LEIGH CREEK COALFIELD

SPONTANEOUS COMBUSTION MANAGEMENT OF WASTE ROCK DUMPS

Prepared for Alinta Energy - Flinders Power Partnership

February 2017

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Leigh Creek Coalfield – Spontaneous Combustion of Waste Rock Dumps

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1 Introduction

This report has been issued to provide a comprehensive summary of spontaneous combustion (spon com) and presents the preferred methods for successful mitigation and management of spon com within waste rock dumps at Lobe B, Leigh Creek Coalfield. This report captures, contains and supersedes all previous reports issued by MWH related to spon com, namely:

- MWH 2015a. Design Considerations to Minimise Spontaneous Combustion at Leigh Creek. Rev 1.0 Issued to Alinta Energy 21/12/2015.
- MWH 2015b. Design Considerations to Minimise Spontaneous Combustion at Leigh Creek. Rev 2.0 Issued to Alinta Energy 1/4/2016.
- MWH 2016a. Letter to Paul Jones 12/4/2016 – Addendum to the 2015 "Design Considerations to Minimise Spontaneous Combustion at Leigh Creek Report" (MWH 2015).
- MWH 2016b. Management of Spontaneous Combustion at Leigh Creek Lobe B Post Mining. Rev 3.0 Issued to Flinders Power 16/12/2016.

As such, this report is designed to present the current knowledge and assessment of spon com management of waste rock dumps at Lobe B. Since October 2015 MWH staff have undertaken various technical studies, reviewed complementary studies and worked closely with Flinders Power Partnership staff to collect, interpret and present key data and information relevant to the successful management of spon com. As part of the development of the Mine Closure Plan for Leigh Creek, a number of other technical studies have been completed during 2016 that provide relevant input to this assessment including:

- B3 Mining Services (January 2017). Assessment of Spontaneous Combustion Propensity of Aged Coal and Rock Samples from Leigh Creek Coal Mine.
- Flinders Power (April 2016). Draft Mine Closure Plan for the Leigh Creek Coalfields.
- Flinders Power (October 2016). Mine Closure Plan for the Leigh Creek Coalfields.
- MWH (2016c). Leigh Creek Coalfield - Soil and Waste Characterisation.
- MWH (2016d). Leigh Creek Coal Field – Surface Water Assessment.
- MWH (2016e). Leigh Creek Coal Mine - Groundwater Aspects of Mine Closure.
- MWH (2016f). Preliminary Mine Waste Characterisation Summary.
- MWH (2016g). Leigh Creek Erosion Modelling – Letter Report.
- MWH (2017). Leigh Creek Coalfield – Cover and Rehabilitation Material Characterisation.

2 History of Spon Com at Leigh Creek (pre 2015)

Research has been undertaken on the combustibility of the carbonaceous material in the Leigh Creek basin since the late 1980s. The historic information is summarised as follows:

- Concerns were first documented regarding coal fires at Leigh Creek in 1988 (Renwick, 1988).
- In early 1989, it was identified that fumes and smoke from waste dumps fires may impact on the terrace mining plans.
- In 1991 the Electricity Trust of South Australia (ETSA) commissioned investigations into "self-heating". From 1991 to 1994 experts visiting site included Prof. D Zhang (then University of Adelaide), Professor D Glasser (then University of Witwatersrand), Crooks Mitchell Peacock Stewart Pty Ltd and Golder Associates.
- At the direction of Glasser, a trial waste dump was constructed in early 1993 with the intent of proving methods for fire prevention and control (Glasser 1993).
- In 1994 procedures were drafted and implemented at the mine (ETSA 1994). This mostly related to the preferred method for waste dump construction and covering as well as the safe execution of work within areas where sponcom is known to occur.
- Infrared surveying of the mine and spoil dumps commenced in the mid 1990s (Williams 1997).
- In 2014 B3 Mining Services (Beamish 2014) undertook analysis of six core samples provided from two boreholes. All samples were from the Main Series (M2) Coal Measures and were subjected to R70 testing (for Intrinsic Spontaneous Combustion Propensity), sponcom simulation (SponComSIMTM) testing to establish time to thermal runaway and coal quality analysis to interpret minimum self-heat and crossing point temperatures.

