under the Australian Government *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and/or the New South Wales *Biodiversity Conservation Act 2016* (BC Act) as requiring special environmental protection due to substantial declines in geographic distribution and/or key species, and because of the presence of ongoing pressures that are likely to continue the trend of degradation and loss.
- 4) **Conservation-significant fauna** Animal species and ecological communities that are identified under the EPBC Act (Cth) and/or the BC Act (NSW) as requiring special environmental protection for the same reasons as above.

The two other components - Other flora and Other fauna - incorporate the species of plants and animals not covered by the above four components, and are included for completeness (Figure 2-3). In the current assessment of potential cumulative impacts of existing and planned mining projects in the vicinity of the GBMA, it was assumed that risks to these two components of OUV relating to natural heritage values could be readily inferred from those to the four components that were assessed in detail.

Figure 2-3 Natural heritage value criteria (ix and x) are represented by six high-level components. Four (highlighted) are assessed in greater detail in this assessment.



The Gondwanan Flora and Scleromorphic Flora components go to the heart of the World Heritage listing under criterion (ix). They are also differentiated because they have evolved in very different environments and are likely to have different sensitivities to potential cumulative impacts of mining.

2.2.2 Integrity

Eight high-level components contribute to the integrity of the GBMA (Figure 2-4). Many of these components are intimately interdependent; a decline in the quality of one of them is likely to detract from others such as the property's cultural value, natural beauty and wilderness value. Some components (e.g. Intactness) also encompass attributes of the property, such as its large size, wilderness quality and largely undisturbed matrix, that were considered unlikely to be impacted by mining in the vicinity of the property.

Again, four of the components were assessed in detail:

- 1) **Boundary integrity** characteristics of the GBMA's boundary (e.g. native vegetation buffers, rocky escarpments) that help protect the GBMA's OUV. The GBMA was listed without a formal buffer zone, yet an essential part of the conservation strategy of World Heritage properties is the protection of the surroundings of inscribed properties.
- 2) **Geodiversity** the diversity of geological structures and landforms such as plateaus, cliffs, escarpments, caves, canyons, gorges and pagoda rocks. These provide the setting for its unique biota and contribute to the property's Indigenous heritage and natural beauty (Washington and Wray 2011).
- 3) Water systems aquatic features (e.g. streams, springs, swamps, lakes, waterfalls, seeps and groundwaters) and associated water-dependent ecosystems that have evolved in tandem with the geomorphic evolution of the landscape. Examples include the Thirlmere Lakes system in Thirlmere Lakes National Park and the Colo, Kowmung and Grose river systems which are declared Wild Rivers under the NSW *National Parks and Wildlife Act 1974* (NPW Act). A Wild River is one that is of natural origin and exhibits substantially natural flow, and must be protected to conserve this condition.

4) Indigenous custodial relationships - includes culturally important sites (e.g. caves, shelters, hearths, rock art, grinding grooves, scar trees and landscape features); species that are important for diet, materials, medicine, cultural identity and spiritual values of the Indigenous peoples of the area; and intangible values that reflect the connections and interdependent relationship between Indigenous people and their ancestral lands.

Most of the remaining components are derivatives of the four components above (Figure 2-4), and collectively contribute to the property's integrity. Following the same reasoning in Section 2.2.1, it was assumed that risks to these remaining components of integrity could be readily inferred from the results of the four components that were assessed in detail.



Figure 2-4 Integrity of the GBMA is represented by eight high-level components. Four (highlighted) are assessed in greater detail in this assessment.

2.3 Threats and trends

At the time of listing in 2000, the main threats to the OUV of the GBMA were considered to be from tourism, fire and invasive species (NSW NPWS 1998). In remote bush areas, fire and pest species are considered the greatest threats and are the focus of management control. Visitor use of the property has tended to be concentrated around the urban corridor and is actively managed to minimise erosion and disturbance impacts (NSW NPWS 1998). More recently, climate change has been added as a fourth key threat to the draft Strategic Plan being prepared for the property (NSW DPIE, in prep).

Mining is prohibited in national parks in NSW, but several coal mines were operating in the vicinity of the GBMA at the time of its nomination and subsequent listing. These mines were reported not to be affecting the water catchments that drain to the area. Although cliff collapse and the alteration of surface drainage were identified as potential impacts from mining, strict development control and pollution licensing requirements in NSW were considered to be effective in managing this threat (NSW NPWS 1998).

There are multiple ways that mining can threaten the OUV of the GBMA. These threats can be grouped by their predominant pathways. Groundwater drawdown and contamination (e.g. hydrocarbons, salts, heavy metals) can affect natural groundwater-dependent ecosystems (GDEs) such as groundwater-fed swamps, seeps and streams as well as many types of vegetation. Surface water extraction alters the flow regimes of waterways entering the GBMA,

affecting flow-dependent plants, animals and ecological processes (e.g. nutrient cycling). Sediment regimes are also changed, affecting natural rates of erosion and deposition in the waterways and along their banks.

Surface water contamination may harm or kill aquatic plants and animals, impact on riparian vegetation and pollute shallow groundwater that exchanges with streams in their beds and banks. Harmful chemicals may be mobilised from contaminated water and bank sediments and may ultimately affect nearby terrestrial ecosystems in the GBMA. Air pollution, dust, and noise and light pollution are all air- or wind-borne, and may have impacts on terrestrial plants and animals. Other potential threats to the components of the OUV of the GBMA include ground subsidence from longwall mining and vibrations from blasting. However, some threats such as accidental fires, vehicle strike, vegetation clearance and invasive plants and animals that may be facilitated by mining are less likely in the GBMA. Importantly, these various threats are often cumulative, and must be considered collectively when assessing potential impacts on the OUV of the GBMA.

In the last decade, two important trends in potential threats to the OUV of the GBMA have become apparent. The first is the escalating threat of potential cumulative impacts of coal mining, especially via water pollution and subsidence, associated with increasing numbers of proposals for new mines or extensions of existing ones in the vicinity of the property.

For example, the Wollangambe, Wolgan and Colo Rivers in the GBMA (Figure 2-1) have already been impacted by polluted water from coal mining activities. In July 2015, coal fines from the Clarence Colliery spilled into the Wollangambe River and the mining company was obligated to remediate the damage (Box 2-3). Pollution from the mine extends at least 22 km downstream in the Wollangambe River from the outflow of coal mine wastes, impairing the aquatic ecosystem and reducing the abundance and taxonomic richness of pollution-sensitive aquatic macroinvertebrates (Wright et al. 2017). This pollution includes increased salinity, thermal pollution and elevated concentrations of heavy metals that appear to have been taken up by riparian vegetation (Wright et al. 2017, Belmer and Wright 2018). Investigations by the Australian Government concluded that there were no long-term impacts on the OUV of the World Heritage property (Commonwealth of Australia 2019, UNESCO 2019c). Heavy metals (notably zinc and nickel) from the Canyon Colliery, closed in 1997, also enter the Grose River (Price and Wright 2016) which flows into the GBMA

Subsidence from longwall coal mining near the GBMA may cause cliff collapse, water pollution and the loss of surface water as well as lower water tables and lead to desiccation of peat swamps (Independent Expert Panel for Mining in the Catchment 2019). Temperate Highland Peat Swamps on Sandstone (THPSS) are a Threatened Ecological Community (TEC) occurring within the GBMA. Impacts on water retention and ecological functions of these swamps due to mining can exacerbate impacts from climate change and bushfires (Cowley et al. 2019). One of the most serious threats from subsidence is when fractures form in the sandstone bedrock of undermined watercourses and substantially increase local hydraulic conductivity. This, in turn, can reduce or even eliminate baseflow, leading to progressive drying of downstream swamps, loss of wetland plant species, desiccation of peat (with increased vulnerability to burning) and greater potential for incision and erosion of the swamps during high flow events. Growing awareness of these potential impacts and the continuing approval of new or extended coal mines around the property led to the WHC's concerns that existing controls may not be effective in managing the threat from coal mining and prompted their request in 2019 for this cumulative impact assessment. Since this request, there has been a second notable event: a change in the Conservation Outlook for the property from 'Good with some concerns' (IUCN 2014, 2017) to 'Significant concern' (IUCN 2020). This change in assessment appears to be largely due to the potentially serious impacts on the property's OUV caused by bushfires from the end of October 2019 to early February 2020 that burnt 71% of the area with varying degrees of severity (Section 4.3.14).

The 2020 Conservation Outlook (IUCN 2020) now lists two climate change-related threats as 'Very high threat': (i) Fire/Fire suppression, and (ii) Habitat shifting/alteration, Droughts, Temperature extremes, Storms/flooding. The only two mining-related threats are listed as 'High threat' and are: (i) Water pollution, and (ii) Oil/gas exploration/development, Mining/quarrying.

As a consequence of the recent severe fires and the elevation of their threat level in the 2020 IUCN Conservation Outlook of the GBMA to 'Very high', we have explicitly considered these threats when assessing the potential cumulative impacts of mining in this report. We acknowledge that more detailed work on the impacts of the fires on the property's OUV is underway and that our interpretations of likely interactions with mining-related impacts are preliminary and based solely on desktop analyses.

Box 2-3 The spill of coal fines from Clarence Colliery into the Wollangambe River in 2015

The Clarence Colliery underground coal mine, a joint venture between Centennial Coal and SKA Energy Australia, is situated in the Western Coalfield approximately 15 km east of Lithgow and produces thermal coal for export and domestic use. Mining commenced in 1979 and production rates vary between 2 and 2.5 Mt/year.

On 2 July 2015, a spill occurred from a coal reject stockpile at the mine site that caused many tonnes of coal fines and coarse reject material such as coal rock and gravel to be dispersed into the environment surrounding the mine site. Coal fines also entered the Wollangambe River, which flows into the GBMA. The mine swiftly reported the incident to the NSW Environment Protection Authority (EPA) who commenced an investigation with an immediate focus on containing and cleaning up the spill. A Clean-up Notice was issued to Centennial Coal on 3 July 2015 directing the company to install 22 silt fences between the mine and the river to contain the material and prevent any further impact to the river. Centennial Coal was also directed to remove coal material from over 350 metres of the drainage line from the river upslope towards the mine site (EPA 2015).

The EPA's inspections confirmed that coal fines, in varying quantities, settled in the river up to eight kilometres downstream of the spill site. Because of the difficult terrain and sensitive environment, removal of deposits of coal fines from the river was either by hand or using a small suction pump. The extensive rehabilitation operation of the contaminated land and water took 12 months, and cost almost two million dollars (AUD). The NSW Land and Environment Court convicted the company of two offences and imposed more than AUD 1,050,000 in penalties. When delivering the judgement, Justice Robson said, *"I find that Clarence Colliery's conduct caused both substantial actual harm and likely environmental harm and that the areas adversely affected were areas of high environmental and conservation value which were specifically preserved and clearly intended to be relatively free of pollution"* (Australian Mining, 18 July 2017).

2.4 Mines in the vicinity of the GBMA

Coal mining has occurred in the geological basin underlying the GBMA and its surrounds for over 200 years, well before its World Heritage listing. While there are no longer any operating mines in the GBMA itself, the property historically supported a number of coal mines (e.g. Blue Mountains Colliery, Canyon Colliery, Katoomba Coal Mine) as well as oil shale mines at Newnes and Baerami in the Wollemi National Park and lead/silver/gold mines at Yerranderie in the Blue Mountains National Park. A number of coal mines within and around the GBMA had ceased extraction prior to the property's World Heritage listing in 2000 or prior to this assessment. Although environmental impacts from these mines may persist after closure, these legacy mines do not meet the 'existing and planned' requirement for inclusion in this assessment.

There are also sand and rock mines operating around the GBMA which supply products to industries associated with road-making, concrete, iron and construction. Like coal mining, this activity has a long history and new developments continue to be proposed to meet the demand for construction materials in nearby urban areas, including Sydney.

A key step in the current assessment was to identify what mining operations that could impact components of the GBMA's OUV exist or are planned in the vicinity of the property (Qii, Section 1.2). All types of mines were considered in scope which, for this region, means coal, sand and kaolin mines. The terms 'existing', 'planned' and 'in the vicinity' were interpreted as follows:

- 'Existing' mines are those under construction, in production or in temporary care and maintenance in 2020.
- A 'planned' mine is a 'reasonably foreseeable' mine, defined by the Minerals Council of Australia (2015) as a project that has been approved and commencement announced or is under assessment with full documentation available.
- 'In the vicinity' is close enough to the GBMA that there are plausible pathways for mining-related hazards to threaten components of the OUV of the property. For underground and open-cut coal mining operations, a conservative distance of 20 km from the property was adopted to select mines; for sand mines, a distance of 5 km from the property was selected.

Further details of these definitions and the process for selecting which mines to include in the assessment are given in Appendix A.

At the time that this assessment commenced (March 2020), 15 coal- and 3 sand-mining operations were identified that met the criteria for inclusion. Fourteen are existing operations and four mines were considered reasonably foreseeable. The 18 mines are listed in Table 2-1, which includes details of mine type, operating status and distance to the GBMA. The mine lease areas, and the mine footprints used by Holland et al. (2021) for delineating stressor extents, for these operations are shown in Figure 2-5. Appendix B provides the time line of approved and proposed operations for the mines included in this assessment (Figure B1) and a short description of each mining operation.

Sixteen coal-mining operations in the vicinity of the GBMA were excluded from this assessment, primarily because they were either in care and maintenance and on a pathway to closure or were assessed as hydrologically disconnected from the GBMA. Details of their exclusion are presented in Appendix A.

Since the assessment was completed, the NSW Court of Appeal has upheld the decision to refuse the Bylong Coal project, and the proposed Hume Coal project has been rejected (although the decision may be appealed). These greenfield projects now appear unlikely to proceed. Their status in Table 2-1 has been updated to reflect recent decisions. As this desktop analysis assumed that they were approved, the area of GBMA potentially threatened by mining in its vicinity is overestimated.

Mine	Company	Туре	Existing/ Planned	Status	Mining started	Approved to	MLA adjoins GBMA	Mine to GBMA (km)
Airly	Centennial Coal	UG	Existing	Operating	1998	2037	Yes	1
Angus Place	Centennial Coal	UG	Existing	C&M (pre-EIS)	1979	2024	Yes	8
Appin	South32	UG	Existing	Operating	1962	2041	No	14
Bulga	Glencore	OC & UG	Existing	Operating	1982	2039	No	7
Bylong Coal Project	KEPCO	OC & UG	Planned	Refused. Appealed but decision upheld	Refused	n/a	Yes	0.5
Clarence	Centennial Coal	UG	Existing	Operating	1979	2026	Yes	0.5
Dendrobium	South32	UG	Existing	Operating	2001	2030	No	15
Hume Coal Project	POSCO	UG	Planned	Refused		22 years	No	17
Hunter Valley Operations	Yancoal / Glencore	OC	Existing	Operating	1949	2030	No	6
Mount Thorley Warkworth	Yancoal	0C	Existing	Operating	1981	2037	Yes	6
Tahmoor	Tahmoor Coal	UG	Existing	Operating	1975	2032	Yes	Adjacent
United/ Wambo	Glencore	OC	Planned	Approved	Approved 2019	2042	No*	1.5
Wambo	Peabody	OC & UG	Existing	Operating	1969	2042	Yes	3
Invincible	Castlereagh Coal	OC	Existing	C&M	1957+	2025	No	7
Springvale	Centennial Coal	UG	Existing	Operating	1995	2028	No	6.5
Kables	Hanson Construction Materials	Sand	Existing	Operating	1988	unknown	No	1.5
Newnes Kaolin Friable Sandstone Project	Newnes Kaolin Pty Ltd	Kaolin, sand	Planned	Not yet mining	Construction started 2011	21 years from start extraction	Yes	Adjacent
Tinda Creek	Hy-tec - Aus10 Rhyolite Pty Ltd	Sand	Existing	Operating	1996	2045	Yes	Adjacent

Table 2-1 Existing and planned open-cut (OC) and underground (UG) mines included in this assessment (briefly described in Appendix B)

C&M = In care and maintenance; MLA = mine lease area; n/a = Not applicable

* United mine lease area does not adjoin GBMA, but the joint venture lease area with Wambo does.





Source: CSIRO 2021, supplied upon request

2.5 Protection and management

The GBMA and its OUV are protected and managed under both Australian and New South Wales (NSW) government legislation. These two levels of protection are summarised below to provide context for this report; more detail is provided for particular stressors and pathways in relevant parts of Appendix C.

2.5.1 Protection of the GBMA by Australian Government legislation

The EPBC Act (Cth) provides a high level of protection for the OUV of the GBMA by regulating all actions that have, will have or are likely to have a significant impact on the OUV of a World Heritage property. Under the definitions of the EPBC Act (Box 2-4), World Heritage properties

are Matters of National Environmental Significance (MNES). Actions that could have a significant impact on MNES can form the basis for a 'controlled action' determination under the Act. A 'controlled action' means that the risks of the action to the MNES must be assessed and, where significant impacts are likely, options to avoid or mitigate the risks must be identified that reduce the risk to acceptable levels. 'Controlled actions' require approval by the Australian Government Minister for the Environment and enable the Minister to set appropriate conditions as part of the project approval to ensure that any significant impacts on World Heritage Areas are acceptable. Conditions can be prescriptive (i.e. specify the actions that a proponent must undertake to comply with the approval), outcomes-based (i.e. specify the environmental outcomes that a proponent is required to achieve, without specifying how they are to achieve these outcomes) or a combination of the two. Approved projects are monitored for environmental performance and compliance with conditions. Where breaches are identified, penalties can be imposed.

Box 2-4 Key terms in the EPBC Act

Action – a project, development, undertaking, activity, or series of activities, or an alteration to any of those things. In this assessment, the action is mining.

Controlled action – an action that needs approval under the EPBC Act if the Australian Government Environment Minister determines that it is likely to have a significant impact on matters of national environmental significance. Coal mines near the GBMA may trigger the World Heritage property controlling provision if significant impacts on World Heritage values are considered likely from the action.

Matter of National Environmental Significance (MNES) – currently nine matters ('triggers') identified by the Australian Government, based primarily on Australia's responsibilities under international agreements on environmental protection, that are the subject of Australian Government environmental protection under the EPBC Act. World Heritage properties are an MNES.

Significant impact - an impact which is *important, notable, or of consequence, having regard to its context or intensity,* which will depend upon the "sensitivity, value, and quality of the environment which is impacted, and upon the intensity, duration, magnitude and geographic extent of the impacts" (DOE 2013). The term is not explicitly defined in the EPBC Act. Significant Impact Guidelines (Commonwealth of Australia 2013) have been developed to guide the assessment of likely significant impact. In relation to World Heritage properties, a significant impact is one where there is a real chance or possibility that it will cause one or more World Heritage values to be lost, degraded, damaged or notably altered, modified, obscured or diminished.

https://www.environment.gov.au/epbc/about/glossary

Water trigger – a new MNES added to the EPBC Act in 2013 that triggers a more rigorous assessment of potential impacts on surface water and groundwater resources from large coal mines and coal seam gas projects. Proposals for new coal mines and expansions of existing coal mining operations trigger this MNES. Where coal mining is near a World Heritage property, this water trigger provides further protection to the property from impacts propagated via water pathways.

https://www.environment.gov.au/epbc/what-is-protected/water-resources

In 2013, an amendment to the EPBC Act specified that all coal seam gas and large coal mining proposals required Australian Government assessment and approval if they were likely to have

a significant impact on a water resource which, for these two activities, is legislated to be an MNES. Since then, coal seam gas and large coal mining proposals have been referred to the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development (IESC) for advice on potential impacts on water resources. The Australian Government Minister for the Environment takes this advice into consideration when making a final decision and setting conditions. This 'water trigger' adds an additional layer of protection for all water resources and water-dependent assets at risk from large coal and coal seam gas developments. Table 2-2 provides details of the most recent referral decisions for mining developments in the vicinity of the GBMA.

Mine	Modification	Year referred	Controlled action	World Heritage	Water trigger
Airly	Airly Mine Extension Project	2013	Yes	Yes	Yes
Angus Place	Angus Place Mine Extension Project	2013	Yes	Yes	Yes
Appin	Nothing current		No	n/a	n/a
Bulga	Bulga Optimisation Project Modification	2018	Yes	No	Yes
Bylong Coal Project	n/a	2014	Yes	No	Yes
Clarence	Clarence Colliery	2012	No	n/a	n/a
Dendrobium	Dendrobium Mine Extension Project	2017	Yes	No	Yes
Hume Coal Project	n/a		Yes	No	Yes
Hunter Valley Operations	Hunter Valley Coal Mining Operations North - State approved mining, NSW	2016	No	n/a	n/a
Invincible	Coalpac Pty Invincible Colliery Modification	2014	No	n/a	No
Mount Thorley Warkworth	Warkworth Extension Project	2009	Yes	No	No
Springvale	Springvale Mine Extension	2013	Yes	Yes	Yes
Tahmoor	Tahmoor South Project	2014	Yes	No	Yes
United/ Wambo	Combined Wambo-United open-cut coal project	2015	Yes	No	Yes
Wambo	South Bates Extension	2016	Yes	No	Yes
Kables	Kables Sand Quarry Depth Extension	2003	Yes	No	No
Newnes Kaolin Friable Sandstone Project	n/a	2002	Yes	Yes	No
Tinda Creek	Expansion of Tinda sand quarry operation, north of Windsor, NSW	2013	Yes	Yes	No

Table 2-2 Recent referral decisions for planned and existing mines in the vicinity of the GBMA. See Appendix B for mine summaries.

n/a - not applicable. Mines under assessment or approved but yet to commence; not seeking modification to existing approval.

2.5.2 Protection of the GBMA by NSW government legislation

The GBMA lies in the state of New South Wales (NSW). Under Australia's federal system of government, management of the GBMA is the responsibility of the NSW government. Each of the eight conservation reserves that make up the GBMA have management plans that set out the specific management objectives, directions and actions for each reserve in accordance with the requirements of the WHC. These are guided by the Greater Blue Mountains World Heritage Area Strategic Plan 2009 (NSW NPWS 2009) which is intended to bring strategic coherence to the overall management of the property. A new plan is currently in preparation and includes specific references to potential impacts of mining in the vicinity of the GBMA as well as the implications of the recent wildfires.

The NSW Government is also responsible for development approvals in its state, including mining. The NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) sets out the requirements in relation to the assessment of risks as part of the development approval process. Coal or mineral sands mining, mining in an environmentally sensitive area of State significance or mining which has a capital investment value of more than AUD30 million are considered to be State Significant Developments (SSDs). SSDs require a more detailed assessment of environmental impacts through preparation of an environmental impact statement (EIS) and greater public participation compared to smaller-scale developments.

A mining proponent is required to undertake a comprehensive environmental impact assessment, which includes assessments of potential impacts on surface water, groundwater, flora and fauna, air quality, visual amenity and cultural heritage and social values. These assessments are informed by geotechnical reports, subsidence impact assessments, blasting assessments, groundwater modelling and reports detailing site water management, waste management and rehabilitation and post-mining land use plans. Where a risk of potentially significant impacts is identified, avoidance and mitigation options must be proposed to bring the residual risk within acceptable limits. There are well-established industry best practices, departmental policies and guidelines, and legislative requirements that inform the preparation of the EIS.

The EIS and accompanying assessment reports are reviewed by relevant state agencies, independent committees such as the IESC and other independent experts. Once the assessment has been done to an acceptable standard and options for mitigating risk have been evaluated, a decision is made by the NSW Government Minister or delegated authority (e.g. the Independent Planning Committee) whether to approve the development and, if so, what conditions are required for consent. The consent conditions specify performance objectives and measures, requirements for monitoring and preparation of specific management plans to avoid or minimise risks. Post-approval processes operate to monitor environmental performance and ensure compliance with approval conditions over the mine life, including post-closure completion criteria such as meeting rehabilitation objectives.

The application of Australian and NSW government regulatory instruments in relation to the assessment and mitigation of risks associated with mining in the vicinity of the GBMA is discussed for each key finding (Chapter 4 and Appendix C) and in the general context of potential cumulative mining-related impacts on the GBMA in Chapter 5.

3 Approach

3.1 Introduction

This section outlines the approach used in the assessment of potential cumulative impacts of mining on components of the OUV of the GBMA. We start first by defining key terms and introducing the fundamental elements of cumulative impact assessment (CIA). The section concludes with key assumptions and limitations of the approach, acknowledging that it is a desktop study and that the potential cumulative impact areas within the property that are identified as part of this assessment do not necessarily mean that impacts have occurred or will occur in these areas. Rather, they identify areas where further investigation of local-scale factors is needed to refine the assessment of risk.

Full details of the causal network method and spatial analysis undertaken by CSIRO are presented in the Technical Report by Holland et al. (2021).

3.2 Some useful terms

Unfortunately, many terms in environmental impact assessment (EIA) and CIA are used inconsistently and interchangeably, causing substantial confusion and misinterpretation (Oesterwind et al. 2016). To address this problem, we explicitly define the terms adopted in this report and give relevant examples (Table 3-1).

Briefly, this CIA involved identifying relevant mining *activities*, their associated *hazards* and the main *causal pathways* (involving *stressors* and *processes*) by which these hazards may affect *assessment endpoints* (AEs) chosen to represent components of the property's OUV. The *collective impacts* of these causal pathways were configured as a *causal network* whose *links* were evaluated for their likelihood and consequence (*risk*) to specific AEs. Superimposing inferred *stressor extents* of the multiple stressors on the mapped extents of AEs indicates areas where *cumulative impacts* on the OUV of the GBMA are possible, and where further investigation of risk, monitoring and, potentially, *mitigation* strategies might be needed. Italicised terms are defined in Table 3-1.

The Australian Government defines a *significant impact* as one "*which is important, notable, or of consequence, having regard to its context or intensity*" (Box 2-4). 'Significant' is widely used in environmental science, usually in this broad sense of 'important' (cf. the narrow sense when used in a statistical context to express levels of probability) and this leads to its frequent interchangeable use with 'material'. In NSW, for example, the term 'material' harm is defined in the NSW Protection of the Environment Operations Act 1997 (POEO Act, Section 147) as involving "actual or potential harm to the health or safety of human beings or to ecosystems that is not trivial".

Typically, defining 'material' is contingent on the idea of a threshold. This tends to be the way that the term is used in environmental science and risk management – i.e. an impact is material if it exceeds a given threshold. However, it is important to recognise that an impact can be deemed significant even if it has not exceeded some threshold of materiality. This is especially true when considering the cumulative impacts of multiple stressors that, while not individually material, have a significant environmental impact when they act in concert.

In this desktop assessment, we use the term 'significant', as defined for the EPBC Act by the Australian Government (DOE 2013), to describe an impact that is important, notable or consequential. We reserve 'material' for use in the context of a threshold for consequence when assessing this component of risk.

Table 3-1 Key terms used in this report

Many of these definitions are context-specific for EIA and CIA. These and other key terms are included in the Glossary.

Term	Definition in the context of this CIA	Relevant examples
Activity	An intentional anthropogenic action, usually associated with obtaining resources (e.g. food, water, minerals), that might result in one or more impacts on one or more assessment endpoints.	Open-cut mining, underground mining
Assessment endpoint (AE)	'An explicit expression of the environmental value to be protected, operationally defined by an ecological entity and its attributes' (US EPA 1998). Here, eight high-level components (Section 2.2) contributing to the OUV of the property have been designated as AEs in the causal network.	Gondwanan flora, Conservation-significant fauna, Boundary integrity
Causal network	A graphical model representing multiple causal pathways between one or more activity nodes and one or more AE nodes. A network diagram is a powerful visual summary of potential direct, indirect and collective impacts of one or more activities on one or more AEs.	Figure 4-1
Causal pathway	A known or inferred sequence of events or steps, typically linking an activity ('cause') with its potential impact ('effect') on an AE. Sometimes called a 'cause-effect' pathway, it is represented on a causal network diagram as a sequence of links and nodes between one or more activity nodes and one or more AE nodes.	Groundwater extraction causal pathway, Accidental ignition causal pathway
Collective impacts	The result of combined causal pathways on one or more AEs, with the impacts generally inferred to be additive. Where a causal network has <u>not</u> explicitly addressed the potential cumulative impacts of multiple geographically clustered activities (i.e. with overlapping stressor extents), we refer to the combined impacts of multiple causal pathways on one or more AEs as collective impacts.	Result of impacts associated with all causal pathways whose links end at the Gondwanan flora AE on Figure 4-1
Cumulative impacts	The result of combined causal pathways from multiple activities, some of which may be geographically clustered (i.e. with overlapping stressor extents), on one or more AEs, with the impacts generally inferred to be additive. (Also see 'collective impacts'). To illustrate potential cumulative impacts, causal networks must include appropriate spatial analyses of multiple geographically clustered activities.	<u>Potentially</u> , the combined result of all impacts occurring within the stressor extents affecting Gondwanan flora in the GBMA
Hazard	An event or sequence of events that may lead to an impact. Hazard analysis is a crucial component of formal risk assessment and entails systematically identifying all possible stressors that, if not mitigated, may ultimately lead to negative impacts on one or more AEs.	Uncontrolled blasting to facilitate open-cut mining
Impact	'Consequence of environmental state change in terms of substantial environmental and/or socio-economic effects which can be either positive or negative' (Oesterwind et al. 2016). Synonymous with 'effect' but used here because it is explicit in the initialisms EIA and CIA. In everyday language, 'impact' implies that the consequences are undesired, and that is usually the case here.	Coal-fines entering a river and smothering bed sediments
Link	In this context, a line (usually an arrow) connecting two nodes to indicate either a direct or inverse relationship between them on a causal network diagram.	Figure 4-1
Mitigation	Any steps or strategies to avoid or reduce the risk of a negative impact on one or more AEs. The best option is avoidance but if this is not possible, strategies include minimising and/or remediating negative impacts on AEs.	Not clearing any vegetation within 500 m of a waterway, selective baiting for invasive predators

Term	Definition in the context of this CIA	Relevant examples
Node	In this context, either a starting or ending point for a link on a causal network diagram where nodes represent different entities (e.g. activities, stressors, processes, AEs).	Figure 4-1
Process	'Aspect of the system that is changed by stressors' (Holland et al. 2021). Typically, processes are mechanisms (many occurring naturally) whose rates are undesirably altered by stressors and lead to negative impacts on AEs.	Erosion, Groundwater drawdown, Habitat fragmentation and loss
Risk	'The integrated assessment of likelihood and severity of an undesired event' (Goussen et al. 2016). For each link along a causal pathway, likelihood and severity (consequence) are assessed in the causal network approach to infer the risk of one or more activities on one or more AEs.	Figure 4-1
Stressor	A natural or anthropogenic physical, chemical or biological agent, environmental condition or external stimulus that might contribute to one or more impacts. Hazards typically include or generate stressors. All causal pathways include at least one stressor.	Accidental chemical spill, Interception of surface runoff
Stressor extent	The maximum distance or area from the source of a stressor over which significant impacts on one or more AEs could occur. Combining stressor extents and inferring the potential additive effects of individual stressors and clustered mines enables estimation of the potential cumulative impact area (PCIA).	Figure 4-2

3.3 Cumulative impact analysis in a risk assessment framework

Cumulative impacts are the combined impacts of one or more activities, such as mining, agriculture and urbanisation, on the environment, society and the economy (Franks et al. 2010). Although our focus in this report is on environmental impacts, we acknowledge that such impacts also detract from societal and economic values, especially when ecosystem services are lost or impaired (MMO 2014).

Cumulative impacts typically result from the collective and interacting effects of multiple stressors, and often arise from multiple sources of multiple activities (Hodgson et al. 2019). For example, collective impacts of stressors such as surface water extraction, air pollution and groundwater drawdown from several adjacent mines may combine with these and other stressors from nearby activities such as agriculture and urbanisation to cumulatively impact on valued assets such as Gondwanan flora in a nearby National Park.

Further, cumulative impacts have spatial and temporal components (Franks et al. 2010). In our example, some parts of the National Park are likely to be more heavily impacted than others, and the intensity of the cumulative impacts may vary over time, depending on temporal changes in different activities. The spatial and temporal components of cumulative impacts are relevant because they can determine the type and magnitude of ecological responses. Importantly, these ecological responses are seldom linear (e.g. Hunsicker et al. 2016), and there may be 'tipping points' when several stressors interact simultaneously to cause a sudden dramatic decline in an environmental value (e.g. an algal bloom in response to water quality exceeding a threshold in dissolved nutrient concentrations).

Understanding how multiple stressors interact and combine in space and time to impact on species and ecosystems is challenging (Canter and Ross 2010) yet vital if we wish to predict

likely responses of valued species and ecosystems to cumulative impacts. Such predictions are usually set in a risk assessment framework where 'risk' to valued species and ecosystems is broadly considered in terms of *likelihood* and *consequence* (e.g. Goussen et al. 2016). A further challenge in CIA is assessing the cumulative risk to a valued asset from multiple stressors, especially as the components of risk are unlikely to be simply additive (Halpern and Fujita 2013).

In an environmental context, CIA aims to assess the risk of potential cumulative impacts of multiple activities and stressors on valued assets and other components of the environment and is increasingly required in Australia as part of the project-specific EIAs at state/territory and Australian Government levels (Kaveney et al. 2015). However, there are multiple types of CIA that can be used in different contexts, along with an equally diverse array of methods and approaches (Hodgson and Halpern 2018). Choosing an appropriate approach rests on the objectives of the assessment, assessment complexity (e.g. numbers of activities, stressors, valued assets), spatial and temporal scope of the project, the environmental data available and other practical considerations such as available expertise, time and funds. The approach must also be able to indicate where uncertainty lies (Hodgson et al. 2019).

For a desktop assessment like this one, a spatial causal network approach (Peeters et al. 2021) was ideal because the focus was comparatively narrow (mining), there were pragmatic constraints on data, time and funds, and the objective was well-defined.

The following sections briefly describe the five broad steps in the approach (Figure 3-1); full technical details are presented in Holland et al. (2021).

Figure 3-1 Flow-chart of the approach used in this assessment.

1. Setting context

- Specify the activity or activities within project scope
- Define the potential impact area (PIA)
- Define the potential impact duration (PID) = likely duration of direct, indirect and cumulative impacts
- · Identify valued assets and map their distributions in the PIA



2. Identifying hazards and causal pathways to valued assets

- Systematically identify hazards associated with activity or activities
- Construct conceptual model portraying how causal pathways from hazards associated with one or more activities might affect ecosystem components and valued assets in the PIA



3. Deriving the causal network

- Use conceptual model to encode nodes and links along causal pathways from activity or activities to assessment endpoints (AEs) comprising high-level components of the GBMA's OUV
- For each link, evaluate likelihood and consequence (risk)

4. Spatial analysis of causal network outputs

- Divide the PIA into a grid of cells of equal area
- For each cell, plot relevant evaluations (risk) to derive the likely spatial extent of potential impacts from specific stressors

5. Interpretation and communication

- Assess spatial overlap of the distribution of valued assets with, for example, likely spatial extent of potential impacts from specific or multiple stressors
- Identify 'hotspots' for monitoring and/or mitigation sites

3.4 Setting context

3.4.1 Specifying activities within scope

The project's objective was to undertake an assessment of potential cumulative impacts of all existing and planned mining projects in the vicinity of the property. 'Existing' mines were considered as those under construction, operational or in temporary care and maintenance in 2020; 'planned' mines were considered as those either approved or under assessment in 2020; and 'in the vicinity' was set at 20 km for underground and open-cut coal mines, and 5 km for sand mines (Section 2.4).

