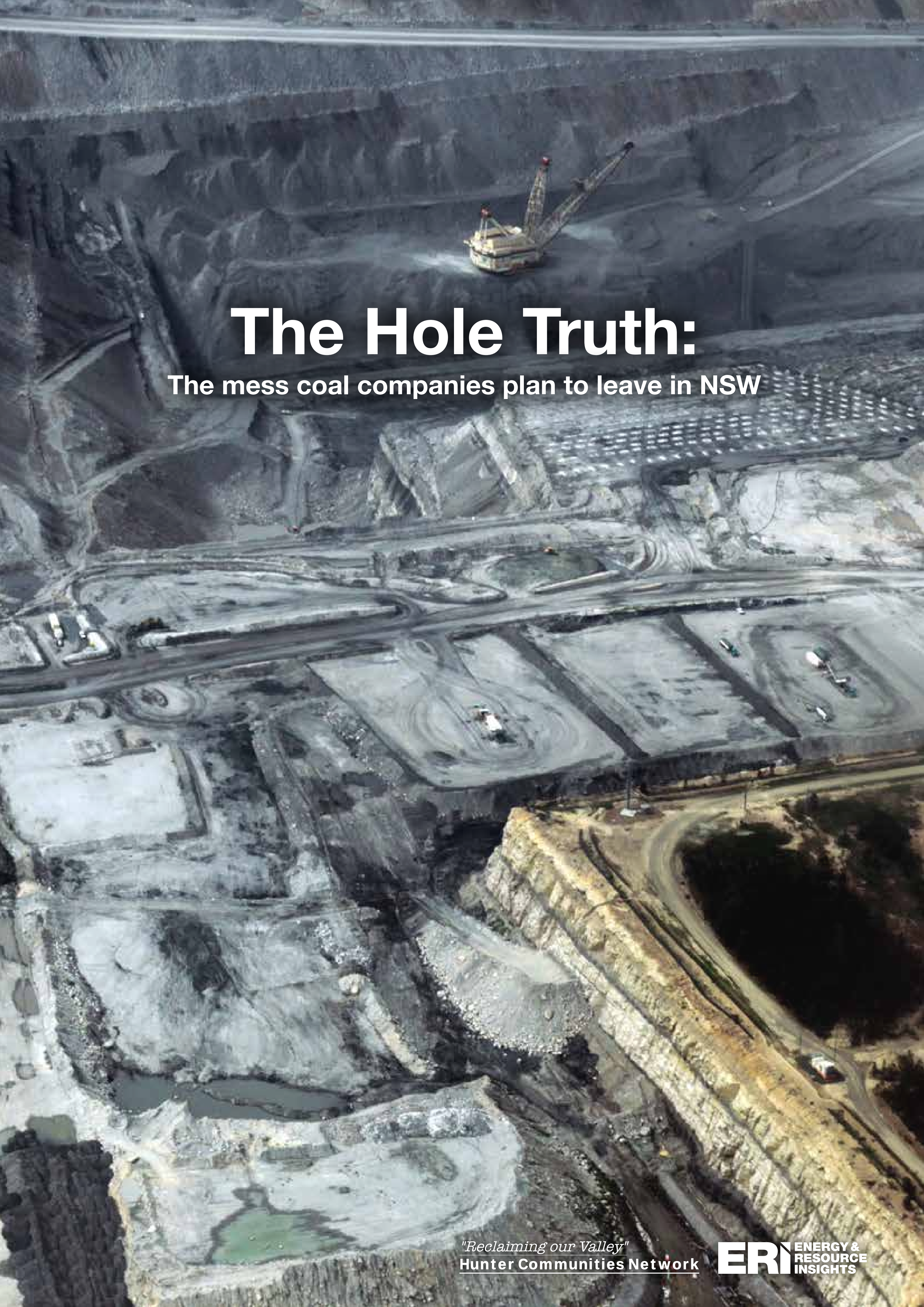

The Hole Truth:

The mess coal companies plan to leave in NSW

"Reclaiming our Valley"
Hunter Communities Network

ERI ENERGY & RESOURCE INSIGHTS

For years the NSW Government has been letting coal companies off the hook on the question of filling in the huge holes created by open cut coal mining. Now, for the first time, the scale and cost of that failure is revealed in all its ugliness. The hole truth is, we've got a big problem.

The Hole Truth
was written by Adam Walters,
Principal Researcher
at Energy & Resource Insights
erinsights.com
and commissioned by
The Hunter Communities Network

June 2016

This page and cover: open cut coal mine in the Hunter Valley
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Open cut coal mine in the Hunter Valley
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Foreword

Australia has long had a love affair with mining – and especially old king coal. We have mined for coal extensively in the eastern states. Until about the 1950s mining was essentially all underground (with the exception of brown coal mines in Victoria) – but with the growing capacity of trucks and ever larger machinery, the industry began to switch to open cut mines. This coincided with rapid growth in demand in Asia for coal for electricity generation and steel production – and from the 1970s things began to get super-sized, especially in the Hunter Valley. All the time local communities were assured that the long-term environmental implications were carefully considered and that pre-mining land uses would be possible once mining finished. They were told that modern coal mining had world-leading environmental regulation – companies would rehabilitate the 'final void' left from open cut mining and everything would be fine.

In reality, of course, the mines kept getting bigger and bigger – and then super-sized. But for every new or expanded mine, the assessment and approvals processes and subsequent regulation of operations would typically consider just that mine alone – the cumulative total of all mines and the long-term outcomes for places like the Upper Hunter Valley were left for the future.

There are now rapid changes occurring worldwide in the electricity sector, especially the incredible growth of solar photovoltaic panels and wind energy (and more positive change on the way), meaning that for old king coal the future is now, and it is time to address the long standing concerns about the future of environments and communities left with such massive voids in their landscapes. Over the past 15 years, many local communities have raised concerns about the environmental impacts of their local mine, only to realise that on their own they could rarely match the might of industry lobbying power within government.

This report is a clinical and careful examination of the extent of the problem of final voids left after massive scale open cut mining. Despite industry and government assurances, there remain many unknowns in the long-term fate and behaviour of such voids – such as hydrology and the effects on surface waters and groundwaters, water quality issues such as salt loads and heavy metals, wall stability in perpetuity, and let alone what all of this means ecologically, socially and economically. This report identifies the probable scale of currently approved final voids in NSW, particularly the Upper Hunter – and the gaps in scientific knowledge, often related to a lack of detailed studies for each final void as well as the lack of regional studies which integrate all current and former mines.

I commend this report to all concerned with the long-term future of such heavily mined landscapes – as the last outcome we need is even bigger mining legacies for future generations to clean up. I hope it help stimulates the debate and give the recognition needed to this critical issue.

Dr Gavin M. Mudd
Head of Environmental Engineering,
Monash University & Chair, Mineral Policy Institute (MPi)

Executive Summary

One responsibility of regulators is long-term custodianship for the land, yet they have allowed mining companies to leave a polluting and pockmarked landscape for future generations.

The size of the mess left by open cut coal mines in NSW

Booming demand for coal exports in recent decades has seen the proliferation of huge open cut mines across New South Wales (NSW). In the last five years, 36 open-cut coal mines have been active in the state. In Australia, when mines cease production their owners are not required to fill in the pit that remains. These “final voids” may be hundreds of metres deep, kilometres in length, and their impact and scale is poorly understood.

For the first time, this report provides an audit of the total size of coal mine final voids in NSW. There are at least 45 voids with a total of 6,050ha of voids either planned or approved, covering a total area greater than all of Sydney Harbour.

The legacy of toxic “final voids”

Modern coal mines have pits that may extend 150 metres or more below the natural water table. This means water impacts are a key issue with final voids. In most cases, lakes will form in the voids. These will draw down local groundwater and take significant periods of time to fill with water, often centuries. Water quality in these final void lakes is typically poor and will worsen over time. These lakes will become increasingly saline. A scientific study estimated that one large void in the Hunter Valley may contain approximately 1 million tonnes of salt after a period of 500 years. Should these lakes overfill, the flooding of water onto surrounding land would have a detrimental impact.