At Leigh Creek, operations have successfully utilised fines dominated and clay rich waste material to extinguish hot spots for over 20 years. As documented in the Leigh Creek Mine Closure Plan (FP, October 2016), a significant trial was undertaken in the 1990s by ETSA. Three trial areas were established with temperature and gas monitoring installed within the dump. It was established that "spontaneous heating" occurred in at least one area of the dump. From this work, Leigh Creek operations established safe work procedures that focussed on the management of spontaneous combustion at Lobe B. A key element of this procedure is to place cover material over a burning area to cut off the oxygen and stop spontaneous combustion. It is important to note that this method of extinguishing fires has been successful since its implementation over 20 years ago, and that it is successful regardless of whether the area is re-profiled or not. As documented in the Leigh Creek Mine Closure Plan (FP, October 2016), recent thermal imaging of the trial dump confirms that no self-heating is evident. **Plate 1** shows a recent photo of the trial dump.

Plate 1. Spontaneous Combustion Test Dump. Note that outer slopes are at angle of repose (i.e. not re-profiled (source: Flinders Power))

3 Recent Findings and Spon Com Knowledge

From 2014, FP have established and progressively widened thermal image monitoring across the Leigh Creek mine (as documented in the Leigh Creek Mine Closure Plan (FP, October 2016)). This ongoing work has demonstrated that in all cases where a hot spot has been detected and subject to intervention, there has been an immediate reduction in the reactivity of the area. Two examples (sourced from Leigh Creek Mine Closure Plan, October 2016) are provided in **Figure 1**.