3.4.2 Specifying potential impact area and duration

The 'potential impact area' (PIA) was set to encompass the GBMA and a 500-m buffer zone around its boundary. This buffer zone comprised the area of the Boundary integrity AE (Holland et al. 2021), one of the high-level components of OUV described in Section 2.2.2.

The 'potential impact duration' (PID) was assumed to span the duration of operations at each mine and some nominal time after cessation of mining to allow for lagged effects, potentially for multiple decades (e.g. for groundwater drawdown to impact surface water tables). In keeping with the overall conservative nature of this CIA, stressor extents were defined based on the likely maximum impact over the entire PID. This conservative 'worst-case scenario' approach was deemed appropriate for the current assessment.

3.4.3 Identifying and mapping valued assets

Valued assets were identified from the statements of natural heritage values and integrity of the OUV (Section 2.2) and through consultation with staff from relevant agencies (Holland et al. 2021). Attention focused on eight high-level components of OUV (described in Section 2.2) that contributed to the property's natural heritage values and integrity. These were used as AEs in the causal network approach described in Section 3.6.

The spatial extents of these AEs in the GBMA were mapped. For AEs such as Conservationsignificant fauna that may occur anywhere in the GBMA, the mapped spatial extent spanned the entire property. The spatial extent of the Boundary integrity AE covered a 500-m wide buffer zone around the GBMA and was the only AE outside the property. For compatibility with the spatial analysis (Section 3.7), the areas of all AEs were mapped as grid cells of 250 x 250 m.

3.5 Identifying hazards and causal pathways to valued assets

3.5.1 Identifying hazards

Mining-related hazards potentially relevant to valued assets in the property were derived from detailed environmental hazard assessments done for Australia's Bioregional Assessment [https://www.bioregionalassessments.gov.au/] and Geological and Bioregional Assessment programs [https://www.bioregionalassessments.gov.au/gba], following the methods described in Ford et al. (2016). These hazards were grouped into fifteen potential stressors (Section 4.2) for the causal network analysis.

3.5.2 Constructing a conceptual model

A 'box-and-arrow' conceptual model (Commonwealth of Australia 2015) was constructed of all potential causal pathways from the fifteen stressors associated with two activities (open-cut and underground mining) to the eight AEs via fifteen processes. 'Boxes' represented activities, stressors, processes and AEs. 'Arrows' represented the direction of likely propagation of potential impact from one or more stressors to one or more AEs.

As the conceptual model was to be used as the basis of the causal network diagram, feedback loops were omitted because these could not be captured by the spatial causal network approach (Holland et al. 2021). Further, the conceptual model only focused on mining-related activities because this was the objective of the current assessment.

3.6 Deriving the causal network

3.6.1 Using conceptual model to assign nodes and links along causal pathways

The 'box-and-arrow' conceptual model described in Section 3.5.2 was converted to a causal network diagram. 'Boxes' were replaced by nodes; 'arrows' were replaced by links. Thus, the inferred causal pathways between activities and AEs were now represented by sequences of nodes and links. Holland et al. (2021) describe this process in detail, including the specific 'rules' used for encoding nodes and links in the causal network.

3.6.2 Evaluating likelihood and consequence (risk)

A binary classification was used to specify *likelihood* (possible, not possible) and *consequence* (material, not material) for each link in the causal network according to criteria presented in Holland et al. (2021).

3.7 Spatial analysis of causal network outputs

3.7.1 Dividing the PIA into grid-cells

The potential impact area (PIA) comprises the GBMA and a 500-m buffer zone around its boundary (Section 3.4.2). For the purposes of the spatial analysis of the outputs of the causal network analysis, it was divided into grid-cells of 250 x 250 m (Holland et al. 2021). The choice of grid-cell size largely reflected the resolution of the maps of AE spatial extents within the property, and was suitable for the objectives of this CIA.

3.7.2 Defining stressor extents

Holland et al. (2021) describe how they determined each stressor's extent as the distance or area from each mining-related stressor source within which a material impact may be possible. Different stressors have different stressor extents, with some impacts expected to be limited to the mine lease area whereas others may extend varying distances off-site and potentially into the GBMA. Within a stressor extent, the risk of material impacts due to the stressor is generally assumed to be greatest close to the stressor source and diminish with distance from the source. However, local factors may also determine if and where material impacts occur. The number of stressors collectively affecting an area also likely diminishes with distance from the mine sites. For example, impacts from altered light, groundwater, streamflow and water quality might be evident up to 20 km from the mining areas. Closer to the mines, additional impacts may arise from subsidence, blasting, vegetation removal, invasive species, traffic movements and noise.
Where mines are near each other, each mine's stressor extents for a given stressor may overlap (e.g. intersecting areas of groundwater drawdown), possibly having compounding effects. Stressor extents for groundwater drawdown and streamflow reduction were defined to account for these possible compounding effects, building on insights from modelling done for the Hunter River BA (Herron et al. 2018a). Where available information allowed, a conservative approach was always used so that stressor extents for cumulative impacts are likely to represent 'worstcase' maximum probable extent.

3.8 Interpretation and communication

3.8.1 Assessing spatial overlap of individual and cumulative stressor extents with AE areas

The goals of the spatial analysis were to define meaningful stressor extents, determine potential cumulative impact areas (PCIAs) and identify overlap with the mapped extents of the AEs (Peeters et al. 2021). The generated maps provide a visual summary of which AEs are at risk and, collectively, where the OUV of the GBMA could be subject to the cumulative impacts of mining in the vicinity of the property. The maps are also used to assess the overlap with the 2019-20 bushfires that burnt 71% of the GBMA and possibly enhanced the risk of mining-related impacts on the eight high-level components of OUV (Section 4.3.14).

The PCIAs represent the 'worst-case' risk scenario; that is, the maximum extent of the GBMA in which there is potential for mining-related impacts on one or more of the eight high-level components of OUV (AEs). They do not account for the effects of any protection and management measures (Sections 2.5 and 4.3, Appendix C) that could be employed to reduce the risk. The residual risk is the risk that remains after feasible protection and management measures have been applied. In the context of stressor extents, these measures should shrink the area within which potentially significant impacts are possible, and hence substantially reduce the PCIA.

The residual risk has been assessed separately for each high-level component of OUV (Section 4.3) having regard to Australian Government and NSW protection and management measures, implemented at a range of scales to minimise the environmental impacts of mining. Residual risk is rated as 'Very low', 'Low' or 'Moderate' (Table 3-2), assessed according to the availability and potential effectiveness of protection and management measures. In some cases, a lack of information about the risk or likely impact pathways led to a rating of 'Indeterminate'.

Given the scope of the assessment, residual risk was assigned at the scale of the GBMA. However, local-scale residual risks to some components of OUV may be greater in areas of the PCIA where landscape characteristics interact with the cumulative impacts of multiple mining-related stressors. For example, some scleromorphic flora associated with water systems may be locally vulnerable within some parts of the PCIA but this is not reflected in the overall residual risk rating of 'Very low' for this high-level component at the scale of the GBMA.

A more detailed assessment of how landscape characteristics alter stressor effects within the PCIA would have enhanced finer-scale spatial evaluation of residual risk from the cumulative impacts of mining. This was not within the scope of this assessment (Section 1.2) but should be considered in any future assessment.

Rating	Criteria
Very low	Mining-related stressor(s) unlikely to have significant impacts on AEs and/or protection and management measures prevent significant impacts in the GBMA; residual risk remains from unforeseen accidents and interactions with non-mining stressors (e.g. climate change and bushfires)
Low	Protection and management measures reduce risks of significant impacts of mining-related stressor(s) on AEs but do not eliminate them; minor potential for cumulative impacts of multiple clustered mines if stressor extents overlap
Moderate	Limited options for protection and management measures to reduce risks of significant impacts of mining-related stressor(s) on AEs; moderate potential for cumulative impacts of multiple clustered mines if stressor extents overlap; limited options for remediation of impacts
High	No options for protection and management measures to reduce risks of significant impacts of mining-related stressor(s) on AEs; high potential for cumulative impacts of multiple clustered mines if stressor extents overlap; no options for remediation of impacts
Indeterminate	Insufficient information about risk, likely impact pathway(s) and/or relevant data on the AEs

Table 3-2 Criteria underpinning the ratings of residual risk in this assessment.

AEs = Assessment Endpoints (usually high-level components of the OUV of the GBMA).

3.8.2 Identifying sites for monitoring and/or mitigation

The PCIA mapping provides a useful starting area for locating sites for monitoring, mitigation or both. More detailed local scale information may help to identify potentially more at risk areas for targetted monitoring. This was not within the scope of the current project but is a useful output from the spatial analysis and relevant for suggested future work (Section 5.5).

Further, by identifying the pathways via which stressors could have potentially significant impacts on AEs within the GBMA, we can determine where and what monitoring would be useful to ensure environmental values are being protected and what mitigation measures might be effective. For example, if a stressor effect is conveyed into the property via a stream, monitoring sites could be set up along the stream and in nearby reference streams where impacts are not predicted. Ideally, mitigation strategies would target stressors at their source because remediation of contaminated or hydrologically altered streams can be challenging, costly and potentially too late to avoid longer-lasting damage.

3.9 Key assumptions and limitations of the approach

All CIA methods necessarily involve assumptions (Halpern and Fujita 2013) and have limitations (Kaveny et al. 2015). These assumptions and limitations should not compromise the objective of the application of the method or lead to misinterpretations of the findings. Ideally, formal assessments of the sensitivity of the interpretations to violation of one or more of the following assumptions should be undertaken to increase rigour in the assessment. This was not feasible for the current project and is considered to be a limitation of the approach.

Key assumptions of the current approach include:

- Stressors associated with sand mining were assumed to be the same as those for opencut coal mines but with smaller stressor extents.
- For most of the high-level components of the OUV of the GBMA that were assigned as AEs, it was assumed that characteristic species, communities, ecosystems and other valued assets could occur anywhere within the GBMA.

- In the absence of any formal description or quantification of 'desired states' for AEs or their valued assets, it was assumed that <u>any</u> negative mining-related impact was undesirable.
- Stressor effects were assumed to be uniform within a grid-cell. Finer-scale features within a grid-cell that might alter an AE's vulnerability to one or more stressors were not differentiated.
- As the scope of the project was to assess cumulative impacts of existing and planned mines near the GBMA, other potential sources of impacts such as tourism, agriculture, urbanisation and climate change were not included in the causal network. Potential legacy impacts of previous mines were also not in the scope of this assessment.
- The fifteen stressors and fifteen processes chosen for the causal network were assumed to adequately capture the main pathways via which mining could impact AEs in the GBMA.
- The eight high-level components of OUV that were assigned as AEs were assumed to adequately represent the components of OUV potentially at risk from mining.
- The spatial causal network approach and grid-cell resolution were assumed to be sufficient to assess and portray the overlap of areas of AEs with stressor extents to reflect potential cumulative mining-related impacts on valued assets in the GBMA.
- The binary assignment and threshold values of likelihood and materiality in the risk evaluation were assumed to be adequate for the purposes of this CIA.

Holland et al. (2021) list the specific assumptions made when determining the extents for each stressor and when evaluating likelihood and materiality for some of the causal pathways.

There were several limitations imposed by the spatial causal network approach and the reliance on a desktop study:

- Feedback loops, although common in natural systems, could not be included on the causal network diagram because of the complexity of deriving causal pathways with the same start and end nodes. This limitation was considered not to substantially alter any of the conclusions but it should be noted that many natural feedback loops are ecological responses that serve to ameliorate the impacts of some stressors (e.g. enhanced plant recruitment following bushfires).
- Without detailed site-specific environmental data on cumulative impacts of individual or multiple mining-related stressors collected over adequate time intervals (preferably since the property was declared as a World Heritage site in 2000), trend analyses (e.g. Mosaffaie et al. 2021) and ground-truthing of stressor extents were not possible. Ways to address these limitations, including the need for suitable baseline and reference data on environmental condition indicators and AEs, are discussed in Section 5.4.
- Inevitably, the cumulative impacts of mining on the OUV of the GBMA will be influenced by the enduring effects from mines within or near the property that have ceased operations (legacy mines, post-mining land uses), other activities (e.g. tourism, agriculture, urbanisation) and other system drivers such as climate change and altered fire regimes. These were not part of the terms of reference from the WHC (Section 1.1), but we acknowledge that not accounting for them is a limitation of this cumulative impact assessment.
- No formal assessments of the contributions of sources of uncertainty or of the sensitivity of the interpretations to violation of one or more of the above assumptions

were undertaken. This limitation should be considered when interpreting the project's findings. They would be a valuable addition to any future CIA of the property.

- Many of the evaluations presented in Holland et al. (2021) were limited by inadequate knowledge (e.g. thresholds of materiality, likely ecological responses of valued assets in AEs to various impacts and causal pathways, inadequate spatial data on distribution of most AEs). Further data and information are needed to address these sources of uncertainty (discussed in Section 5.4). Inevitably, limitations also arise from uncertainty arising from natural randomness.
- Throughout this CIA, a conservative perspective has been adopted to err on the side of over- rather than under-estimating potential cumulative impacts of mining on the OUV of the GBMA. This perspective results in a 'worst-case' scenario where the areas identified as PCIAs imply a far greater risk than is occurring or is likely to occur. Although this limitation may lead to unwarranted additional sampling and mitigation efforts, it is more than balanced by the immense value and irreplaceability of this World Heritage-listed area.

4 Findings

4.1 Introduction

This chapter presents the main findings of the desktop assessment of the potential cumulative impacts of existing and planned mining projects in the vicinity of the GBMA, drawing on the analyses undertaken by CSIRO (Holland et al. 2021). In Section 1.2, eight questions were posed to address the assessment's objective, and the answers to these are presented in Section 4.2 below.

The assessment's findings, many of which underpin the responses to the eight questions, are summarised as ten key messages (KMs) in Section 4.3, along with a brief review of relevant threats, pathways, mitigation measures and residual risk ratings for each key message. More details on each key message (context and threats, pathways, protection and management, and residual risk) are given in Appendix C. Appendix C also includes diagrams of causal pathways and maps of components that intersect the PCIA, along with supporting information and references to relevant literature that have been omitted from the text below for brevity.

4.2 Brief answers to the eight questions addressing the assessment's objective

i) What are the main components of the OUV of the GBMA, and how might these be summarised to efficiently assess potential cumulative mining-related impacts?

The OUV of the GBMA can be summarised into eight high-level components that represent the property's natural heritage values and integrity (Section 2.2) and are considered potentially at risk from mining in the vicinity of the GBMA. The high-level natural heritage components are Gondwanan flora, Scleromorphic flora, Conservation-significant flora and Conservation-significant fauna. The integrity components are Boundary integrity, Geodiversity, Water systems and Indigenous custodial relationships.

ii) What and where are the existing and planned mining operations in the vicinity of the GBMA that could impact components of its OUV?

In 2020, fifteen coal- and three sand-mining operations were identified as existing or planned in the vicinity of the GBMA and could impact components of its OUV (Section 2.4). Locations of these mines are shown in Figure 2-5 and their details are summarised in Table 2-1 and Appendix B. Sixteen other mines within 20 km of the GBMA (Appendix A) were excluded from this assessment because they are on a pathway to closure or are hydrologically disconnected from the GBMA.

iii) What are the key mining-related stressors, processes and causal pathways that could impact components of the OUV of the GBMA?

Fifteen key mining-related stressors and fifteen processes (Table 4-1) were identified by Holland et al. (2021) as potentially impacting the eight high-level components of OUV (AEs) of the GBMA. The relevant causal pathways are illustrated on the causal network diagram generated by the CSIRO analysis (Figure 4-1).

Table 4-1 Stressors and processes potentially impacting the eight high-level components of the OUV of the GBMA (described in Holland et al. 2021).

Stressors	Processes
Accidental chemical spills	Air pollution
Accidental ignition	Bushfires
Artificial water sources	Competition and predation
Blasting	Erosion
Bore leakage	Groundwater contamination
Groundwater pumping	Groundwater drawdown
Industrial machinery	Habitat fragmentation and loss
Interception of surface runoff	Light pollution
Invasive species	Mass movement
Mine water discharge	Native species loss
Mining waste	Noise pollution
Subsidence	Soil contamination
Surface water extraction	Stream scour
Traffic movement	Streamflow contamination
Vegetation removal	Streamflow reduction

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Figure 4-1 Causal network showing the main causal pathways between open-cut and underground mining and the high-level components of OUV in the GBMA

Source: Holland et al. 2021, Figure 4.

iv) In which areas of the GBMA could key mining-related stressors individually and cumulatively impact the high-level components of OUV of the GBMA?

Holland et al. (2021, Figures 8 and 9) present maps showing the estimated probable maximum extents for individual mining-related stressors. When combined and superimposed on the PIA (i.e. the GBMA plus a 500-m buffer), they identify areas in the property where there is potential for cumulative impacts on the high-level components of OUV defined for this assessment (Figure 4-2, Section 4.3.1). The potential cumulative impact area (PCIA) has been defined conservatively, which means we are confident that mining-induced impacts outside the PCIA are very unlikely. The true PCIA, particularly when appropriate protection and management measures are in place, is expected to be much smaller.

Figure 4-2 The potential cumulative impact area (PCIA) from mines around the GBMA based on stressor extents defined by Holland et al. (2021).



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v) To what extent and where do these areas of potential impact overlap with the distributions of components of the OUV of the GBMA OUV, and with areas burnt in 2019-20?

For those components of the OUV of the GBMA that could occur anywhere within the property (Scleromorphic flora, Conservation-significant flora, Conservation-significant fauna, Geodiversity, Indigenous custodial relationships), the overlap is the same as the 1984 km² of PCIA (19% of the GBMA) derived by Holland et al. (2021). For the Boundary integrity component, which is represented by a 500-m buffer outside the GBMA, the overlap is 86 km² (5.6% of the entire buffer area). Distribution mapping of key species of the Gondwanan flora component suggest the PCIA has no overlap with known and likely areas of Blue Mountain Pine and a small overlap with known and likely areas containing *Acrophyllum australe* and localised patches of rainforest. Overlap with the only known stand of Wollemi Pine cannot be determined because distribution data for this species are not publicly available. For the Water systems component, a maximum of 420 km² of streams and riparian areas could be impacted (19% of mapped water systems in the GBMA). These extents and areas are discussed further in Section 4.3.

Approximately 71% of the GBMA was burned with varying severity in 2019-2020, partially overlapping with the PCIA and the distributions of the eight high-level components of OUV of the GBMA. Section 4.3.14 (KM10) describes the extent, locations and implications of this overlap.

vi) Which components of the OUV of the GBMA are potentially most at risk of cumulative mining-related impacts, and where?

Components of the OUV of the GBMA that occur within the PCIA could be at risk of cumulative mining-related impacts. The actual risk depends on the sensitivity of characteristic species and elements of each component to the stressors. For example, most scleromorphic flora are not groundwater-dependent and unlikely to be sensitive to groundwater drawdown. Most at risk are probably the species and communities that depend on habitats associated with water systems in the GBMA, and include streams and riparian areas, wetlands, swamps and other GDEs. The Boundary integrity component is physically closest to mining operations and is most at risk from effects of vegetation removal on mine lease areas. These risks are discussed in more detail in Sections 4.3.2-4.3.13 (KMs 2-9).

vii) What mechanisms (e.g. protection and management) are in place to protect and manage components of the OUV of the GBMA from potential cumulative mining-related impacts, and are they likely to be adequate in how and where they are currently applied?

Australian and NSW government legislation is in place to specifically protect World Heritage properties from environmental impacts of development. Mining in the vicinity of the GBMA is a highly regulated activity, with conditions of consent formulated to avoid and minimise off-site impacts from mining. Although the World Heritage controlling provision (Section 2.5.1) under the EPBC Act appears not to have been the basis for declaring many of the mining developments in this assessment to be controlled actions (Table 2-2, Appendix B), the EISs for these developments demonstrate that OUV or World Heritage values should be protected through the assessment and management of risk to other MNES and state environmental values.

Australia's long history of mining has seen increasingly stringent requirements for operators to demonstrate that the environmental impacts of their mines are minimised to acceptable limits. Demonstration of awareness and a declared intention to adhere to industry standards and guidelines designed to miminise the likelihood of significant environmental impacts are fundamental to obtaining development consent. The various protection and management measures in place to manage the risks from different stressors, their adequacy and specific applications are detailed in each KM (Section 4.3 and Appendix C).

viii) What is the residual risk to the components of the OUV of the GBMA from cumulative impacts of mining?

The residual risk (i.e. after application of all feasible protection and management strategies) to the components of OUV of the GBMA from cumulative impacts of mining is assessed as 'Low' or 'Very low' (Table 4-2). The Gondwanan flora component is rated 'Very low' residual risk because key species such as the Blue Mountains Pine are outside the PCIA, the likely occurrence of *Acrophyllum australe* is at the margins of the PCIA and the constituent rainforest patches are seldom groundwater-dependent (Section 4.3.2). Although data on the location of the Wollemi Pine stand are not publicly disclosed, the species' national and international significance ensures that it has the highest level of protection and the residual risk from mining can be assigned 'Very low'. Scleromorphic flora and Geodiversity are also rated as being at 'Very low' residual risk (Sections 4.3.3 and 4.3.6). The residual risk to Water systems is 'Low' but this extends over a comparatively large area (Section 4.3.7) and is 'Indeterminate' for two constituent habitats (Table 4-2). Smaller areas of the other components of OUV of the GBMA are at 'Low' residual risk. Consultation with Indigenous custodians was not sufficient to enable a reliable rating of residual risk to Indigenous custodial relationships within the GBMA, important to the integrity of the property, so it was rated as 'Indeterminate'.

Further work is needed to confirm some of these ratings of residual risk to specific components or their constituent elements (e.g. particular species, geological structures). It is also unclear how much the 2019-20 fires may have increased the residual risk because of impacts on ecological resilience and modifications to the landscape of the GBMA, especially within the PCIA (Section 4.3.14).

4.3 Key Messages

The main findings of the analyses by Holland et al. (2021) and further work in this desktop analysis are presented as ten key messages (Residual risk ratings are defined in Table 3-2. A residual risk rating is not applicable to the final key message.

Table 4-2). Given the focus of the request by the WHC, attention focuses on the residual risk of potential cumulative impacts of mining on the components of the GBMA's OUV rather than specific stressors or processes. The following subsections (4.3.1-4.3.14) briefly summarise the supporting information for each key message; further details with maps, diagrams of causal pathways and relevant supporting literature are presented in Appendix C.

Residual risk ratings are defined in Table 3-2. A residual risk rating is not applicable to the final key message.

Table 4-2 Key messages (KM) and residual risk ratings on components of OUV.

КМ	Key message	Residual risk
KM1	Up to 1984 km ² of the GBMA could be affected by cumulative impacts of mining in the vicinity of the property if appropriate protection and management measures are not in place. However, most potential impacts are currently effectively mitigated by strict environmental conditions imposed on mine operators.	Low
KM2	The remote, isolated and protected environments in which relict Gondwanan flora occur in the GBMA mean that they are unlikely to be affected by cumulative impacts of mining in the vicinity of the GBMA.	Very low
КМЗ	Physiological adaptation to water-limited and harsh environments means scleromorphic flora of the GBMA can tolerate most mining stressors. Some scleromorphic flora in riparian and wetland habitats that are hydrologically connected to mining areas could be affected across 420 km ² (4%) of the GBMA.	Very low
KM4	Conservation-significant flora in potential cumulative impact areas in the GBMA could be impacted by one or more mining-related stressors. Stringent Australian and NSW government legislation protects these flora by requiring mine proponents to specify avoidance, mitigation and offset options to minimise impacts.	Low
KM5	Conservation-significant fauna occur in potential cumulative impact areas in the GBMA and may be impacted by one or more mining-related stressors. Stringent Australian and NSW government legislation protects these fauna, obligating mine proponents to specify avoidance, mitigation and offset options to minimise impacts.	Low
KM6	The GBMA's geological landscape features and their diversity are at very low risk from the cumulative impacts of mining in the vicinity of the property because (i) most of the features are far from the potential cumulative impact area and (ii) strict mining consent orders now tightly regulate blasting and longwall mining. Historically, subsidence from longwall mining damaged some geological features in and near the GBMA.	Very low
KM7	Water systems in the GBMA are at risk from the cumulative effects of mining in the vicinity of the property on local hydrology and water quality. Current protection and management measures substantially reduce this risk but cannot eliminate the residual risk from mining-induced groundwater drawdown and accidental spills.	Low
KM7.1	Channel form, flows and water quality of some streams and their riparian habitats in the GBMA are at low residual risk from the cumulative effects of mining in the vicinity of the property.	Low
KM7.2	Freshwater wetlands are rare in the GBMA. The Thirlmere Lakes system supports a unique plant assemblage and is a 'coastal freshwater lagoon' near the property's boundary that is potentially threatened by groundwater drawdown from nearby coal mines.	Indeterminate
КМ7.3	Diverse types of swamps, many with endemic and threatened species, occur in the GBMA. One example is the Temperate Highland Peat Swamps on Sandstone (THPSS), some of which have been severely and irreversibly damaged by subsidence and groundwater drawdown on mine lease areas near the GBMA	Low
KM7.4	Groundwater-dependent ecosystems other than rivers and wetlands are poorly known in the GBMA but may be at risk from the cumulative effects of mining in the vicinity of the property on groundwater levels and water quality.	Indeterminate
KM8	The Boundary integrity of the GBMA can be impacted by subsidence damaging escarpments and cliffs, and by clearing or accidental burning of vegetation buffers on mine lease areas that adjoin the GBMA.	Low
KM9	Indigenous custodial relationships within the GBMA are underpinned by components of its OUV. Mining-related stressors that impact components of OUV may also impact Indigenous cultural connections with land and custodial relationships. Consultation with Indigenous custodians was not sufficient to permit a reliable residual risk rating.	Indeterminate
KM10	Bushfires that burnt 71% of the GBMA with varying severity in 2019-20 modified the property's landscape and probably reduced the ecological resilience of the biological components of the OUV to the potential cumulative impacts of mining in the vicinity of the GBMA.	n/a

4.3.1 Potential cumulative impacts of mining across the GBMA

Up to 1984 km² of the GBMA could be affected by cumulative impacts of mining in the vicinity of the property if appropriate protection and management measures are not in place. However, most potential impacts are currently effectively mitigated by strict environmental conditions imposed on mine operators.

Residual risk: 'Low'

Threats

The PCIA from mining near the property is 1984 km² (19% of the GBMA). The area that is actually impacted by nearby mining is probably much smaller because of the current protection and management measures.

The main threats posed by mining to the OUV of the GBMA include altered flows and water regimes, reduced water quality of surface and groundwater, groundwater drawdown, atmospheric pollution (noise, light and dust), ground movements such as subsidence, and the ecological impacts of vegetation clearing outside the property. There are also lesser threats such as increased traffic movement and potentially increased densities of some invasive species.

Pathways

Mining near the GBMA may have cumulative impacts on the eight components of OUV via land, water and atmospheric pathways. Land pathways (e.g. arising from vegetation removal) are usually confined to the mine lease area, sometimes reaching the GBMA boundary but seldom extending more than a few kilometres into the property. Conversely, water pathways for stressors such as groundwater drawdown, altered stream flows and stream contamination may extend many kilometres into the GBMA. Impacts of atmospheric pathways can also extend far into the GBMA. Holland et al. (2021) set the stressor extent of noise and light pollution from industrial machinery at 20 km with high confidence.

Mitigation measures

Strict Australian and NSW government legislation underpin Australia's obligations under the World Heritage Convention and help mitigate the potential cumulative impacts of mining. In NSW, a State Significant Mining Development (SSMD) must now assess 'the likely impacts of all stages (life cycle) of the development, including any cumulative impacts'.

Mitigation measures relevant to specific high-level components of the OUV of the GBMA are detailed in Appendix C (Sections C.2-C.9). Collectively, these measures substantially reduce the residual risk of potential cumulative impacts and protect the property's OUV.

Residual risk

Overall, the residual risk of potential cumulative impacts of existing and planned mines in the vicinity of the GBMA to its OUV is rated 'Low', reflecting the extent and effectiveness of current protection and management measures. For some components of OUV such as Geodiversity, Gondwanan flora and Scleromorphic flora, the residual risk is rated as 'Very low' whereas for the remaining components, it is rated as 'Low' (Table 4-2) or, in two types of Water systems and for Indigenous custodial relationships, 'Indeterminate' where there is too little information to make a judgement.

4.3.2 KM2: Potential cumulative impacts of mining on Gondwanan flora in the GBMA

The remote, isolated and protected environments in which relict Gondwanan flora occur in the GBMA mean that they are unlikely to be affected by cumulative impacts of mining in the vicinity of the GBMA.

Residual risk: 'Very low'

Threats

Extensive rainforests covered most of Australia during Gondwanan times but only remnant patches now remain, including those across about 1% of the GBMA. Several isolated patches are in the PCIA.

Key representatives of the Gondwanan flora in the GBMA are the endemic Wollemi Pine (*Wollemia nobilis*), the Blue Mountains Pine (*Pherosphaera fitzgeraldii*) and *Acrophyllum australe*. The known distribution of the Blue Mountains pine puts it outside the PCIA, while mapping of *Acrophyllum australe* indicates possible occurrences at the margins of the PCIA. The exact location of the only known stand of Wollemi Pine is not in the public domain. It is known to occur in a remote sandstone canyon in the Wollemi NP, and mining is not an identified threat.

This high-level component of the OUV of the GBMA is considered very unlikely to be threatened by mining near the GBMA. The only possible threats may be to those few patches of rainforest in the PCIA that depend on a reliable water supply from perennial seeps, waterfalls and drip zones from surrounding cliffs and rock overhangs. These threats would include mining-related stressors that alter the supply and/or quality of this water, mass movements that may damage rock formations supporting the rainforest patches and their water supplies, and invasive species.

Pathways

The main pathways that may threaten the few patches of Gondwanan flora in the PCIA are those associated with the supply and quality of reliable water to pockets of rainforest. Other pathways include those mediated by mass movements that may damage Gondwanan flora near cliffs and overhangs in response to subsidence and blasting impacts, and the impacts of invasive species whose introduction or spread may be facilitated by nearby mining.

Mitigation measures

The Wollemi Pine, the Blue Mountains Pine and *Acrophyllum australe* are protected under the EPBC Act (Cth) and the BC Act (NSW). Although there is not a formal protection and management strategy for Gondwanan rainforest patches in the GBMA, many of the measures described in the recovery plans for species such as the Wollemi Pine and the Blue Mountains Pine would be appropriate. In the few areas of remnant rainforest in the PCIA, protection and management from potential cumulative impacts of nearby mining may need to compensate for likely reduced ecological resilience of Gondwanan flora resulting from the 2019-20 fires and post-fire impacts such as increased pressure from invasive weeds and *Phytophthora cinnamomi* (a soil-borne pathogen that causes root rot and dieback).

Residual risk

The residual risk from the potential cumulative impacts of mining in the vicinity of the GBMA to Gondwanan flora such as the Blue Mountains Pine and *Acrophyllum australe* is rated as 'Very low' because the pine occurs outside the PCIA and known populations of *Acrophyllum australe* are at the margins of the PCIA. This rating would also apply to patches of Gondwanan rainforest in the GBMA, especially given their very small area of overlap with the PCIA. Mining is not an identified threat to the known stand of Wollemi Pine in a remote canyon in the Wollemi NP.



Young Wollemi Pine. © Department of Agriculture, Water and the Environment

Department of Agriculture, Water and the Environment

4.3.3 KM3: Potential cumulative impacts of mining on Scleromorphic flora in the GBMA

Physiological adaptation to water-limited and harsh environments means scleromorphic flora of the GBMA can tolerate most mining stressors. Some scleromorphic flora in riparian and wetland habitats that are hydrologically connected to mining areas could be affected across 420 km² (4%) of the GBMA.

Residual risk: 'Very low'

Threats

Most of the GBMA is covered by sclerophyllous vegetation, mainly dry sclerophyll forests and wet sclerophyll forests, comprising 85% and 6% of the GBMA respectively. The remaining scleromorphic flora formations comprise heathlands, woodlands, forested wetlands (including riparian zones) and freshwater wetlands. There is almost complete overlap between the PCIA and the distribution of scleromorphic flora in the GBMA.

The main mining-related threats to most scleromorphic flora are from clearing, habitat fragmentation, changes in fire regime and invasive species such as *Phytophthora cinnamomi*, a soil-borne pathogen that causes dieback. The scleromorphic flora of forested wetlands and freshwater wetlands may also be threatened by changes in hydrology and water quality of their associated water systems.



Wet sclerophyll forest in the GBMA © Department of Agriculture, Water and the Environment

Department of Agriculture, Water and the Environment

Pathways

The pathways via which potential cumulative impacts of mining near the GBMA could affect this high-level component of the OUV of the property are: (i) accidental ignition leading to bushfires moving from the mine lease area into the GBMA, (ii) dispersal of invasive species into the GBMA, and (iii) alterations to flow, volumes and water quality of water systems in the GBMA.

The accidental ignition pathway is more likely for mine lease areas that share a boundary with the GBMA but cannot be ruled out for non-adjoining mines if conditions such as fuel load and wind strength and direction are suitable. Dispersal of invasive species from mine lease areas is also more likely if these areas adjoin the GBMA. Scleromorphic flora in forested wetlands and freshwater wetlands of the GBMA that are hydrologically connected to mining areas near the property could be impacted via water pathways that affect streamflow, groundwater level and/or water quality.

Mitigation measures

In addition to the GBMA's protection as an MNES (Section 2.5.1), threatened species of scleromorphic flora are protected from potential impacts of mining under the EPBC Act (Cth) and the BC Act (NSW). All mine sites have strict procedures to manage fire risk and invasive species so these are unlikely to spread to the GBMA. Mitigation measures to protect Water systems and their associated vegetation communities are detailed in Sections C.7 and C.7.1-C.7.4.

Residual risk

The residual risk from the potential cumulative impacts of mining near the GBMA to Scleromorphic flora is rated as 'Very low' because (i) most scleromorphic flora in the GBMA occur outside the PCIA and (ii) few scleromorphic flora within the PCIA are heavily dependent on streams and groundwater. The higher potential residual risk to water-dependent scleromorphic flora in aquatic habitats is reflected in the 'Low' rating for Water systems (KM 7).

4.3.4 KM4: Potential cumulative impacts of mining on Conservationsignificant flora in the GBMA

Conservation-significant flora in potential cumulative impact areas in the GBMA could be impacted by one or more mining-related stressors. Stringent Australian and NSW government legislation protects these flora by requiring mine proponents to specify avoidance, mitigation and offset options to minimise impacts.

Residual risk: 'Low'

Threats

Conservation-significant flora are well-represented in the GBMA. Over 80 flora species and 15 TECs listed as threatened under the EPBC Act (Cth) are known or likely to occur in the GBMA. Of these, at least 40 species and seven TECS are known or likely to occur in the PCIA. Under the BC Act (NSW), 32 endangered ecological communities and more than 110 threatened species are known or likely to occur in the GBMA. It is not known how many of these are likely to occur in the PCIA.