The full extent of this toxic legacy is poorly understood. Groundwater assessments for mining approvals often address final void water chemistry very poorly. In addition, there are significant variations in both the quality and nature of predictions contained in environmental impact assessments.

Most companies plan to close their operations when mining is occurring at the deepest point they consider economical. At this point, the highwall is therefore at its greatest - potentially hundreds of metres tall. These highwalls are often unstable over long time periods. This can present a safety risk, with land slips endangering nearby people, animals and structures.

No requirement to backfill final voids in Australia

Backfilling final voids can mitigate many of their social and environmental risks, and presents the opportunity to return land to a form that supports pre-mine use. In the United States, filling in coal mine final voids has been required by law since the 1970s. Yet, in Australia, this is still not the case.

An incremental approach to project approvals prevails in NSW, where mining companies routinely revise project plans after initial approval is granted. The current paradigm does not force mining companies to plan for mine closure in such a way to achieve the best outcome at the least cost. This can only be achieved by embedding major closure requirements into mining plans from their outset.

Mining companies usually present cost as a critical factor in their decision to not backfill final voids and avoid it if possible. Or point to the possibility of mining at a future date. However, retrospectively filling in voids after mining is finished is the most expensive option. If, as in the United States, a mine was planned on the basis that all voids must be filled, the associated costs would be lower.

Regulatory failure leaves an expensive mess for future generations

One responsibility of regulators is long-term custodianship for the land, yet they have allowed mining companies to leave a polluting and pockmarked landscape for future generations. Continued regulatory failure and flawed assessment processes are permitting considerable swathes of NSW to be rendered into ugly, vast, saline lakes.

For years the NSW Government has been letting coal companies off the hook on the question of filling in the huge holes created by open cut coal mining. Now, for the first time, the scale and cost of that failure is revealed in all its ugliness. The hole truth is, we've got a big problem.

Mine voids, open cut coal mining Hunter Valley
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Introduction

Historically, coal mining was an underground affair: the commodity extracted through a network of shafts and tunnels. Due to advances in mining technology it became possible to move vast quantities of rock relatively cheaply. As a result, where the coal lay within a few hundred metres of the surface, it became economic to extract it through an open pit: the modern, large open-cut mine.
As demand for coal exports increased dramatically in recent decades, huge open-cut mines have proliferated across New South Wales (NSW) coal regions.

In the last four years, 2011-2015, 68 coal mines have been active in NSW. Of these, 36 are open-cut operations: 16 located in the Hunter Coalfield, 9 in the Western Coalfield, 6 in the Gunnedah Coalfield, 3 in the Newcastle Coalfield and 2 in the Gloucester Coalfield. Some of these contain pits hundreds of metres deep and kilometres long.

The largest open-cut mines by production volume are located in the Hunter, with a few other large operations located in the Western (Wilpinjong and Moolarben) and Gunnedah coalfields (Boggabri and Maules Creek).

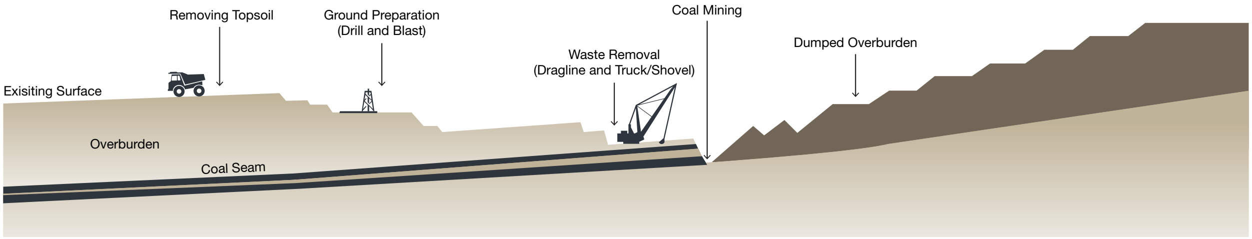
When these mines close, millions, if not billions, of cubic metres of rock will have been moved, resulting in a massively altered landscape. Key features typically will include tailings dams, large new ‘hills’ of deposited waste rock and, in most cases, an open pit where mining was occurring immediately prior to closure: the final void.

In Australia, it is standard practice to not fill coal mine final voids. Mining companies typically have plans, of varying quality, to rehabilitate their pits. However, beyond taking relatively low-cost steps to render the voids stable, they plan to leave the voids as a large – if somewhat sculpted- permanent scar in the landscape: a long-term legacy of the short-term benefits of mining operations, posing multiple threats to both the environment and local residents.

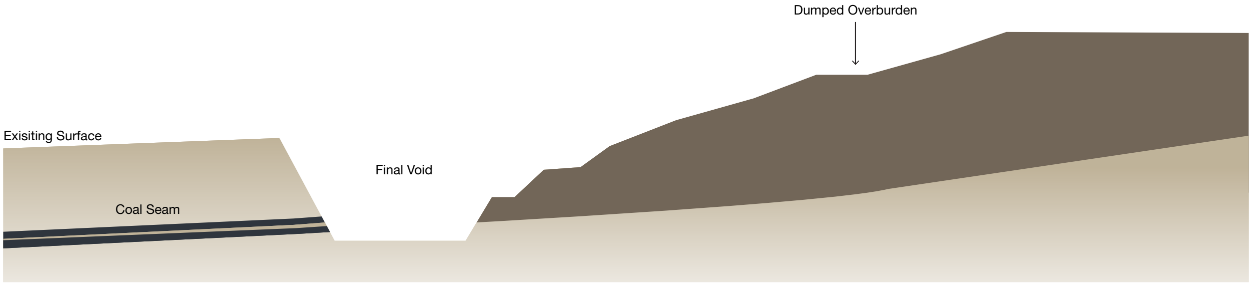
This report describes both the nature of impacts resulting from final voids and explores mining companies’ rationale for leaving the voids open. It also estimates the scale of the legacy that will remain when coal mining in NSW concludes.

Open-cut mining and final voids

Simplified representation of open cut coal mining in NSW



Active mining



Mine at closure

Open-cut mining is a surface mining method where a resource is extracted by means of a void. Overburden (rock and soil above or between seams of the resource) is removed and deposited in another location. Moving this rock is expensive, so mines are designed in such a way as to minimise both the volume of overburden moved and the distance it is transported.

Open-cut coal mines normally extract seams of coal that are orientated on a gentle decline of a few degrees from horizontal. Initially, removed overburden is dumped in out of pit overburden emplacement areas. Then, as the mine proceeds, the void effectively moves horizontally, with overburden both dumped out of pit and used to backfill behind the active mining area. Open-cut coal mines reach the end of their economic life when the cost of resource extraction outweighs its financial value – such as when the coal seam has dipped so far that the cost of removing rock from above it is prohibitively expensive. At this point a void remains that may be hundreds of metres deep and kilometres in length. This is known as the 'final void'.

Defining final voids

There is no universal or industry standard approach for defining final voids. Options include the volume of the void, its depth or its surface area. In some cases, final voids are described only by either their catchment area or the surface area of the pit lake predicted to form post-closure. It is understandable that these measures are used, as they are determined during modelling of the surface water impacts of the final landform. They do not, however, provide a reliable proxy for the physical scale of a final void as they are determined by local hydrological conditions and, potentially, by the modelling technique used to predict the extent of the pit lake. Therefore, final voids in this report are characterised by planar area at the lowest point of the void's crest (the spill point if the void filled with water) and by depth - measured from this height. These physical parameters can be easily estimated, enabling comparisons to be drawn and cumulative scale determined.

Scale of coal mine final voids in NSW

'..... a total of 45 final voids covering 6,050ha were identifed as are either planned or approved for NSW coal mines. By comparison, Port Jackson (Sydney Harbour) encompasses approximately 5,500ha.'

In 1999 a NSW Department of Mineral Resources' publication, The Coal Industry Synoptic Plan, stated that planned final mine voids will cover 1,272ha across the Hunter Valley.[1] Since then, a number of mines and expansions have been approved.