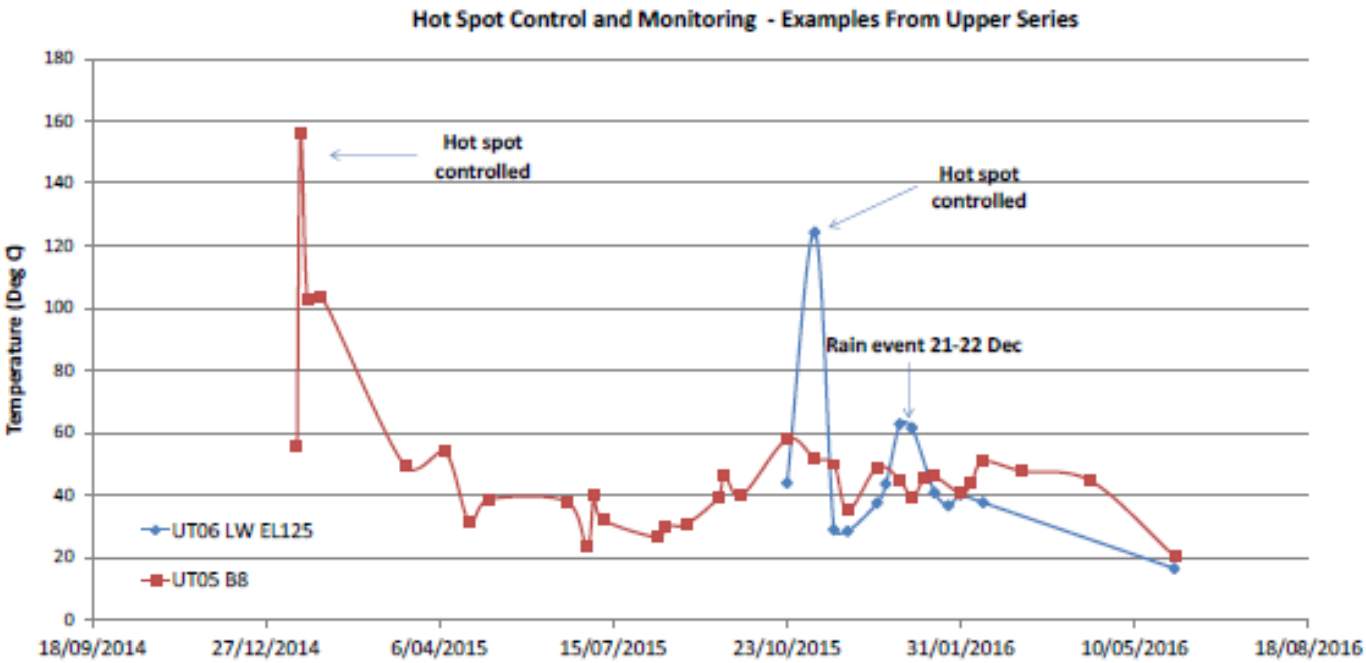

Figure 1. Example temperature profiles of monitoring hot spots (source: Leigh Creek Mine Closure Plan, October 2016).

There are several key observations arising from the data presented in **Figure 1**:

- In both cases the hot spots immediately cooled down;
- In both cases the hot spots did not re-heat;
- Monitoring point UT05 B8 has been subject to 18 months of monitoring. Key potential spontaneous combustion triggers such as rainfall events and summer ambient heating have not resulted in the re-activation of spontaneous combustion;
- Monitoring point UT05 B8 is demonstrating the diurnal ambient heating (summer) and cooling (winter) of the waste rocks; and
- The rain event in December 2015 provides a valuable learning to the longevity of a cover.

Since late 2015, MWH staff have undertaken numerous site visits to Leigh Creek to make observations, collect samples and data for analysis and discuss findings and implications with Flinders Power staff. Key observations relevant to spon com at Leigh Creek mine site are:

- The individual stratigraphic formations that comprise the Leigh Creek coalfield are thin and shallow dipping (**Plate 2**). From a mining perspective this results in no ability to selectively mine and handle units separately, resulting in overburden units being mined in bulk and combined together in waste dumps, diluting the materials.
- Up until the 1990s, all overburden was moved with draglines. Since then, all mining has been by truck and shovel. The creation of waste dumps by truck dumping creates different internal structures within the waste dumps. As shown in **Figure 2**, the location of material within dumps can have a significant impact on spon com.
- The majority of spon com occurs inpit and on waste dump batters where the angle of repose had been initially maintained. Active areas are typically halfway up the face (**Plate 3** and **Plate 4**). This is an expected area and a very common location for spon com to occur; oxygen (often forced by wind) pushes into the lower coarser areas of waste dumps. Once self-heating commences a convection cell is established and oxygen gets pulled into and consumed within the dump.
- Leigh Creek's methodology for extinguishing fires is to push inert material over the top of the area, track-roll into place and mound additional cover material over the top. This is effective for hot spots in both waste dumps and on pit walls. It is unusual for hot spots to re-heat following extinguishment; however where techniques have not been properly applied then self-heating can re-occur.
- Leigh Creek operations follow the current version of LCC-HSSE-PHMP-008 Spontaneous Combustion Principal Hazard Management Plan. This document was originally developed in the 1990s.

- Low walls with a large surface area of loose, broken material, and containing exposed carbonaceous material are more likely to spon com (**Plate 5**).
- In pit walls with stratigraphic units dipping away from the pit void, and where berms are mined back to a hard face, the likelihood of spontaneous combustion is reduced (**Plate 6**).
- There is no history of fires on the highwalls.
- During summer, the high ambient heat of the Leigh Creek area provides less natural cooling time for rocks.

Plate 2: Due to the shallow dip of units and thin layering, it is difficult to mine out carbonaceous versus inert waste. However in the waste dump this will create a mixing effect meaning that any spon com is likely to be localised.