Threats to these TECs include clearing, soil erosion and habitat degradation, introduction of weeds and disease, changes in fire regime and climate change. Other mining-related threats that would be particularly relevant to TECs dependent on surface water or groundwater include altered flows, changes to downstream water quality and/or lowering of watertables.

These threats are also relevant to species of conservation-significant flora but vary according to each species' water requirements, habitat preferences and tolerance of fire. This last threat is particularly relevant because the 2019-20 fires likely eliminated or severely reduced remnant patches of many species of conservation-significant flora in the GBMA (Section 4.3.14).



Dwarf kerrawang (*Commersonia prostrata*), a conservation-significant species found at Thirlmere Lakes. Source: Martin Krogh, NSW Department of Planning, Industry and Environment

Pathways

The main pathways for potential cumulative impacts of mining near the GBMA to affect conservation-significant flora in the property are: (i) invasive species spreading from mining lease areas into the GBMA, (ii) accidental ignition leading to bushfires moving from the mine lease area into the property, and (iii) alterations to flows, volumes and quality of surface water and groundwater in the GBMA.

Mitigation measures

Conservation-significant flora and TECs are protected under the EPBC Act (Cth) and the BC Act (NSW). When a species or community is listed under one of these Acts, its protection and recovery are promoted using conservation advice and recovery plans and through the assessment and approval provisions for developments such as mining (Section 2.5). Actions that are likely to have a significant impact on a listed threatened species or ecological community cannot commence without approval from the Australian or NSW Government.

Residual risk

The residual risk of mining near the GBMA to conservation-significant flora and TECs that occur in the PCIA is rated as 'Low' because of the stringent protection and management measures specified by the EPBC Act (Cth) and BC Act (NSW) and described in relevant conservation advice and recovery plans. As it is unlikely that any conservation-significant flora species only occur in the PCIA, there are potential 'insurance populations' outside the PCIA if mining-related impacts threaten species and TECs within the PCIA. This assumes the 2019-20 fires did not eliminate any species or 'insurance' populations.

4.3.5 KM5: Potential cumulative impacts of mining on Conservationsignificant fauna in the GBMA

Conservation-significant fauna occur in potential cumulative impact areas in the GBMA and may be impacted by one or more mining-related stressors. Stringent Australian and NSW government legislation protects these fauna, obligating mine proponents to specify avoidance, mitigation and offset options to minimise impacts.

Residual risk: 'Low'

Threats

More than 400 vertebrate taxa and many thousands of invertebrate species have been recorded in the GBMA. Of these, 39 species are listed as threatened under the EPBC Act (Cth) and 67 are listed as threatened under the BC Act (NSW).

The main threats to Conservation-significant fauna are habitat loss, fragmentation and/or degradation; competition or predation by invasive species; impacts on water systems such as altered streamflow, falling groundwater levels and changes in water quality; death or habitat loss through fire; and noise and light pollution. Threats to the Gondwanan flora and Scleromorphic flora components of the OUV of the GBMA also threaten the fauna that use these components for habitat, food or movement corridors. Conservation-significant fauna in the GBMA's water systems are threatened by mining impacts such as altered streamflows, falling groundwater levels and reduced water quality.

Some faunal taxa are vulnerable to light and noise pollution. Artificial light at night can disrupt behaviour of nocturnal species, and noise may affect some wildlife by interfering with communication, masking sounds of approaching predators, and causing elevated stress levels.



Blue Mountains water skink (*Eulamparis leuraensis*), a conservation-significant species associated with peat swamps in the GBMA. Source: Martin Krogh, NSW Department of Planning, Industry and Environment

Pathways

The pathways for potential cumulative impacts of mining near the GBMA to affect Conservationsignificant fauna in the property are the same as those for Conservation-significant flora, with the addition of pathways for impacts of noise and light pollution. The shared pathways are those that may affect habitats or food resources whereas noise and light pollution are only likely to disrupt fauna.

Mitigation measures

The same Australian and NSW government legislation and other measures protecting Conservation-significant flora applies to Conservation-significant fauna. Measures to minimise impacts of mine lighting on surrounding areas include use of low-level lighting and directional lighting to minimise sky glow; strategic tree plantings to screen lit areas; and ensuring light beams in mine pits are below the pit wall. Impacts of noise on surrounding areas are mitigated by limiting noise and hours of mining operations.

Residual risk

The residual risk to Conservation-significant fauna in the GBMA is rated as 'Low'. This rating is based on the strict conditions of approval for mines operating near the GBMA boundary and the fact that populations of most conservation-significant fauna of the GBMA are highly likely to occur outside the PCIA.

4.3.6 KM6: Potential cumulative impacts of mining on Geodiversity in the GBMA

The GBMA's geological landscape features and their diversity are at very low risk from the cumulative impacts of mining in the vicinity of the property because (i) most of the features are far from the potential cumulative impact area and (ii) strict mining consent orders now tightly regulate blasting and longwall mining. Historically, subsidence from longwall mining damaged some geological features in and near the GBMA.

Residual risk: 'Very low'

Threats

The GBMA contains many valued geological features and landscapes, including sandstone plateaus that are dissected by deep canyons with dramatic cliffs that dominate much of the landscape; the pagoda rocks in the Gardens of Stone National Park and adjoining Newnes, Airly and Genowlan plateaus; and the karst landscapes, which contain the world's oldest open cave system, the Jenolan Caves. Several threatened plant species and many Indigenous rock art sites occur amongst the pagoda rocks.

The principal mining-related threat to the geodiversity of the GBMA is structural damage caused by extraction methods such as longwall mining and blasting. This damage may lead to rock topples and landslides, potentially impacting cliff habitats (e.g. for bats and cliff-nesting birds), hanging swamps, river canyons and Indigenous rock art and habitation sites.



Pagoda rocks near Currant Mountain Gap in the GBMA. Photo: Barry Collier, NSW Department of Planning, Industry and Environment

Pathways

The two principal pathways via which mining near the GBMA may impact on its geodiversity are via ground movements (subsidence and upsidence from underground mining) and blasting (from open-cut mining). Subsidence occurs when the overburden above a mined longwall panel collapses into the void left by the excavated coal. Other ground movements such as upsidence (when rocks are forced upwards by faults during or after longwall mining) are less common but may occur in some geological formations such as plateaus and rock pavements. Blasting at open-cut mining operations can generate ground waves that may exploit existing weaknesses (e.g. joints and fractures), destabilise features such as pagoda rocks or initiate new weaknesses in rock structures.

Mitigation measures

Strict Australian Government and state regulations govern blasting operations for all mining and constrain how far ground vibrations are allowed to extend beyond the mine lease. These include measures such as orienting the blast face to direct energy away from sensitive sites and coordinating blasting schedules with adjoining mines to minimise cumulative impacts. The management of subsidence related to underground coal mining operations is also a key focus of the NSW government's regulation of mining. Mitigation measures include providing setbacks of longwall panels and pits from sensitive rock features and the use of partial extraction methods to reduce subsidence.

Residual risk

The residual risk of potential cumulative impacts of mining near the GBMA to its geodiversity is rated as 'Very low'. This rating was assigned because (i) most of the mines around the GBMA are further than 1 km from the property's geological features, exceeding the expected range of these types of impacts, and (ii) strict regulations currently control blasting and subsidence associated with mining.

4.3.7 KM7: Potential cumulative impacts of mining on Water systems in the GBMA

Water systems in the GBMA are at risk from the cumulative effects of mining in the vicinity of the property on local hydrology and water quality. Current protection and management measures substantially reduce this risk but cannot eliminate the residual risk from mining-induced groundwater drawdown and accidental spills.

Residual risk: 'Low'

Threats

Water systems in the GBMA include rivers, streams, wetlands, swamps, waterfalls and groundwater features expressed at the surface. Holland et al. (2021) estimate the area of water systems in the GBMA to be 2260 km². They are threatened by mining-related activities that may alter the volumes, frequency and timing of flows, change sediment regimes and other geomorphological features, crack stream beds and the bases of swamps, cause mass movement (e.g. cliff collapses and landslides into water systems), damage the integrity of riparian zones, alter the water regimes of standing waters, lower the water table (groundwater drawdown), and/or decrease water quality.

Potential impacts are expected to vary depending on the type of water system. The following are considered in separate key messages:

- i) streams and riparian habitats (KM7.1)
- ii) freshwater wetlands, exemplified by Thirlmere Lakes (KM7.2)
- iii) swamps, exemplified by Temperate Highland Peat Swamps on Sandstone (KM7.3) and
- iv) other groundwater-dependent ecosystems (KM7.4)

Pathways

Multiple pathways from mines in the vicinity of the GBMA lead to potential cumulative impacts on the property's water systems. They vary in their risk for different water systems and are strongly influenced by the hydrogeological context and drainage characteristics around individual mine sites.

Holland et al. (2021) estimate about 420 km² (19%) of the GBMA water systems could be affected by cumulative impacts of existing and planned mines in the vicinity of the property. Most of this area is streams and riparian habitats (Section 4.3.8).

Mitigation measures

Stringent legislation at Australian Government and state levels, along with close scrutiny of EISs by relevant agencies, an independent expert scientific committee and, sometimes, independent state panels help ensure maximum protection and effective mitigation of mining-related impacts on water systems, especially those in the GBMA. Remediation of some impacts (e.g. cracked streambeds, groundwater drawdown) is seldom feasible which means that avoidance and mitigation measures are crucial.



Leura Cascade, part of a water system in the GBMA. © Department of Agriculture, Water and the Environment

Residual risk

The residual risk of potential cumulative impacts of mines near the GBMA to its Water systems is rated as 'Low'. Residual risks of altered flows, streamflow contamination, and impacts from cliff collapse and rockfalls are all rated as 'Low'. The residual risk of groundwater drawdown under some parts of the GBMA is rated as 'Moderate' because it cannot be remedied, is difficult to avoid or mitigate without changing the mine layout, and can be exacerbated by legacy impacts of previous groundwater extraction (including mines that have ceased operation).

4.3.8 KM7.1: Potential cumulative impacts of mining on streams and riparian habitats in the GBMA

Channel form, flows and water quality of some streams and riparian habitats in the GBMA are at low residual risk from the cumulative effects of existing and planned mines in the vicinity of the property.

Residual risk: 'Low'

Threats

Most of the estimated 420 km² of water systems in the PCIA (Holland et al. 2021) is streams and riparian habitat. Streams flowing into the GBMA from mined catchments can act as conduits for mining-related threats into the property, potentially up to 40 km away. Rivers in the GBMA that are potentially impacted by mining include the Wollongambe, Wolgan and Coxs rivers, and Tinda Creek.

Threats from mining-related activities to some of the GBMA's streams and riparian habitats include altered flow and sediment regimes, damage to channel form and integrity (e.g. cracked stream beds), lowered water tables and decreased water quality. Mine wastewater discharges can contain heavy metals and other contaminants that may accumulate in stream sediments and their biota, potentially posing a threat to adjacent terrestrial ecosystems where bioaccumulation may occur.



Wolgan River and riparian area in the GBMA. Photo: Rosie Nicolai, NSW Department of Planning, Industry and Environment

Pathways

The main pathways for impacts on streams and riparian habitats are those that alter streamflow, water quality or groundwater conditions. Blasting and subsidence can trigger mass movements such as landslides that impede stream flow, destabilise riverbanks, and damage riparian zones. Underground mining can cause subsidence that may crack streambeds and divert stream water to near-surface groundwater. Groundwater drawdown from mine dewatering can reduce or eliminate baseflows. Mine water discharge, extraction of surface water or interception of runoff all may alter stream flows, with repercussions for aquatic biota and riparian habitats.

Accidental spills and mine wastewater contaminated with coal fines, heavy metals, hydrocarbons and other pollutants can enter GBMA streams. Contaminated water may leach from poorly managed mine waste areas (e.g. tailings dams) and pollute groundwater. Groundwater contamination can also occur when polluted stream water infiltrates shallow unconfined aquifers below the streambed.

Mitigation measures

Numerous legislative controls prevent or mitigate environmental impacts of mining on streams and riparian habitats. Avoidance options include not permitting a mine to extract water from or discharge wastewater into streams that flow into the GBMA. Surface water management systems must meet industry standards in the design and construction of tailings dams to minimise the risk of spills. Stringent regulations govern underground mining to reduce subsidence, especially as remediation of its impacts on streams is seldom successful. Impacts of groundwater drawdown can be partly mitigated by modifying the mine layout and dewatering regime.

Residual risk

The residual risk of potential cumulative impacts of mining near the GBMA to its streams and riparian habitats is rated as 'Low' because current national and state regulations protecting waterways from mining and other activities substantially reduce the residual risks of groundwater drawdown, altered flows and contamination, especially in World Heritage properties.

4.3.9 KM7.2: Potential cumulative impacts of mining on freshwater wetlands (Thirlmere Lakes) in the GBMA

Freshwater wetlands are rare in the GBMA. The Thirlmere Lakes system supports a unique plant assemblage and is a 'coastal freshwater lagoon' near the property's boundary that is potentially threatened by groundwater drawdown from nearby coal mines.

Residual risk: 'Indeterminate'

Threats

Less than 0.5% of the area of the GBMA is covered by freshwater wetlands. Here, we focus on the Thirlmere Lakes system, a 'coastal freshwater lagoon' potentially threatened by groundwater drawdown because it lies near the boundary of the property adjoining the Southern Coalfield mines. The threats, pathways and mitigation measures described here apply to other wetlands in the PCIA.

Thirlmere Lakes are a complex of five freshwater lakes that contain diverse wetland vegetation associations, including the *Lepironia* freshwater wetland community listed as an Endangered Ecological Community under the BC Act (NSW). The wetlands also contain a number of rare and threatened plant species, such as Dwarf Kerrawang (*Commersonia prostrata*), Tall Knotweed (*Persicaria elatior*) and Water Shield (*Brasenia schreberi*).

The main threats to the Thirlmere Lakes and their associated ecological communities are declining water levels, fire and invasive species. Over the last half-century, water levels have fallen in the Lakes, attributed to changes in climate and groundwater drawdown (including from



Thirlmere Lakes – a freshwater wetland in the GBMA. Photo: Ian Brown, NSW Department of Planning, Industry and Environment

mining operations). However, there is substantial uncertainty whether lake water levels depend on a groundwater connection, whether faults might act as conduits for groundwater drawdown impacts from further afield, and whether drawdown for mining and non-mining purposes threatens the Lakes.

Pathways

The primary pathway via which mines near the GBMA could impact Thirlmere Lakes is groundwater drawdown caused by groundwater pumping. It is potentially enhanced by subsidence-induced fracturing that contributes to increased connectivity between the pumped aquifer and the water table. This pathway presupposes that the Lakes are connected to groundwater and can be impacted by groundwater lowering.

Mitigation measures

The Thirlmere Lakes National Park Plan of Management outlines mitigation measures to protect Thirlmere Lakes. Choice of these measures depends on establishing the potential mining-related risks to the Lakes, especially of any proposed expansions of mining nearby. To better understand the hydrology of the Lake system, the Thirlmere Lakes Research Program (due to end in 2021) has been funded by the NSW government. Meanwhile, conditions of consent for any expansion of mining require more extensive monitoring and further groundwater modelling.

Residual risk

The lack of understanding about the hydrology and groundwater connectivity leads to a rating of 'Indeterminate' residual risk from mining near the GBMA. If it can be demonstrated that there are structural connections (potentially enhanced by subsidence) between the mined area and the Lakes, then there is a 'Moderate' residual risk that further declines in water levels are likely and, given the limited mitigation and remediation options, will impact on water levels and the Lakes' biota.

4.3.10 KM7.3: Potential cumulative impacts of mining on swamps (Temperate Highland Peat Swamps on Sandstone) in the GBMA

Diverse types of swamps, many with endemic and threatened species, occur in the GBMA. One example is the Temperate Highland Peat Swamps on Sandstone (THPSS), some of which have been severely and irreversibly damaged by subsidence and groundwater drawdown on mine lease areas near the GBMA.

Residual risk: 'Low'

Threats

In addition to 'coastal freshwater lagoons' (Section 4.3.9), the GBMA has two other wetland types: 'coastal heath swamps' and 'montane bogs and fens'. Both these support diverse assemblages of plants, including three TECs. Many of the swamps and their plants depend on groundwater (e.g. 'hanging swamps' that occur on steeper valley sides associated with groundwater seepage). The two wetland types encompass the Temperate Highland Peat Swamps on Sandstone (THPSS) ecological community, listed as an Endangered Ecological Community under the EPBC Act (Cth). As there has been much research on the impacts of mining, potential for recovery and options for mitigation for THPSS, we focus on this type of swamp here.

Mining-related threats to swamps include subsidence-induced fracturing and tilting of underlying sandstone, subsidence-induced valley closure and cliff collapse in steep terrain, altered water regimes, and water quality impacts from discharge of mine waste water. Another threat is fire, potentially arising from accidental ignition on a mine site but more common as bushfires started by lightning. Where THPSS and other peat swamps have been fully or partly dried out, damage by bushfires can be particularly severe. Although serious ecological impacts on THPSS have resulted from subsidence and subsequent drying, these have not occurred in THPSS in the GBMA.



Newnes Plateau Swamp endangered ecological community (NSW BC Act) in flower. Photo: Ian Baird

Pathways

The two principal pathways for mining-related impacts on swamps, particularly THPSS, are via: (i) subsidence caused by underground mining where ground movements result in a loss of stored water, and (ii) discharge of contaminated water in surface waters entering the swamps. Other pathways include groundwater drawdown caused by pumping, mass movement such as cliff collapse resulting from blasting (which can affect 'hanging swamps' in steep terrain), reduced streamflow into swamps where subsidence-induced cracking of stream beds drains away inflowing water, and any alterations to streamflow that may cause scouring or sedimentation of swamps downstream.

Mitigation measures

The best way to protect THPSS from subsidence is by avoiding underground mining below or near these swamps and their inflows. Where this cannot be done, partial extraction methods can be used to ensure subsidence in swamp areas does not exceed 20 mm. The risk from mine water discharges on THPSS can be avoided by not permitting water to be discharged into swamps or into streams that flow into these swamps. Mine sites also have strict measures to avoid fires from accidental ignition.

Residual risk

The residual risk of potential cumulative impacts of mining near the GBMA to its THPSS and other swamps is rated as 'Low'. This rating reflects the current strict regulations and conditions of consent that protect THPSS on mine leases near the GBMA and acknowledges the lack of remediation options once a swamp is damaged.

4.3.11 KM7.4: Potential cumulative impacts of mining on other GDEs in the GBMA

Groundwater-dependent ecosystems other than rivers and wetlands are poorly known in the GBMA but may be at risk from the cumulative effects of mining in the vicinity of the property on groundwater levels and water quality.

Residual risk: 'Indeterminate'

Threats

Groundwater-dependent ecosystems (GDEs) are ecosystems that need access to groundwater to meet all or some of their water requirements to maintain their communities, ecological processes and ecosystem services. Although some elements of the Water systems discussed so far are GDEs, there are other GDEs such as aquifers and saturated cave ecosystems. These are poorly known in the GBMA but may support stygofauna (specialised invertebrates that live permanently in groundwater) and active microbial assemblages. There is also likely to be other groundwater-dependent vegetation in the property that is not associated with rivers, wetlands or swamps.

The main threats to GDEs are alterations of the natural patterns of seasonal or annual availability of groundwater, dewatering of parts of aquifers for long periods (severing ecological connectivity and depriving stygofauna of saturated habitat), and/or reductions in groundwater quality. Groundwater-dependent vegetation is also threatened by the same stressors that impact other terrestrial vegetation such as fire, habitat fragmentation and invasive species (Sections 4.3.2 and 4.3.3).

Pathways

The main pathways by which mining near the GBMA boundary may impact other GDEs such as aquifers, saturated cave systems and groundwater-dependent terrestrial vegetation are groundwater drawdown from pumping or subsidence, and groundwater contamination from either accidental waste spills or intentional discharge of contaminants into a stream that eventually enter the groundwater. Blasting and subsidence may cause mass movements that could alter aquifer integrity or saturation, and impact on the GDEs.

Mitigation measures

As described in Sections 4.3.8-4.3.10, stringent regulations and conditions of consent are imposed on mines near the GBMA's boundary to limit the extent of groundwater drawdown and potential contamination. However, dewatering of mines inevitably leads to some drawdown which is likely to be cumulative in areas where multiple mines occur. The importance, ubiquity and conservation values of GDEs have only been recognised in the last decade or so, and there are now more mitigation strategies to avoid or minimise impacts on groundwater levels and water quality. These complement the strict conditions governing releases of mine wastewater and limiting the risks of accidental spills and leaching from mine waste areas such as tailings dams.

Residual risk

The residual risk of potential cumulative impacts of mines near the GBMA to the GDEs discussed here is rated as 'Indeterminate' because of the lack of knowledge about their distribution in the

PCIA and the rest of the GBMA. As the PCIA does not overlap with the Jenolan Caves area, the residual risk of mining near the GBMA to this GDE is rated as 'Very low'. Reliable baseline data on the distribution of GDEs in the GBMA will help refine the assessment of residual risk.

4.3.12 KM8: Potential cumulative impacts of mining on Boundary integrity in the GBMA

The Boundary integrity of the GBMA can be impacted by subsidence damaging escarpments and cliffs, and by clearing or accidental burning of vegetation buffers on mine lease areas that adjoin the GBMA.

Residual risk: 'Low'

Threats

Boundary integrity refers to the characteristics of the GBMA's boundary such as native vegetation and rocky escarpments that help buffer the unique ecosystems, their biota and their ecological processes from the effects of land uses outside the property. When listed in 2000, the GBMA lacked a formal buffer zone despite this being a key part of the conservation strategy of World Heritage properties. Fortuitously, about 670 km (13%) of the boundary adjoins national parks, conservation and nature reserves and these provide valuable protection to the GBMA. However, around 50 km of the 5160-km long boundary abuts mine-lease areas (excluding quarries).

Threats to boundary integrity arise where a mine removes vegetation along the GBMA boundary or causes a fire that damages this vegetation. Another threat is where rockfalls and landslides along the property boundary might be initiated by blasting and underground mining leading to subsidence. Impairment or loss of boundary integrity increases the risk of invasive species entering the GBMA, reduces connectivity for populations of mobile native fauna and compromises beneficial ecosystem processes provided by adjoining native vegetation (e.g. recruitment from seed banks).

Pathways

Vegetation removal and accidental ignition leading to fire are the key pathways via which mining can reduce boundary integrity. In both cases, there is only an impact if the action results in vegetation degradation or loss along the GBMA boundary. New mining developments invariably require clearing of vegetation for access roads, mine pits, site facilities and other infrastructure. This vegetation removal leads to habitat loss as well as increasing edge effects that may impact remaining habitats. These increased edge effects may facilitate incursion of weeds and other invasive species from disturbed areas during and after mining that further disrupts boundary integrity.

Subsidence and blasting effects are also possible pathways for mining to impact boundary integrity, primarily through reducing the stability of escarpments. Mass movements causing cliff collapses and landslides along the property boundary can compromise natural barriers around the property, remove vertical rocky habitats and open up pathways for weeds and other invasive species.

Mitigation measures

Management of the removal of native vegetation on mining sites is regulated by the development consent process under the EP&A Act (NSW). The NSW guidelines for managing development next to NSW national parks and World Heritage properties recommend that site layouts be designed with vegetated buffers and setbacks to mitigate impacts on adjacent parks.

Leaving a buffer can be specified as a condition of consent. Mitigation measures have already been described to minimise the risk of accidental ignition (Section 4.3.3) and subsidence and blasting (Section 4.3.6).

Residual risk

The residual risk to the Boundary integrity of the GBMA is rated as 'Low'. This rating reflects the spatial overlap of this component with the PCIA and the strict conditions of approval imposed on mines operating near the GBMA boundary.



Narrow Neck Plateau on the boundary of the GBMA © Department of Agriculture, Water and the Environment

4.3.13 KM9: Potential cumulative impacts of mining on Indigenous custodial relationships in the GBMA

Indigenous custodial relationships within the GBMA are underpinned by components of its OUV. Mining-related stressors that impact components of OUV may also impact Indigenous cultural connections with land and custodial relationships. Consultation with Indigenous custodians was not sufficient to permit a reliable rating of residual risk.

Residual risk: 'Indeterminate'

Threats

Indigenous custodial relations and Indigenous heritage values, which contribute to the integrity of the GBMA, are broadly conceived in terms of tangible elements (e.g. culturally significant sites and species) and intangible values relating to cultural connections to Country. Any degradation or loss of ecosystems, communities and species can impact these tangible and intangible components. The GBMA has more than 1500 culturally significant sites including occupation sites (caves, shelters and hearths), grinding grooves, scar trees, rock art and natural landscape features that are integral to Indigenous connections to Country.

Threats to the seven other high-level components of the OUV of the GBMA also likely threaten Indigenous custodial relationships because of the many cultural connections to Country that include intimate ties to the environment, its geodiversity and its flora and fauna. One threat that has not been mentioned for the other high-level components of OUV is air pollution, specifically from dust generation by mining. Dust can accumulate in sheltered locations and become incorporated in surface mineral deposits that obscure or compromise rock art.

Pathways

All pathways via which mining near the GBMA can impact the other high-level components of OUV and their elements (Sections 4.3.1-4.3.12) may potentially impact Indigenous custodial relationships within the GBMA. One other pathway is via air pollution (predominantly dust) which can threaten rock art. Dust is generated during operations at open-cut coal and sand mines. It also comes from traffic movement on unsealed roads around the site and potentially from poorly managed waste piles and cleared areas.

Mitigation measures

The NPW Act (NSW) provides for the protection and management of Aboriginal heritage places and objects in NSW. In relation to mining, the Act requires proponents to undertake an Aboriginal archaeology and cultural impact assessment to identify risks and, if needed, prepare a management plan describing the intended mitigation measures to protect sites and objects. Dust accumulation on rock art can be treated but must be done carefully to avoid damaging the artwork. Strict air quality standards and regulatory frameworks help minimise the level of dust and other air-borne particulates produced by mines. Operations are planned and conducted to minimise dust generation, stockpiles are sprayed with water, and water carts keep unpaved roads damp to limit dust.

Residual risk

The residual risk of cumulative impacts of nearby mining on Indigenous custodial relationships in the GBMA, important to the integrity of the property, is rated as 'Indeterminate'.
This rating reflects the need to engage further with Indigenous stakeholders to better understand the risks to this high-level component of OUV. Although regulatory controls exist to protect Indigenous heritage, places and objects, the residual risk from mining on Indigenous custodial relationships with the GBMA remains unclear.



Post-fire regrowth in the GBMA © Department of Agriculture, Water and the Environment

Department of Agriculture, Water and the Environment

4.3.14 KM10: Implications of the 2019-20 bushfires on the potential cumulative impacts of mining near the GBMA on the eight high-level components of OUV

Bushfires that burnt 71% of the GBMA with varying severity in 2019-20 modified the property's landscape and probably reduced the ecological resilience of the biological components of the OUV to the potential cumulative impacts of mining in the vicinity of the GBMA.

Between October 2019 and February 2020, multiple bushfires burnt 71% of the GBMA's area with varying severity (Figure C-24). These fires killed countless plants and animals, dislocated many others and – because of their extent and intensity – substantially modified the landscape of the GBMA. These landscape modifications included destruction of habitat and food resources for many animal species (some of which are Conservation-significant fauna, Section 4.3.5) and severe reduction or loss of large stands of native vegetation, including some species and associations of Conservation-significant flora (Section 4.3.4).

Short-term declines in air quality may have had severe impacts on wildlife that escaped the fire. Widespread starvation is also highly likely because the loss of vegetation, leaf litter and woody debris across most of the burnt area severely reduced food resources and habitat for many species. To combat this food shortage for native wildlife, aerial food drops (e.g. carrots, sweet potatoes) were repeated across some parts of the GBMA soon after the fires. Loss of cover also destroyed nesting sites and increased many species' vulnerability to predation and exposure.

In severely and moderately burnt areas of the GBMA, large expanses of bare ground covered in ash and charcoal were left. Heavy rains following the fires would have mobilised fine sediments, ash and charred organic matter that then entered waterways, clogging their beds and threatening water quality. As microbes break down the pulse of organic matter washed into the waterways, dissolved oxygen concentrations plummet and probably led to deaths of fish and other aquatic life. Further post-fire impacts on aquatic life in the GBMA's waterways may include clogging of gills, smothering of food sources and reduction of light penetration into the water.

All these fire-induced landscape modifications are likely to reduce the overall ecological resilience of biological components of the GBMA, including to the potential cumulative impacts of mines near the property. Where burnt areas overlap those areas subject to one or more stressors associated with mining, the cumulative impact may be the difference between recovery or loss of a given habitat or species in the GBMA. We have no direct evidence of this but it deserves further investigation (Section 5.5).

Post-fire impacts are still being evaluated in the GBMA, but there are serious concerns about the long-term survival of some species and communities. One study (Smith 2020) estimated over 110 million mammals, birds and reptiles in the GBMA were impacted by the fires. However, fires also benefit many taxa and are a natural component of most Australian ecosystems. The GBMA lies in one of the most fire-prone regions in the world. Many of its scleromorphic plants depend on fire to break seed dormancy, release seeds from woody cones, stimulate flowering and create the conditions needed to thrive (Hammill and Tasker 2010). The impacts of fire are not easily predicted because they depend on the timing, intensity and scale of fire as well as the area's fire history. Importantly, exposure to other stressors affects ecological resilience to fire,

and communities that under normal conditions would recover well from a fire can show poor levels of recovery when their condition has been degraded by other stressors, including mining.

This is illustrated for post-fire recovery of vegetation of the THPSS ecological community on the Newnes Plateau (Baird and Benson 2020). After the 2019-20 bushfires, recovery rates of intact swamps differed dramatically from those of swamps undermined by coal mines. The 2019-20 fires were followed by good rain in February and March 2020, and vegetation recovery in intact reference swamps was rapid and vigorous with little evidence of combustion of surface peat. However, in swamps outside the GBMA that have been undermined by longwall coal operations, Baird and Benson (2020) report that the effect of the fires has been catastrophic. Undermined swamps tend to be characterised by lower water tables and desiccated peaty swamp soils. The fires have burnt the surface peat and the root bases within it, destroying crucial seed banks. Lack of moisture in the swamp soils prevents many typical swamp species from recruiting. Instead, there has been recruitment of non-swamp eucalypt and acacia seedlings in the undermined swamps, reflecting a shift from groundwater-dependent to rainfall-dependent vegetation and the loss of the characteristic plant associations of THPSS.

Superimposing the PCIA of stressors associated with existing and planned mines in the vicinity of the GBMA on top of the map of areas burned in 2019-20 fires (Figure C-24) indicates extensive areas of high- and very high-severity burns in the Blue Mountains and Gardens of Stone NPs near Western Coalfield mining operations and in the Wollemi and Yengo NPs around Tinda Creek sand quarry. Catchments of many rivers entering or within the GBMA were partially or largely burnt, and resulting changes to the waterways may exacerbate the impacts of mining-related stressors on affected Water systems. Approximately 42% of the boundary was burned to varying degrees of severity, often overlapping with areas already potentially impacted by mining and possibly compromising Boundary integrity. Further work (Section 5.5) is needed to assess the potential cumulative impacts of mining and burning on these and the other high-level components of OUV.

Various options exist to reduce the severity and intensity of bushfires (e.g. fuel reduction burns, maintaining fire breaks) but these can be overwhelmed by climatic events as seen in 2019-20 across much of eastern Australia. During the fires, there were strategic and often courageous fire-fighting attempts to protect irreplaceable natural assets (e.g. relict stands of Wollemi Pine) as well as infrastructure and human dwellings. Post-fire remediation measures include stabilising burnt areas, reducing or preventing sediment runoff, feeding native wildlife and rescuing injured animals. Given the likely increases in bushfire frequency and severity associated with future climatic conditions predicted for the GBMA region in coming decades, measures for avoiding or mitigating mining-related impacts should complement those planned for reducing impacts of extreme bushfires.

5 Discussion

5.1 Summary of main findings

Eight high-level components of the GBMA's Outstanding Universal Value (OUV) were chosen to represent its natural heritage values and integrity. Fifteen existing and planned open-cut and underground coal mines and three sand mines within 20 km of the GBMA were identified as potential threats to these high-level components of its OUV.

The regional analysis of risk to the OUV of the GBMA estimated that *in the absence of any protection and management measures* to minimise the likelihood of environmental impacts, up to 20% of the GBMA (1984 km²) could be impacted by the cumulative effects of existing and planned mining in the vicinity of the GBMA (Holland et al. 2021). This potential cumulative impact area (PCIA) is largely defined by the extent of: (i) potentially significant groundwater drawdown, which is assumed to extend up to 20 km from the mine footprints; and (ii) effects on streamflow, which are assumed to be potentially significant up to 40 km from the mine sites in some areas. It must be emphasised that this PCIA is a 'worst-case scenario' that encompasses the maximum area where impacts of nearby mining may occur in the absence of any protection and management measures.

Within the PCIA, the potential for significant impacts is largely confined to stream corridors and groundwater-dependent ecosystems (GDEs), corresponding to the Water systems high-level component of OUV. Across the remaining 80% of the PCIA, significant impacts on the OUV of the GBMA are assessed as very unlikely (Holland et al. 2021).

Smaller extents were assumed for significant impacts from the other mine stressors. The likelihood of multiple, overlapping stressor effects is greatest at the margins of the GBMA where mine lease areas adjoin the property. Localised areas (<5%) of Boundary integrity could be impacted by clearing or accidental burning of vegetated buffers on the six mine lease areas that adjoin the GBMA. There may also be damage to boundary escarpments from ground movements associated with subsidence and blasting.

Most of these potential impacts are managed and mitigated through Australian and NSW government legislation intended to protect the GBMA and its biodiversity values, and to regulate the environmental assessment requirements and performance standards for mining approvals. Such protection and management measures are expected to markedly reduce the PCIA. Quantifying this reduced area – the probable maximum extent of the PCIA when effective mitigations are in place – was not possible from the current desktop analysis. To ascertain this area, adequate field data on appropriate environmental and cultural parameters, collected over a suitable time period, are needed (Section 5.5).

Residual risk is the risk remaining after all legislated protection and feasible management measures have been applied to avoid or mitigate impacts on valued assets. It was rated as 'Very low' or 'Low' for potential cumulative impacts of mining near the GBMA for seven of the eight high-level components of OUV, and 'Indeterminate' for Indigeneous custodial relationships because consultation with Indigenous custodians was not sufficient to permit a reliable rating. Three of the seven high-level components of OUV were assessed as unlikely to be significantly impacted by cumulative impacts of mining because of geographic location, insensitivity to stressor effects and/or effective management. The remaining four – Water systems, Conservation-significant flora, Conservation-significant fauna and Boundary integrity – could be impacted within six discrete areas of the GBMA by existing or planned mines near the property.

The severe bushfires in 2019-20 on the GBMA are likely to exacerbate the potential cumulative impacts of mining near the property. Although it was not part of the scope of the current desktop assessment to quantify this influence, evidence is emerging that some habitats, such as swamps, impacted by mining are recovering more slowly than their unmined counterparts (Section 4.10). Field data and targeted survey work are needed to assess the magnitude of this influence and identify where specific management and remediation may be needed. It would also be useful to assess what additional protection and management might be required to protect the OUV of the GBMA under altered climatic conditions and likely increased fire frequency and severity (Section 5.5).