During the 2015 Planning Assessment Commission review of the planned extension to the Mount Thorley Warkworth mine complex, it became evident that NSW regulators did not have an accurate handle on the cumulative scale of the final voids it had approved. The 2015 PAC Review report said: "*The Commission also sought advice on the cumulative impact of final voids from mining within the Hunter Valley and was advised by the Department that approximately 30 final voids are currently approved (not yet complete) in the Hunter Valley with the proposed Warkworth Mine void being one of the largest. The Department noted that whilst it was not aware of the total size of existing and approved voids, it estimated that the area of voids would be very small compared to the total land area of the Hunter Valley (approximately 0.5% of the area of the Upper Hunter region).*"[45]

Indeed, it is not easy to predict with accuracy the likely final landforms for NSW open-cut coal mines for a number of reasons:

- As previously discussed, the NSW planning system does not typically require final landforms to be definitively planned until near to mine closure.
- Mining operations are dependent upon market conditions. Mines may close early if commodity prices remain below break-even for a protracted period, resulting in a different final landform than if the mine had operated to its full extent.
- Unplanned mine closures occur, for example, as a result of bankruptcy or sustained low coal prices.
- Mining companies routinely seek approvals for modifications to mine plans after initial approvals.

However, it is possible to glean an understanding of what may occur using currently approved and under assessment final landforms presented in Development Approvals, Environmental Assessment documents and Mine Operations Plans. The documents allow for a conservative estimate of the surface area of planned final voids using the contour line closest to the crest, but within, the void. For the full methodology and sources used in this paper refer to Appendix 1.

The results of this analysis are presented in Table 1. As can be seen, a total of 45 final voids covering 6,050ha were identified as are either planned or approved for NSW coal mines. By comparison, Port Jackson (Sydney Harbour) encompasses approximately 5,500ha. This is a conservative estimate of the total area and number of voids approved both due to the methodology and because it was not possible to source suitable plans from which to assess void numbers and size for a number of mines.

5,340ha of the assessed voids are approved and located at existing mines. A further 630ha are currently in the planning system. These are associated with three planned mine expansions and would replace other currently approved voids that do not form part of this analysis. In addition, the proposed Watermark mine would result in a further 80ha of voids. While it is likely that some of the final voids that do eventuate will deviate from those currently presented in plans, this represents the best available current estimate.

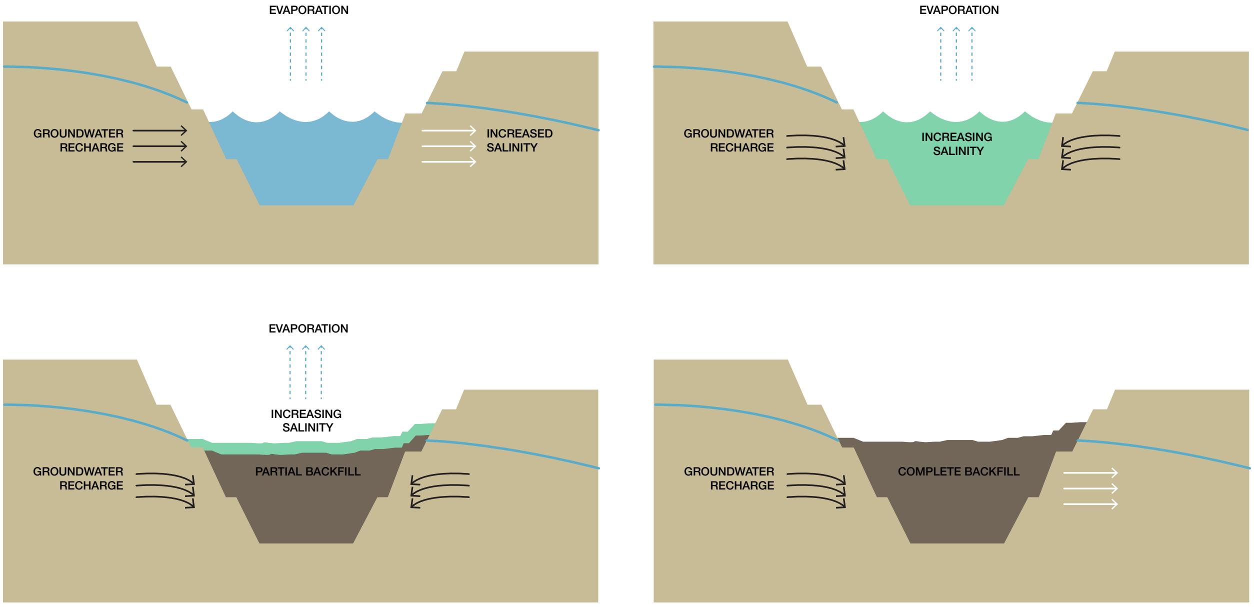
Scale of coal mine final voids in NSW

Table 1 - planned and approved final voids at selected NSW coal mines

Mine/ Project	Coalfield	Status of void plans	Number of voids	Total Area (Ha)
Warkworth	Hunter	Approved	2	880
Mount Arthur	Hunter	Approved	3	700
Bulga	Hunter	Approved	1	550
Hunter Valley Op (S)	Hunter	Approved	2	440
Boggabri	Gunnedah	Approved	1	430
Maules Creek	Gunnedah	Approved	1	380
Bengalla	Hunter	Approved	1	270
United and Wambo	Hunter	Project	2	260
Mount Owen Continued Operations	Hunter	Project	1	240
Ravensworth Operations	Hunter	Approved	3	180
Liddell	Hunter	Approved	2	170
Drayton	Hunter	Approved	3	170
Stratford	Gloucester	Approved	3	166
Rixs Creek Continuation of Mining	Hunter	Project	2	130
Hunter Valley Op (N)	Hunter	Approved	1	120
Integra	Hunter	Approved	1	120
Glendell	Hunter	Approved	1	110
Werris Creek	Gunnedah	Approved	1	92
Tarrawonga	Gunnedah	Approved	1	89
Moolarben	West	Approved	3	82
Duralie	Gloucester	Approved	2	82
Watermark	Gunnedah	Project	1	80
Mangoola	Hunter	Approved	1	79
Mount Owen Complex	Hunter	Approved	2t	73
Muswellbrook	Hunter	Approved	1	62
Rocglen	Gunnedah	Approved	1	60
Wilpinjong	West	Approved	2	35
		Total Approved	39	5340
		Total Expansion Project	5	630
		Total Planned Mines	1	80
		Overall Total	45	**6050**

The problems with final voids

Possible hydrogeological scenarios for final voids, based on Mccullough et al [70]



Most of the modern open-cut coal mines in NSW are yet to close, therefore the long-term effects of the pit lakes they will contain are a new, partially unknown phenomenon. This is the case for the Upper Hunter region where the first generation of large-scale open cut coal mines are only now beginning to reach the ends of their operational lives, such as the Drayton mine, an export thermal coal producing operation opened in 1983.

Key problems associated with final voids include impacts on local groundwater, water quality in final void pit lakes, and long term safety of the final landform. These are discussed below.

Final voids and water

Modern coal mines have pits that may extend 150 metres or more below the natural water table.[2] Therefore, water impacts are a key consideration when assessing final voids.

Water dynamics

If a final void is left open, a pit lake may form. The depth and nature of this lake is governed by a range of factors. Essentially, the final depth of the lake, and the rate at which it forms, is governed by flows of water entering and exiting the void. Water influx is dependent upon precipitation (either directly into the void, as surface run-off, or indirectly as spoil seepage) and groundwater migration.[2] Water may leave the pit lake through evaporation, groundwater outflow or as surface run-off if the void is completely filled.

The dynamics of these water flows are site specific and change as the void fills. Depending on the relative rates of inflows and outflows, three outcomes are possible once an equilibrium has been reached. Should evaporative losses from the pit lake balance all inflows, groundwater will permanently flow towards the void and the pit lake becomes what is known as a **terminal sink.** If this not the case, and evaporative losses are less than inflows, groundwater outflows may either be balanced by inflows (a **through flow** system) or the lake may act as an

The problems with final voids

overflow system (a source of additional groundwater or surface water).

In many Australian final voids precipitation and evaporation are the dominant water flows. The balance of rain-gains and evaporative-losses varies greatly both between regions and even localities. However, given the arid or semi-arid climate encountered in much of the country, most large open voids become terminal sinks because evaporation rates are so high. Through flow or overflow systems are typically only encountered where evaporative losses are significantly reduced by either partially or completely backfilling the voids. Situations where voids intersect particularly productive aquifers are exceptions to this general characterisation.