5.2 Implications of the assumed stressor extents

Fundamental to this desktop assessment are the assumptions that (i) the potential cumulative risk to the OUV of the GBMA from mining decreases with increasing distance of mining from the GBMA, and (ii) there is a distance beyond which cumulative impacts from mining are negligible. For example, Holland et al. (2021) assumed that potential impacts on Water systems in the GBMA are very unlikely beyond 20 km for ground waters and could occur up to 40 km along only a few streams. These assumed distances greatly contribute to the sizable proportion (approximately 20%) of the GBMA in the PCIA and warrant further discussion. In reality, the stressor extents are likely to be much less than this, even before protection and management measures are factored in.

5.2.1 Groundwater drawdown

Groundwater drawdown is an inevitable consequence of open-cut and underground mining, but the extent of drawdown effects on the water table is difficult to predict. The 20-km stressor extent adopted in this analysis is defined by the 0.2-m drawdown contour from a 'worst case' drawdown scenario (Herron et al. 2018a). In the absence of more detailed local-scale information, this is a reasonable assumption. However, groundwater drawdown does not occur as an idealised cone. The local hydrogeological setting, including properties of the overburden and connectivity between aquifers (e.g. presence of aquitards, degree of fracturing, fracture orientation, faults), means that this drawdown extent is likely to be smaller and more irregular in shape. There are also likely to be patchy and localised effects on the water table, reflecting topographic lows (e.g. along larger streams) and geological discontinuities such as faults and fractures.

This was demonstrated in the Hunter Bioregional Assessment for the Wallarah 2 coal mine where local-scale hydrogeological information was used to constrain the regional scale assessment of risk. The predicted 0.2-m drawdown was largely within 1-2 km of the mine footprint, with some localised drawdown up to 10 km away (Herron et al. 2018b). Although local information will not eliminate all the uncertainties, it provides a much better basis for assessing groundwater impacts. Groundwater modelling in the EIAs of mines in this assessment indicates that drawdown impacts are unlikely to extend beyond about 10 km. Modelled maximum extents of the 0.2-m drawdown contour ranged from 0.3-0.5 km (Tinda Creek (Umwelt 2014) and Newnes sand mines (Kalf and Associates 2004)) and 1-2 km at the United Wambo open-cut coal

(AGE 2016) and Dendrobium (Hydrosimulations 2019) mines to 7-10 km for the Tahmoor (Hydrosimulations 2020) and Springvale (RPS 2014) underground mines.

5.2.2 Altered streamflow and water quality

Altered flows in streams flowing through a mine lease area into the GBMA are likely to propagate downstream, affecting aquatic and riparian biota and ecological processes. These streams may also act as conduits, conveying contaminants from the mine lease area into the GBMA. Impacts of altered flows or streamflow contamination can persist over considerable distances. The 1% change in average annual flow adopted as the material threshold for this stressor (Holland et al. 2021) means that the spatial extent may sometimes extend further than the 20-km stressor extent for groundwater.

The assumption that stream and riparian habitats could be significantly impacted by a 1% change in average annual streamflow is tenuous because (i) a change of this size is considered below detection levels and (ii) such a change in average annual flow is not a meaningful indicator for ecosystem responses in many streams. It could be argued that this threshold is excessively conservative and grossly exaggerates the PCIA along some streams.

Even for streamflow contamination, the stressor distances identified from this 1% change in average annual streamflow metric are highly conservative. However, the true extent of contamination will be highly context-dependent among streams, and even within a stream, depending on flow and spill magnitude at the time. Impacts can be short-lived (e.g. when a spill is quickly contained and the contaminant plume occurs as a single pulse) or more sustained where contaminated water continues to flow into waterways over long periods (e.g. from unremediated legacy mine sites. Data from the Wollongambe River (Box 2-3) and the Nepean and Bargo rivers that drain the Tahmoor mine (Fleming et al. 2021) report elevated contaminants at distances of 22 km, 16 km and 9 km, respectively, indicating potential for significant impacts beyond 22 km from a mining area.

Overall, the greatest risk is expected to be in streams that are closest to the stressor source. If water extractions coincide with discharges of contaminants or if mine-affected water releases occur during natural periods of low flows, contaminant concentrations may pose substantial risks to downstream aquatic biota in the receiving waters.

Effective management of mine waste and water is critical to constraining this stressor extent and its potential impacts. Most of the threats to streams draining from mine lease areas into the GBMA can be managed effectively to avoid or minimise the risk through strict regulation of mine wastewater discharges, limits on streamflow extractions and appropriate management of waste and water on-site to avoid spills and leaching of contaminants into groundwater.

The risk from potential groundwater drawdown effects on streams draining into the GBMA is harder to assess and mitigate. It is unlikely that all the streams identified in Figure 4-2 are connected to groundwater and vulnerable to potential drawdown effects. Similarly, not all swamps are groundwater-dependent and there remain questions about the groundwater connection of the Thirlmere Lakes (Section 4.3.9). Thus, the actual extent of Water systems at risk from mining-induced groundwater drawdown is likely to be far less than that estimated from the current regional scale analysis.

5.3 Protection and management

Australia provides a high level of legislative protection for its World Heritage properties through Australian and NSW government controls. The EPBC Act (Cth) establishes the over-arching framework for protecting World Heritage values as a Matter of National Environmental Significance (MNES) but other MNES such as the 'water trigger' and threatened species and ecological communities MNES (Section 2.5) also contribute to this high level of protection.

Most large mining developments are likely to be considered as 'controlled actions'. A controlled action means that the risk to an MNES must be assessed and, where significant impacts are likely, options to avoid or mitigate the risk must be identified that reduce the risk to acceptable levels (Section 2.5). World Heritage status did not form the basis for a controlling provision for nine of the mines identified as 'in the vicinity' of the GBMA for this assessment (Table 2-2). In four of the cases where World Heritage status did trigger the declaration of the proposed mine as a controlled action, the mine lease areas share a boundary with the GBMA, but this attribute does not seem to be a definitive criterion. For example, World Heritage was not a controlling provision for the proposed Bylong Coal project which shares a boundary with the GBMA but it was a controlling provision for the proposed extension of the Springvale mine which does not. Although not decided on the basis of protecting World Heritage values of the GBMA, recent decisions by NSW to not approve the proposed Bylong Coal project (December 2019), the Hume Coal Project (September 2021) and the extension to Dendrobium mine (March 2021) reduce the number of operations and duration of mining around the GBMA that potentially could have occurred.

The experience garnered over a long history of mining in NSW along with greater competition for land resources, changing community values about the environment and growing expectations that industry should actively protect the environment have led to increasingly stringent regulation of mines to minimise environmental impacts. The current EIA process involves a comprehensive risk assessment that includes all the stressors considered in this assessment and the identification of mitigation measures to avoid and minimise risks. The onus is on the mining proponent to demonstrate that the residual risk of significant impacts is minimal. Although the EIA process involves some level of self-assessment, the resulting EISs are reviewed by government agencies, NGOs, the general public and, frequently, independent experts and panels who can raise concerns and seek more information through the formal submission process. These checks and balances ensure that the assessments are done rigorously, especially when there may be a risk to World Heritage properties such as the GBMA.

Sometimes, the residual risk is deemed to be too great and the proposed mine is not approved. Relevant examples include the recent decisions by the NSW Independent Planning Commission in relation to the Bylong and Hume coal projects.

Where a development is approved, the key mechanism for managing the environmental risks within acceptable limits is through imposing carefully framed contractual conditions on the development through the consent orders (NSW) and approvals under the EPBC Act (Cth). The Australian Government favours outcomes-based conditions for protecting MNES. This puts the focus on the desired result and encourages the mine operators to determine the most cost-effective ways to achieve the result. However, outcomes-based conditions require good baseline data, clearly defined and measurable outcomes, and the proponent must have control over the variables responsible for achieving the desired outcomes. One or more of these three

requirements are not always available and the proponent must make a convincing case for addressing them. Regulators also often set conditions that prescribe particular approaches that are known to be effective in mitigating risks (e.g. partial extraction methods).

Despite these powerful legislative tools, there remains a risk of non- or only partial compliance with the agreed conditions. To reduce the likelihood of non- or partial compliance, the Australian and NSW governments have post-approval processes intended to ensure proponents meet the conditions of their approval set under planning legislation. These include maintaining regular engagement with project personnel and undertaking monitoring inspections and compliance audits to establish whether projects are being implemented as planned. Both governments typically require mines to submit environmental compliance reports, at least annually, as a condition of approval. These reports provide the results of monitoring and show how operators are performing in terms of their conditions of approval and approved management plans. Failure to meet performance measures or submit a compliance report can trigger enforcement actions and penalties.

Under the EPBC Act (Cth), approved projects may be subject to compliance audits, either through attaching conditions to an approval or directing an approval holder to undertake an independent audit. The Australian Government has recently required audits at Bulga Coal mine (2019, approval condition) and Springvale Coal mine (2017, directed audit). One compliance breach was identified at Bulga mine, which was determined to not to require further action, while no compliance breaches were identified at Springvale (<u>Compliance auditing | Department of Agriculture, Water and the Environment</u>). In NSW, conditions of development consents issued under the EP&A Act (NSW) for major mining projects include a requirement for regular independent auditing against conditions of consent and statutory requirements. NSW DPIE undertake regular inspections works and may also commission independent audits. DPIE works with other regulators, including the NSW EPA in relation to pollution control requirements, and the Resources Regulator in relation to mine rehabilitation, to ensure that there is ongoing and systematic review of environmental performance and to drive continuous improvement in mining operations.

Both jurisdictions provide a broad range of enforcement mechanisms for managing suspected or identified instances of non-compliance, including breaches of approval conditions and undertaking an unapproved action. These include civil or criminal penalties, remediation orders to repair or mitigate environmental damage, and enforceable undertakings to negotiate civil penalties and provide for future compliance. In 2011, for example, Springvale Coal and Centennial Angus Place signed an enforceable undertaking with the Australian Government to fund an AUD 1,450,000 research program at the Australian National University, following the destruction of a THPSS on the mine lease area in breach of their consent orders. In 2017, Hunter Valley Operations signed an enforceable undertaking following unapproved clearing of an area of critically endangered Central Hunter Valley Eucalypt Forest and Woodland ecological community, committing them to the purchase and management of 210 hectares of ecological offsets at a minimum cost of AUD 2,350,000 (Coal and Allied Operations 2017). Severe penalties can be imposed on mines for breaches of their licence conditions, such as the AUD 1,050,000 penalty imposed on the Clarence Colliery following the spill of coal fines in 2015 (Box 2-3).

The Australian Government continues to review and improve its processes under the EPBC Act. The establishment of the IESC in 2012 has led to a stronger scientific basis for setting approval conditions focussed on environmental outcomes. Importantly, the advice provided by the IESC is independent and publicly available on the Committee's website within 10 business days of it being provided to the regulator. This transparency and scientific independence greatly enhances the quality of the assessments and proposals, and helps ensure rigorous consistency in the evaluation of potential risks of proposed coal mining to water resources and their dependent ecosystems.

The combination of Australian and NSW government legislative measures, intensive independent scrutiny of EISs, and the exacting industry standards and best-practice measures adopted by the mining industry to reduce their environmental impacts collectively, provides for the protection and management of Australia's World Heritage properties such as the GBMA. This protection and management framework continues to benefit from review and revision.

Cumulative impacts of multiple industries are always especially challenging to mitigate because of the many drivers and their complex interactions. Nonetheless, stringent regulation of individual developments is an effective tool in reducing these cumulative impacts, even when major events such as severe bushfires exacerbate the situation.

5.4 Limitations of the current assessment

It is important to reiterate that the current assessment is a desktop-based study drawing on diverse sources of information and data that have been gathered for other purposes and are therefore potentially limited for the current application. This constraint in targeted data also applies to the supporting information for the spatial causal network approach, especially to inferences about stressor extents, materiality thresholds and likely ecological responses to cumulative impacts.

The spatial causal network approach used by Holland et al. (2021) is a useful method for identifying the hazards and logically constructing the pathways and interconnectedness of stressors and effects on components of OUV. However, the success of the approach depends on the availability and quality of the data underlying assessments of stressors and likely responses of the high-level components of OUV, the level of understanding of significant impact thresholds for evaluating materiality, and how far from the mining areas the risk of potentially significant impacts might realistically extend. Holland et al. (2021) expressed high confidence in stressor extents adopted for groundwater and stream impacts in their assessment, but had low confidence in other stressor extents such as invasive species, fire extent from accidental ignition and dust effects from blasting. Targeted surveillance monitoring in the GBMA near mining areas could help resolve the magnitude of change and distance over which this is likely for key stressors (Section 5.5).

To represent the innumerable landscape features, biodiversity components and cultural components that contribute to the OUV of the GBMA, we adopted eight high-level components. The mapped distributions for these high-level components were necessarily broad-scale, sometimes encompassing the entire GBMA (e.g. Conservation-significant fauna). As it was not possible to assess the risk to all the individual species, communities, habitats and landscape and cultural elements, only a few key elements were chosen for closer investigation. The water systems, ecological communities and species chosen for further consideration are of conservation significance, highly endemic, are known or likely to occur in the GBMA near mining areas and/or are potentially vulnerable to changes in hydrology. In other words, they were

considered to be realistic examples of the elements of OUV of the GBMA that are most at risk from nearby mining. Threats to these elements indicate the levels of risk to similar habitats and their associated biota and values. It would be valuable to assess further species, communities and ecosystems in the GBMA more systematically, but this would probably entail collecting field data and monitoring levels of stressors associated with mining near the GBMA (Section 5.5).

Other drivers such as climate change were not in the scope of this assessment (Section 1.2). However, we did briefly address the catastrophic 2019-20 bushfires that burnt 71% of the GBMA and portend the increasing likelihood of extreme climate-driven events to drastically transform the GBMA landscape. The observed loss of ecological resilience and recovery potential in swamps impacted first by mining and then by fire (Section 4.3.14) is unlikely to be an isolated example. Minimising, but preferably avoiding, hydrological impacts on the water systems of the GBMA from mining developments should give sensitive aquatic habitats and their biota a greater chance of surviving fire effects. Other drivers such as urbanisation, tourism, agriculture, previous park management, roads and the legacy effects of past mines continue to put pressures on the GBMA and require ongoing vigilance. There would also be merit in a more comprehensive cumulative impact assessment of all these drivers beyond only mines that exist or are planned near the GBMA (Section 5.5).

A final limitation of this assessment was the lack of knowledge about the effectiveness of the current protection and management framework in preventing significant impacts from mining on the GBMA's OUV. Assessing this effectiveness was outside the scope of the current desktop study. Evaluation in terms of environmental outcomes would require good quality data on the condition of components of OUV of the GBMA before, during and after the cessation of mining, as well as reliable monitoring data of potential stressors from all relevant nearby mines and within the GBMA. These data are not available. From the legislative perspective, the evaluation would also require a comprehensive review of compliance behaviour by the mines, including the effectiveness and enforceability of penalties intended to ensure compliance, and a review of the efficacy of the regulatory instruments in meeting policy objectives. Such an evaluation could be considered in subsequent assessments of potential cumulative impacts of mining and other activities on the GBMA's OUV.

5.5 Future work

This assessment has identified a number of areas where further scientific research would enhance the assessment of potential cumulative impacts of nearby mining on the OUV of the GBMA.

The ratings of residual risk presented here are based solely on desktop analysis of available information and literature, and are applied at the scale of the whole GBMA and not just within the PCIA. The ratings and spatial extents of stressors need to be confirmed with appropriate field data, including remotely sensed information, collected using targeted methods over a suitable time period. The discrete areas comprising the PCIA identified in the current assessment are the logical focus for this field work.

In particular, future work could include a well-planned and fully resourced surveillance monitoring program within the GBMA that is dedicated to assessing potential cumulative impacts of mining and evaluating the effectiveness of mitigation measures in protecting the OUV of the GBMA. Such a program would also provide useful insights into the potential effects of other disturbances such as bushfires and their interactions with mining-related stressors. Monitoring of stream flows and water quality, groundwater levels and water quality, habitat condition, ground movements, weed dispersion, and noise and light pollution in the GBMA in all the areas near existing mines would help answer questions about stressor extents and the magnitude and duration of impacts. It would also be valuable to include suitable reference areas where mining is not planned, and to survey areas near planned mines to collect 'pre-impact' baseline data.

There is limited understanding of the contribution of groundwater to streams and riparian habitats in the GBMA, limiting assessment of potential impacts of groundwater drawdown on these systems. Similarly, the extent to which mining-related contaminants may bioaccumulate in stream sediments and riparian vegetation, potentially impacting on adjoining terrestrial ecosystems, is poorly understood. Detailed mapping of the riparian zones of the GBMA, especially in the PCIA, would provide useful baseline data against which to assess any potential impacts arising from mining upstream. This mapping could complement assessments of groundwater-dependence by riparian vegetation.

Substantial amounts of work are currently being done to elucidate potential mining-related impacts on the Thirlmere Lakes through the Thirlmere Lakes Research Program. Further work could include assessment of the extent and importance of far-field effects of groundwater drawdown on the Lakes as well as the potential for faults to act as conduits of groundwater.

There has been considerable research on swamps in the Blue Mountains area and the potential impacts of mining on these ecosystems (Section 4.3.10). There has also been some monitoring work, primarily on mine lease areas to inform EISs or as a regulatory requirement to monitor condition of particular THPSS. However, there is scope for more systematic hydrological and ecological monitoring of swamps in the GBMA to provide baseline data and ensure that there are no impacts of nearby mining on these ecosystems. Each swamp is likely to have a unique water regime and community composition of plants and animals. Comprehensive surveys would establish the extent of swamp-to-swamp variability and how this varies over time, especially during post-fire recovery.

More quantitative information on the tolerance of GDEs to mining-related drawdown and groundwater contamination, including critical thresholds (tipping points) would assist regulators in guiding proponents on how best to minimise the environmental impacts of planned mines. The animals (e.g. stygofauna) and ecological values of subsurface GDEs such as saturated cave systems and aquifers in the GBMA are very poorly documented, and there are probably many new species in these GDEs that contribute further to the property's OUV. Without baseline data on the biodiversity and distribution of groundwater fauna, it is impossible to assess the potential impacts of mining and other activities that may alter groundwater levels and water quality.

Other relevant work includes establishing the extent of groundwater-dependence of vegetation across the GBMA, how this is affected by post-fire recovery, and whether there are any trends in the distribution or ecology of terrestrial groundwater-dependent vegetation that may be associated with mining-related stressors. In particular, the way that ecological resilience of this vegetation may be reduced by bushfires could inform the choice of mitigation measures in different areas.

Given the very low residual risk from mining in the vicinity of the GBMA to Gondwanan flora, there are no immediate needs for future work on this high-level component, beyond ensuring that the ecological surveys undertaken as part of their EIA by proponents of mines near the GBMA identify and plan appropriately for any rainforest pockets that could be hydrologically connected to their proposed operations. It would be informative to assess how post-fire recovery in rainforest patches in the PCIA compares with that in other areas of rainforest deeper within the park that had equivalent burning histories. This work would provide insights into how impacts from mining might affect the ecological resilience of Gondwanan flora to fire.

Similarly, the very low residual risk to Geodiversity in the GBMA means there are no priorities for future work beyond surveillance monitoring of geological features in the GBMA near the Airly, Clarence, Tahmoor and Wambo mine sites. There could be merit in assessing whether the 2019-20 fires have increased the risk of rock falls and other potential impacts to geological structures in the GBMA as observed in California (De Graff et al. 2015) and Austria (Melzner et al. 2019).

There is a need to better understand the risk of mining to tangible and intangible Indigenous heritage values in the GBMA and its surrounds. Addressing the foregoing science questions should contribute to more effective protection and management of some Indigenous heritage values (e.g. rock shelters, rock art, biodiversity) but the risks to other elements such as from dust on rock art sites are less well understood. Coal dust is reported to have coated a rock art site in the broader GBMA area, but there remains a question about whether industry standards relating to dust levels, which are designed to minimise risks to human health, are appropriate for protecting rock art sites. Most important yet perhaps more challenging is reliably assessing the risks of nearby mining to Indigenous connections to Country, especially if environmental surrogates are inadequate.

Finally, it would be useful for future assessment of the potential cumulative impacts of mining on the OUV of the GBMA to also consider (i) legacy effects of existing mines and (ii) potential effects of drivers (including climate change) other than mining. Urbanisation, tourism, agriculture, previous park management, roads, the legacy effects of past mines and post-mining land uses can all put pressure on the OUV of the GBMA and require ongoing vigilance. If there were data from a systematic and dedicated surveillance monitoring program of these potential stressors and the key elements of the components of OUV of the GBMA, future assessments of cumulative impacts could be more quantitative and enable more reliable ratings of residual risk.

Appendix A: Mine selection for this assessment

The terms of reference for this assessment (Section 1.1) specify that 'existing or planned mining projects in the vicinity of the GBMA' are to be considered in the assessment. Legacy mines that are no longer operating and mines that are on a pathway to closure were classed as not 'existing or planned'.

A.1 Defining 'in the vicinity'

A.1.1 Coal mines

The distance between the source of a stressor and the valued asset (e.g. a high-level component of OUV used as an AE in the causal network analysis) is an important determinant of the likelihood of a material effect. Potentially severe effects close to a stressor source attenuate with increasing distance from the stressor source. At some distance from the source, the effect of a mining-related stressor becomes immaterial and no longer poses a substantial risk to the valued asset.

To define 'in the vicinity', we reviewed previous studies, regulations and guidelines to determine a maximum distance from mining areas beyond which the impacts of mining from the most pervasive stressors were considered very unlikely. This distance was chosen based on the greatest of the likely stressor extents (Holland et al. 2021), considering:

- Groundwater drawdown in the Hunter Subregion Bioregional Assessment (BA), the results of groundwater modelling of cumulative impacts of mining showed that groundwater drawdowns of at least 0.2 m were theoretically possible up to about 20 km from the mining areas (Herron et al. 2018a). The 0.2-m decrease in water table levels was adopted in the BA as the threshold for potentially significant groundwater impacts. It was informed by minimal impact thresholds defined in the *NSW Aquifer Interference Policy* (NSW DPI 2012) for GDEs across all classes of high- and low-production groundwater sources in NSW.
- Streamflow impacts surface water modelling results from the Hunter Subregion BA (Herron et al. 2018a) showed the cumulative impacts of runoff interception and groundwater drawdown from multiple mines were very unlikely to cause reductions in annual flow, low-flow days and high-flow days of more than 5% at distances of 10 km downstream of mine sites¹.

¹ Note that CSIRO (Holland et al. 2021) subsequently adopted a threshold of a 1% change in annual flow for determining the distances downstream from mine sites within which there is a potential for significant impacts.

- Light pollution the National Light Pollution Guidelines for Wildlife (Commonwealth of Australia 2020) recommend that impacts from light pollution be assessed if the light source is within 20 km of important habitat for a listed species.
- Other stressors (noise, dust, ground movement, invasive species, vegetation clearing) – these other stressors from coal and sand mines operating under existing regulations and guidelines were assessed as not likely to have significant impacts beyond 5 km. Details of stressor extents are provided in Holland et al. (2021).

Based on this review, the distance from the GBMA adopted as 'in the vicinity' of the GBMA was 20 km for coal mines. We identified 31 existing and planned coal mines as being 'in the vicinity' of the GBMA, which are shown in Figure A-1.





Mines included in this assessment are shown by dark grey symbols and brown text; those excluded from the assessment are shown in green. The grey line surrounding the GBMA represents the 20-km contour. If a mine lies within this contour

but its catchment drains away from the property, it was excluded unless other causal pathways of mining-related impacts on the GBMA were likely. As the mine lease area for Dendrobium extends to 15 km from the GBMA, this mine was included.

A.1.2 Sand mines

In general, sand mines and quarries are expected to have less extensive off-site impacts. Due to the shallower extraction depths and lower requirement for groundwater pumping, the impact on water table levels is unlikely to extend as far as for deep open-cut mines and underground mines. Risks from noise, dust, ground movement, invasive species and vegetation removal were assumed to be similar to those from open-cut coal mines. Therefore, existing and planned sand mines that were within 5 km of the GBMA were considered 'in the vicinity' for the purposes of this assessment. Three sand mines met this criterion and are shown in Figure A-1.

A.2 Plausible pathways check

To assess which mines might potentially impact high-level components of the OUV of the GBMA, each mine within 20 km of the property was evaluated to determine its operating status and whether there were plausible physical pathways that might convey mining-related impacts into the GBMA (e.g. streams draining the mine site that enter the GBMA).

Twelve coal mines were determined to be hydrologically and hydrogeologically disconnected from the GBMA because they lie north of the Hunter River (Figure A-1). The Hunter River does not flow into the GBMA and these twelve mines with catchments draining into this river system have no surface water connection to the GBMA. The Hunter River is also a regional groundwater discharge area, which means that the hydraulic gradient of the water table around the Hunter River is towards the river and that groundwater pathways of mines to the north of the river are largely constrained to the north of the river, hence very unlikely to convey mining-related impacts into the GBMA. This assessment is supported by the results of the groundwater modelling undertaken in the Hunter Subregion BA (Herron et al. 2018b).

Five mines (Berrima, Charbon, Cullen Valley, Cumnock and Drayton) are in care and maintenance and on a pathway to closure. Two of these are also located north of the Hunter River. A sixth mine (Pine Dale) is in care and maintenance and operations could resume. However, no application has been lodged with NSW DPIE for project approval and therefore it does not meet the definition of 'reasonably foreseeable' (Section 2.4).

These sixteen mines excluded from the desktop assessment are listed in Table A-1 with the reasons for their exclusion.

Mining Operation	Туре	Status	Distance to GBMA (km)	North of Hunter River
Berrima	UG	Closure	>5 km	n/a
Charbon	OC & UG	Closure	>5 km	n/a
Cullen Valley	00	C&M - closure	<5 km	n/a
Pine Dale	00	C&M - pre-EIS	<5 km	n/a
Cumnock	UG	C&M - closure	>5 km	Y
Drayton	0C	C&M - closure	>5 km	Y
Ashton	UG	Operating	>5 km	Y
Glendell/Mt Owen	00	Operating	>5 km	Y
Liddell	00	Operating	>5 km	Y
Mangoola	0C	Operating	>5 km	Y
Maxwell (Drayton South)	UG	EIS assessment	>5 km	Y
Mt Arthur	OC & UG	Operating	>5 km	Y
Ravensworth	OC & UG	Operating	20 km	Y
Rix's Creek	0C	Operating	>5 km	Y
Savoy Hill	0C	Pre-EIS	>5 km	Y
Spur Hill	UG	Pre-EIS	5 km	Y

Table A-1 Mines excluded from the assessment,	listed with their type,	status, distance to
GBMA and location relative to the Hunter River.		

OC- open-cut coal mine; UG - underground coal mine; C&M - Care and maintenance

n/a - not applicable - these mines are not in the Hunter Valley

Appendix B: Summary of mining operations included in the assessment

This appendix briefly describes each of the coal and sand mines that were included in this desktop assessment. Over half of them were operating in 2000 when the GBMA was inscribed on the World Heritage list (Figure B-1). Bylong Coal project is not shown in Figure B-1 as it was refused development consent by the NSW Government, was going through an appeals process and had an uncertain commencement date.



Figure B-1 Timelines (from 1980) of the coal and sand mines included in this assessment.

OC- open-cut coal mine; UG - underground coal mine; p - partial extraction method.

Mines are grouped by coalfield: Hunter Coalfield – green; Southern Coalfield – blue; Western Coalfield – orange; not part of a coalfield - black

Thick lines indicate coal mines; thinner lines identify sand mines.

Dashed lines indicate mines that have not yet started – the starting and end dates assume a 2022 start, but this is uncertain.

The following sections provide short summaries of the mining operations included in this assessment. They are ordered alphabetically for coal mines (section B1) and sand mines (section B2).

B1 Coal mines

B1.1 Airly Mine (Airly Mine Extension Project)

Airly Mine is an underground coal mine in the Western Coalfield of the Sydney Geological Basin. The mine lease area adjoins the GBMA on the western side of Wollemi NP and north of the Gardens of Stone NP. Mining is outside the World Heritage property.

Operations at Airly Mine were approved in April 1993 and commenced in 1998. The mine was placed in care and maintenance in late 2012 but reopened in February 2014. An application was subsequently lodged with the NSW government to extend operations for a further 25 years, past their approved October 2016 end date. This Airly Mine Extension Project was approved in May 2017 with strict conditions requiring implementation of a site water management system to manage the risk to OUV of the GBMA. A statement of reasons for this decision was made available to the public on 20 March 2019.

The extension permits operations until end of January 2037. This consent has been modified twice and a third modification, to increase the coal production rate, is currently under assessment. World Heritage status is a controlling provision (Section 2.5.1) for the project under the EPBC Act (Cth).

B1.2 Angus Place Colliery (Angus Place Mine Extension Project)

Angus Place Colliery is an underground coal mine in the Western Coalfield of the Sydney Geological Basin. The north-eastern corner of the mine lease area is in the Gardens of Stone NP in the GBMA, but mining is not permitted within the World Heritage property. It lies immediately to the north of the Springvale coal mine.

Operations began at Angus Place Colliery in 1979. The current development consent was granted in September 2006 and has been modified several times since, including to increase the number of longwall panels and annual extraction rate. Current operations are approved until August 2024, but the mine has been in care and maintenance since 2015. An application to extend operations (the Angus Place Mine Extension Project) was submitted in September 2012, which included longwall mining under the Newnes Plateau. This application was still under assessment by both the NSW and Australian governments when this cumulative impact assessment was completed, with World Heritage as a controlling provision (Section 2.5.1) under the EPBC Act.

In July 2021, the proposed Angus Place Mine Extension Project was withdrawn from further assessment. A new application for a smaller bord and pillar project (Angus Place West) was lodged in August 2021.

B1.3 Appin Colliery (Bulli Seam Operations)

Appin Colliery is an underground coal mine in the Southern Coalfield of the Sydney Geological Basin. It is east of the Nattai and Thirlmere Lakes NPs in the GBMA and does not share a boundary with the World Heritage property.

Operations commenced at Appin Colliery in 1962. The current development consent for the Bulli Seam Operations with West Cliff Colliery was approved on 22 December 2011 and permits mining operations at the site until the end of 2041. The project was approved under the EPBC Act in May 2012. World Heritage was not a controlling provision (Section 2.5.1). This consent has been modified twice and a third modification is currently under consideration. Operations approved under the current consent have not included expansions or extensions of mining.

B1.4 Bulga Coal

Bulga Coal currently operates an open-cut coal mine in the Hunter Coalfield of the Sydney Geological Basin. It is adjacent to the Mount Thorley Warkworth mine. It does not share a boundary with the GBMA.

Coal mining began in 1982 when BHP (Broken Hill Propriety Company Limited) was granted approval to mine coal at the Saxonvale Colliery. Operations have been modified several times to expand the area and depth of coal extraction and extend operations, including in 2014 to 2035 and again in 2020 to 2039. The most recent expansion was approved under the EPBC Act on 22 September 2020. World Heritage was not a controlling provision (Section 2.5.1).

Underground mining has also been undertaken at Bulga Coal. Longwall extraction commenced at the South Bulga Colliery in 1992, moving to Beltana in 2001 and Blakefield South in 2008. The current Bulga Underground Mine Consent was granted in 2004. Mining ceased at Bulga Underground in May 2018 and the mine was sealed in July 2018. Approvals for underground mining have been retained and the operators are actively investigating opportunities to recommence underground operations.

B1.5 Bylong Coal Project

The Bylong Coal Project is an open-cut and underground coal mining operation proposed on a greenfield site in the Western Coalfield of the Sydney Geological Basin. It adjoins the GBMA along the north-western boundary of Wollemi NP. There are no other coal mines nearby. The proposal is for a 25-year operation, comprising 9 years of open-cut mining and 20 years of underground mining.

The application for the project was submitted to the NSW government in January 2014. The project was determined to be a controlled action under the EPBC Act but World Heritage was not a controlling provision (Section 2.5.1).

The NSW government refused the project in September 2019 for various reasons, including incompatibility with local land use objectives, unacceptable groundwater impacts, unacceptable heritage impacts (not to the GBMA) and lack of evidence to demonstrate that Biophysical Strategic Agricultural Land (BSAL) impacted by the project could be rehabilitated to BSAL-equivalent land.

At the time that this assessment commenced, an appeal had been lodged with the NSW Land and Environment Court (LEC). It was included in this assessment as a reasonably foreseeable mine on the basis that the decision had not been finalised. However, it was not shown in the mining operation time lines (Figure B-1) due to the uncertainty about when it might commence if the appeal was successful.

In December 2020, the LEC upheld the decision. Upon subsequent appeal, the NSW Court of Appeal upheld the LEC decision on 14 September 2021.

B1.6 Clarence Colliery

Clarence Colliery is an underground coal mine in the Western Coalfield of the Sydney Geological Basin. The mine lease area adjoins the GBMA. It is surrounded by the Blue Mountains NP on three sides. No mining occurs within the World Heritage property. It is adjacent to the Kables Sand Quarry and the Newnes Kaolin Friable Sandstone Project site.

Clarence Colliery commenced operations in 1979 prior to the operation of the EPBC Act. The current development consent was granted in December 2005 and will lapse at the end of 2026. The consent has been modified several times, but none of the modifications has involved extensions of the consent timeframe or an increase in coal output.

B1.7 Dendrobium Mine (Dendrobium Mine Extension Project)

Dendrobium Mine is an underground coal mine in the Southern Coalfield of the Sydney Geological Basin. At its closest point, the mine lease area is about 15 km from the Nattai NP and the GBMA.

Mining operations began at Dendrobium Mine in April 2005 and are approved until 31 December 2030. An application to expand underground mining operations and extend the project to 2048 was submitted in 2017. The project was assessed as a controlled action under the EPBC Act, but World Heritage was not a controlling provision (Section 2.5.1).

In March 2021, the NSW Independent Planning Committee refused consent for the project This decision is now (October 2021) the subject of a court appeal.

B1.8 Hume Coal Project

The Hume Coal Project is a proposed underground coal mine in the Southern Coalfield of the Sydney Geological Basin. The proposed site is south of the Nattai NP outside the GBMA.

The development application for the project was submitted in March 2017 and was under assessment when this desktop assessment started. The project was assessed as a controlled action under the EPBC Act, but World Heritage was not a controlling provision (Section 2.5.1).

On 31 August 2021, the NSW Independent Planning Committee refused consent for the project because the impacts of the project could not be reasonably and satisfactorily avoided, mitigated and managed.

B1.9 Hunter Valley Operations

Hunter Valley Operations (HVO) is an open-cut coal mine in the Hunter Coalfield of the Sydney Geological Basin. It does not adjoin the GBMA. It is adjacent to the Mount Thorley Warkworth Mine and Wambo Coal Mine.

Mining at HVO began in 1949. Since then, developments at HVO have occurred through a series of expansion and acquisitions that have resulted in the operation managing 43 development approvals. In 2004, the 18 approvals were consolidated into a single development consent for HVO North, and in 2009 the remaining approvals were consolidated into a single consent for HVO South. Operations at HVO North are currently approved until 2025 and at HVO South until 2030, but there are plans to extend the life of HVO North to 2050 and HVO South to 2045. The continuation of operations at HVO was approved under the EPBC Act in October 2016, but World Heritage was not a controlling provision (Section 2.5.1).

B1.10 Invincible Colliery (Coalpac Pty Invincible Colliery Modification)

Invincible Colliery is an open-cut coal mine in the Western Coalfield of the Sydney Geological Basin. The mine lease area does not adjoin the GBMA and is south of the Gardens of Stone NP.

The original Invincible Colliery was an underground coal mine that operated from around 1901 to 1957, prior to the operation of the EPBC Act. Mining operations were subsequently moved to its present location, where underground mining continued until 1998. Some open-cut mining was undertaken to the south of the mine's current location during World War II and between 1998 and 2001, before being placed in care and maintenance. In 2006, an open-cut mine was approved by the NSW government for mining until December 2016.

The mine went into care and maintenance in 2013. An application was submitted in 2014 for a southern extension to mining. The proposed mining operation is more than eight kilometres from the GBMA at the closest point and separated from the GBMA by eucalypt forest, cleared farmland, Coxs River and several other streams. It was assessed under the EPBC Act as unlikely to have a significant impact on the OUV of the GBMA and World Heritage was not a controlling provision (Section 2.5.1). The project was approved on 2 February 2018 and extends mining consent to 31 December 2025, however the mine remains in care and maintenance.

B1.11 Mount Thorley Warkworth

Mount Thorley Warkworth comprises two open-cut pits in the Hunter Coalfield of the Sydney Geological Basin. The two operations (Mount Thorley and Warkworth) are under different ownership but are operated as a single mine. The mine lease areas do not adjoin the GBMA but are about 6 km to east of Wollemi NP. It is north of Bulga Coal and south of Wambo Coal Mine.

Operations at the Mount Thorley mine commenced in 1981. In June 1996, approval for extension and expansion of the operations was granted until June 2017. This development consent has since been modified several times, including further extension of the approval timeframe and expansion of the mining area. In November 2015, approval was granted for operations at the Mount Thorley mine to continue for a further 21 years to enable the ongoing provision of services to the Warkworth mine. Coal extraction is currently expected to cease in 2022.

Operations at the Warkworth mine also began in 1981. Approval for an extension and expansion of mining activities was granted in May 2003. The NSW government approved a further expansion and extension in February 2013, but the application was subsequently refused by the NSW Land and Environment Court and upheld by the Court of Appeal. A revised application was submitted to the NSW government in 2014 for expansion of operations, which proposed major changes to the project, including revisions to the biodiversity offset strategy and final landform design. This application was approved in November 2015 for 21 years from the date of commencement of the consent (to 2038 at the latest). The Warkworth Extension Project was approved under the EPBC Act in August 2012. World Heritage was not a controlling provision (Section 2.5.1).

B1.12 Springvale Mine (Springvale Mine Extension)

Springvale Mine is an underground coal mine in the Western Coalfield of the Sydney Geological Basin. It is about 6 km west of the GBMA and south of the Angus Place Colliery.

Underground coal mining commenced at Springvale Mine in 1995. Operations under the original development consent expired in September 2015. Consent to extend operations to the end of

2028 was granted in September 2015. World Heritage was a controlling provision under the EPBC Act (Section 2.5.1) as subsidence has reduced flows into some streams that run into the GBMA. The Australian Government approved the proposed action as it assessed that the project was unlikely to have a significant impact on the GBMA.

The NSW government considered that although levels of salt, heavy metals and other contaminants are above natural background levels, they would not impact the OUV of the GBMA. The NSW government put in place conditions related to water management operations.

B1.13 Tahmoor Coal Mine (Tahmoor South Project)

Tahmoor Coal Mine is an underground coal mine in the Southern Coalfield of the Sydney Geological Basin. It is adjacent to the Thirlmere Lakes NP.

Mining was first approved in March 1975. Currently, mining is undertaken at Tahmoor North under a development consent granted in February 1999 that permits mining until June 2024. A proposal for a new underground operation at Tahmoor South was approved by the NSW Independent Planning Committee on 26 April 2021. World Heritage was not a controlling provision under the EPBC Act (Section 2.5.1) for the Tahmoor South Project. The risk of groundwater impacts on the Thirlmere Lakes in the GBMA was a key consideration in the 'water trigger' (Section 2.5.1) forming the basis for a controlled action.

B1.14 United Wambo Coal Mine

The United Wambo Coal Mine combines open-cut coal mine operations at Wambo Coal Mine and United Mine. It is in the Hunter Coalfield of the Sydney Geological Basin. The Wambo mine lease adjoins the GBMA, but the site for the proposed open-cut mine is separated from the GBMA by other open-cut operations at Wambo that are already approved. The project was determined to be a controlled action under the EPBC Act in December 2019, but World Heritage was not a controlling provision (Section 2.5.1).

The United Wambo Coal Mine was approved in August 2019 with mining operations permitted until the end of August 2042.

B1.15 Wambo Coal Mine (South Bates Extension)

Wambo Coal Mine is in the Hunter Coalfield of the Sydney Geological Basin. It adjoins the eastern boundary of Wollemi NP. Wambo mine is near other coal operations, including the United Wambo mine, HVO and Mount Thorley Warkworth.

Open-cut and underground operations have been conducted at Wambo Coal Mine since 1969. Both are permitted under the current development consent, which was granted in 2004. Underground operations at Wambo Coal Mine are currently permitted until August 2042. Expansion of underground coal mining was approved under the EPBC Act in April 2017 and May 2018 for different areas of the mine. World Heritage was not a controlling provision (Section 2.5.1) for either expansion.

B.2 Sand mines

B.2.1 Kables Sand Quarry

The Kables Sand Quarry is located on the Newnes Plateau in the Western Coalfield of the Sydney Geological Basin. The quarry is separated from the GBMA by the Clarence Colliery. Underground

mining at Clarence Colliery occurs approximately 60 m below the floor of the quarry. The yet-tocommence Newnes Kaolin Friable Sandstone Project site is to the south.

Development consent for the Kables Sand Quarry was granted in March 1988 by the Lithgow City Council. An application to increase the depth of quarrying was approved in 2008 by the Lithgow City Council and the Australian Government. World Heritage was not a controlling provision (Section 2.5.1) as the Clarence Colliery site was assessed to be buffering the GBMA from the effects of sand quarrying.

B2.2 Newnes Kaolin Friable Sandstone Project

The Newnes Kaolin Friable Sandstone Project is a proposed sand and kaolin clay mine in the Western Coalfield of the Sydney Geological Basin. The approved site adjoins the Blue Mountains NP. Mining will occur outside the GBMA. It is near the Clarence Colliery and Kables Sand Quarry.

The project was approved in 2006. Construction began in 2011 but operations cannot commence until approval is obtained for a proposed processing plant in Glenlee to the southwest of Sydney. The mine development was approved under the EPBC Act in 2006, with World Heritage as a controlling provision (Section 2.5.1).

B2.3 Tinda Creek Quarry

Tinda Creek Quarry is a sand quarry located adjacent to the Wollemi and Yengo NPs, outside the GBMA.

The current development consent for the quarry was granted in 1996 by Hawkesbury City Council. An application to expand the extraction area was approved in April 2015, permitting extraction until December 2045. The NSW government approved the expansion in April 2015. The project was approved under the EPBC Act, with World Heritage as a controlling provision (Section 2.5.1).

Tinda Creek Quarry is not close to the other mines and quarries in this assessment.

Appendix C: Detailed key messages

This appendix presents the details, figures and supporting information for each key message summarised in Section 4.3.

C.1 KM1: Potential cumulative impacts of mining across the GBMA

Up to 1984 km² of the GBMA could be affected by cumulative impacts of mining in the vicinity of the property if appropriate protection and management measures are not in place. However, most potential impacts are currently effectively mitigated by strict environmental conditions imposed on mine operators.

Residual risk: 'Low'

Context and threats

The analysis by Holland et al. (2021) identifies an area of 1984 km² of the GBMA in which components of its OUV could be impacted by the cumulative impacts of nearby mining (Figure 4-2). This potential cumulative impact area (PCIA) represents almost 20% of the property's area. The PCIA is based on extremely conservative assumptions about the stressor extents (Holland et al. 2021) so it is very unlikely that there would be any cumulative impacts of nearby mining on components of the OUV of the GBMA outside this area. The area of the GBMA that is actually impacted by nearby mining is probably much smaller, especially when current protection and management measures are taken into account (see below).

The main threats from mining include altered flows and water regimes, reduced quality of surface water and groundwater, groundwater drawdown, atmospheric pollution (noise, light and dust), ground movements such as subsidence, and the ecological impacts of vegetation clearing outside the property. There are also lesser threats such as increased traffic movement and potentially increased densities of weeds and other invasive species.

The importance of different threats varies according to the vulnerability of the individual components of OUV, the distance from the stressor source (e.g. mine site), various landscape characteristics, the protection and management measures that are in place (and their effectiveness) and the effects of other disturbances such as drought and bushfires. For example, in the Australian summer of 2019-20, the bushfires that burnt 71% of the GBMA, causing loss of habitat, food and breeding individuals for many species in the property, probably reduced their ecological resilience to mining-related threats (Section C.10).

Stressor extents are the distances or areas from each mining-related stressor source within which a material impact might be possible. The largest stressor extents are associated with atmospheric, surface water and groundwater pathways. The risk of atmospheric stressors (noise, light and dust pollution) to most components of the OUV of the GBMA is low. Water systems in the PCIA are probably most at risk from cumulative impacts of mining because of their vulnerability and large stressor extent. This has implications for other components such as Conservation-significant fauna and Scleromorphic flora that are associated with the GBMA's

water systems. Sections C.2 to C.9 give more details on the threats facing each of the eight highlevel components of the OUV of the GBMA.

Pathways

The causal network considered land, water and atmospheric pathways (Figure 4-1) via which mining in the vicinity of the GBMA may have cumulative impacts on the high-level components of the OUV of the property. Land pathways (e.g. arising from vegetation removal) are usually confined to the mine lease area, sometimes reaching the GBMA boundary, and generally have limited stressor extents extending into the property. The spatial extent of ground movements from subsidence was set at 1 km with high confidence whereas accidental ignition may extend up to 3 km (low confidence) from the mine area (Table 7 in Holland et al. 2021).

The key pathways for off-site stressor effects are via water and atmospheric pathways. For example, the stressor extent of groundwater pumping was set at 20 km with high confidence to represent the likely contour where drawdown may lower the water table by 0.2 m (Table 7 in Holland et al. 2021). Similarly, altered water flows and/or stream contaminants may have impacts many kilometres into the GBMA depending on the magnitude of the stressor and the cumulative effects of other activities (including previous mining in the catchment).

The impacts of atmospheric pathways can also extend far into the GBMA. Holland et al. (2021) set the stressor extent of noise and light pollution from industrial machinery at 20 km with high confidence. Although these stressors may not be material for some components of OUV such as Scleromorphic flora or Geodiversity, they are likely to impact other components such as Conservation-significant fauna.

In general, the attenuation of impacts with increasing distance from the mine site corresponds to a decreasing likelihood and severity of impacts. Thus, the most intense impacts are likely at the boundary of the GBMA near existing and planned mines where multiple stressors overlap and their magnitudes are greatest.

Another relevant aspect of assessing the potential cumulative impacts of nearby mining on the OUV of the GBMA is the potential impact duration (PID). Some pathways and their impacts may be comparatively short-lived and only occur when the mine is active (e.g. noise and light pollution) whereas others may persist long after the mine has ceased operation (e.g. groundwater drawdown, stream water contamination), sometimes for decades. The durations of these possible legacy pathways and their cumulative impacts must be considered when assessing the effectiveness of protection and management measures (see below). The ability to detect these impacts can also vary between pathways and stressors. For example, the effects of groundwater drawdown on river flows and GDEs can take decades to manifest whereas impacts of altered flows and stream contamination may be evident within days or weeks (Box 2-3).

Protection and management

Australian Government and state assessment processes and legislation for implementing Australia's obligations under the World Heritage Convention and for mitigating the potential impacts of mining are described in Section 2.5. Increasingly, Australian and NSW government assessment processes are requiring that potential cumulative effects of mining on other environmental, cultural and economic assets be specifically considered as part of the assessment and approvals process. The Australian Government's Bioregional Assessment Program (https://www.bioregionalassessments.gov.au/), which assessed the cumulative impacts of coal and CSG developments on water resources and water-dependent assets in major coalfields of Australia, is a relevant example. The guidelines prepared by the IESC for proponents about the types of information needed in a proposal and its EIS includes a specific chapter on assessing cumulative impacts (IESC 2018).

In NSW, a State Significant Mining Development (SSMD) must now assess 'the likely impacts of all stages (life cycle) of the development, including any cumulative impacts' (NSW Government 2015a). This requirement is reflected in NSW's *Aquifer Interference Policy* (NSW DPI 2012), and in the Mine Application Guideline (NSW Government 2015b) which sets out the development application requirements for SSMDs under the EP&A Act (NSW) and recommends proponents consider 'cumulative impacts with other nearby projects and proposals' in developing the mine design.

From the industry perspective, cumulative impact assessment of mining developments has been adopted as a principle of the Minerals Council of Australia (MCA) (Kaveney et al. 2015). This underpins the MCA's commitment towards ecologically sustainable development by the mining sector. However, it is acknowledged that assessing cumulative impacts when data are scarce or have been collected over short periods is challenging, and most assessments are usually qualitative.

In the following sections (C.2-C.9), protection and management measures relevant to specific key messages are described. All of these measures should also reduce the residual risk of potential cumulative impacts of nearby mining on components of the OUV of the GBMA, especially if they are being applied consistently and effectively at all mine sites within the vicinity of the property.

Residual risk

Overall, the residual risk of potential cumulative impacts of existing and planned mines in the vicinity of the GBMA to its OUV is rated 'Low'. Furthermore, the area of the GBMA that is actually at this low residual risk from the potential cumulative impacts of nearby mining is probably much smaller than the highly conservative PCIA derived by Holland et al. (2021).

The rating of 'Low' residual risk reflects the extent and effectiveness of current protection and management measures that substantially reduce the impacts of potential cumulative impacts of nearby mining to the OUV of the GBMA. For some components of OUV such as Geodiversity, Gondwanan flora and Scleromorphic flora, the residual risk is rated as 'Very low' whereas for the remaining components, it is rated as 'Low' (Table 4-2) or, in a few cases, 'Indeterminate' where there is too little information to make a judgement or where consultation has not been sufficient.

C.2 KM2: Potential cumulative impacts of mining on Gondwanan flora in the GBMA

The remote, isolated and protected environments in which relict Gondwanan flora occur in the GBMA mean that they are unlikely to be affected by cumulative impacts of mining in the vicinity of the GBMA.

Residual risk: 'Very low'

Context and threats

Extensive rainforests covered most of Australia during Gondwanan times but only remnant patches now remain, including those across about 1% of the GBMA (Hammill and Tasker 2010; Figure C-4). Patches of rainforest in the GBMA are scattered and some isolated patches have been mapped in the PCIA (Figure C-1; Figure C-4). Key representatives of the Gondwanan flora in the GBMA are the endemic Wollemi Pine (*Wollemia nobilis*), the Blue Mountains Pine (*Pherosphaera fitzgeraldii*) and *Acrophyllum australe*.

The exact location of the only known stand of Wollemi Pine is not in the public domain but is known to occur in a remote sandstone canyon in the Wollemi NP. Mining is not an identified threat to its survival. The Blue Mountains Pine is known from several locations between Katoomba and Wentworth Falls whereas *Acrophyllum australe* occurs at 27 sites, also in the Blue Mountains area. Distribution mapping for the Blue Mountains Pine (Figure C-1) puts it outside the PCIA, while mapping of *Acrophyllum australe* indicates possible occurrences at the margins of the PCIA associated with Western Coalfield mines (Figure C-2).

As almost all the areas of remnant rainforest and the distributions of the Blue Mountains Pine and *Acrophyllum australe* lie outside or at the margins of the PCIA, this high-level component of the OUV of the GBMA is considered very unlikely to be threatened by cumulative impacts of mining in the vicinity of the GBMA. The only possible threats may be to those few patches of rainforest within the PCIA that depend on a reliable water supply from perennial seeps, soaks, waterfalls and drip zones from surrounding cliffs and rock overhangs. These threats would include mining-related stressors that alter the supply and/or quality of this water, and mass movements that may fracture or damage rock formations supporting the rainforest patches and their water supplies. Invasive species (with perhaps the exception of *Phytophthora cinnamomi*, a soil-borne pathogen that causes dieback) pose a lesser threat to Gondwanan flora.



Figure C-1 'Likely to occur' and 'may occur' extents of the Blue Mountains Pine (*Pherosphaera fitzgeraldii*) in relation to the potential cumulative impact area (PCIA)

Mapping of areas of rainforest and wetland formations has been enhanced for visbility

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Figure C-2 'Likely to occur' and 'may occur' extents of *Acrophyllum australe* in relation to the potential cumulative impact area (PCIA)



Pathways

The main pathways (Figure C-3) that may threaten the few patches of Gondwanan flora in the PCIA are those associated with the supply and quality of reliable water to pockets of rainforest. Some of these waters may be springs, seeps and waterfalls high in cliff faces and on plateaus whereas others are small perennial streams in deep canyons or small headwater feeders.

Other pathways (Figure C-3) include those mediated by mass movements that may damage Gondwanan flora near cliffs and overhangs in response to subsidence and blasting impacts, and the impacts of invasive species whose introduction or spread may be facilitated by nearby mining.





Protection and management

The Wollemi Pine, the Blue Mountains Pine and *Acrophyllum australe* are protected under the EPBC Act (Cth) and the BC Act (NSW). Australian Government and NSW recovery plans (e.g. NSW DECC 2006) set out protection and management actions that are needed to stop population decline, support recovery and maximise long-term survival of the protected species. These plans also suggest relevant research to improve the knowledge and management of these species. As these species have not been identified as at risk from mining in the vicinity of the GBMA, no specific provisions have been made for them in consent orders for mining developments.

Although there is not a formal protection and management strategy for Gondwanan rainforest patches in the GBMA, many of the measures described in the recovery plans for species such as the Wollemi Pine and the Blue Mountains Pine would be appropriate. It is also important to consider the potential impacts of the 2019-20 fires on Gondwanan rainforest patches and their management, especially where there has been severe fire damage to the canopy or groundcover.

Some areas supporting cool temperate rainforest trees and shrubs in the GBMA had not been burnt for 90 years or more, including patches of Possumwood (*Quintinia sieberi*) in sheltered areas below cliff faces in the Kanangra Walls area (National Parks Association of NSW 2020). In the few areas of remnant rainforest in the PCIA, protection and management from potential cumulative impacts of nearby mining may need to compensate for reduced ecological resilience of Gondwanan flora resulting from burning and post-fire impacts such as increased pressure from invasive weeds and *Phytophthora cinnamomi*.

Residual risk

The residual risk from the potential cumulative impacts of mining in the vicinity of the GBMA to Gondwanan flora such as Blue Mountains Pine and *Acrophyllum australe* is rated as 'Very low'. This rating also applies to patches of Gondwanan rainforest in the GBMA, given the very small area of overlap of these patches with the PCIA. Without geographic information to confirm the location of the Wollemi Pine relative to the PCIA, a residual risk to the Wollemi Pine cannot be ruled out, although mining has not been identified threat as a threat to this stand.

C.3 KM3: Potential cumulative impacts of mining on Scleromorphic flora in the GBMA

Physiological adaptation to water-limited and harsh environments means scleromorphic flora of the GBMA can tolerate most mining stressors. Some scleromorphic flora in riparian and wetland habitats that are hydrologically connected to mining areas could be affected across 420 km² (4%) of the GBMA.

Residual risk: 'Very low'

Context and threats

The vast majority of the GBMA is covered by sclerophyllous plant formations, comprising hundreds of scleromorphic species. The dominant formations (based on the classification by Keith and Simpson 2010) are the dry sclerophyll forests and wet sclerophyll forests, comprising 85% and 6% of the GBMA respectively (Hammill and Tasker 2010). The remaining scleromorphic flora formations are heathlands, grassy woodlands, forested wetlands (including riparian zones) and freshwater wetlands (Figure C-4). Heathlands are found in the central western area of the GBMA near the Western Coalfield mines; grassy woodlands are largely restricted to an area in the northeast, close to Hunter Coalfield mines; and wetlands occur predominantly along streamlines throughout the GBMA.

Many Australian scleromorphic plants are well adapted to water-limited environments (Moore 2013). They rely predominantly on rainfall and soil moisture to meet their water requirements but will make opportunistic use of surface water and groundwater where it is accessible. However, the scleromorphic flora of forested wetlands and freshwater wetlands often occupy poorly drained areas that are permanently or temporarily inundated or waterlogged, and some species may be groundwater-dependent. Consequently, mining-related threats to individual species of scleromorphic flora are likely to vary according to aspects of each species' biology such as water requirements, habitat preferences and tolerance of fire.

The main mining-related threats to most scleromorphic flora are from clearing, habitat fragmentation, changes in fire regime and invasive species such as *Phytophthora cinnamomi*, a soil-borne pathogen that causes root rot and dieback. The scleromorphic flora of forested wetlands and freshwater wetlands may also be threatened by changes in hydrology and water quality of their associated water systems.

There is almost complete overlap between the PCIA and the distribution of scleromorphic flora in the GBMA (Figure C-4). Although most of the scleromorphic flora is in the dry sclerophyll forest and wet sclerophyll forest formations, there are also smaller areas of forested wetlands (including riparian zones) and freshwater wetlands.

Figure C-4 The potential cumulative impact area (PCIA) of nearby mining and mapped distribution of scleromorphic flora in the GBMA.



Mapping of areas of rainforest and wetland formations has been enhanced for visibility.

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Pathways

The pathways via which potential cumulative impacts of mining in the vicinity of the GBMA could affect this high-level component of the OUV of the property are: (i) accidental ignition leading to bushfires moving from the mine lease area into the GBMA, (ii) alterations to flow, volumes and water quality of water systems in the GBMA, and (iii) dispersal of invasive species into the GBMA (Figure C-5).





Accidental ignition of fires can occur due to sparks from mine machinery, build-up of gas in the mine, and spontaneous combustion of coal in mines or coal stockpiles. If not brought under control quickly, there is a risk of the fire escaping from the mine lease area. This risk is higher for mine lease areas that share a boundary with the GBMA but cannot be ruled out for non-adjoining mines if conditions such as fuel load and wind strength and direction are suitable.

The introduction of invasive species onto mine lease areas and their subsequent dispersal into the GBMA is considered a low risk. Weed species and *P. cinnamomi* could be introduced through revegetation during mine site rehabilitation.

Scleromorphic flora in forested wetlands (including riparian zones) and freshwater wetlands of the GBMA that are hydrologically connected to mining areas near the GBMA could be affected by mining-induced streamflow, groundwater level and water quality effects. These pathways are considered further in Section C.7.

Protection and management

The protection of scleromorphic flora of the GBMA from potential impacts of mining is largely provided through two controlling provisions (World Heritage, and threatened species and ecological communities) under the EPBC Act (Section 2.5). This protection extends to plant communities that are not listed under the EPBC Act (Cth) or the BC Act (NSW) yet provide habitat or serve as a movement corridor for threatened fauna species (Section C.5).

The management of fire risk on the mine site is part of standard industry practice. Monitoring of gas levels in underground tunnels, installing appropriate ventilation to avoid gas from building up, ensuring accessible firefighting equipment in vehicles and near at-risk areas, providing firebreaks and preparing fire management plans are standard practice for reducing the likelihood of accidental ignition events and containing the risk should an event occur. The *Bushfire Management Plan* for the Clarence Colliery (Centennial Coal 2019) details their measures to manage potential sources of ignition via a 'hotworks' (activities involving open flames or producing heat and/or sparks capable of initiating fires or explosions) management system, maintaining firebreaks around mine operations, providing firefighting equipment, maintaining a water supply for firefighting and ensuring appropriately trained and competent firefighting personnel. They report having had no cases of spontaneous combustion and coal testing suggests an extremely low potential for spontaneous combustion. The mine uses a telemetric continuous monitoring system to detect ventilation flow, methane and carbon monoxide levels with different alarm levels triggering different responses.

All mines are required to assess the risks from weeds and invasive pest species and to ensure that appropriate mitigation measures are in place to manage the risks based on best management practices. The specific measures are usually set out in flora and fauna management plans (or equivalent documents) and include details of how weeds will be controlled during vegetation clearing, protections for non-cleared vegetation, pest control, monitoring protocols and controlling site access. For example, the consent orders for the Newnes kaolin and friable sandstone site require a government-endorsed, suitably qualified ecologist to prepare a *Pest and Weed Management Plan* which identifies potential threats, describes measures to prevent occurrence of pests and weeds, and outlines their management and eradication on and near the site (NSW Minister for Planning 2006). This plan also must specify a monitoring program for on-site and adjacent areas including the GBMA and the Wollangambe River and its tributaries.

Protection and management strategies to avoid or mitigate the risk to water systems and their associated vegetation communities are detailed in Sections C.7 and C.7.1-C.7.4.

Residual risk

The residual risk from the potential cumulative impacts of mining in the vicinity of the GBMA to its scleromorphic flora is rated as 'Very low'. The two main reasons for this rating are that (i) most scleromorphic flora in the GBMA occur outside the PCIA and (ii) the majority of scleromorphic flora within the PCIA is not heavily dependent on streams and groundwater. The higher potential residual risk to water-dependent scleromorphic flora in aquatic habitats is reflected in the 'Low' ratings for Water systems (discussed in Sections C.7 and C.7.1-C.7.4).

Although vegetation removal on mine lease areas is highly likely, this is not assessed as a risk to scleromorphic flora in the GBMA because mining is not allowed in the property. The stringent

controls on accidental ignition and invasive species at mine leases near the GBMA substantially reduce the residual risk from these stressors.

C.4 KM4: Potential cumulative impacts of mining on Conservation-significant flora in the GBMA

Conservation-significant flora in potential cumulative impact areas in the GBMA could be impacted by one or more mining-related stressors. Stringent Australian and NSW government legislation protects these flora by requiring mine proponents to specify avoidance, mitigation and offset options to minimise impacts.

Residual risk: 'Low'

Context and threats

Conservation-significant flora are well-represented in the GBMA. Under the EPBC Act (Cth), approximately 82 flora species in the GBMA are listed as threatened, including three species that are critically endangered (i.e. at an extremely high risk of extinction in the wild in the immediate future) and thirteen species whose entire distribution is in the GBMA. Under the BC Act (NSW), 110 flora species found in the GBMA are listed.

Most of the conservation-significant flora in the property are scleromorphic species. Notable exceptions are the three Gondwanan species discussed in Section C.2.

TECs are ecological communities at risk of extinction either because of a major reduction in their distribution or a decline in their ecological function. All communities listed as vulnerable, endangered or critically endangered under either the BC Act (NSW) or the EPBC Act (Cth) are considered to be TECs. There is considerable overlap between the listings under the two Acts.

Seven TECs listed under the EPBC Act (Cth) and the BC Act (NSW) are known or considered likely to occur in the PCIA identified in this assessment (Figure C-6). Except for the Temperate Highland Peat Swamps on Sandstone (THPSS), they are representatives of three scleromorphic flora formations – dry sclerophyll forest, wet sclerophyll forest and grassy. Distribution mapping for a further seven endangered ecological communities under the BC Act (NSW) suggest a likelihood of occurrence within the PCIA.

Most of the 'likely to occur' distributions of the seven EPBC Act-listed TECs (Figure C-6) are outside the GBMA and, hence, outside the PCIA. Patches of Upland Basalt Eucalypt Forests of the Sydney Basin Bioregion and the White Box-Yellow Box-Blakely's Red Gum Grassy Woodland and Derived Native Grassland ecological communities are mapped within the PCIA. There may be some Central Hunter Valley eucalypt forest and woodland near the Hunter Coalfield mines and some Turpentine Ironbark Forest of the Sydney Basin Bioregion near the Southern Coalfield.
Figure C-6 The potential cumulative impact area (PCIA) of nearby mining and mapped distribution of EPBC Act-listed TECs that occur in the PCIA.



Mapped distributions are indicative. They have been produced by spatial ecologists using modelling software and environmental data to map the 'likely' occurrence of EPBC Act listed species, including areas of potential habitat (Species of National Environmental Significance | Department of Agriculture, Water and the Environment).

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Threats to these TECs include clearing, soil erosion and habitat degradation, introduction of weeds and disease, changes in fire regime and climate change. In the context of mining near the GBMA, most of these stressors would occur only at the mine site but there is a risk that fires or some invasive species might spread into the property. Other mining-related threats that would be particularly relevant to TECs dependent on surface water or groundwater (e.g. THPSS) include altered flows, changes to downstream water quality and/or lowering of water tables.

Around 40 of the EPBC Act-listed threatened flora species in the GBMA are known or likely to occur in the PCIA. Some highly endemic examples are Fletcher's Drumsticks (*Isopogon fletcherii*), a scleromorphic shrub occurring only in a very small area around Blackheath in the Blue Mountains NP, Dwarf Kerrawang (*Commersonia prostrata*), a ground-hugging shrub which has its largest population in Thirlmere Lakes NP, and *Eucalyptus* sp. 'Howes Swamp Creek' which occurs in a small area of alluvium along Howes Swamp Creek near the Tinda Creek sand mine.

The same threats facing TECs are relevant to these species of conservation-significant flora, and vary according to the species' water requirements, habitat preferences and tolerance of fire. This last threat is particularly relevant because the 2019-20 fires likely eliminated or severely reduced remnant patches of many species of conservation-significant flora in the GBMA. Many individuals of species that survived have probably had their ecological resilience to mining-related threats reduced by the fires, potentially increasing their vulnerability to threats such invasive species and altered availability or water quality of surface or groundwater.

Pathways

The main pathways for potential cumulative impacts of mining near the GBMA to affect conservation-significant flora in the property are: (i) invasive species spreading from mining lease areas into the GBMA, (ii) accidental ignition leading to bushfires moving from mine lease areas into the property, and (iii) alterations to flows, volumes and quality of surface water and groundwater in the GBMA (Figure C-7). Not surprisingly, these pathways closely resemble those for Gondwanan and scleromorphic flora (Figure C-3 and Figure C-5).

Invasive species Accidental ignition Fire Vegetation loss Mass Blasting movement Groundwater Subsidence drawdown Conservation-Groundwater Streambed significant pumping cracking flora Altered Water Surface water extraction streamflow systems Runoff interception Stream scour Streamflow Mine water contamination discharge Groundwater Accidental contamination waste spills

Figure C-7 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on Conservation-significant flora.

There is a low risk of invasive species being introduced onto mine lease areas and then dispersing into the GBMA, with the most likely source being weed species associated with revegetation during mine-site rehabilitation. Another low-risk pathway is accidental ignition from sparks from mine machinery, build-up of gas in the mine, and spontaneous combustion of coal in mines or stockpiles.

Conservation-significant flora that rely on either surface water or groundwater may be impacted by hydrological pathways from mining areas near the GBMA that alter streamflow, groundwater levels and/or water quality in the property. These pathways are considered further in Section C.7.

Protection and management

Conservation-significant flora and TECs are specified under the EPBC Act (Cth) and BC Act (NSW) as requiring special environmental protection due to their scarcity and vulnerability to ongoing threats. When a species or community is listed under one of these Acts, its protection and recovery are promoted using conservation advice and recovery plans and through the assessment and approval provisions for developments such as mining (Section 2.5). Conservation advices provide the rationale for the listing and what can be done to stop the decline in population and enhance recovery. Recovery plans (called 'strategies' in NSW) present a more comprehensive management plan with specific recovery actions identified for implementation. Actions that are likely to have a significant impact on a listed threatened

species or ecological community cannot commence without approval from the Australian or NSW Government.

To obtain development approval, mining proponents must identify potential risks to threatened species and ecological communities on and around the mine-lease area. Flora surveys must be undertaken to establish what species and communities are present and document their condition. The lack of sighting of a threatened species is not conclusive evidence that it is not present, and often protection and management strategies must assume that the species is present if its preferred habitat is recorded.

Residual risk

The residual risk of mining near the GBMA to conservation-significant flora and TECs that occur in the PCIA is rated as 'Low' because of the stringent protection and management measures specified by the EPBC Act (Cth) and BC Act (NSW) and described in relevant conservation advice and recovery plans.

Further, it is likely that there are no conservation-significant flora species in the GBMA that <u>only</u> occur in the PCIA. Consequently, there are potential 'insurance populations' outside the PCIA if mining-related impacts threaten species and TECs within the PCIA. What is unclear is whether these potential 'insurance populations' are viable sources of recolonists and whether they survived the 2019-20 fires.

There is a 'Low' residual risk to conservation-significant flora and TECs in forested-wetland and freshwater-wetland vegetation formations where protection and management measures cannot eliminate the risk of surface water and groundwater impacts from nearby mines.

C.5 KM5: Potential cumulative impacts of mining on Conservation-significant fauna in the GBMA

Conservation-significant fauna occur in potential cumulative impact areas in the GBMA and may be impacted by one or more mining-related stressors. Stringent Australian and NSW government legislation protects these fauna, obligating mine proponents to specify avoidance, mitigation and offset options to minimise impacts.

Residual risk: 'Low'

Context and threats

More than 400 vertebrate taxa have been recorded in the GBMA, including 52 mammals, 63 reptiles, 30 frogs and 265 bird species. Invertebrates are less well known but 120 species of butterflies and some 4000 moth species have been recorded in the area, along with 67 taxa of cave invertebrates (NSW NPWS 2009). Of these, there are 39 species listed as threatened under the EPBC Act (Cth) and 67 under the BC Act (NSW).

The main threats to conservation-significant fauna are loss, fragmentation and/or degradation of their habitat; competition or predation by invasive species; impacts on water systems such as altered streamflow, falling groundwater levels and changes in water quality; death or habitat loss through fire; and noise and light pollution.

Threats to the Gondwanan flora and Scleromorphic flora high-level components of the OUV of the GBMA (Sections C.2 and C.3) also threaten the fauna that use these components for habitat, food or movement corridors. As mining is not allowed in the GBMA, the threat of habitat clearance for this activity is avoided in the property.

Conservation-significant fauna in the GBMA that are associated with its water systems (e.g. streams, wetlands, riparian zones and groundwater-dependent ecosystems, Section C.7) are threatened by mining impacts such as altered streamflows, falling groundwater levels and reduced water quality. Examples of potentially threatened fauna include the endemic Blue Mountains Water Skink (*Eulamprus leuraensis*) and the Bathurst Copper Butterfly (*Paralucia spinifera*), as well as the Giant Burrowing Frog (*Heleioporus australiacus*) and the Macquarie Perch (*Macquaria australasica*), which have more extensive distributions (Figure C-8).

Some faunal taxa are vulnerable to light and noise pollution. Artificial light at night is known to disrupt behaviour of nocturnal species, such as disorienting migratory birds, which reduces their potential roosting areas, or diverting migratory moths, which can change food availability for predators (Commonwealth of Australia 2020). Noise can affect some wildlife by interfering with communication (e.g. bird calls), masking sounds of approaching predators, and causing elevated stress levels (Buxton et al. 2019).