In the Hunter Valley, almost all final voids proposed are expected and, indeed, designed, to act as terminal sinks. Here, evaporation rates exceed precipitation-derived water and groundwater inputs. A key design feature for encouraging the formation of a terminal sink is limiting the surface run-off catchment of the void by land contouring and the construction of swales and drainage ditches to divert water away.

A typical Hunter Valley pit lake scenario is described below.

- Once mining ceases, water will begin to accumulate in the void from precipitation, seepage through backfill, and groundwater inflows because pits are usually much deeper than pre-mining groundwater levels.
- As the void typically has sloping sides, its lake will initially have a relatively small surface area so inflows of water will exceed evaporative losses. It will begin to fill.
- As the void fills its surface area will increase, resulting in greater evaporation and slower water level rise. Groundwater inflows will decrease non-linearly as the water level reaches closer to pre-mining levels. Percolation through backfill will continue.[2]
- Eventually the surface area will increase to a point where an equilibrium is achieved: evaporative losses balance all inflows. Typically, this will occur below the pre-mining groundwater level so groundwater will continue to flow towards the void, resulting in a permanent local groundwater sink.[1]
- Given the magnitude of evaporative losses, this equilibrium will not usually occur for a significant period of time (see Table 2).

It is essential to recognise that all predictions of water dynamics in final landforms are dependent upon modelling. Groundwater models are often subject to considerable uncertainty, due in part to the paucity of data on groundwater systems available prior to mining commencing.

Time taken to fill with water

As described in the previous section, the final voids planned for NSW open cut coal mines will take a significant period of time to fill with water, often centuries. Table 2 lists the predicted times required for selected mine final voids to reach equilibrium, the point at which inflows and outflows are balanced and the pit lake water level has stabilised.

Table 2 - estimated time for void pit lake to reach equilibrium at selected NSW mines

Mine	Time to reach equilibrium
Liddell	50 years[3]
Mangoola	100 years[4]
Drayton	>200 years[5]
Warkworth	800 years[6]
Bengalla	1000 years[7]
Mt Arthur Coal	>200 years[8]
Wilpinjong	>300 years for one void, other already full at completion of mining[9]
Maules Creek	300-400 years[10]

As would be expected, given the range of sizes of planned final voids and the diversity of different groundwater systems they interact with, the estimates for how long voids will take to fill varies significantly. It is important to note that considerable levels of uncertainty exist within the predictive models used to forecast final void water behaviour.

In addition to the inherent uncertainties associated with modelling poorly understood groundwater systems, changes in precipitation as a result of changing climatic conditions further complicates predictions of future pit lake water levels and are typically not considered in the predictive models used in mine approvals. The models

The problems with final voids

examined for this study commonly employ historic rainfall data as a model input and, at best, offer only commentary on its relevance under possible future climates.

Poor water quality

As described previously, the water in final voids originates from a range of sources. Direct rainwater inflows have a very low mineral content. The quality of leachate, resulting from rainwater and groundwater percolating through backfilled spoil, is influenced by both the initial water quality and the mineralogy and fragmentation of the spoil. Typically, rainwater-derived leachate is likely to attain a quality similar to local groundwater but with lower dissolved solids, while groundwater-derived leachate passing though spoil may exhibit up to a 50% increase in total dissolved solids or remain relatively unchanged.[2]

Salinity

In the case of Hunter Valley coal mines, groundwater and spoil leachate entering the void is likely to be saline as a result of high salinity of the Permian deposits from which coal is extracted. If the void is a terminal sink, then over time the salinity of the void water will increase. This is due to both evaporation-driven concentration and additional salt loading caused by inflows of leachate and groundwater.[1] As a result, water quality in final void lakes is typically poor and will worsen over time. An independent, academic study of the long-term behaviour of a large void at the Mount Arthur mine predicts that after 500 years the void may contain approximately one million tonnes of salt.[1] Mine Environmental Impact Statements typically model final void salinity as increasing for hundreds of years (see Table 3). The eventual salinity of void water in some cases is expected to approach that of seawater (approximately 35,000mg/L).[9]

Groundwater assessments for mining approvals are typically focussed on direct hydrological factors and consequences. Final void water chemistry is often very poorly addressed within these studies. Water quality beyond salinity or even the broader metric of conductivity (a measure of the ionic content of water) is almost always neglected. As noted by Mackie:

> *"Regional groundwater chemistry and the impacts relating there to, are often addressed in a simplistic way while spoils leachate which is generated following pit re-saturation, is poorly characterised if at all."*[2]

As can be seen from Table 3, predicted final void pit lake salinity varies significantly between mines, reflecting differing physical properties of the voids and hydrological regimes. Differences in the methodology used by the various mining companies is also evident. In some cases, no prediction of long term salinity was offered. In one case only the quality of water entering the final void was predicted.

Acidity/toxicity

Coal mines are also commonly associated with Acid Mine Drainage (AMD).[16] AMD results from the weathering of sulfide minerals, such as pyrite, contained in mine wastes such as tailings, exposed open cut walls or overburden. This increases the acidity in the run-off which becomes water in the pit lake. The more acidic conditions cause more material to dissolve into the water, resulting in higher concentrations of other elements, potentially including toxic heavy metals.

The sulphide and carbonate content of coal and associated strata at Upper Hunter Coalfield mines, however, is lower than in other regions – reducing the likelihood of AMD.[1,17] In the Lower Hunter the situation is very different. There, seven derelict mines are affected by AMD because of much higher sulphide content in the coals of the Greta and Tomago coal measures.[18] Runoff from tailings and other sources at these sites has poisoned local creeks.[19]

Studies have noted that the toxicity of pit lakes may also present a threat to humans as a result of planned or unplanned fisheries. Toxic contaminants such as mercury, selenium, cadmium and other heavy metals may accumulate in aquatic ecosystems that develop in the pit lake. These can bio-concentrate in predator fish species, resulting in a risk to fishers who consume their prey.[16] Such risks are site-specific but, in most cases, receive at best scant treatment within the environmental impact assessment process for NSW coal mines. To fully understand final void pit-lakes it is essential that water quality risks including heavy metals, especially selenium which is very common in coals, are properly assessed on a site by site basis.

The problems with final voids

Table 3 - long term salinity predictions for selected final voids produced by project proponents

Mine	**Predicted salinity of final void pit lake**
Rixs Creek (proposed Continuation of Mining Project)	7,454 mg/L (11,125 µS/cm), at the end of mining, to in excess of 20,000 mg/L (~30,000 µS/cm) by 2,000 years after mining[11]
Maules Creek	5,000mg/L after 500 years[10]
Warkworth	"predicted to increase by 30uS/cm per year reaching 30,000 uS/cm at the end of the 1000 year modelled period"[12]
Ravensworth	Not reported
Mt Owen/Ravensworth East	Three voids: 1. "expected to become a source of groundwater and so will not become particularly saline" 2. "North Pit void is expected to reach a salinity of 5,000 mg/l after 200 years." 3. "In the RERR void the salinity is expected to reach 13,000 mg/l after 200 years, with modelling indicating that the salinity is expected to continue increasing in a linear fashion reaching 25,000 mg/l later in the millennia"[13]
Bulga	"Preliminary assessments support a discharge water likely to exhibit an ionic species distribution where Na>Mg>>Ca and HCO3>Cl-SO4 and an approximate dissolved salts content of the order of 4000 mg/L (EC about 6000uS/cm)".[14] Long term salinity is not predicted for the pit lake water - IESC note this omission
Bengalla	The long term salinity is expected to increase initially at a rate of 5 µS/cm per year (average over 1,000 years) and reach a stable salinity less than 20,000 µS/cm15
Drayton	Not reported by proponent
Mt Arthur Coal	Not reported by proponent
Wilpinjong	4,000 mg/L in one and over 35,000 mg/L in another after 700 years and still rising[9]
Liddell	4,200 mg/L in one void, over 14,000 mg/L in other after 250 years[3]
Mangoola	Not quantified by proponent

The problems with final voids

Groundwater impacts

Most final voids planned for coal mines in NSW are predicted to act as terminal sinks. Therefore, local aquifers will be permanently depressurised to some distance from the mine site, depending upon local hydrological conditions and the degree to which the water level in the final void at equilibrium approaches pre-mining groundwater levels.