Figure C-8 The potential cumulative impact area (PCIA) of nearby mining and the mapped distributions of four endemic conservation-significant fauna species



Mapped distributions are indicative. They have been produced by spatial ecologists using modelling software and environmental data to map the 'likely' occurrence of EPBC Act listed species, including areas of potential habitat (Species of National Environmental Significance | Department of Agriculture, Water and the Environment).

Pathways

The pathways for potential cumulative impacts of mining near the GBMA to affect conservationsignificant fauna in the property are the same as those for conservation-significant flora (Figure C-7) with the addition of pathways for impacts of noise and light pollution (Figure C-9). The shared pathways are those that may affect habitats or food resources whereas noise and light pollution are only likely to disrupt fauna.





Protection and management

The EPBC Act (Cth) and BC Act (NSW) protect threatened fauna species through provisions relating to the threatened species and TECs MNES, as well as the World Heritage and the 'water trigger' MNES (Section 2.5). The threatened species and TECs MNES tend to focus on impacts occurring on the mining lease whereas the World Heritage and 'water trigger' MNES require greater consideration of potential off-site impacts.

As an example, when the Kables Sand Quarry sought approval in 2004 to increase the depth of extraction on an existing lease area, threats to the endangered Blue Mountains Water Skink and the vulnerable Giant Burrowing Frog were the basis for a controlled action determination under

the EPBC Act. There was a risk of potential impacts to these species from destruction of perched swamps (i.e. not connected to groundwater) resulting in loss of foraging habitat and fragmentation of movement corridors. The project was approved on the condition of monitoring groundwater levels and flow through the swamp, annual surveys of the Blue Mountains Water Skink and rehabilitation of extraction areas to restore and establish suitable habitat for the skink (EA 2003).

National light pollution guidelines (Commonwealth of Australia 2020) recommend that environmental impact assessment should be undertaken if the light source is within 20 km of 'important habitat' for a listed species. Important habitat is considered to be habitat where activities such as foraging, roosting, breeding or dispersal take place. Assessments of light (and noise) pollution are a standard requirement of EIAs but usually focus on minimising impacts to the amenity of nearby residents rather than wildlife.

Measures to minimise impacts of night-time lighting on surrounding areas include use of lowlevel lighting and directional lighting to minimise sky glow; strategic tree plantings to screen lit areas; and ensuring light beams in mine pits are below the pit wall. External lighting is expected to comply with Australian Standards (Australian Standard AS4282 (INT) 1997) to control the obtrusive effects of outdoor lighting.

Measures to minimise impacts of noise on surrounding areas include prescribing limits on mining operations such as upper noise limits and hours of operation. In some cases, conditions of consent have required a particular type of extraction method or the use of acoustic barriers (e.g. Newnes Kaolin mine). Mining proponents are required to take all reasonable and feasible measures to minimise noise and ensure compliance with prescribed noise levels. The mitigation measures and monitoring program that will be undertaken to meet noise level requirements must be set out in a Noise Management Plan.

Residual risk

The residual risk to Conservation-significant fauna in the GBMA is rated as 'Low'.

This rating is based on the strict conditions of approval for mines operating near the GBMA boundary and the fact that populations of most conservation-significant fauna of the GBMA are highly likely to occur outside the PCIA.

C.6 KM6: Potential cumulative impacts of mining on Geodiversity in the GBMA

The GBMA's geological landscape features and their diversity are at very low risk from the cumulative impacts of mining in the vicinity of the property because (i) most of the features are far from the potential cumulative impact zone area and (ii) strict mining consent orders now tightly regulate blasting and longwall mining. Historically, subsidence from longwall mining damaged some geological features in and near the GBMA.

Residual risk: 'Very low'

Context and threats

The GBMA contains many valued geological features and landscapes. These include the sandstone plateaus that are dissected by deep canyons with dramatic cliffs that dominate much of the landscape; the pagoda rocks in the Gardens of Stone NP and adjoining Newnes, Airly and Genowlan plateaus; and the karst landscapes, which contain the world's oldest open cave system, the Jenolan Caves. Rare and threatened species such as the Pagoda Daisy (*Leucochrysum graminifolium*), *Prosanthera hindii*, *Pseudanthus divaricatissimus* and *Banksia penicillata* (Washington and Wray 2011) as well as many Indigenous rock art sites occur amongst the pagodas.

The principal threat to the geodiversity of the GBMA from mining in the vicinity of the property is structural damage caused by extraction methods such as longwall mining and blasting. This damage is especially threatening to vertical features, leading to rock topples and cliff collapse along boundary escarpments of the property and into river canyons. These events can impact cliff habitats (e.g. for bats and cliff-nesting birds), damage 'hanging swamps' (Section C.7), potentially dam streams below collapsed cliffs, and damage or destroy Indigenous rock art and habitation sites (Section C.9).

Broadly speaking, the geological features and landscapes comprising the geodiversity of the GBMA extend across almost the entire property as landforms underlying its terrestrial and aquatic ecosystems. Plateaus, cliffs, canyons, pagoda rocks and karstic systems are common across different parts of the GBMA and some occur in the PCIA, along with associated underlying geological landforms (Figure C-10 and Figure C-11). Cliffs and pagoda rocks occur close to the GBMA boundary in the Western Coalfield (Figure C-10) and there are some cliffs within 1 km of the boundary near the Hunter Coalfield mines. Cliffs in the PCIA from Southern Coalfield mines are generally many kilometres from the mine operations (Figure C-11).

Figure C-10 Distribution of cliff lines and pagoda rocks in the potential cumulative impact area (PCIA) from mining in the Western Coalfield



Figure C-11 Distribution of cliff lines in the potential cumulative impact area (PCIA) from mining in the Hunter Coalfield (top) and Southern Coalfield (bottom).



Pathways

The two principal pathways via which mining near the GBMA may impact on its geodiversity are via ground movements (subsidence and upsidence from underground mining) and blasting (from open-cut mining), both potentially leading to fractures and mass movements that cause rock falls, landslides and cliff collapse (Figure C-12). These pathways are not relevant for the sand mining operations in this assessment.

Figure C-12 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on its Geodiversity.



Blasting at open-cut mining operations can generate ground waves with the potential to exploit existing weaknesses (e.g. joints and fractures), destabilise precarious rock features such as pagoda rocks or initiate new weaknesses in rock structures.

Subsidence occurs when the overburden above a mined longwall panel collapses into the void left by the excavated coal. Other ground movements such as upsidence (when rocks are forced upwards by faults during or after longwall mining) are less common but may occur in some geological formations such as plateaus and rock pavements. When ground movements and fracturing occur under or near cliffs, there is an increased probability of localised rock-falls and cliff collapse (Holla and Barclay 2000).

Historical examples in and around the GBMA include 180 cliff collapses over a 2-3 year period from subsidence following mining at the Baal Bone and Angus Place mines (Washington and Wray 2011), and large cliff collapses at Katoomba in 1931 and Nattai North in 1965 due to subsidence (Pells et al. 2014). Rock-falls generally occur within months of the cliff-line being undermined but may still happen up to 18 years after surface cracking was first observed (ACARP 2001).

Protection and management

Strict Australian Government and NSW state regulations govern blasting operations for all mining and constrain how far ground vibrations are allowed to extend beyond the mine lease. These include measures such as orienting the blast face to direct energy away from sensitive sites, designing the detonation sequence with delays between holes so that the blast waves from individual holes do not arrive simultaneously at a location (NSW Mineral Council 2009) and coordinating blasting schedules with adjoining mines to minimise cumulative impacts. Often the objective is to manage the risk to infrastructure and cultural values, but at some sites the objective can be protection of geodiversity features such as cliffs and pagodas.

The management of subsidence related to underground coal mining operations is also a key focus of the NSW government's regulation of mining. Assessment of potential subsidence

impacts and risk mitigation and management are undertaken as part of the assessment and approval process under the EPBC Act.

Consent orders set out the requirements in relation to managing the risk of subsidence effects from underground coal mining. An extraction plan must be prepared that describes how impacts of subsidence will be managed to meet the requirements of the development consent. It must be prepared by suitably qualified persons, provide for first and second workings, include performance indicators for each of the performance measures in the consent order, set out the monitoring plan, and plan for revising subsidence predictions as new information becomes available.

Subsidence mitigation measures include providing setbacks of longwall panels and pits from sensitive rock features and the use of partial extraction methods. Partial extraction methods involve designing a mine layout of alternating panels and pillars that ensures that the the tilt and strain values are acceptably small between panels to avoid or minimise surface subsidence.

For example, the EIS for Airly mine assessed the risk of impacts of proposed mining on cliff lines and pagodas in some areas bordering the GBMA as extremely high. The proponent suggested using partial extraction methods and protection zones around cliff lines to minimise subsidence effects and the risk of impacts (Golder Associates 2014). An independent review panel assessed the residual risk to sensitive landforms and confirmed the appropriateness of the proposed extraction methods to minimise this risk. The panel also recommended monitoring subsidence in areas with less sensitive landform features to validate predictions and, where necessary, adjust extraction plans before mining under more sensitive landform features (Mills et al. 2016). The NSW Planning and Assessment Commission approved the project with these mitigation and monitoring conditions and established an ongoing role for the panel in advising the proponent on the extraction plan into the future (NSW PAC, 2016).

Residual risk

The residual risk of potential cumulative impacts of mining near the GBMA to its geodiversity is rated as 'Very low'. This rating was assigned because (i) most of the mines around the GBMA are further than 1 km from the property's geological features (Figure C-10, Figure C-11), exceeding the expected range of these types of impacts, and (ii) strict regulations currently control blasting and subsidence associated with mining.

Although existing and proposed longwall panels at Airly, Clarence, Tahmoor and Wambo mines are close enough to the GBMA to potentially impact features of its geodiversity, approval processes have substantially reduced the residual risk by requiring additional modelling, changes to panel layouts and use of partial extraction methods. These mitigation measures also minimise the risk of impacts on Boundary integrity (Section C-8). The proposed Tahmoor South project is about 2.5 km from the GBMA at its closest point and poses little risk to the geodiversity of the GBMA.

C.7 KM7: Potential cumulative impacts of mining on Water systems in the GBMA

Water systems in the GBMA are at risk from the cumulative effects of mining in the vicinity of the property on local hydrology and water quality. Current protection and management measures substantially reduce this risk but cannot eliminate the residual risk from mining-induced groundwater drawdown and accidental spills.

Residual risk: 'Low'

Context and threats

Water systems in the GBMA include ground waters and surface waters such as streams, wetlands, swamps, waterfalls, seeps, and saturated cave systems and rock fissures. These support a diverse flora and fauna, many adapted to aquatic or moist environments with a reliable water supply. The GBMA's water systems are crucial refuges for many threatened aquatic species, including at least four species of frogs, over twenty species of aquatic and semi-aquatic plants, and the highly endemic Blue Mountains Water Skink (*Eulamprus leuraensis*).

Holland et al. (2021) estimate 420 km² (19%) of water systems of the GBMA could be affected by cumulative impacts of existing and planned mines in the vicinity of the property (Figure C-13). Most of this PCIA corresponds to streams and riparian habitats (Section C7.1).

The GBMA's water systems are threatened by mining-related activities that may alter the volumes, frequency and timing of flows, change sediment regimes and other geomorphological features, crack stream-beds and the bases of swamps, cause mass movement (e.g. cliff collapses and landslides into water systems), damage the integrity of riparian zones, alter the water regimes of standing waters, lower the water table (groundwater drawdown), and/or decrease water quality. The effects of these threats frequently interact (e.g. increases in discharges of contaminated mine water often concurrently increase volumes and reduce water quality in receiving waters). Many of these threats and their impacts are also cumulative, especially where multiple mines affect the same water system and in situations where contaminants accumulate in sediments and biota.

As mining-related threats and their impacts vary among different water systems in the GBMA, the next four subsections cover threats, pathways, protection and management, and residual risk to:

- v) streams and riparian habitats (Section C.7.1),
- vi) freshwater wetlands, exemplified by Thirlmere Lakes (Section C.7.2),
- vii) swamps, exemplified by Temperate Highland Peat Swamps on Sandstone (Section C.7.3), and,
- viii) other groundwater-dependent ecosystems (Section C.7.4).

The rest of this section describes the main pathways, protection and management measures, and residual risk to GBMA's water systems collectively to provide an overview of the potential cumulative effects of existing and planned mines in the vicinity of the property.





The Water Systems mapping may not include small GDE features, which are not well mapped in the GBMA. Source: Holland et al. 2021, Figure 18

Pathways

Multiple pathways from existing and planned mines in the vicinity of the GBMA may lead to potential cumulative impacts on the property's water systems. These pathways vary in their likelihood and consequence (risk) for different types of water systems and are strongly influenced by the hydrogeological context and drainage characteristics around individual mine sites.

Seven mining-related stressors can impact water systems in the GBMA (Figure C-14). They are discussed in more detail in the following sections (Sections C.7.1-C.7.4) for the four different types of water system types.

Figure C-14 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on its Water systems.



GDEs = groundwater-dependent ecosystems. For clarity, some minor links are omitted but were included in the causal network analysis

Protection and management

The EPBC Act and its 2013 Amendment protect the GBMA's surface waters and ground waters at two complementary levels: protection of World Heritage properties as an MNES as well as the 'water trigger' associated with any potential impacts of coal mining and coal seam gas development on all water resources (Section 2.5).

Two pieces of NSW legislation are relevant to the protection and management of water sources: (i) the POEO Act (NSW) which regulates polluting activities in NSW, and (ii) the *Water Management Act 2000* which provides for the implementation of water-sharing plans (WSPs) to manage the 'take' of water from surface water and groundwater sources.

Under the POEO Act, a mine is required to have an Environment Protection License (EPL) to discharge pollutants into streams and groundwater. The EPL specifies volumes, pollutant concentrations and conditions on discharge mine water (e.g. only when flows are above a certain level) permitted at approved discharge points from the mine site. It also specifies requirements for pollution-reduction programs and monitoring and reporting. The POEO Act regulates pollution incidents, which include leaks, spills or escape of contaminants causing or threatening material harm to the environment. Mines have a duty to report pollution incidents and undertake all necessary action to minimise the size and impacts of the release and may be fined for breaches of license conditions (Box 2-3).

Under the *Water Management Act*, rules governing the 'take' of water from surface waters and ground waters by mines in the Southern and Western Coalfields are set out in the *Water Sharing Plan for the Greater Metropolitan Region Unregulated River Water Sources* 2011 and the *Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources* 2011. In the Hunter

Coalfield, the WSP for the Hunter Unregulated and Alluvial Water Sources 2009 and the WSP for the North Coast Fractured and Porous Rock Groundwater Sources 2016 apply.

A mine is required to hold a licence to take water from a water source, including pumping from groundwater or a river or intercepting catchment runoff. Each licence specifies the water source and the entitlement. Extractions from each water source are capped to protect environmental needs and 'take' is subject to water levels in each water source. If a water source is fully allocated, a mine can be prevented from operating until it can obtain another licence or demonstrate that it can meet its need through the water market.

Specific measures for protection and management of particular mine-related risks (e.g. subsidence, stream water contamination) for the four main types of water systems in the GBMA are discussed in Sections C.7.1-C.7.4.

Residual risk

Overall, the residual risk of potential cumulative impacts of existing and planned mines in the vicinity of the GBMA to its water systems is rated as 'Low'.

The residual risk of altered flows is 'Low' because of the strict limits on extractions and the rules governing mine water discharges. WSPs manage the risk of cumulative impacts of water extractions on water sources by specifying a long-term average annual extraction limit based on environmental considerations. Uncertainties about hydrological connections between aquifers and surface water sources and the potential for unanticipated impacts where extractions from one water source affect water levels, flows and quality of other water sources contribute to this residual risk.

The residual risk of streamflow contamination is also 'Low'. This is due to tight restrictions on mine wastewater discharges to streams. Although accidental spills can happen (Box 2-3), best-practice waste and water management on site are usually effective in minimizing this risk. There could be historical contamination from previous mining in and near the GBMA (Section 2.3) and this is relevant when considering residual risks of bioaccumulation of contaminants in aquatic and riparian biota.

Although blasting and subsidence could cause cliff collapses and landslides (mass movement) that then damage some water systems, these events are unlikely and heavily regulated (Section C.6) so the residual risk is considered 'Very low' even though remediation is not feasible.

The residual risk of groundwater drawdown under some parts of the GBMA is rated as 'Moderate' because it cannot be remedied, is difficult to avoid or mitigate without changing the mine layout, and may be exacerbated by legacy impacts of previous groundwater extraction (including mines that have ceased operation). This drawdown may be due to groundwater pumping for open-cut mines or caused by cracking and altered groundwater flowpaths associated with subsidence due to longwall mining. Again, both of these have occurred historically in the vicinity of the GBMA. Substantial uncertainty about groundwater connectivity and local geological conditions (e.g. Section C.7.2) also contributes to this higher rating of residual risk.

C.7.1 KM7.1: Potential cumulative impacts of mining on streams and riparian habitats in the GBMA

Channel form, flows and water quality of some streams and riparian habitats in the GBMA are at low residual risk from the cumulative effects of existing and planned mines in the vicinity of the property.

Residual risk: 'Low'

Context and threats

Streams draining the GBMA vary widely in size, flow permanence and groundwater-dependency. Some flow into the GBMA from catchments containing mines in the vicinity of the property, which could be exposed to and/or act as conduits for mining-related threats into the GBMA. Most GBMA streams have vegetated riparian habitats whose ecological integrity and condition are strongly influenced by flows and water quality and can also include plants that access groundwater. Threatened fish species which are known or likely to occur in the GBMA include the endangered Macquarie Perch (*Macquaria australasica*), and the vulnerable Australian Grayling (*Prototroctes maraena*).

Threats from mining-related activities to some of the GBMA's streams and riparian habitats include altered flow and sediment regimes, damage to channel form and integrity (e.g. cracked stream-beds), lowered water tables and decreased water quality.

The severity of these different threats for individual streams depends heavily on their flow regime. Streams and rivers can be broadly differentiated into three flow regime classes that reflect their connectivity to groundwater (Gordon et al. 2004). Ephemeral streams are not connected to groundwater and flow in response to rainfall; intermittent streams are variably connected to groundwater and typically cease flow during dry periods; and perennial streams are usually permanently connected to groundwater and flow year-round with low flows dominated by groundwater inflows. Mining-related threats to groundwater are more relevant to intermittent and perennial streams than to ephemeral streams.

The biota and ecological processes of all three types of streams and their riparian habitats may be threatened by decreased water quality caused by mining. Mine wastewater discharges are typically more saline than natural stream flows and can contain heavy metals and other contaminants. The severity of their ecological threats will depend on the concentration and duration of the contaminated inflows and the tolerance of aquatic and riparian species to the changes in water quality. Some contaminants also accumulate in stream sediments and associated biota (e.g. aquatic invertebrates, fish), potentially posing a threat to predators in adjacent terrestrial ecosystems where bioaccumulation and biomagnification may occur (Boulton et al. 2014).

Most of the estimated 420 km² of water systems in the PCIA (Holland et al. 2021) is streams and riparian habitat (Figure C-13). Major rivers in the GBMA that are potentially impacted include Wollongambe River (mining at Clarence Colliery (Box 2-3) and the yet-to-start Newnes kaolin and sand quarry); Wolgan and Coxs rivers (mining at Angus Place); and Tinda Creek, a tributary of Wollemi Creek (mining at the Tinda Creek sand quarry). Although there may be reductions in baseflow in some of the smaller streams around Tahmoor, Bylong and the Hunter Coalfield

mines, streams draining these mining areas do not flow into the GBMA and therefore do not pose a threat to its OUV.

Pathways

All the pathways described for Water systems in Section C.7 can apply to one or more of the streams and riparian habitats in the GBMA (Figure C-15).

Figure C-15 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on its streams and riparian habitats.



Blasting and subsidence can trigger large-scale mass movements, such as landslides and cliff collapses that dam or impede stream flow, destabilise riverbanks and canyons, and damage riparian zones and waterfalls. Although such mass movements occur naturally, mining can increase the frequency and potentially the severity of such events.

Underground mining can result in subsidence and other ground movements that may crack streambeds and result in the loss of water to near-surface groundwater flows. In severe cases, flow can be lost completely. Hughes (2005) describes how longwall mining in the Southern Coalfields cracked a section of the Cataract River bed, a tributary of the Nepean River, outside the GBMA. Mining began in 1988; in 1994, the river downstream of the longwall mining operations had dried up. The water that re-emerged downstream was deoxygenated, contaminated with iron deposits and lacked aquatic life (Everett et al. 1998). The reduction in river flow was accompanied by release of gas, fish kills, iron bacteria mats and deterioration of water quality and instream habitat. Dieback of riparian vegetation in the area also occurred, possibly caused by the generation of anoxic conditions in the soil as the released gas was oxidised (Everett et al. 1998).

Groundwater drawdown from mine dewatering can reduce or eliminate baseflows in intermittent and perennial streams. Extractions of surface water for on-site uses and the interception of runoff generated or entering the property reduce inflows to draining streams. Altered stream flows can trigger bank and bed scour and sediment redistribution processes, with potential impacts on riparian habitats.

Water released from mine sites can increase flows above natural levels which can have ecological consequences (especially for biota of ephemeral and intermittent streams (Chiu et al. 2017)). Accidental spills and mine wastewater contaminated with coal fines, heavy metals, hydrocarbons and other pollutants can enter GBMA streams with severe impacts on its aquatic and riparian ecosystems (Box 2-3). Heavy metals and other contaminants may accumulate in stream and riparian sediments and biota (Boulton et al. 2014), with potential pathways transferring the contaminants to adjacent terrestrial ecosystems via predation and microbial uptake.

Contaminated water may leach from poorly managed mine waste areas (e.g. tailings dams, stockpiled overburden) and pollute groundwater. Groundwater contamination can also occur when polluted stream water infiltrates shallow unconfined aquifers below the streambed and riverbanks, potentially harming groundwater-dependent riparian vegetation.

Protection and management

In the GBMA, some streams and rivers receive special protection for their 'wilderness' values and near-natural conditions. For example, the Kowmung River was declared a 'wild river' in 2005 under the *National Parks and Wildlife Act 1974*, and this was followed by 7600 km of the Grose and Colo Rivers in 2008 (NSW 0EH 2018).

Numerous legislative controls prevent or minimise environmental impacts of mining in the vicinity of the GBMA on its streams and riparian habitats. Avoidance options include not permitting a mine to extract water from surface water sources that flow into the GBMA and not allowing mine wastewater discharge points into GBMA streams. Where the discharge of mine wastewater to a draining stream is permitted from a mine site (e.g. the Clarence, Angus Place and Tahmoor mines), risks of impacts from impaired water quality on instream and riparian habitats are managed through conditions imposed on the mine in its EPL under the POEO Act (NSW) (Section C.7). At Clarence Colliery and Tahmoor, mine wastewater must be treated to water quality standard in their EPLs prior to discharge. Discharge sites should be located to avoid sensitive habitats and ensure that the receiving stream has sufficient flows to dilute the mine water. Discharge points are also required to be engineered to appropriate standards to avoid local scouring.

Surface water management systems are required to meet industry standards in the design and construction of settlement ponds, tailings dams and storage dams to minimise the likelihood of spills. These impoundments are usually required to contain a 1-in-100-year rainfall-runoff event, although more stringent conditions may be imposed in light of predicted climate change and more extreme weather events and rainfall intensity. Contour banks, bunding and other runoff- and sediment-control structures are standard practices to contain eroded sediment on-site. Where possible, uncontaminated site runoff that is not harvested for mining operations should be diverted around disturbed areas and allowed to flow back into the drainage network. All surface water management plans must be approved by the relevant NSW Minister.

Similarly stringent regulations govern protection and management from risks associated with subsidence (described in detail in Section C.7.3). As remediation of cracked stream-beds is seldom successful (Hughes 2005), changes to underground mine layout and extraction methods are usually the only effective protection strategy to prevent subsidence-associated impacts on streams, rivers and riparian habitats.

Protection and management options for minimising the impacts of groundwater drawdown can involve modifying the mine layout and dewatering regime. Maximum drawdown can occur after cessation of mining, with lagged impacts on flow regimes of intermittent and perennial streams and riparian habitats. Again, remediation options are limited which means that avoidance and mitigation strategies are especially important.

Residual risk

Overall, the residual risk of potential cumulative impacts of existing and planned mines in the vicinity of the GBMA to its streams and riparian habitats is rated as 'Low'.

Existing national and state regulations protecting waterways limit the residual risk of altered flows and streamflow contamination, especially in World Heritage properties. Accidental spills and historical contamination have occurred in rivers in the GBMA (Section 2.3) but improvements in mine-site waste and water management have helped minimise this risk. Nonetheless, there is a 'Low' residual risk of further accidental spills.

The residual risk from groundwater drawdown on groundwater-dependent streams and riparian habitats in some parts of the GBMA is rated as 'Moderate'. This rating reflects the difficulty of avoiding or mitigating this stressor without changing the mine layout and operation, the lack of remediation options, and the potential for legacy impacts of previous groundwater extraction (including mines that have ceased operation).

Although impacts associated with subsidence (e.g. stream-bed cracking, loss or reduction of surface flows) are also challenging to avoid, mitigate or remediate, the residual risk of this stressor is rated as 'Low' because of the strict regulations controlling the location, depth and extraction methods used for underground mining. Rigorous scrutiny by independent review panels (e.g. IESC, IEPMC) of proposals of mines that may cause subsidence further contribute to a 'Low' residual risk from this stressor.

C.7.2 KM7.2: Potential cumulative impacts of mining on freshwater wetlands (Thirlmere Lakes) in the GBMA

Freshwater wetlands are rare in the GBMA. The Thirlmere Lakes system is the only representative of the 'coastal freshwater lagoon' type in the property and is close to the property boundary and nearby mining. Their unique plant assemblage is potentially threatened by mining-induced groundwater drawdown.

Residual risk: 'Indetermintate'

Context and threats

Less than 0.5% of the area of the GBMA is covered by freshwater wetlands (Hammill and Tasker 2010). Here, we consider the risk to the Thirlmere Lakes system, the only representative of the 'coastal freshwater lagoons' within the freshwater wetlands formation (Keith 2004) in the GBMA, which are located near the boundary of the property and Southern Coalfield mines (Figure C-16). Most of the threats, pathways and protection and management measures described here apply to other wetlands and lakes in the PCIA of the GBMA. Swamps are discussed in Section C.7.3.

Thirlmere Lakes are a complex of five freshwater lakes associated with a sinuous former river valley incised in the Hawkesbury Sandstone, and are the centrepiece of the Thirlmere Lakes NP (Figure C-16). They contain a dynamic mosaic of sedges, aquatic and floating herbs, and other wetland vegetation associations (Hammill and Tasker 2010). These associations include the *Lepironia* freshwater wetland community which is listed as an Endangered Ecological Community (EEC) under the BC Act (NSW) and occurs in shallow waters on the fringes of Thirlmere Lakes and the Thirlmere Sand Swamp Woodland. The wetlands contain a number of rare and threatened plant species, such as Dwarf Kerrawang (*Commersonia prostrata*), Tall Knotweed (*Persicaria elatior*) and Water Shield (*Brasenia schreberi*). These species are threatened by major changes in water levels in the Thirlmere Lakes, particularly those species along the lake margins (NSW DPIE 2019).

The main threats to the Thirlmere Lakes and their associated ecological communities are declining water levels, fire and invasive weed and pest species (NSW DPIE 2019). Over the last half-century, water levels have fallen in the Lakes, attributed to changes in climate and groundwater drawdown (including from mining operations). However, there is substantial uncertainty about the dependence of lake water levels on a groundwater connection, whether faults act as conduits for groundwater drawdown impacts to the Lakes, and whether drawdown caused by mining poses serious threats to the Lakes and their ecological communities (Riley et al. 2012, Schädler and Kingsford 2016, Banerjee et al. 2016).

Figure C-16 Thirlmere Lakes lie near the boundary of the GBMA and its unique plant assemblages may be threatened by groundwater drawdown associated with underground mining at Tahmoor Coal site.



Pathways

The primary pathway via which mines in the vicinity of the GBMA could impact Thirlmere Lakes is groundwater drawdown (Figure C-17) caused by groundwater pumping, potentially enhanced by subsidence-induced fracturing that contributes to increased connectivity between the pumped aquifer and the water table. This pathway presupposes that the Lakes are connected to groundwater and can be impacted by groundwater lowering.

Figure C-17 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on its freshwater wetlands such as Thirlmere Lakes



The Tahmoor mine lease area adjoins the Thirlmere Lakes National Park and the GBMA (Figure C-16). Underground mining commenced in 1980, and the longwalls closest to the Lakes (700 m and at a depth of 300 m) were mined between 1996 and 2004 (Pells and Pells 2016). Discharge from the mine is almost entirely groundwater, and increased from 800 ML/year in 1995 to 1200-2000 ML/year after 2002. Water levels in the Lakes declined sharply from about 2008, attributed to groundwater drawdown by Tahmoor mine (Pells and Pells 2016) and potentially other coal mines in the Southern Coalfields.

Protection and management

Strategies for the protection and management of Thirlmere Lakes system are provided in the Thirlmere Lakes National Park Plan of Management (NSW DPIE 2019). Choice of these strategies depends on establishing the potential mining-related risks to the Lakes, especially of any proposed expansions of mining nearby.

For example, risks to the Lakes from the proposed South Tahmoor mine expansion were examined closely during the assessment and approval process, including by the IESC, an independent hydrogeologist and staff of NSW water agencies. The proponent was required to account for the potential cumulative effects of the proposed expansion, the existing Tahmoor North operation and nearby mines (Dendrobium and Appin) in assessing the risk of groundwater impacts.

NSW DPIE Water (2020) recommended the development and implementation of a mitigation strategy for Thirlmere Lakes and a Trigger-Action-Response-Plan as conditions on consent. The IESC raised concerns about the proponent's assessment of risk to the Thirlmere Lakes, given the ongoing uncertainty about the hydrology of the lakes and the possibility of hydrogeological connections between the mined areas and the lakes along a fault line (IESC 2019), and the proponents were required to undertake additional modelling that took greater account of uncertainties.

To improve understanding of the Lake system, the four-year Thirlmere Lakes Research Program has been funded by the NSW government. It is due to end in 2021 and is expected to provide a

better understanding of the hydrology of the lakes and the causes of the recent declines in water levels. Meanwhile, the NSW government's conditions of consent for any expansion of mining require more extensive monitoring and further groundwater modelling to be done as new data become available and the results of the Thirlmere Lakes Research Program are delivered.

Residual risk

The lack of understanding about the hydrology and groundwater connectivity of the Thirlmere Lakes means that there is an 'Indeterminate' residual risk to this water system from existing and planned mines in the vicinity of the GBMA.

If groundwater-dependence is confirmed and it can be demonstrated that there are structural connections (potentially enhanced by subsidence) between the mining area and the Lakes, then there is a 'Moderate' residual risk that further declines in water levels are likely. This rating reflects the lack of mitigation and remediation options for groundwater drawdown that has or will occur in the short-term, and its likely impacts on water levels and the Lakes' biota.

C.7.3 KM7.3: Potential cumulative impacts of mining on swamps (Temperate Highland Peat Swamps on Sandstone) in the GBMA

Diverse types of swamps, many with endemic and threatened species, occur in the GBMA. One example is the Temperate Highland Peat Swamps on Sandstone (THPSS), some of which have been severely and irreversibly damaged by subsidence and groundwater drawdown on mine lease areas near the GBMA.

Residual risk: 'Low'

Context and threats

In addition to 'coastal freshwater lagoons' (Section C.7.2), the GBMA has two other broad wetland types (Hammill and Tasker 2010): 'coastal heath swamps' and 'montane bogs and fens'.

Coastal heath swamps typically have spongy, sandy-peat, low-nutrient soils that support several species of *Lepidosperma* sedges, herbs such as Sundew (*Drosera*) and Coral Fern (*Gleichenia*), and sclerophyllous shrubs such as Crimson Bottlebrush (*Callistemon citrinus*), Coral Heath (*Epacris microphylla*), Heath-Leaved Banksia (*Banksia ericifolia*), Dagger Hakea (*Hakea teretifolia*) and various tea trees (*Leptospermum* species). Many of these 'hanging swamps' occur on steeper valley sides in association with groundwater seepage (Hammill and Tasker 2010).

Montane bogs and fens are similar to coastal heath swamps but occur at higher altitudes in the GBMA (up to about 1300 m above sea level). They also support various sedges, grasses and lowgrowing herbs as well as sclerophyllous shrubs such as Grey Tea Tree (*Leptospermum myrtifolium*), Alpine Bottlebrush (*Callistemon pityoides*), Mountain Baeckea (*Baeckea utilis*) and *Boronia deanei* (Hammill and Tasker 2010).

These two wetland types include three EECs: the Blue Mountains Swamps (vulnerable), the Montane Peatlands and Swamps (endangered) and the Newnes Plateau Shrub Swamps (endangered). The latter two EECs are closely affiliated with the Temperate Highland Peat Swamps on Sandstone (THPSS) ecological community which also occurs in the GBMA and is listed as a TEC under the EPBC Act (Commonwealth of Australia 2014a). As there has been a considerable amount of research on the impacts of mining, potential for recovery and options for mitigation and remediation for THPSS, we focus on this type of swamp here. Although some swamp types may be subject to different threats (e.g. cliff falls and landslides are especially threatening to 'hanging swamps'), the potential cumulative impacts of mining on THPSS are similar to those for other types of swamps in the PCIA of the GBMA.

THPSS occur at high elevations (600-1200 m) and, in addition to many rare and threatened plant species, they support a number of threatened animal species. The most notable of these is the Blue Mountains Water Skink (*Eulamprus leuraensis*), considered to be endemic to this swamp community and listed as Endangered (Figure C-8). Other threatened species include the Giant Burrowing Frog (*Heleioporus australiacus;* Figure C-8), Red-Crowned Toadlet (*Pseudophryne australis*) and the Giant Dragonfly (*Petalura gigantea*).

Although some THPSS occur in the GBMA (Figure C-18), most occur outside the property and include swamps on mining leases in the vicinity of the GBMA. Mining-related threats to these

Figure C-18 The potential cumulative impact area (PCIA) of nearby mining and the mapped distribution of swamps such as THPSS.



swamps include subsidence-induced fracturing and tilting of underlying sandstone, subsidenceinduced valley closure and cliff collapse in steep terrain and altered water regimes (Commonwealth of Australia 2014a). Other threats are water quality impacts arising from discharge of mine waste water upstream of swamps. For example, impacts on THPSS have been reported due to mine wastewater discharges into swamps in the headwaters of the Wolgan River and the probable impacts of rock fracturing and groundwater loss (Springvale Coal and Centennial Angus Place 2011). Where mining has damaged groundwater-dependent ecosystems (e.g. 'hanging swamps' on Newnes Plateau) in catchments of waterways entering the GBMA, there is a risk that impacts may propagate downstream and affect aquatic systems and their associated ecosystems within the GBMA.

Another threat is fire, potentially arising from accidental ignition on a mine site but more common as bushfires started by lightning. Where THPSS and other peat swamps have been fully or partly dried out because of water loss through cracked beds or due to reduced inflows, damage by bushfires can be particularly severe (Section C.10). A recent study (Fryirs et al. 2021) reported that the 2019-20 fires burned 59% of THPSS, 72% of those with a high severity that could be partly attributed to previous drying and included swamps that had been impacted by subsidence.