In the case of final voids which intersect with productive alluvial aquifers, the long-term impacts of groundwater drawdown caused by terminal sink voids can be considerable. Where voids are distant from productive alluvial aquifers, and local rock is considered relatively impermeable, impacts are typically predicted to be localised and minimal. Table 4 presents the groundwater inflows predicted for selected final voids. As can been seen, the predicted flow entering the Liddell final voids is much larger than at other mines, as these intersect with a productive alluvial aquifer.

It is important to note that groundwater modelling for environmental assessments and the impact predictions drawn from the models are often criticised.[22] Doubts regarding project impacts often remain even when projects are approved. As noted by Mackie, *"[g]roundwater impact studies are a pre-requisite for mine pit regulatory approvals. Such studies often rely heavily upon computer based numerical models to simulate pit development and predict impacts. These models are sometimes poorly designed and reliant upon conjecture in prescribing strata hydraulic properties and other parameters".*[2]

Flooding

As the quality of water within most final voids discussed in this report is expected to be poor and to become worse with time, the spilling of this water onto surrounding land would have a detrimental impact. This threat is typically considered a minimal risk by mine proponents based on modelling predictions that the void will act as an evaporative sink, with the lake's surface far below the spill height. This is not, however, a robust assumption in all cases.

Table 4 - final void estimated groundwater in-flows (proponent reported)

Mine	Groundwater in-flow
Liddell	At peak: – 43 ML/day – 14ML/day[20]
Mangoola	Not reported
Mt Thorley Warkworth	Long term: – 1.365ML/day from Permian coal measures – 2.700ML/day from spoil to the east[21]
Bengalla	Not reported
Drayton	Stabilises after more than 100 years at: – 0.9ML/day (eastern void) – 0.4ML/day (northern void) – 0.15ML/day (southern void)[5]
Mt Arthur Coal	Maximum groundwater and seepage inflow rates: – 1.4 ML/day[8]
Wilpinjong	Not reported
Maules Creek	Long-term average inflows: – approx. 1.7 ML/day[10]
Ravensworth	Not reported
Mt Owen / Ravensworth East	Predicted equilibrium water flows from coal seam measures: – 0.22 (north pit) – 0.24 (RERR mining area) – Predicted equilibrium water flow from void into coal seam measures (as the BNP is located above the regional groundwater table): – 0.05 (BNP final void)[13]
Bulga	Flow rate stated but context not provided: – 0.2 ML/day[14]

The problems with final voids

The now approved Bulga Continuation Project will result in a final void approximately 300 metres deep. This void is predicted to fill with water over 500 years and then may overflow. The long term quality of water within the void has not been modelled by the project proponent and so the impact of it flooding the surrounding area has not been assessed.[i]

The Response to Submissions and Revised and Amended Project Assessment Report states that, should the void spill, it will be into the Loders Creek Catchment. It states that, *"[w]ater quality in the void is predicted to trend towards a pH of between 7 and 9 and a TDS of below 4000 mg/L. These levels are consistent with historical recorded baseflow quality in the Loders Creek system."* However, this is actually the characterisation of leachate entering the void reported in the project's groundwater assessment. The groundwater assessment makes no prediction of the water quality within the void. This point was noted by the Independent Expert Scientific Committee ('IESC') in its advice to the federal government on the project. The IESC found:

"Water held within the void is expected to become highly saline and may be a source for surface or groundwater contamination, particularly as the pit lake water level at equilibrium is predicted to exceed the void spill height. The proponent predicts that spill will occur in a "spring like manner" through the emplaced waste rock and into the surrounding surface waterways through the identified leakage points. There is a risk that these "springs" will contain contaminants or leachates, including elevated salt levels and acid forming materials. Assessment of this risk should be informed by hydrochemical characterisation of the pit lake and surrounding emplacement areas." [23]

Despite being recommended by the IESC, this hydrochemical characterisation was never conducted. The implications of any future spill were not considered or recognised as an uncharacterised potential impact by the Planning Assessment Commission in its assessment of the project.[24]

Safety of highwalls and pit lakes

Typically coal mines begin operating where the coal seams are shallow, because that is where the cost of extraction is least. As mining progresses, the seams typically get deeper. To minimise the cost of production, mines are planned to minimise the amount of overburden removed to extract the coal. Therefore, the highwall - the unexcavated face of exposed overburden and coal in a surface mine - is typically as steep as possible while retaining structural stability.

Most mines plan to close when the last active mining is occurring at the deepest point considered economical. Therefore, the highwall at mine closure is at its greatest, potentially hundreds of metres in height. Highwalls are often unstable over long time periods. This can present a safety risk, because land slips can endanger nearby people, animals and structures.

Highwall failures do happen. In June 2015, a highwall at the operating Moolarben coal mine failed. A 160 metres long and 55 metres high section collapsed resulting in a 28 metres deep section of the ground falling into the pit, bringing it to within 12 metres of a public road. An investigation found that pre-mining exploration had failed to detect an area of loose silty sands and weaker clays located below 25 metres of stronger material. As a result, *"no adjustment to the wall design, or change to the mining sequence, was possible and the failure of the highwall was unable to be prevented during the mining process."*[25]

As with most mine closure operations, the fate of the highwall is a trade-off between best long-term outcome and cost. When a void is to remain open, rendering highwalls safe can be expensive. This is because reducing their angle or stabilising the slope with buttresses involves considerable earthmoving, and either increasing the overall size of the final void, or reducing the volume of coal extracted. Backfilling final voids obviously resolves the issue of highwall safety.

As few large, open-cut mines have closed, there has been little chance for detailed scrutiny of the efficacy of plans for rendering highwalls safe. One contemporary example, however, is provided by the Drayton mine in the Hunter Valley. Here, at closure three main final voids will remain with highwalls between 84 and 120 metres tall. The miner plans to create "sustainable highwalls" through increased stability by reducing the slope height by blasting the top half of the highwall, reducing its slope angle to approximately 37°. The loose blasted material will be

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[i] The Response to Submissions and Revised and Amended Project Application Assessment Report states that "Modelling indicates that the void will take in excess of 500 years to reach a level where it could spill into the broader environment. The spill point for the void (should the pit lake reach a level where a spill would occur) has been identified as being into the Loders Creek catchment. Water quality in the void is predicted to trend towards a pH of between 7 and 9 and a TDS of below 4000 mg/L." This is incorrect. The groundwater assessment commissioned for the assessment states that the leachate entering the void will have those qualities but makes no prediction of the water quality within the void.

Yancoal's Moolarben open-cut coal mine wall collapsed on 6 June 2015, just metres from a public road
© Kate Ausburn

pushed into the final void to form a buttress against the lower portion of the highwall. The upper slope will then be capped and re-vegetated, an undertaking that can fail on such steep slopes.[26,27]

A peer review of this plan noted that there was "no precedent experience for such inundation in the Australian open pit coal mining context" and the "high to very high likelihood of instability of the buttressing spoil under long-term inundation".[28] It assessed the stability of the overall slope to be adequate over a 20-60 year timeframe but noted the lack of any geomorphological assessment – which is necessary to assess stability over longer timeframes.

The highwalls at Drayton are much smaller than those are planned for some other mines, such as Bulga and Warkworth. Using the same proposed methods to reduce the slope height at these mines would involve significant amounts of earthmoving, would result in a significant increase in the surface area of the voids and be expensive. Indeed, the proponents of both the Warkworth Continuation Project and the Bulga Optimisation project have both discounted reducing the slope angle of the highwall citing the additional area of land required and the cost. This argument was accepted by the regulator (DPE) without forcing consideration of opportunities to reduce the slope by broader mine plans. It is therefore unclear what, if any, measures will be undertaken to improve highwall stability when these mines close.