Pathways

The two principal pathways for mining-related impacts on swamps, particularly THPSS, are via: (i) subsidence caused by underground mining where ground movements cause tilting and cracking of the rock substrate below the swamps and cause a loss of stored water, and (ii) accidental or intentional discharge of contaminated water in surface waters entering the swamps (Figure C-19). This second pathway is less likely because improved protection and management measures now legislate that discharge sites should be downstream of swamps (Commonwealth of Australia 2014a).

Other pathways (Figure C-19) associated with mining operations that may impact THPSS include groundwater drawdown caused by pumping, mass movement such as cliff collapse resulting from blasting (which can affect 'hanging swamps' in steep terrain), reduced streamflow into swamps where subsidence-induced cracking of stream-beds drains away inflowing water, and any alterations to streamflow that may cause scouring or sedimentation of swamps downstream. Soil and groundwater contamination from accidental waste spills that then affect THPSS is less likely but a possible pathway for impacts on swamps at lower elevations. Figure C-19 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on its swamps, especially THPSS.



Protection and management

Although serious ecological impacts on THPSS have resulted from subsidence and subsequent drying (reviewed in Commonwealth of Australia 2014b), these have not occurred in THPSS in the GBMA. Nonetheless, impacts on THPSS and other swamps outside the GBMA potentially detract from the integrity of the property because of the impairment or loss of ecological connectivity (e.g. gene flow and recruitment from adjacent natural areas into the GBMA). These wetlands should not be viewed as isolated systems but instead as part of a mosaic of aquatic ecosystems in the landscape that have evolved over long periods of time and are hydrologically and ecologically connected. Effective protection and management of THPSS and other swamps on mining leases outside the GBMA will benefit these types of wetlands and their associated ecosystems within the property.

The best way to protect THPSS is by designing the layout of longwall panels to avoid underground mining below or near these swamps and their inflows. Where longwalls cannot be arranged to avoid potential impacts on swamps, the risk of subsidence and other stressors can be reduced through partial extraction methods, where the dimensions and arrangement of panels are designed to ensure subsidence in swamp areas is less than 20 mm. Recent mining development proposals at the Clarence, Airly and Angus Place coal mines have been approved on condition that they are undertaken using partial extraction methods to minimise the risk to overlying or nearby THPSS. Once damaged, remediation of these swamps is seldom if ever feasible (Commonwealth of Australia 2014b) which is why preventing or minimising the impacts is so important.

Similarly, the risk of subsidence-induced flow reductions on swamps downstream of mine sites and within the GBMA can be minimised using carefully designed mine layouts or partial extraction methods. In particular, attention should be paid to potential impacts on fault lines and lineaments because these often coincide with drainage channels and/or groundwater flowpaths. These protection and management options apply to all mines, not just underground coal mines. For example, the original proposal for the Newnes kaolin and friable sandstone project involved excavating a swamp site. To obtain consent for this project, the proponent was required to modify the mine plan to avoid directly impacting the swamp, provide a 50-m buffer around the wetland and divert natural runoff from upstream of the mine area into the swamp site (NSW Minister for Planning 2006).

The risk from mine water discharges on THPSS can be avoided by not permitting water to be discharged into swamps or into streams that flow into these swamps. This also removes the risk of erosion of peat in the swamp from increased flows as well as avoiding excessive sedimentation. If necessary, discharge points may be located downstream of swamps. Treating mine wastewater to an acceptable level prior to discharge is usually required as a condition of consent, which reduces but does not necessarily eliminate the risk.

Residual risk

The residual risk of potential cumulative impacts of existing and planned mines in the vicinity of the GBMA to its THPSS and other swamps is rated as 'Low'.

This rating reflects the current strict regulations and conditions of consent that protect THPSS on mine leases near the GBMA and that acknowledge the lack of remediation options once a swamp is damaged. If subsidence, wastewater discharges, groundwater drawdown and other potential stressors are managed appropriately on-site, the residual risk to swamps in the GBMA is 'Very low'.

There is a 'Low' residual risk to THPSS and other swamps in the GBMA downstream from locations where treated mine wastewater is discharged. Mass movement in the GBMA from blasting is very unlikely but this residual risk cannot be eliminated.

C.7.4 KM7.4: Potential cumulative impacts of mining on other GDEs in the GBMA

Groundwater-dependent ecosystems other than rivers and wetlands are poorly known in the GBMA but may be at risk from the cumulative effects of mining in the vicinity of the property on groundwater levels and water quality.

Residual risk: 'Indeterminate'

Context and threats

Groundwater-dependent ecosystems (GDEs) are defined as 'ecosystems that need access to groundwater to meet all or some of their water requirements to maintain their communities of plants and animals, ecological processes and ecosystem services' (Richardson et al. 2011). Thus far, we have discussed streams (Section C7.1), freshwater wetlands (Section C7.2) and swamps (Section C7.3), many of which are fed by groundwater. Their fringing vegetation is also often groundwater-dependent but it is likely that there are other plants across the GBMA that always or occasionally require groundwater and are therefore GDEs. Aquifers and saturated cave ecosystems are another type of GDE (Eamus et al. 2006) that is likely to occur across the GBMA and contribute to its natural heritage values and integrity. However, with a few exceptions such as Jenolan Caves, the distribution and biota of these subsurface GDEs are very poorly known in the GBMA.

This section on 'Other GDEs' focuses on groundwater-dependent vegetation, aquifers and saturated cave ecosystems. It seeks to raise their profile, infer likely threats and pathways of nearby mining on them, and encourage their documentation and assessment in the GBMA as potentially important elements of the OUV of the property, especially as they often occur at the nexus of terrestrial and aquatic ecosystems, governed by geological features.

Many vegetation associations of the GBMA where the water table is close to the surface (less than 20 m) include plant species that obtain part or all of their water from groundwater. This water is usually accessed via the capillary fringe (the non-saturated zone above the saturated zone of the water table) when roots penetrate this zone (Eamus et al. 2006). Groundwater is especially important to plants during dry periods and prolonged drought, and many species in this type of GDE use groundwater opportunistically rather than all the time.

Aquifers and saturated cave systems often support stygofauna (specialised invertebrates that live permanently in groundwater) and active microbial assemblages (Boulton et al. 2014). Although some stygofauna are known from the Jenolan Caves in the GBMA (Thurgate et al. 2001), there have been no systematic surveys of this type of GDE across the property and it is likely that new species await discovery, especially in karstic areas. The GBMA is underlain by various aquifers, some of which are likely to contain stygofauna because of their good water quality, connectivity to other ecosystems (including streams and wetlands) and interstitial spaces that are large enough to provide habitat for groundwater invertebrates. These aquifer systems and their stygofauna also await systematic surveys in the GBMA.

The main threats to GDEs are alterations of the natural patterns of seasonal or annual availability of groundwater, dewatering of parts of aquifers for long periods (severing ecological connectivity and depriving stygofauna of saturated habitat), and/or reductions in groundwater quality. Groundwater-dependent terrestrial vegetation is also threatened by the same stressors

that impact other terrestrial vegetation such as fire, habitat fragmentation and invasive species (Sections C.2 and C.3).

Groundwater drawdown dries out previously saturated aquifers, displacing or killing stygofauna that cannot tolerate desiccation. Sometimes, drawdown can strand groundwater invertebrates, especially if water tables fall quickly (Stumpp and Hose 2013). Stygofauna are also threatened by poor water quality, especially high salinities and heavy metals, and aquatic cave invertebrates are also vulnerable to sedimentation (Boulton et al. 2003). If drawdown lowers the water table so that it is no longer accessible to the roots of groundwater-dependent vegetation, these plants are likely to decline in condition and may die. Timing and duration of access are also important, and changes to the natural groundwater regime can be a serious threat to some plant species (Eamus et al. 2006).

Based on groundwater numerical modelling in the region, cumulative groundwater drawdown from multiple mines is very unlikely to exceed 0.2 m more than 20 km from any individual mine (Herron et al. 2018b). Drawdown less than 0.2 m is assumed unlikely to impact GBMA aquifer and cave GDEs or groundwater-dependent vegetation. Holland et al. (2021) plotted 20-km contours of drawdown around open-cut and underground mines (and 3-km contours around quarries) to infer the PCIA of groundwater drawdown in the GBMA (Figure 4-2). This map indicates that groundwater drawdown is not a threat to the Jenolan Caves but may be relevant for aquifers, cave systems and groundwater-dependent vegetation within the PCIA.

Pathways

The main pathways by which mining near the GBMA's boundary may have impacts on other GDEs such as aquifers, saturated cave systems and groundwater-dependent terrestrial vegetation are groundwater drawdown from pumping or subsidence, and groundwater contamination from either accidental waste spills or intentional discharge of contaminants into a stream that eventually enter the groundwater (Figure C-20). Blasting and subsidence may also cause mass movements that could alter aquifer integrity or saturation, and impact on the GDEs.

These types of GDEs may occur near streams, accessing groundwater from shallow alluvial aquifers. Therefore, there may be some pathways shared with stream and riparian habitats (Section C.7.1) where groundwater quantity or quality might be affected.

Figure C-20 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on its other GDEs.



Protection and management

As described in the previous three subsections, stringent regulations and conditions of consent are imposed on mines near the GBMA's boundary to limit the extent of groundwater drawdown and potential contamination. However, dewatering of mines inevitably leads to some drawdown which is likely to be cumulative in areas where multiple mines occur. Maximum drawdown may occur late in the mine's operation and sometimes even after mining has ceased. These historical and lagged effects of past and present mining on groundwater levels in the PCIA cannot be readily stopped or remediated.

Furthermore, recognition of the importance, ubiquity and conservation values of GDEs is comparatively recent (Boulton 2009) and they were not a prominent component of the GBMA's nomination in 2000 because they were poorly known in Australia at that time. In recent years, understanding of their ecological importance has increased substantially and they are now routinely assessed in EISs and by the IESC when evaluating these documents (Doody et al. 2019). Consequently, there are now more protection and management strategies to avoid or minimise impacts on groundwater levels and water quality. These complement the strict conditions governing releases of mine wastewater and limiting the risks of accidental spills and leaching from mine waste areas such as stockpiled overburden and tailings dams.

Remediation options for GDEs damaged by groundwater drawdown and contamination are seldom feasible, leading a much greater focus on conservation options (Boulton 2009), including systematic reserve planning to optimise stygofauna biodiversity (Boulton 2020). Such systematic planning may be feasible for GDEs in forests, patches of native vegetation and other natural areas around the GBMA, and would contribute to the protection and management of the integrity of the property's GDEs and connected surface ecosystems.

Residual risk

The residual risk of potential cumulative impacts of existing and planned mines near the GBMA to the GDEs discussed in this subsection is 'Indeterminate' because of the lack of knowledge about their distribution in the PCIA and the rest of the GBMA. As the PCIA does not overlap with the Jenolan Caves area and nearby karstic formations, the residual risk of mining near the GBMA to this GDE is rated as 'Very low'.

Reliable baseline data on the distribution of these types of GDEs in the GBMA will help refine the assessment of residual risk. In addition, information on the tolerance of these GDEs to mining-related drawdown and groundwater contamination is needed to guide strategies for effective protection and management to further minimise residual risk.

C.8 KM8: Potential cumulative impacts of mining on the Boundary integrity of the GBMA

The Boundary integrity of the GBMA can be impacted by subsidence damaging escarpments and cliffs, and by clearing or accidental burning of vegetation buffers on mine lease areas that adjoin the GBMA.

Residual risk: 'Low'

Context and threats

Boundary integrity refers to the characteristics of the GBMA's boundary such as native vegetation and rocky escarpments that help buffer the unique ecosystems, their biota and their ecological processes from the effects of more intensive land uses outside the property (Section 2.2.2). When the property was listed in 2000, it lacked a formal buffer zone despite this being a key part of the conservation strategy of World Heritage properties. Fortuitously, around 670 km (13%) of the boundary adjoin national parks, nature reserves and conservation reserves and these provide valuable protection to the GBMA. Around 50 km (1%) of the boundary adjoin mine lease areas (excluding other extractive industries). Holland et al. (2021) identified an area of 85 km² of the Boundary integrity spatial extent that could be significantly impacted by cumulative effects of nearby mining (Figure C-21).

Threats to boundary integrity arise where a mine removes vegetation (especially natural stands of native vegetation) along the GBMA boundary or causes a fire that damages this vegetation. Another threat to boundary integrity is where rockfalls and landslides along the property boundary might be initiated by operations such as blasting and underground mining leading to subsidence (Section C.6).

Impairment or loss of boundary integrity increases the risk of invasive species entering the GBMA, reduces connectivity for populations of mobile native fauna and compromises beneficial ecosystem processes provided by adjoining native vegetation (e.g. recruitment from seed banks, inputs of organic matter). The severity of the impacts of vegetation removal will likely be context-specific, and depends on factors such as the area, vegetation type, vegetation condition and ecological connectivity with ecosystems within the GBMA.

Pathways

Vegetation removal and accidental ignition leading to fire are the key pathways via which mining can reduce boundary integrity (Figure C-22). In both cases, there is only an impact if the action results in vegetation degradation, fragmentation or loss along the GBMA boundary.

New coal mining developments invariably require clearing of vegetation for access roads, site and coal processing facilities, mine pits, powerlines and other infrastructure. This vegetation removal leads to habitat loss as well as fragmentation and reduced habitat condition through increased edge effects that may, for example, facilitate incursion of weeds and other invasive species. The stressor extent for vegetation removal corresponds to the area of clearing, and only mines that adjoin the GBMA can impact boundary integrity through vegetation removal.

Figure C-21 The potential cumulative impact area (PCIA) of nearby mining on the boundary integrity of the GBMA (based on a 500-m buffer around the property boundary).


Figure C-22 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on its Boundary integrity.



Fires escaping from mine leases adjoining the GBMA are also likely to impact boundary integrity. Fires could spread from a mine site into the GBMA even where there is no shared border, but this is considered less likely. It is difficult to predict the stressor extent for fire because this depends on many site-specific conditions such as vegetation flammability, fire history, wind direction, fire severity and access for firefighting.

Subsidence and blasting effects are also possible pathways for mining to impact boundary integrity (Figure C-22), primarily through reducing the stability of escarpments. Mass movements causing cliff collapses, rockfalls and landslides along the property boundary can compromise natural barriers around the property, remove vertical rocky habitats and open up pathways for weeds and other invasive species.

Protection and management

Management of the removal of native vegetation on mining sites is regulated by the development consent process under the EP&A Act (NSW). The NSW guidelines for managing impacts of development next to NSW national parks (NSW NPWS 2020) recommend that site layouts be designed with vegetated buffers and setbacks to avoid or minimise environmental impacts on NSW national parks. Where there is no buffer, the guidelines recommend developing appropriate conditions or land management practices that minimise the potential edge effects from development. These guidelines also apply to World Heritage properties such as the GBMA.

Leaving a buffer can be specified as a condition of consent. For example, to protect the GBMA from the effects of nearby sand quarrying, buffers of 100 m at the Newnes Kaolin and Friable Sandstone project (NSW Minister of Planning 2006) and of 250 m at the Tinda Creek sand quarry (NSW DPE 2015) were conditions of consent for those projects.

Where the proposed development involves clearing of native vegetation, the proponent must consider options for avoiding or minimising the losses. This can mean re-siting mining infrastructure, modifying the proposed extraction area or reducing the reject emplacement area. The NSW *Biodiversity Offsets Policy for Major Projects* (NSW Government 2014) requires mines to provide offsets for the removal of native vegetation. The policy sets out the requirements for

biodiversity offsets and is underpinned by six principles, including that offsets only be considered once options to avoid removal and minimise impacts have been considered; that offsets are targeted to the biodiversity values being lost or higher conservation priorities; and offsets be enduring, enforceable and auditable. If appropriate offsets cannot be found, proponents need to contribute funds to support supplementary measures, such as actions outlined in threatened species recovery programs, threat abatement programs, research and survey programs and rehabilitation of degraded habitat.

Protection and management to avoid or mitigate the risk of accidental ignition and incursion of weeds and other invasive species are described in C.3, and to minimise the impact of subsidence and blasting are described in C.6.

Residual risk

The residual risk to the Boundary integrity of the GBMA is rated as 'Low'. This rating acknowledges the spatial overlap of this high-level component of OUV with the PCIA and the strict conditions of approval imposed on mines operating near the GBMA boundary.

The residual risk of subsidence and other ground movements on Boundary integrity from operations at Airly mine and Clarence Colliery is assessed as 'Low'. Expansions of underground mining at these sites have been approved on the condition of using partial extraction methods to limit subsidence to within 20 mm within the GBMA. However, at the Wambo (South Bates) site, there remains a residual risk to the Wollemi Escarpment along the GBMA boundary due to the proximity of the longwall panels to the GBMA. In 2016, the Wambo mine sought approval to extend their underground mining operations with new South Bates panels. The proposed longwall panels were to come as close as 120 m from the Wollemi Escarpment, potentially impacting on its cliffs via subsidence. Following detailed investigations, the NSW Planning and Assessment Commission were satisfied that the Wollemi Escarpment was outside the 26.5-degree angle of draw above the proposed longwall panels and that subsidence within the GBMA would be less than 20 mm (NSW PAC 2017).

The vegetation approved or currently being assessed for removal at the Airly, Clarence, Tahmoor and Wambo (South Bates) mines is in areas that are at least 500 m from the GBMA boundary. Although the vegetation clearance in these examples is very unlikely to impair GBMA boundary integrity, the residual risk is rated 'Low' rather than 'Very low' because not all areas of native vegetation on mine leases adjoining the GBMA will necessarily share these same consent conditions and proximity to a World Heritage property is not always flagged as a controlling provision (Section 2.5).

The residual risk of blasting effects on Boundary integrity is assessed as 'Very low' because no open-cut coal mines are close enough to have a significant impact and the sand mines do not involve blasting. Similarly, the residual risk of accidental ignition events leading to fires that spread into GBMA boundary vegetation is 'Very low' because strict regulations minimise fire risks on mine sites (Section C.3), together with the GBMA's fire management strategies such as fire breaks and other cleared areas.

C.9 KM9: Potential cumulative impacts of mining on Indigenous custodial relationships in the GBMA

Indigenous custodial relationships within the GBMA are underpinned by components of its OUV. Mining-related stressors that impact components of OUV may also impact Indigenous cultural connections with land and custodial relationships. Consultation with Indigenous custodians was not sufficient to permit a reliable rating of residual risk.

Residual risk: 'Indeterminate'

Context and threats

Indigenous custodial relationships and Indigenous heritage values, which contribute to the integrity of the GBMA, are broadly conceived in terms of tangible elements such as culturally significant sites and species, and more intangible values relating to cultural connections to Country. Any degradation of land and water systems and loss of habitats, communities and species can impact tangible and intangible components of Indigenous custodial relationships. Six tribal groups (Darug, Gundungurra, Wiradjuri, Wanaruah, Darkinjung and Tharawal) maintain continuous connections to the lands and waters of the GBMA (Taçon et al. 2007). The property has more than 1500 culturally significant sites including occupation sites (caves, shelters and hearths), grinding grooves, scar trees, rock art and natural landscape features that are integral to Indigenous connections to Country.

Threats to the seven other high-level components of the OUV of the GBMA also potentially threaten Indigenous custodial relationships because of the many cultural connections to Country that include intimate ties to the environment, its geodiversity and its flora and fauna. In addition, Indigenous cultural features such as caves, rock art, hearths and grinding grooves associated with cliffs and escarpments of the GBMA are assessed as at risk of damage or loss from rock instabilities and cliff collapse. Eagle's Reach is an important rock art site in Wollemi NP with painted, engraved and stencilled rock art (McDonald and Clayton 2016). One notable aspect of this site is the skill and accuracy with which the animals were drawn (Taçon et al. 2007), and the site includes uncommon motifs such as an eagle, a double-headed human-like figure and rare animal-headed human beings (Taçon et al. 2006). Indigenous rock shelters in the Wollemi Escarpment cliffs have been identified as threatened by subsidence from mining of the South Bates panels at the Wambo mine site, prompting the NSW Planning and Assessment Commission to investigate and confirm that subsidence within the GBMA would be less than 20 mm (NSW PAC 2017).

One threat that has not been mentioned for the other seven high-level components of OUV is air pollution, specifically from dust generation by mining. Dust can be a threat to sheltered rock art, particularly when generated close to a rock art site (Watchman 1999). Although dust tends to be washed away at open sites, it can accumulate in sheltered locations and can become incorporated in surface mineral deposits that obscure or compromise the art. This has been reported at rock art sites near Wilpinjong coal mine, where monitoring showed a layer of dust containing coal forming over the artwork (Peabody 2017). The accumulation of dust on rock art can increase the threat of colonisation by lichens, accelerate weathering and cause formation of secondary mineral deposits.

Pathways

All pathways via which mining near the GBMA can impact the other seven high-level components of OUV may potentially impact Indigenous custodial relationships within the GBMA. This dependency is shown on Figure C-23 as links from the other seven high-level components. Details of these pathways are given in the preceding subsections (Sections C.1-C.8).

One pathway that is material to some elements of Indigenous custodial relationships but has not been flagged as an important one for the other high-level components of OUV is air pollution (predominantly dust) which can threaten rock art. Dust is generated during mine operations at open-cut coal and sand mines during the excavation of sand, rock and coal. It also comes from traffic movement on unsealed roads around the site and possibly from poorly managed waste piles and cleared areas.

Figure C-23 Principal pathways by which impacts associated with mining in the vicinity of the GBMA may impact on its Indigenous custodial relationships.



Dashed lines acknowledge that Gondwanan flora and Scleromorphic flora are components of Conservation-significant flora

Protection and management

The NPW Act (NSW) provides for the protection and management of Aboriginal heritage places and objects within NSW. Its objective is to prevent unnecessary or unwarranted destruction of Aboriginal objects and to protect and conserve objects where such action is considered warranted. In relation to mining and other developments, the Act is given effect through the planning and approval process which requires the proponent to undertake an Aboriginal archaeology and cultural impact assessment to identify risks and, where necessary, develop mitigation and management measures to minimise impacts. The survey to identify culturally significant features and sites should extend beyond the mine site. Codes of practice and guidelines have been prepared to assist in preparation of the assessments (NSW 0EH 2011, DECCW 2010a, b).

Where a risk to Indigenous heritage, places or objects is identified, the development will require the mine to prepare an Aboriginal cultural heritage management plan that details the avoidance and mitigation measures to protect the sites and objects from harm. In some cases where degradation or damage to an Indigenous site occurs, remediation can be an option. For example, at the impacted Castle Rock art site near the Wilpinjong Coal mine (not part of this assessment), Peabody Coal who operate the mine are working with local Aboriginal community and archaeological consultants to dry-brush coal dust from the site (Dave Lambert, *pers. comm.*). Dust accumulation on rock art can be treated, but treatment becomes increasingly difficult the longer dust is allowed to collect. If dust accumulates for too long, water and harder brushes can be necessary to remove the coating but there is also the potential to damage the artwork.

Strict air quality standards and regulatory frameworks help minimise the level of dust and other air-borne particulates produced by mines. Mining operations are planned and conducted to minimise disturbed areas and progressively rehabilitate mined areas, stockpiles are sprayed with water, and water carts keep unpaved roads damp so that dust generation is kept to a minimum. Some mines also have improved modern technology to forecast when weather conditions are going to contribute to dust generation so that they can modify their operations accordingly. For example, if a windy day is forecast, operations can be moved into deeper areas of an open-cut mine pit to avoid producing dust at heights that can be blown off-site.

Residual risk

Although it is assumed that Indigenous custodial relationships are deeply bound with the other seven high-level components of the OUV of the GBMA, the residual risk of cumulative impacts of nearby mining on Indigenous custodial relationships in the GBMA is rated as 'Indeterminate'. This rating reflects the need to engage further with Indigenous stakeholders to better understand the risks to this high-level component of OUV. Although there are regulatory controls in place to protect Indigenous heritage, places and objects, the residual risk from mining on Indigenous custodial relationships with the GBMA remains unclear.

C.10 KM10: Implications of the 2019-20 bushfires on the potential cumulative impacts of mining near the GBMA on the eight high-level components of OUV

Bushfires that burnt 71% of the GBMA with varying severity in 2019-20 modified the property's landscape and probably reduced the ecological resilience of the biological components of the OUV to the potential cumulative impacts of mining in the vicinity of the GBMA.

Between October 2019 and February 2020, multiple bushfires burnt 71% of the GBMA's area with varying severity (Figure C-24). These fires killed countless plants and animals, dislocated many others and – because of their extent and intensity – substantially modified the landscape of the GBMA. These landscape modifications included destruction of habitat and food resources for many animal species (some of which are Conservation-significant fauna, Section C.5) and severe reduction or loss of large stands of native vegetation, including some species and associations of Conservation-significant flora (Section C.4).

Short-term declines in air quality may have had severe impacts on wildlife that escaped the fire. Widespread starvation is also highly likely because the loss of vegetation, leaf litter and woody debris across most of the burnt area severely reduced food resources and habitat for many species. To combat this food shortage for native wildlife, aerial food drops (e.g. carrots, sweet potatoes) were repeated across some parts of the GBMA soon after the fires. Loss of cover also destroyed nesting sites and increased many species' vulnerability to predation and exposure.

In severely and moderately burnt areas of the GBMA, large expanses of bare ground covered in ash and charcoal were left. Heavy rains following the fires are likely to have mobilised fine sediments, ash, soot and charred organic matter that then entered waterways, clogging their beds and threatening water quality. Blooms of undesirable toxic cyanobacteria may have been triggered by increased dissolved nutrient concentrations from ash and release from the mobilised material. As microbes break down the pulse of organic matter washed into the waterways, dissolved oxygen concentrations plummet and probably led to deaths of fish and other aquatic life. Further post-fire impacts on aquatic life in the GBMA's waterways may include clogging of gills, smothering of food sources and reduction of light penetration into the water.

All of these fire-induced landscape modifications are likely to reduce the overall ecological resilience of biological components of the GBMA's OUV, including to the potential cumulative impacts of existing and planned mining projects in the vicinity of the property. Where burnt areas overlap those areas subject to one or more stressors associated with mining, the cumulative impact may be the difference between recovery or loss of a given habitat or species in the GBMA. We have no direct evidence of this mechanism but we suggest that it is plausible and deserves further investigation (Section 5.5).

Post-fire impacts are still being evaluated in the GBMA, but there are serious concerns about the long-term survival of some species and communities. One study (Smith 2020) estimated over 110 million mammals, birds and reptiles in the GBMA were impacted by the fires. However, fires also benefit many taxa and are a natural component of most Australian ecosystems. The GBMA lies in one of the most fire-prone regions in the world. Many of its scleromorphic plants depend on fire to break seed dormancy, release seeds from woody cones, stimulate flowering and create

Figure C-24 2019-20 bushfire extent and severity across the GBMA and nearby protected areas. The PCIA identifies areas that could be impacted by the cumulative effects of mines near the GBMA.



the conditions needed to thrive (Hammill and Tasker 2010). The impacts of fire are not easily predicted because they depend on the timing, intensity and scale of fire as well as the area's fire

history. Importantly, exposure to other stressors affects ecological resilience to fire, and communities that under normal conditions would recover well from a fire can show poor levels of recovery when their condition has been degraded by other stressors, including mining.

This is illustrated for post-fire recovery of vegetation of the Temperate Highland Peat Swamps on Sandstone (THPSS) TEC on the Newnes Plateau (Baird and Benson 2020). After the 2019-20 bushfires, recovery rates of intact swamps differed dramatically from those of swamps undermined by coal mines. The 2019-20 fires were followed by good rain in February and March 2020, and vegetation recovery in intact reference swamps was rapid and vigorous with little evidence of combustion of surface peat. However, in swamps that were undermined by longwall coal operations, Baird and Benson (2020) report that the effect of the fires has been catastrophic. Undermined swamps tend to be characterised by lower water tables and desiccated peaty swamp soils. The fires have burnt the surface peat and the lignotubers and root bases within it, destroying crucial seed banks. Lack of moisture in the swamp soils prevents many typical swamp species from recruiting. Instead, there has been recruitment of non-swamp eucalypt and acacia seedlings in the undermined swamps, reflecting a shift from groundwaterdependent to rainfall-dependent vegetation and the loss of the characteristic plant associations of THPSS.

Superimposing the PCIA of stressors associated with existing and planned mines in the vicinity of the GBMA on top of the map of areas burned in 2019-20 fires (Figure C-24) indicates substantial overlap (58% of PCIA burnt, with half (29%) at high to very high severity), especially in the Western (inset 1) and Southern Coalfield (inset 2) PCIA areas. Catchments of many rivers entering or within the GBMA were partially or largely burnt (Figure C-24), and resulting changes to the waterways may exacerbate the impacts of mining-related stressors on affected Water systems. Approximately 42% of the GBMA boundary was burned, including about 40% of areas identified as potentially impacted by mining, possibly compromising Boundary integrity. Further work (Section 5.5) is needed to assess the potential cumulative impacts of mining and burning on these and the other high-level components of OUV.

Various options exist to reduce the severity and intensity of bushfires (e.g. fuel reduction burns, maintaining fire breaks) but these can be overwhelmed by climatic events as seen in 2019-20 across much of eastern Australia. During the fires, strategic and often courageous fire-fighting attempts to protect irreplaceable natural assets (e.g. relict stands of Wollemi Pine) as well as infrastructure and human dwellings. Post-fire remediation measures include stabilising burnt areas, reducing or preventing sediment runoff, feeding native wildlife and rescuing injured animals. Given the likely increases in bushfire frequency and severity associated with future climatic conditions predicted for the GBMA region in coming decades, protection and management measures for avoiding or mitigating mining-related impacts should complement those planned for reducing impacts of extreme bushfires.

Initialisms

АСТ	Australian Capital Territory
AE	Assessment Endpoint
AUD	Australian dollars
BA	Bioregional Assessment
BC Act	Biodiversity Conservation (NSW)
BHP	Broken Hill Propriety Company Limited
BSAL	Biophysical Strategic Agricultural Land
C&M	Care and maintenance
CIA	Cumulative Impact Assessment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWE	Department of Agriculture, Water and the Environment
DPIE	Department of Planning, Industry and Environment
EEC	Endangered Ecological Community
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EP&A	Environmental Planning and Assessment (Act, NSW)
EPA	Environment Protection Authority
EPL	Environment Protection License
EPBC	Environment Protection and Biodiversity Conservation (Act, Cth)
GBMA	Greater Blue Mountains Area (used in this report to refer to the World Heritage Area)
GDE	Groundwater-dependent ecosystems
HVO	Hunter Valley Operations
IEPMC	Independent Expert Panel for Mining in the Catchment
IESC	Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development
IUCN	International Union for Conservation of Nature
LALC	Local Aboriginal Land Council
KM	Key message
MCA	Minerals Council of Australia
MLA	Mine lease area
MNES	Matter of National Environmental Significance
Mt	Million tonnes
n/a	Not applicable
NP	National Park
NPW Act	National Parks and Wildlife (NSW)
NPWS	National Parks and Wildlife Service
NSW	New South Wales
OC	Open-cut
OEH	Office of Environment and Heritage
OUV	Outstanding Universal Value

PCIA	Potential cumulative impact area
PIA	Potential impact area
PID	Potential impact duration
POEO Act	Protection of the Environment Operations (NSW)
SEA	Strategic Environmental Assessment
SSD	State Significant Development
SSMD	State Significant Mining Development
TEC	Threatened Ecological Community (under the EPBC Act (Cth) and BC Act (NSW))
THPSS	Temperate Highland Peat Swamps on Sandstone
UG	Underground
WHC	World Heritage Committee
WSP	Water sharing plan

Glossary

These words and terms are defined according to their intended use in this report. Consequently, some of the definitions may differ from those used conventionally, in common language or in other reports. Where possible, the definitions are consistent with those used by Holland et al. (2021).

Term	Definition
Activity	An intentional anthropogenic action, usually associated with obtaining resources (e.g. food, water, minerals), that might result in one or more impacts on one or more assessment endpoints.
Assessment Endpoint	'An explicit expression of the environmental value to be protected, operationally defined by an ecological entity and its attributes' (US EPA 1998).
Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt). Includes two broad types:
	• <i>confined</i> – the aquifer is surrounded by layers of impermeable material, causing it to be under pressure; when penetrated by a well, the water will rise above the top of the aquifer.
	• <i>unconfined</i> – the aquifer has its upper water surface (water table) at atmospheric pressure and can rise and fall in response to changing conditions at the surface.
Avoidance	The steps or strategies that prevent a negative impact on one or more components of OUV by either avoiding the activity completely or locating it where it cannot have any negative impacts. The best option in the mitigation hierarchy is avoidance but if this is not possible, less-preferred strategies include minimising and/or remediating negative impacts on AEs.
Bioaccumulation	The gradual accumulation of substances, such as pesticides or other chemicals, in an organism. Bioaccumulation occurs when an organism absorbs a substance at a rate faster than that at which the substance is lost or eliminated by catabolism and excretion.
Biomagnification	The process by which a compound (such as a pollutant or pesticide) increases its concentration in the tissues of organisms with increasing levels up the food chain such that concentrations are greatest in the tissues of top predators
Bord-and-pillar mining	An underground coal extraction method used in first workings of a deposit, and when irregularly shaped deposits, or sensitive environmental conditions, call for a lighter touch. Bord is a mining term for an underground space or room, traditionally with the coal face parallel to the natural fissures. Pillars of coal are left behind to support the roof as the coal is cut away.
Boundary Integrity	Characteristics of the GBMA's boundary (e.g. native vegetation buffers, rocky escarpments) that help protect the GBMA's OUV. This is one of the high-level components of OUV of the GBMA.
Care and maintenance	Describes the status of a mine site where production has ceased but there is potential to recommence operations at a later date. During the care and maintenance phase, the site is managed to ensure it remains in a safe and stable condition.
Causal network	A graphical model representing multiple causal pathways between one or more activity nodes and one or more AE nodes (e.g. Figure 4-1)
Causal pathway	A known or inferred sequence of events or steps, typically linking an activity ('cause') with its potential impact ('effect') on an AE. Sometimes called a 'cause-effect' pathway, it is represented on a causal network diagram as a sequence of links and nodes between one or more activity nodes and one or more AE nodes.
Collective impacts	The result of combined causal pathways on one or more AEs, with the impacts generally inferred to be additive. Where a causal network has not explicitly addressed the potential cumulative impacts of multiple geographically clustered activities (i.e. with overlapping spatial impacts), we refer to the combined impacts of multiple causal pathways on one or more AEs as collective impacts.