Mining companies typically state that final voids will be fenced to prevent injury (or death) to the public from either falling into final voids or from highwall instability. Fences require ongoing maintenance and monitoring, placing a perpetual burden upon future landowners should the mine site be sold or relinquished.

Backfilling final voids

"Backfilling is increasingly seen as 'best practise' for mine closure rehabilitation and an important aspect to whole of mine planning. This is because long term management of environmental risks and return of land to an acceptable post mining land use can in some circumstances only be achieved by pit backfilling." [29]

Backfilling final voids can mitigate many of their social and environmental risks, and presents the opportunity to return land to a form that supports pre-mine use.[29,30] In the United States, filling in coal mine final voids has been required by law since the 1970s.[31] Yet, in Australia, this is still not the case.

The United States' Surface Mining Control and Reclamation Act of 1977 (SMCRA) requires that surface coal mine operations *"backfill, compact (where advisable to insure stability or to prevent leaching of toxic materials), and grade in order to restore the approximate original contour of the land with all highwalls, spoil piles, and depressions eliminated".*[31] Mines where the operator demonstrates that, due to the thickness of the coal seam being much greater than the thickness of the overburden, insufficient material exists on site to completely backfill to the approximate original contour is required to use "all available overburden and other spoil and waste materials to attain the lowest practicable grade". In addition, special provision is also provided for mines where mountaintop removal occurs. While issues with implementation and enforcement of SMCRA have been identified[32], the legislation sets clear and commendable rehabilitation objectives that exceed those required in Australia.

Australian mining companies recognise the benefits of filling in voids. The current Final Void Management Plan for Bloomfield Group's Rixs Creek mine notes, *"[t]he progressive infilling of voids (in preference to leaving voids open) is often regarded as the most effective and (where possible) the preferred means of minimising the long term effects of mining activity post closure."*[11] However, in most cases mining companies do not undertake backfilling. Essentially, this is due to cost and the lack of a legal requirement to do so.

At mine sites with multiple pits, the economics of backfilling at least some pits are often most favourable. Voids in pits where mining has completed can be backfilled with overburden from active mine areas and waste from processing facilities. The cost of this operation may be relatively low compared to developing new tailings storage facilities or out-of-pit rock dumps. A key variable is the distance waste must be transported from where it is generated.[29]

Indeed, some active and proposed coal mines in NSW plan to fill in voids as part of their operations, such as Watermark and Mount Thorley Warkworth (where the Mount Thorley final void will be filled while the Warkworth mine is still active). In these cases, mining companies present plans to fill voids as a positive environmental outcome and the initiatives are supported by regulators. However, in all cases, plans to fill voids form a component of overburden management strategies for active mining in other pits.

Cost of filling

In all cases, miner's commitment to filling voids abruptly ends when mining stops. Essentially, the issue is cost. Filling a void post-closure is a cost borne after revenue generation has ceased. Therefore, mining companies avoid it where possible. Instead, the focus shifts to stabilising the mine landform while conducting minimal earth moving.

The cost of filling final voids is often quantified by mining companies. In the case of the Mount Thorley Warkworth Continuation Project, the proponent estimated that filling the void at the Warkworth Mine would cost approximately AUD $2 billion. Estimates for other mines and projects are presented in Table 5.

Table 5 - proponent estimated costs of filling final voids

Mine	Cost estimate
Maules Creek	$388 - $813 million[33]
Moolarben	$133 million[34]
Warkworth	$2,085 million[35]
Watermark	$461 million[36]

Boggabri and Tarrawonga coal mines and the Leard forest 2012
© T. Pickard

Mining companies typically present cost as a critical factor in their decision to not backfill final voids. It is important to understand the context in which these cost estimates are generated. Typically, mine planning decisions are made on the assumption that filling in voids will not be required. It is therefore not surprising that the cost is prohibitive. This justification is accepted by state regulators who do not challenge the underlying assumptions of the estimate even where the mine has not begun construction (and so the cost is not fixed). Filling in voids retrospectively is the most expensive option. If, as in other countries such as the United States, a mine was planned based on the precondition that all voids must be filled, the associated costs would be lower.

Mines planned to leave no final voids may look very different to those currently operating in NSW. Practices that can reduce filling costs include staging the mine to progress in strips and in an up dip direction on the final strip. This results in a smaller void at mine closure and a smaller exposed highwall. Other options include reducing the depth of open cut operations and ensuring overburden placement is optimised for later backfilling. While occasionally practiced or proposed[37] within the NSW coal industry, such practices represent a paradigm shift from typical mine planning because backfilling is not required by the regulator. These alternative approaches may reduce the volume of resource extracted and have other negative consequences upon a project's economic feasibility.

Availability of filling material

A factor critical to how easy it is to fill final voids is the availability of fill material. The most easily available material is overburden removed from the pit. When overburden is removed to facilitate coal extraction it is blasted and fragmented. This physically increases its volume. The difference between the volume of rock in-situ pre-mining and post-mining is referred to as a "swell" or "bulking" factor. In the case of NSW coal mines, it is common to apply a factor of 25% increase for mine design purposes[,36,38] with the actual factor typically in the range of 20%-30%.[17] Many NSW coal mines typically have relatively high ratios of overburden to extracted coal (the strip-ratio); combined with the swell factor this results in enough material existing on site when mining ceases to fill the final void.

The location of overburden at mine closure is often problematic. In the case of existing mines, the material is usually placed within overburden emplacement areas (OEAs) creating artificial hills that are rehabilitated by being rendered into stable structures covered with soil and plants. Proponents of mine extensions typically highlight

Backfilling final voids

the short-term negative impacts of disturbing these areas of the mine site. They argue that doing so would create unacceptable levels of dust and noise. This is an argument that might be convincing if the mining operation had not already been responsible for creating arguably greater levels of dust and noise for decades before the backfilling operation.

Groundwater consequences of backfilling

In most cases, final voids are predicted to act as terminal sinks for local groundwater. This is characterised as a positive outcome by mine proponents based on the rationale that the voids will therefore not act as sources of saline water potentially entering local aquifers. This argument is endorsed by regulators yet is not necessarily robust. Intrinsic within it is an acceptance that a permanent drawing down of local aquifers is preferential to the risk of more saline water entering them from the voids. In order to accurately draw this conclusion, it would be necessary to properly characterise the quality and flows of local groundwater, model and assess the impacts of filling in the void, and then conduct a cost-benefit analysis. This has not occurred. Such a lack of robust assessment renders questionable this justification for leaving the voids open.

Further uncertainty in the veracity and applicability of the argument that leaving voids open always protects groundwater is provided by approval for backfilling other voids in the region. In some cases, proponents argue that backfilled voids will be a source of water with a lower salinity than local groundwater with beneficial consequences (such as Mount Thorley, see case study on page 22). In other cases, final voids have been approved despite predictions that high salinity water will flow from them to local groundwater.

The Liddell coal mine, approved to leave two final voids, proves that even voids negatively impacting on groundwater can be approved by NSW regulators. The voids are connected by old underground mine workings, allowing water to flow between them. Modelling predicts that pit lakes will form in the voids. The water level in both voids is expected to stabilise within approximately 50 years of mining ending. At equilibrium, one of the voids (in the Entrance Pit) will act as a sink for groundwater and the other (in the South Pit) as a source. Salinity in the Entrance pit void is expected to stabilise at 4,200 mg/L due to constant replenishment from surface and groundwater sources. Evaporative losses are predicted to account for 80% of outflows from the South Pit void.[3] As a result, salinity is expected to increase continuously over time, reaching over 14,000 mg/L after 250 years. The remaining 20% of outflows constitute a flow of this increasingly saline water into the local hard rock aquifer. This is reported to have a salinity of approximately 3,000 mg/L. The groundwater impact assessment for the project notes *"impacts to groundwater in the hard rock aquifer may result from leakage of increasingly saline water from the South Pit final void."*[20] In its assessment of the project, the regulator notes "the flows are not expected to result in any significant impacts on the hard rock aquifer given its already brackish nature, and are not predicted to affect water quality in the alluvial aquifer".[39] This case demonstrates the regulator's acceptance of final voids that are not terminal sinks and casts doubt on the validity of justifying final voids on grounds of protecting groundwater from increased salinisation without rigorous, case-specific assessment.