Term	Definition
Condition (approval)	A requirement under a development approval to undertake an action in a prescribed way or to meet an environmental outcome or other performance measure.
Confidence	A subjective estimate (High, Medium or Low) of the uncertainty surrounding evaluations of likelihood and consequence in the spatial causal network analysis.
Consequence	The severity and negative repercussions of the outcome of one or more impacts on a valued asset (events that have significant consequences are considered 'material' and increase risk).
'Controlled action'	A term used in the EPBC Act to refer to actions deemed by the Minister for Environment to be likely to have significant impacts on a Matter of National Environmental Significance or the National Heritage values and therefore will require approval under the Act (also see Section 2.5).
Controlling provisions	The matters of national environmental significance under the EPBC Act on which a proposed action may have a significant impact (also see Section 2.5).
Cumulative Impact Assessment	The formal process of assessing the risk of cumulative impacts of one or more activities on the environment, society and/or the economy, and often including some evaluation of ways to avoid or minimise this risk.
Cumulative impacts	The result of combined causal pathways from multiple activities, some of which may be geographically clustered (i.e. with overlapping spatial impacts), on one or more AEs, with the impacts generally inferred to be additive.
Dewatering	The process of removing groundwater from the mine pit or tunnel to ensure work can occur safely.
Dieback	A condition in which a tree or shrub begins to die from the tip of its leaves or roots backwards, owing to disease or an unfavourable environment.
Drawdown	(Also 'cone of depression'). Lowering of the watertable (unconfined aquifer) or potentiometric surface (confined aquifer), which results from groundwater pumping. Drawdown depth is the vertical distance between he original water level and the pumping water level. The extent of drawdown depends on characteristics of the aquifer (transmissivity and storativity), pumping rate and duration of pumping. Aquifers with low transmissivity create deeper, narrower cones; aquifers with low storativity create deeper, wider cones.
Driver	A superior complex phenomenon (i.e. beyond direct control or management) governing the direction of ecosystem change, which could be both of human and nature origin – including major bushfires, climate events, earthquakes (Oesterwind et al. 2016)
Ecological resilience	The ability of ecosystems to resist regime shifts and maintain ecosystem functions, potentially through internal reorganisation (i.e. their 'adaptive capacity') (Oliver et al. 2015), where regime shiftsare defined as large, persistent changes in the structure and function of systems, with significant impacts on the suite of ecosystem services provided by these systems.
Endemic	Restricted to a limited geographical area, and usually used to refer to species. Species can be endemic to large (e.g. a continent) or small areas (a single, isolated habitat, such as the Wollemi Pine).
Environmental Impact Assessment	The formal process of assessing the risks of individual, collective and cumulative impacts of one or more activities on the environment, and often including some evaluation of ways to avoid or minimise these risks.
Existing (mine)	A term that refers to mines that are under construction, in production or in temporary care and maintenance in 2020, and was used to define mines that were in this assessment's scope.
Geodiversity	The diversity of geological structures and landforms such as plateaus, cliffs, escarpments, caves, canyons, gorges and pagoda rocks; these provide the setting for the GBMA's unique biota and contribute to its Indigenous heritage and natural beauty. This is one of the high
Gondwanan flora	Plant species with Gondwanan affinities that have survived in isolated pockets of the GBMA (e.g. Wollemi Pine, Blue Mountains Pine). Gondwana was a supercontinent that existed from about 550 million years ago to about 180 million years ago when it

Term	Definition
	began to break up to form the current continents. This is one of the high-level components of the OUV of the GBMA.
Hanging swamp	A wetland named for its appearance of hanging off cliff faces or steep hillsides
Hazard	An event or sequence of events that may lead to an impact.
Groundwater dependent ecosystem (GDE)	'Ecosystems that need access to groundwater to meet all or some of their water requirements to maintain their communities of plants and animals, ecological processes and ecosystem services' (Richardson et al. 2011).
High-level component of OUV	One of eight special features of the GBMA that were selected to represent the property's OUV and were used as the endpoints in the causal network analysis by CSIRO (Holland et al. 2021).
Hyporheic zone	The saturated sediments where surface and groundwater exchanges in the beds and banks of streams and rivers
Impact	'Consequence of environmental state change in terms of substantial environmental and/or socio-economic effects which can be either positive or negative' (Oesterwind et al. 2016). Synonymous with 'effect' but used here because it is explicit in the initialisms EIA and CIA. In everyday language, 'impact' implies that the consequences are undesired, and that is usually the case here.
Indigenous custodial relationships	A collective term that encompasses culturally significant sites (e.g. caves, shelters, hearths, rock art, grinding grooves, scar trees and landscape features); species that are important for diet, materials, medicine, cultural identity and spiritual values of the Indigenous peoples of the area; and intangible values that reflect the interdependent relationship between Indigenous peoples and their ancestral lands. This is one of the high-level components of the integrity of the GBMA's OUV.
Integrity (OUV)	A measure of the wholeness and intactness of the natural and/or cultural heritage and its attributes. Examining the conditions of integrity, therefore requires assessing the extent to which the property (i) includes all elements necessary to express its OUV; (ii) is of adequate size to ensure the complete representation of the features and processes which convey the property's significance;and (iii) suffers from adverse effects of development and/or neglect. (UNESCO 2019a, paragraph 88)
In the vicinity	A phrase that was used in this assessment to refer to mines that are close enough to the GBMA that there are plausible pathways for mining related hazards to threaten components of the OUV of the property.
Link	A line (usually an arrow) connecting two nodes to indicate either a direct or inverse relationship between them on a causal network diagram.
Longwall mining	A method of undeground coal mining, in which giant machines called longwall miners shear away a "wall" of coal at a time. As the miner moves forward, hydraulic supports are removed and the roof collapses into the void left behind, creating an area known as the goaf. Longwall mining extracts more coal than bord-and-pillar because the pillars are not left behind. The method can cause significant subsidence, with the ground above potentially cracking and sinking.
Likelihood	The probability of occurrence of an event leading to one or more impacts on a valued asset.
Matter of National Environmental Significance	Entities that are protected under Australian environmental laws (e.g. the EPBC Act) and that include listed threatened species and communities, listed migratory species, Ramsar wetlands of international importance, the Commonwealth marine environment, World Heritage properties, national heritage places, the Great Barrier Reef Marine Park, nuclear actions, and any water resource in relation to coal seam gas development and large coal mining development.
Mine footprint	The area of resource extraction within a mine lease area – i.e. the open-cut pits and the area of underground panels projected at the surface. The mine footprint can also include other areas of surface disturbance associated with coal and sand processing and waste management. However, in this assessment the footprint identifies the resource extraction areas (e.g. Figure B2).
Mine lease area	The specific area of land under a mining lease within which the lessee has exclusive rights to mine for minerals.

Term	Definition
Mitigation	Any steps or strategies to avoid or reduce the risk of a negative impact on one or more AEs. The best option is avoidance but if this is not possible, strategies include minimising and/or remediating negative impacts on AEs.
Natural heritage value (OUV)	Natural features consisting of physical and biological formations or groups of such formations, which are of Outstanding Universal Value from the aesthetic or scientificpoint of view; geological and physiographical formations and precisely delineated areas which constitute the habitat of threatened species of animals and plants of Outstanding Universal Value from the point of view of science or conservation; natural sites or precisely delineated natural areas of Outstanding Universal Value from the point of science, conservation or natural beauty (UNESCO 2019a, paragraph 45, Article 2)
Node (causal networks)	Either a starting or ending point for a link on a causal network diagram where nodes represent different entities (e.g. activities, stressors, processes, AEs).
Offset (in mitigation hierarchy)	Biodiversity offsets are the last step in the mitigation hierarchy after every effort has been made to avoid, minimise and rehabilitate impacts. They constitute measurable conservation gains, designed to balance any significant impacts that cannot be avoided or minimised from the start.
Open- cut mining	Mining that involves removal of overlying material to access the desired mineral resource, and usually involving an open pit that sometimes remains after operations cease.
Outstanding Universal Value	Cultural and/or natural significance which is so exceptional as to transcend national boundaries and to be of common importance for present and future generations of all humanity. As such, the permanent protection of this heritage is of the highest importance to the international community as a whole (UNESCO 2019a, paragraph 49)
	Australian definitions of Outstanding Universal Value
Pagoda (rocks)	A geological structure resembling a rock tower, often with a flattened top and very steep irregular sides
Planned (mine)	A term that refers to mines that have been approved and commencement announced or are under assessment with full documentation available, and was used to define mines that were in this assessment's scope.
Potential cumulative impact area	The area in the GBMA where cumulative impacts are possible from all stressors associated with one or more activities, and usually derived from overlaying all stressor extents onto the potential impact area and making corrections for geographic clusters of the activities. In this assessment, the potential cumulative impact area is the overlapping stressor extents from existing and planned mines in the vicinity of the GBMA that extend into the potential impact area of the property and before any protection and management measures have been adopted (Figure 4-2).
Potential impact area	The entire area subject to an environmental impact assessment or desktop analysis of potential impacts of a driver (e.g. existing and planned mines in the vicinity of the GBMA). In this assessment, the potential impact area is the GBMA plus a 500-m buffer.
Potential impact duration	A time spanning the period of operations of an activity (e.g. a mine) as well as a realistic time period after its cessation when lagged effects (e.g. peak groundwater drawdown) are likely, potentially for multiple decades.
Process	'Aspect of the system that is changed by stressors' (Holland et al. 2021). Typically, processes are mechanisms (many occurring naturally) whose rates are undesirably altered by stressors and lead to negative impacts on AEs.
Protection and management (OUV)	(Often referred to as the third pillar of OUV). An administrative requirement on the state party to have "an adequate protection and management system to ensure its [OUV] safeguarding".
Relict	Refers to flora and fauna that have survived while others have become extinct. An example in the GBMA is Gondwanan flora.

Term	Definition
Remediation	Refers to rehabilitation of areas where impacts are unavoidable and measures are needed to return the impacted area to a near-natural state or agreed land use after mine closure.
Residual risk	The risk that remains after all feasible avoidance, mitigation and other management strategies have been applied to remove or reduce negative impacts on, for example, a high-level component of the OUV of the GBMA.
Riparian	Refers to land adjacent to and influenced by rivers, often supporting wetlands. In this assessment, riparian areas are defined by the grid cell size (250 m) used to delineate the stream network.
Risk	'The integrated assessment of likelihood and severity of an undesired event' (Goussen et al. 2016). For each link along a causal pathway, likelihood and severity (consequence) are assessed in the causal network approach to infer the risk of one or more activities on one or more AEs. Also see 'Residual risk'.
Scleromorphic	Refers to plants having hard, short and often spiky leaves that have evolved in response to low fertility and dry conditions (e.g. Myrtaceae – eucalypts, Fabaceae – acacias, Proteaceae - banksias, grevilleas and hakeas). Scleromorphic flora is one of the high-level components of the OUV of the GBMA.
Sclerophyll (vegetation)	A vegetation type having plants (typically eucalypts, wattles and banksias) with hard, short and often spiky leaves. Examples include the dry sclerophyll and wet sclerophyll forests across the GBMA.
Stressor	A natural or anthropogenic physical, chemical or biological agent, environmental condition or external stimulus that might contribute to one or more impacts. Hazards typically include or generate stressors. All causal pathways include at least one stressor.
Stressor extent	The distance or area from each mining-related stressor source within which a material impact might be possible
Subsidence	Ground movements that occur when the overburden above a mined longwall panel collapses into the void left by the excavated coal. These movements may propagate to the surface, creating dips and cracks, shearing roots, renewing fault zones and sometimes leading to rockfalls, drained streams and collapsed canyons. Subsidence is usually expressed in units of millimetres (mm).
Threat	Any factor that can exploit a vulnerability and damage or destroy something of value. Mining is a threatening activity for values encapsulated in the OUV of the GBMA
Threatened Ecological Communities	Ecological communities listed as Vulnerable, Endangered or Critically Endangered under the EPBC Act (Cth). The listing usually arises because of a significant reduction in the community's distribution or a decline in its ecological function.
Underground mining	Extraction of resources located in seams and deposits below the ground surface and undertaken in a completely enclosed geological setting (i.e. tunnel). Access to the coal seam is gained by openings from the surface, and a network of roadways driven in the seam then facilitates the installation of service facilities for transport, ventilation, water handling, drainage and power. Longwall and bord-and-pillar are types of underground coal extraction methods.
Upsidence	Results from the buckling (updward thrust) of the ground surface in the base of a valley from redistribution and increase in horizontal stresses in the underlying rock layers as mining occurs
Water systems	Aquatic features (e.g. streams, springs, swamps, lakes, waterfalls, seeps and groundwaters) that have evolved in tandem with the geomorphic evolution of the GBMA's landscape and support its diverse habitats. This is one of the high-level components of the OUV of the GBMA.
'Water trigger'	An amendment to the EPBC Act in 2013 that specified that all coal seam gas and large coal mining proposals required federal assessment and approval if they were likely to have a significant impact on a water resource which, for these two activities, is legislated to be an MNES (also see Section 2.5).

References

ACARP. 2001. Impacts of mine subsidence on the strata and hydrology of river valleys -Management guidelines for undermining cliffs, gorges and river systems. Final Report C8005 Stage I. Australian Coal Association Research Program, Brisbane, Queensland.

AGE. 2016. <u>United Wambo open-cut coal mine project. Groundater impact assessment</u>. July 2016.

Australian Mining. 2017. <u>Clarence Coal fined \$1m for coal slurry spillage in Blue Mountains</u>, 18 July 2017.

Baird IRC, Benson D. 2020. Serious impacts of longwall coalmining on endangered Newnes Plateau Shrub Swamps, exposed by the December 2019 bushfires. Australasian Plant Conservation, 29, 12-15.

Banerjee BP, Raval S, Timms W. 2016. Evaluation of rainfall and wetland water area variability at Thirlmere Lakes using Landsat time-series data. International Journal of Environmental Science and Technology, 13, 1781–1792.

Belmer N, Wright I. 2018. Heavy metal contamination of water column from a coal mine waste water discharge resulting in mobilisation of metal contaminants to riparian vegetation, Wollangambe River, Blue Mountains, Australia. Proceedings of the 9th Australian Stream Management Conference, 12-15 August 2018, Hobart, Tasmania, 484-492.

Boulton AJ. 2009. Recent progress in the conservation of groundwaters and their dependent ecosystems. Aquatic Conservation: Marine and Freshwater Ecosystems, 19, 731-735.

Boulton AJ. 2020. Conservation of groundwaters and their dependent ecosystems: integrating molecular taxonomy, systematic reserve planning and cultural values. Aquatic Conservation: Marine and Freshwater Ecosystems, 30, 1-7.

Boulton AJ, Brock MA, Robson BJ, Ryder DS, Chambers JM, Davis JA. 2014. Australian Freshwater Ecology: Processes and Management. Second Edition. Wiley-Blackwell, Chichester.

Boulton AJ, Humphreys WF, Eberhard SM. 2003. Imperilled subsurface waters in Australia: biodiversity, threatening processes and conservation. Aquatic Ecosystem Health and Management, 6, 41-54.

Buxton RT, McKenna MF, Mennitt D, Brown E, Fristrup K, Crooks KR, Angeloni LM, Wittemyer G. 2019. Anthropogenic noise in US national parks– sources and spatial extent. Frontiers in Ecology and the Environment, 17, 559–564.

Canter LW, Ross W. 2010. State of practice of cumulative effects assessment and management: The good, the bad and the ugly. Impact Assessment and Project Appraisal, 28, 261-268.

Centennial Coal. 2019. <u>Clarence Colliery Mining Operations Plan 2018-2022</u> Amendment A. Centennial Coal, Sydney, NSW.

Chiu M-C, Leigh C, Mazor R, Cid N, Resh V. 2017. Anthropogenic threats to intermittent rivers and ephemeral streams. In Intermittent Rivers and Ephemeral Streams: Ecology and Management. (Eds. T Datry, N Bonada and AJ Boulton), pp. 433-454. Academic Press, London.

Coal and Allied Operations. 2017. <u>Enforceable Undertaking</u>, pursuant to section 486DA of the <u>Environment Protection and Biodiversity Conservation Act 1999</u>.

Commonwealth of Australia. 2014a. <u>Temperate Highland Peat Swamps on Sandstone: ecological characteristics, sensitivities to change, and monitoring and reporting techniques</u>. Report prepared by Jacobs SKM for the Department of the Environment, Commonwealth of Australia, Canberra, ACT.

Commonwealth of Australia. 2014b. <u>Temperate Highland Peat Swamps on Sandstone: evaluation</u> <u>of mitigation and remediation techniques</u>. Report prepared by the Water Research Laboratory, University of New South Wales, for the Department of the Environment, Commonwealth of Australia, Canberra, ACT.

Commonwealth of Australia. 2015. <u>Modelling water-related ecological responses to coal seam</u> <u>gas extraction and coal mining</u>. Prepared by Auricht Projects and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) for the Department of the Environment, Commonwealth of Australia, Canberra, ACT.

Commonwealth of Australia. 2019. State Party Report on the state of conservation of the Greater Blue Mountains Area (Australia), Canberra, ACT.

Commonwealth of Australia. 2020. <u>National Light Pollution Guidelines for Wildlife</u>, January 2020.

Cowley KL, Fryirs KA, Chisari R, Hose, GC. 2019. Water sources of upland swamps in eastern Australia: implications for system integrity with aquifer interference and a changing climate. Water, 11, Article 102.

De Graff JV, Shelmerdine B, Gallegos A, Annis D. 2015. Uncertainty associated with evaluating rockfall hazard to roads in burned areas. Environmental and Engineering Geoscience, 21, 21–33.

DECCW. 2010a. Code of Practice for Archaeological Investigation of Aboriginal Objects in New South Wales, Part 6 National Parks and Wildlife Act 1974. Department of Environment, Climate Change and Water, Sydney, NSW.

DECCW. 2010b. Aboriginal Cultural Heritage Consultation Requirements for Proponents 2010, Part 6 National Parks and Wildlife Act 1974. Department of Environment, Climate Change and Water, Sydney, NSW.

DOE. 2013. <u>Matters of National Environmental Significance, Significant Impact Guidelines 1.1</u> Environment Protection and Biodiversity Conservation Act 1999. Department of Environment, Australian Government, Canberra, ACT.

Doody TM, Hancock PJ, Pritchard JL. 2019. Information Guidelines Explanatory Note: Assessing groundwater-dependent ecosystems. Report prepared for the Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development through the Department of the Environment and Energy, Commonwealth of Australia, Canberra, ACT.

EA 2003. Decision on referral under EPBC Act (Chapter 4) Pioneer Construction Materials Pty Ltd - Kables Sand Quarry Depth Extension. Environment Australia (EPBC Reference: 2003/934)

Eamus D, Froend R, Loomes R, Hose G, Murray B. 2006. A functional methodology for determining the groundwater regime needed to maintain the health of groundwater-dependent vegetation. Australian Journal of Botany, 54, 91–114.

EPA 2015. Clarence Colliery – <u>APS's licence review and current investigation</u>. NSW Environment Protection Authority, Sydney, NSW.

Everett M, Ross T, Hunt G. (Eds) 1998. Final Report of the Cataract River Taskforce. A report to the Upper Nepean Catchment Management Committee of the studies of water loss in the lower Cataract River during the period 1993 to 1997. Cataract River Taskforce, Picton, NSW.

Fleming C, Morrison K, Robba L, Reynolds J. 2021. 14-month water quality investigation of coal mine discharge on two rivers in NSW, Australia: implications for environmental regulation. Water Air and Soil Pollution 232, Article 90.

Ford JH, Hayes KR, Henderson BL, Lewis S, Baker PA, Schmidt RK. 2016. <u>Systematic analysis of</u> <u>water-related hazards associated with coal resource development. Submethodology M11 from</u> <u>the Bioregional Assessment Technical Programme</u>. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Franks DM, Brereton D, Moran CJ. 2010. Managing the cumulative impacts of coal mining on regional communities and environments in Australia. Impact Assessment and Project Appraisal, 28, 299-312.

Fryirs KA, Cowley KL, Hejl N, Chariton A, Christiansen N, Dudaniec RY, Farebrother W, Hardwick L, Ralph T, Stow A, Hose G. 2021. Extent and effect of the 2019-20 Australian bushfires on upland peat swamps in the Blue Mountains, NSW. International Journal of Wildland Fire, 30, 294-300.

Golder Associates. 2014. <u>Subsidence predictions and impact assessment for Airly Mine</u>. Report prepared for Airly Mine, Centennial Coal Pty Ltd.

Gordon ND, McMahon TA, Finlayson BL, Gippel CJ, Nathan RJ. 2004. Stream Hydrology: An Introduction for Ecologists. 2nd Edition. John Wiley & Sons, Chichester, England.

Goussen B, Price O, Rendal C, Ashauer R. 2016. Integrated presentation of ecological risk from multiple stressors. Scientific Reports, 6, Article 36004.

Halpern BS, Fujita R. 2013. Assumptions, challenges, and future directions in cumulative impact analysis. Ecosphere, 4, Article 131.

Hammill K, Tasker E. 2010. <u>Vegetation, Fire and Climate Change in the Greater Blue Mountains</u> <u>World Heritage Area</u>. Department of Environment, Climate Change and Water, Sydney, NSW.

Herron NF, Macfarlane C, Henderson BL, Post DA, O'Grady A, Rachakonda PK, Wilkins A, Peeters L, Dawes WR, McVicar TR, Hosack G, Ickowicz A, Hayes KR, Dambacher J, Barry S, Brandon C, Zhang YQ, Crosbie R, Viney NR, Sudholz C, Mount R, Tetreault-Campbell S, Marvanek S, Buettikofer H, Gonzalez D, Crawford D, Schmidt RK and Lewis S. 2018a. <u>Impact and risk analysis</u> for the Hunter subregion. Product 3-4 for the Hunter subregion from the Northern Sydney Basin

<u>Bioregional Assessment</u>. Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Herron NF, Peeters L, Crosbie R, Marvanek SP, Pagendam D, Ramage A, Rachakonda PK, Wilkins A. 2018b. <u>Groundwater numerical modelling for the Hunter subregion. Product 2.6.2 for the Hunter subregion from the Northern Sydney Basin Bioregional Assessment.</u> Department of the Environment and Energy, Bureau of Meteorology, CSIRO and Geoscience Australia, Australia.

Hodgson EE, Halpern BS. 2018. Investigating cumulative effects across ecological scales. Conservation Biology, 33, 22-32.

Hodgson EE, Halpern BS, Essington TE. 2019. Moving beyond silos in cumulative effects assessment. Frontiers in Ecology and Evolution, 7, Article 211.

Holla L, Barclay E. 2000. Mine Subsidence in the Southern Coalfield, NSW, Australia. Department of Mineral Resources, St. Leonards, NSW.

Holland KL, Merrin LE, McInerney P, Gilfedder M. 2021. World Heritage-listed Greater Blue Mountains Area – Regional-scale assessment of potential cumulative impacts of mining on the outstanding universal value (OUV) of the property. CSIRO, Australia.

Hughes L. 2005. <u>Alteration of habitat following subsidence due to longwall mining - key</u> <u>threatening process listing</u>. NSW Threatened Species Scientific Committee, Sydney, NSW.

Hunsicker, ME, Kappel VC, Selkoe KA, Halpern BS, Scarborough C, Mease L, et al. 2016. Characterizing driver–response relationships in marine pelagic ecosystems for improved ocean management. Ecological Applications, 26, 651–663.

Hydrosimulations. 2019. <u>Dendrobium Mine – Plan for the Future: Coal for Steelmaking -</u> <u>Groundwater Assessment</u>. May 2019. Prepared for South32 – Illawarra Coal

Hydrosimulations. 2020. <u>Tahmoor South amended project report – Groundwater assessment</u>. February 2020.

IESC. 2018. Information Guidelines for proponents preparing coal seam gas and large coal mining development proposals. Australian Government, Canberra, ACT.

IESC. 2019. <u>Advice to decision maker on Tahmoor South coal mining project. IESC 2019-101:</u> <u>Tahmoor South Coal Project (EPBC 2017/8084; SSD 8445) – Expansion</u>. Independent Expert Scientific Committee on Coal Seam Gas and Large Coal Mining Development, Canberra, ACT.

Independent Expert Panel for Mining in the Catchment 2019. Independent Expert Panel for Mining in the Catchment Report: <u>Part 2. Coal Mining Impacts in the Special Areas of the Greater</u> <u>Sydney Water Catchment</u>. Prepared for the NSW Department of Planning, Industry and Environment, Sydney, Australia.

IUCN 2014. Greater Blue Mountains Area - 2014 Conservation Outlook Assessment. IUCN World Heritage Outlook: <u>https://worldheritageoutlook.iucn.org/</u>

IUCN 2017. Greater Blue Mountains Area - 2017 Conservation Outlook Assessment. IUCN World Heritage Outlook: <u>https://worldheritageoutlook.iucn.org/</u>

IUCN 2020. Greater Blue Mountains Area - 2020 Conservation Outlook Assessment. IUCN World Heritage Outlook: <u>https://worldheritageoutlook.iucn.org</u>

Kalf and Associates. 2004. Hydrogeological impact Newnes kaolin proposed open-cut, December 2004. Prepared for Newnes Kaolin Pty Ltd (trading as Sydney Construction Materials)

Kaveney T, Kerswell A, Buick A. 2015. Cumulative Environmental Impact Assessment Industry Guide. Minerals Council of Australia, Forrest, ACT.

Keith DA. 2004. Ocean Shores to Desert Dunes: the Native Vegetation of New South Wales and the ACT. NSW Department of Environment and Conservation, Sydney, NSW.

Keith DA, Simpson CC. 2010. <u>Vegetation formations of NSW (version 3.0)</u>: A seamless map for <u>modelling fire spread and behaviour</u>. Report to the Rural Fire Service. Version 2 data: NSWmap_v2_p1750_VIS_3846 & NSWmap_v2_ext_VIS_3847. NSW Department of Environment & Climate Change, Sydney, NSW.

McDonald J, Clayton L. 2016. <u>Rock Art Thematic Study</u>. Report to the Department of the Environment and the Australian Heritage Council prepared by the Centre for Rock Art Research and Management, University of WA, Crawley, WA.

Melzner S, Shtober-Zisu N, Katz O, Wittenberg L. 2019. Brief communication: Post-wildfire rockfall risk in the eastern Alps. Natural Hazards and Earth System Sciences, 19, 2879–2885.

Mills K, Canbulat I, Kay D. 2016. <u>Report of the Independent Review Panel established to review</u> <u>and report on Accuracy and reliability of mine subsidence impacts on sensitive features across</u> <u>the Airly Mine Extension Project application area</u>. 1 July 2016.

MMO. 2014 <u>A strategic framework for scoping cumulative effects</u>. A report produced for the Marine Management Organisation, MMO Project No: 1055. MMO, United Kingdom.

Moore GM. 2013. Adaptations of Australian tree species relevant to water scarcity in the urban forest. Arboriculture and Urban Forestry, 39, 109-115.

Mosaffaie J, Jam AS, Tabatabaei MR, Kousari MR. 2021. <u>Trend assessment of the watershed</u> <u>health based on DPSIR framework</u>. Land Use Policy, 100, Article 104911.

National Parks Association of NSW. 2020. <u>Blue Mountains World Heritage and Bushfire</u>. National Parks Association of NSW, Pyrmont, NSW.

NSW DECC. 2006. <u>Wollemi Pine (Wollemia nobilis) Recovery Plan</u>. NSW Department of Environment and Conservation, Hurstville, NSW.

NSW DPE. 2015. <u>State Significant Development Assessment – Tinda Creek Sand Project</u> (SSD 4978), NSW Department of Planning and Environment, Sydney, NSW.

NSW DPI. 2012. <u>NSW Aquifer Interference Policy</u>, NSW Department of Primary Industries – Office of Water, September 2012.

NSW DPIE. 2019. <u>Thirlmere Lakes National Park Plan of Management</u>. NSW Department of Planning, Industry and Environment, Sydney, NSW.

NSW DPIE (in prep) Greater Blue Mountains Area World Heritage Property – Draft Strategic Plan 2020 – 2030.

NSW DPIE Water. 2020. <u>DPIE – Water and NRAR detailed comment and recommendations.</u> <u>Second Amendment Report for the Tahmoor South Coal Project (SSD 8445)</u>, September 2020, NSW Department of Planning, Industry and Environment, Sydney, NSW.

NSW Government. 2015a. <u>Indicative Secretary's environmental assessment requirements</u> (SEARs) – For State Significant Mining Developments, NSW Government, Sydney, NSW.

NSW Government. 2015b. Mine application guideline, NSW Government, Sydney, NSW.

NSW Minister for Planning. 2006. <u>Development Consent for Newnes Kaolin Pty Ltd -</u> <u>Development of a kaolin mining and sand quarrying operation</u>.

NSW NPWS 1998. <u>The Greater Blue Mountains Area World Heritage Nomination</u>. Nomination of the Greater Blue Mountains Area for inscription on the World Heritage List by the Government of Australia 1998. New South Wales National Parks and Wildlife Service, Sydney, NSW.

NSW NPWS 2009. <u>Greater Blue Mountains World Heritage Area Strategic Plan</u>. New South Wales National Parks and Wildlife Service, Sydney, NSW.

NSW NPWS 2020. <u>Developments adjacent to NPWS lands: Guidelines for consent and planning</u> <u>authorities</u>. National Parks and Wildlife Service, Department of Planning Industry and Environment, Sydney, NSW.

NSW OEH. 2011. <u>Guide to Investigating, Assessing and Reporting on Aboriginal Cultural Heritage</u> <u>in NSW</u>. State of NSW and the Office of Environment and Heritage, Department of Premier and Cabinet, Sydney, NSW.

NSW OEH. 2018. <u>Greater Blue Mountains World Heritage Area Strategic Plan Addendum 2016</u>. State of NSW and Office of Environment and Heritage, Sydney, NSW.

NSW PAC. 2016. <u>NSW Planning Assessment Commission Determination Report – Airly Mine</u> <u>Extension Project (SSD 5581)</u>, December 2016, Sydney, NSW.

NSW PAC. 2017. <u>Wambo Coal Mine Determination Report (DA 305-7-2003 MOD 17)</u>, NSW Planning and Assessment Commission, Sydney, NSW.

NSW RR. 2020a. <u>Compliance audit program – Subsidence management: Tahmoor Colliery,</u> <u>Tahmoor Coal Pty Ltd</u>, July 2020, NSW Resources Regulator, Sydney, NSW

NSW RR. 2020b. <u>Compliance audit program – Subsidence management: Dendrobium Colliery,</u> <u>Dendrobium Coal Pty Ltd</u>, May 2020, NSW Resources Regulator, Sydney, NSW

Oesterwind D, Rau A, Zaik A. 2016. Drivers and pressures – Untangling the terms commonly used in marine science and policy. Journal of Environmental Management, 181, 8-15.

Oliver TH, Isaac NJB, August TA, Woodcock BA, Roy DB, Bullock JM. 2015. Declining resilience of ecosystem functions under biodiversity loss. Nature Communications, 6, Article 10122.

Peabody. 2017. <u>Wilpinjong Coal Aboriginal Cultural Heritage Management Plan</u>, August 2017.

Peeters LJM, Holland KL, Huddlestone-Holmes C, Boulton AJ. 2021. A spatial causal network approach for multi-stressor risk analysis and mapping for environmental impact assessments. Science of the Total Environment, 802, Article 149845.

Pells P, Pells S. 2016. <u>The water levels of Thirlmere Lakes – Where did the water go and when</u> <u>will it return?</u> Proceedings of the 20th Congress of the Asia Pacific Division of the International Association for Hydro Environment Engineering & Research, Colombo, Sri Lanka.

Pells PJN, Young A, Turner P. 2014. On the establishment of acceptability criteria for subsidence impacts on the natural environment. In Proceedings of the 9th Triennial Conference on Mine Subsidence, 2014, Pokolbin 11-13 May 2014.

Price P, Wright, IA. 2016. <u>Water quality impact from the discharge of coal mine wastes to</u> <u>receiving streams: comparison of impacts from an active mine with a closed mine</u>. Water, Air, and Soil Pollution, 227, Article 155.

Richardson E, Irvine E, Froend R, Book P, Barber S, Bonneville B. 2011. <u>Australian Groundwater</u> <u>Dependent Ecosystems Toolbox Part 1: Assessment Framework</u>. National Water Commission, Canberra, ACT.

Riley S, Finlayson M, Gore D, McLean W, Thomas K. 2012. <u>Thirlmere Lakes Inquiry: Final Report</u> <u>of the Independent Committee</u>. NSW National Parks and Wildlife Service, Sydney, NSW.

RPS. 2014. <u>Springvale Mine extension project – groundwater impact assessment</u>. 9 February 2014. Prepared for Springvale Coal.

Schädler S, Kingsford R. 2016. Long-term Changes to Water Levels in Thirlmere Lakes – Drivers and Consequences. Centre for Ecosystem Science, University of New South Wales, Sydney, NSW.

Smith P. 2020. Impact of the 2019-20 fires on the Greater Blue Mountains World Heritage Area – Final Report. Report to Blue Mountains Conservation Society, Wentworth Falls, NSW.

Springvale Coal and Centennial Angus Place. 2011. <u>Enforceable Undertaking, pursuant to section</u> 486DA of the Environment Protection and Biodiversity Conservation Act 1999.

Stumpp C, Hose GC. 2013. The impact of water table drawdown and drying on subterranean aquatic fauna in in-vitro experiments. PLoS One, 8, Article e78502.

Taçon PSC, Hooper SB, Brennan W, King G, Kelleher M, Domicelj J, Merson J. 2007. Assessment of the Aboriginal Cultural Heritage Values of the Greater Blue Mountains World Heritage Area. A Report for the Department of Environment and Water Resources. Blue Mountains World Heritage Institute's Natural and Cultural Heritage Program, Sydney, NSW.

Taçon PSC, Kelleher M, Brennan W. 2006. Wollemi petroglyphs, N.S.W., Australia: An unusual assemblage with rare motifs. Rock Art Research, 23, 227–238.

Thurgate ME, Gough JS, Clarke AK, Serov P, Spate A. 2001. Stygofauna diversity and distribution in eastern Australian cave and karst areas. Records of the Western Australian Museum Supplement, 64, 49-62.

Umwelt. 2014. <u>Assessment of groundwater impacts on Tinda Creek</u>, June 2014. Prepared for Aus10 Rhyolite Pty Ltd by Umwelt, Newcastle, NSW.

UNESCO 2019a. <u>Operational Guidelines for the Implementation of the World Heritage</u> <u>Convention</u>. United Nations Educational, Scientific and Cultural Organisation, Paris.

UNESCO. 2019b. <u>Decisions adopted during the 43rd session of the World Heritage Committee</u>. WHC/19/43.COM/18, Baku p. 13.

UNESCO. 2019c. <u>Report on the State of Conservation of Greater Blue Mountains Area</u>, Australia. State of Conservation Information System of the World Heritage Centre, UNESCO World Heritage Centre, Paris, France.

US EPA. 1998 <u>Guidelines for ecological risk assessment</u>, EPA/630/R-95/002F. U.S. Environmental Protection Agency, Washington, DC.

Washington HG, Wray RAL. 2011. The geoheritage and geomorphology of the sandstone pagodas of the north-western Blue Mountains region (NSW). Proceedings of the Linnean Society of New South Wales, 132, 131-143.

Watchman A. 1999. A universal standard for reporting the ages of petroglyphs and rock paintings. In: Dating and the Earliest Known Rock Art, M. Strecker (Ed.) pp. 1-3. Oxbow Books: Barnsley, UK.

Wright IA, Belmer N, Davies PJ. 2017. Coal mine water pollution and ecological impairment of one of Australia's most 'protected' high conservation-value rivers. Water, Air, and Soil Pollution, 228, Article 90.

Department of Agriculture, Water and the Environment