Impact on future coal mining operations

Mining companies often object to backfilling open cut mines due to the possibility of 'resource sterilisation'- the possibility that if the pit is filled additional resource extraction could be prevented. In the case of NSW open cut coal mines, this argument typically takes one of two forms. Either the miner notes the possibility that with additional approvals the open-cut mine may continue operating beyond the currently planned extent, or the miner notes that an additional coal resource exists beyond the planned mine boundary that may be recovered by a switch to underground mining.

In some cases, any further coal mining operations beyond the planned project would require a shift to underground operations. This is because as the coal seam dips significantly far beneath the earth's surface, removal of overburden above it becomes economically unfeasible. Mining companies then commonly state that leaving the void open is preferential as it will allow easy access to the coal seam for the future mine. The reality is, however, that backfilling will only have a slight negative impact on the future mine's economics[29] as the access shaft is only a small portion of the overall costs. Despite this, mining companies often use this as an additional reason for not filling voids.

In the case of Shenhua's proposed Watermark Mine, the proponents plan to leave one of the mine's three pits unfilled because if "underground mining is entertained

Backfilling final voids

following the completion of open cut mining it will provide access for this purpose". The proponent determined that "the cost/benefit analysis found that the retention of a safe and stable final void … was the most appropriate outcome",[40] rather than a filled in void. Other examples where this justification was deployed include the 2013 modification to the Liddell mine, where one use of the proposed voids was "access to potential future underground coal reserves".[39] The now structural decline of the coal export market reduces the likelihood that these future mines will ever eventuate.

In cases where the miner notes that, with additional approvals, the open-cut mine may continue operating beyond its currently planned extent, the planning system permits approval of proposed final landforms despite regulators recognising that the proposals are unlikely to eventuate. An incremental approach to project approvals prevails in NSW where mining companies routinely revise project plans after initial approval is granted. A facility that enables projects to adapt to unforeseeable circumstances by modifying project approvals and plans is an obvious necessity. However, the system is currently exploited, resulting in a lack of proper whole-of-mine-life planning at a project's inception.

In the case of the recently constructed Maules Creek Mine, the NSW Department of Planning and Infrastructure determined that it, "does not believe that backfilling the final void for the Maules Creek project is either reasonable or feasible", largely due to, "the significant coal sterilisation, the very high capital costs, the future mining potential in the lease area beyond the 21-year project life".[41] As a consequence, the Department recognised that the proposed mine closure scenario before them may not eventuate. However, the Department did not require the mine's proponent to determine what final landform may occur if mining continued after year 21. This is an example of how the planning system fails to handle whole mine-life scenarios. By not requiring the proponent to examine opportunities to minimise final void formation, and by considering mine plans under alternative possible scenarios, voids may have been locked in that could have either been smaller or prevented altogether.

Revised plans are approved, with future outcomes defined and judged relative to the current state of the project at the point of revision. These may well be inferior to what could have been achieved through longer-sighted initial project planning. This is particularly true for mine closure. The current paradigm does not force mining companies to plan for mine closure in such a way that achieves the best outcome at the least cost - something that can only be achieved by all major closure scenarios being considered at a project's inception. The cost of filling the final void is essentially dependent upon the availability and location of overburden at the point of closure. Minimising this cost is best achieved by planning for this mine closure goal from the outset and retaining it as the mine plan is revised over its lifetime.

Value of pit lakes to communities

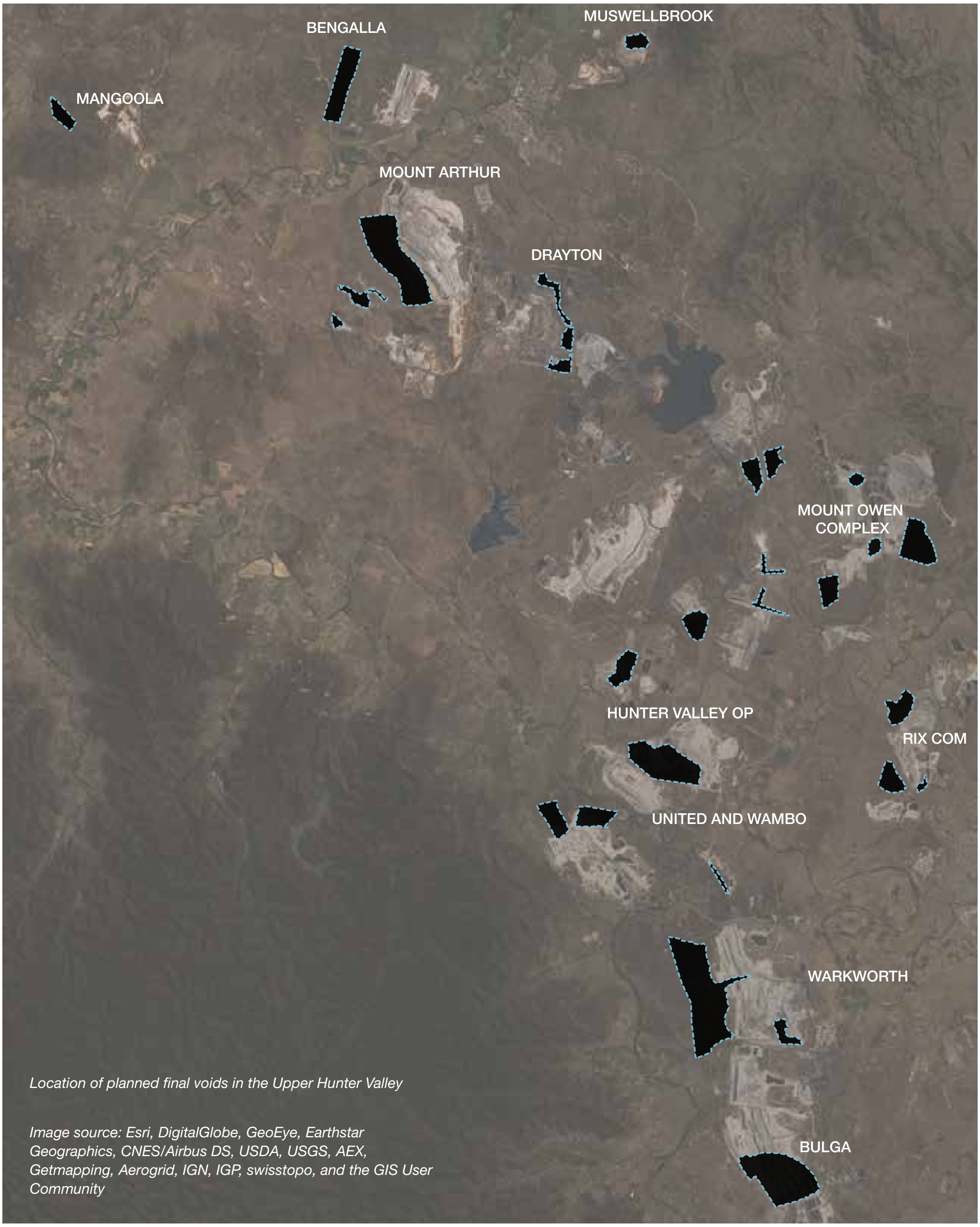
The utility of a pit lake is ultimately dependent upon the quality and quantity of water that it contains. In cases where water quality is high and the volume abundant, these lakes can act as important local reservoirs of water for applications such as agriculture, aquaculture and recreation. The lakes can also support environmental values too. However, these outcomes are highly dependent upon local site conditions. Success stories in other countries typically involve smaller pits or are located in areas where water is more plentiful. In most cases, NSW coal mine pit lake water is likely to be of poor quality and of limited utility for irrigation or other uses.[30]

Maps of final void locations

Location of planned final voids in and near Leard State Forest, Gunnedah Basin

Image Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Maps of final void locations



Location of planned final voids in the Upper Hunter Valley

Image source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Case Study

Rural scene near Bulga with coal mine in background
© Kate Ausburn

Mount Thorley Warkworth mine complex

The Mount Thorley and Warkworth mines form a complex that is one of the largest in the Hunter Valley. It is comprised of two mines, operationally integrated with the sharing of coal, overburden, rejects and water as required. Its owners, (Rio Tinto is the major shareholder), have recently gained approval for the continuation and expansion of operations.

Under the newly approved plan at Mount Thorley, mining in the large Loders Pit is expected to be completed by 2020. At the Warkworth Mine, the new approvals permit an additional 698ha to the west of current operations to be incorporated into the mine. This will permit mining to continue in a westerly direction (down dip) for an additional 14 years beyond what was previously approved.

Once extraction of coal at the Mount Thorley Mine has ceased, overburden will be dumped into the final voids from the still active Warkworth Mine. The voids will be largely filled in and "a more natural looking final landform" will be achieved.[42] A small depression will remain in one part of the Loders Pit area (approximately 10 m below the pre-mining ground level).

In contrast, at the Warkworth Mine, at the end of operations, its two pits will form one huge final void, approximately 250 m to 300 m deep, 5km long and 1.5km wide.[21] Project proponent commissioned modelling predicts that the void will be a terminal sink, with the pit lake water level eventually stabilising approximately 54 metres below the void's crest. As a result of evaporative-concentration, salinity within the pit lake is predicted to reach 30,000 uS/cm at the end of the 1000 year modelled period[12] (sea water has a conductivity of approximately 50,000 uS/cm).

The assessment of this extension project provides an insight into the current approach to final voids within the NSW planning process. The miner's justification for the void was fundamentally grounded in cost. The void is so large to fill it would require over 800 million bank cubic metres of material to fill it. In communication with the Department for Planning & Environment (DPE), the proponent estimated this cost of this operation to be $2billion and noted that this was "over 190 times that of the underlying rural land value."[43] This cost was considered "prohibitively expensive". However, the miner failed to consider opportunities to reduce the final void size that needs filling by altering the mine plan.

The DPE fully endorsed the proponent's assessment. In a memorandum to the Planning Assessment Commission (PAC) it echoed the project proponent's arguments, concluding that due to the estimated cost, *"the Department accepts that it would not be reasonable to impose a condition that requires Rio Tinto to completely or even partially backfill the final void."*[44]

In addition, the Department noted that filling the void could present "risks to groundwater resources as the final void may not act as groundwater sink and therefore saline water may migrate off the site". The strength of this argument is highly questionable. In the case of the concurrently assessed Mt Thorley project, where the same proponent proposed filling a similar void, the DPE raised no objections or concerns.

The subsequent PAC review did not accept DPE's assessment, stating that it "considers that the size of the final void as currently proposed is unacceptable and that opportunities exist to reduce its size."[45] Despite this, aside from a minor adjustment, the existing final void plans were further defended by the proponent, broadly supported by DPE and ultimately approved. This case study demonstrates the broad acceptance of massive final voids. The regulator fails to critically assess the strength of miner's claims and accepts that any backfilling and final landform considerations can only be assessed within the constraints of maximum resource extraction.

Breeza farmland close to the site Shenhua proposes to mine
© Kate Ausburn

Conclusion

Occasionally mining companies go to considerable lengths to ensure that land impacted by their operations is at least partially rehabilitated. In some cases, the goal of these efforts is the re-instatement of cropping or grazing farmland. In others, it is the establishment of habitat designed to mimic native ecosystems potentially with sculpting of the landform to emulate natural topography.

However, in almost all cases these efforts stop short of one key undertaking: filling in the final voids left when mining ceases. Here, the role of economics in determining the extent of mining companies' rehabilitation efforts is laid plain. It is arguable that environmental quality will be locked into worsening over time as the pit lake increases in salinity and the groundwater is drawn down.

Moving overburden costs significant amounts of money. Once a mine has ceased producing saleable product this expensive undertaking is minimised as much as possible. Returning the landscape to its approximate original form by filling in the hole left by open-cut mining is viewed as an excessive cost to be avoided, and not an essential obligation incumbent upon the miner in exchange for the right to disturb the landscape to extract resources – and profit.

That a miner should focus strongly upon maximising profitability is understandable. What is more questionable, however, is that regulators whose responsibility also encompasses long term custodianship for the land allow mining companies to leave a polluting and pockmarked landscape whose remediation is likely to be beyond the means of even the best intentioned future government.

A practice that has been banned in the United States since the late 1970's continues today in NSW. Here, as has been demonstrated within this report, continued regulatory failure and flawed assessment is permitting considerable swathes of the State to be rendered into vast, saline lakes. This is creating a legacy that will not be easily remedied by future generations.

Appendix 1 - Methodology for sizing voids and data sources

The most recent final landform plan for each mine was located from a range of sources including: development approvals, mine operations plans, rehabilitation management plans and environmental impact statements. See Table 6 for details of the data source for each individual mine.

Raster images derived from the plans were geo-referenced in GIS software using, where possible, graticules on the image or a combination of other information present including mining lease boundaries and physical features such as roads. The quality of the fit was checked using the scale bar printed on each plan.

The approximate outline of the final void was obtained by tracing the contour line closest to the top of and located fully within the final void. The estimated area of the final void was then calculated using this contour line. This is an inherently conservative estimate of the void extent, with the degree of underestimation dependent upon the resolution of the presented contour lines.

Table 6 - source of final void plans

Mine	Source of final landform plans	Notes
Bengalla	Bengalla Continuation Project Development Consent (incorporating modification 1)[46]	Appendix 9
Boggabri	Project Approval (incorporating modification 4)[47]	Appendix 9
Bulga	Bulga Optimisation Project Development Consent[48]	Appendix 13
Drayton	Mine Operation Plan (July 2015 – June 2020)[26]	Plan 4
Duralie	Duralie Extension Project Modification 2014. Environmental Assessment, Appendix 5, [49] (Consistent with Duralie Extension Project Development approval - incorporating modification 2- Appendix 8)	Figure 5-1
Glendell	Mount Owen Complex Mining Plan of Operations[50]	Landscape Management Plan 2012 Plan 1
Hunter Valley Operations	HVO North: Appendix C, Carrington West Wing - Environmental Assessment.[51] Consistent with current Development Consent NOTE: The west pit of HVO North was not assessed as a suitable final landform plan could not be located	Figure 15
	HVO South Coal Project, Environmental Assessment Report, Appendix K[52] (Consistent with current Development Consent -Appendix 6)	Figure 3.1
Integra	Integra Open Cut Project Approval (incorporating modification 5)[53]	Appendix 9
Liddell	Development Consent (incorporating modification 6)[54]	Appendix 3
Mangoola	Development Consent (incorporating modification 6)[55]	Appendix 5
Maules Creek	Consistent with Mining Operations Plan (2016-18)[56]	Plan 4
Moolarben	Stage 2 Project Approval (incorporating modification 2)[57]	Appendix 10

Appendix 1 - Methodology for sizing voids and data sources

Mine	Source of final landform plans	Notes
Mount Arthur	Modification 1, Environmental Assessment,[8] Consistent with Mt Arthur Coal Mine – Open Cut Consolidation Project, Development Consent (incorporating modification1) Appendix 8	Figure 20, Appendix C
Mount Owen Continued Operations Project	Environmental Impact Statement. Mount Owen Continued Operations Project[58]	Figure 2.12
Muswellbrook	Mining Operations Plan[59]	Map 4
Ravensworth Operations	Development Consent (incorporating modification 3)[60]	Appendix 7
Rixs Creek Continuation of Mining Project	Environmental Impact Statement[61]	Appendix R, Figure 31
Rocglen	Mining Operations Plan[62]	MOP Plan 6
Stratford	Stratford Extension Project Development Consent[63]	Appendix 8
Tarrawonga	Mining Operations Plan (2015-20)[64]	Plan 4
United and Wambo Project	Preliminary Environmental Assessment[65] NOTE: The currently operating Wambo mine was not assessed as a suitable final landform plan could not be located	Figure 3.6
Warkworth	Warkworth Continuation Project Development Consent[66]	Appendix 6
Watermark	Development Consent[67]	Appendix 10
Werris Creek	Development Consent[68,60](incorporating modification 2)	Appendix 5
Wilpinjong	Development Consent[69](incorporating modification 6)	Appendix 4

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contact@erinsights.com
www.erinsights.com