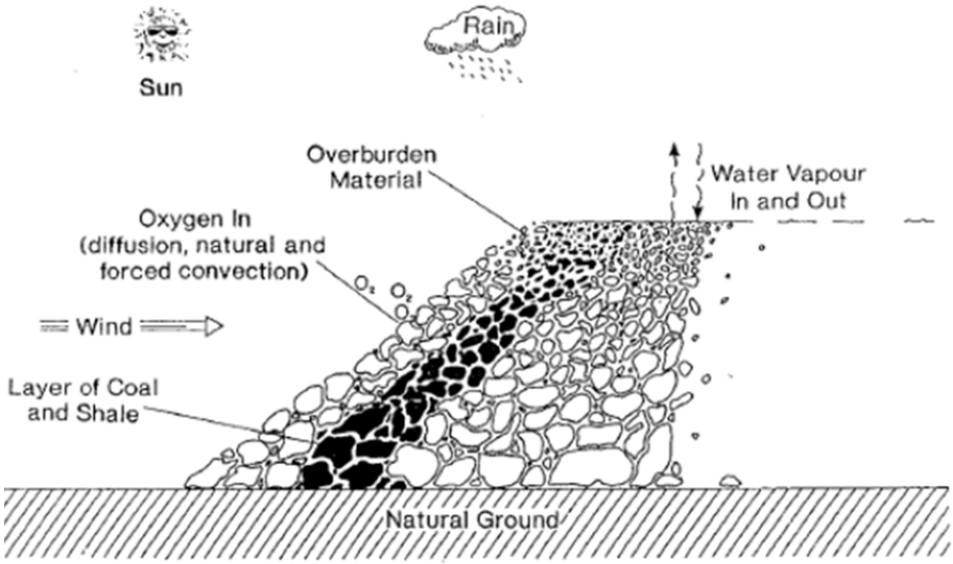

Figure 2: Schematic representation of a waste dump (from Carras et al, 1994)

Plate 3: In-pit dump in main pit. Note smouldering half-way up the face of the slope

Plate 4: In-pit dump, exposed tip-head. Note smouldering half-way up the face. Also note segregation of particle size; coarse at the base and finer towards the top.

Plate 5: Upper Series Pit, Low Wall (right side of the photo).

Plate 6: High wall, showing units dipping away from the pit void. Minimal chance for spon com as surface area exposed is lower and berms are mined back to a hard face.

Plate 7: Old rehabilitated waste dump north of main pit. No heating was detected around these rehabilitated dumps. Deep gullying is the result of uncontrolled stormwater runoff. Depth of cover is approximately 1m (note red and white pole is 1.5m).

During 2016, characterisation of potential cover material was undertaken at Leigh Creek in order to better define potential fill and cover materials available for rehabilitation, ((Leigh Creek Coalfield - Soil and Waste Characterisation, (MWH 2016c), Preliminary Mine Waste Characterisation Summary (MWH, October 2016f) and Leigh Creek Coalfield Cover and Rehabilitation Material Characterisation (MWH 2017)). These investigations, combined with the current field testing that is routinely undertaken by FP, provides necessary supporting and verification data to characterise the cover requirements.

There is abundant evidence (documented in Leigh Creek Mine Closure Plan, October 2016 as well as field observations) that, for waste rock dumps at Lobe B, once spontaneous combustion has been effectively curtailed then the area does not re-ignite. Examples include:

- **Figure 1**. Both monitored points have not re-ignited. The rain event in December 2015 noted on **Figure 2** is particularly important, as this demonstrates a mixed response by the older and more recently controlled hot spot. The temperature at Area UT05B8 did not respond at all to rainfall, indicating that the potential for re-ignition was no longer present. However UT06LW, only extinguished a few months before this rain event, did show a muted temperature increase to rainfall but quickly cooled down subsequent to the rainfall event.

- This response is typical of observations from FP operational staff (various pers comms) over the last 20 years that once a fire is successfully controlled it does not “re-ignite”. **Plate 1**, a recent photo of the mid 1990s test plot trial where a spontaneous combustion trial was undertaken, shows extensive erosion of the outer cover yet recent thermal imaging has not detected any self (re)heating in this waste rock dump (Flinders Power Mine Closure Plan October 2016).

- Verification on field visits undertaken by MWH staff to numerous locations where spontaneous combustion has previously occurred and subsequently extinguished. In all instances observed, and despite evidence of erosion of the cover re-exposing the previous hot spot, no re-heating to trigger spontaneous combustion has occurred (eg. **Plate 7**).

- Section 10.1 of the Leigh Creek Mine Closure Plan, October 2016 details many other locations and monitoring data from Lobe B to support these observations which have been verified with thermal imaging measurements.

To support the above data and observations, FP commissioned B3 Mining Services to undertake spon com testwork. FP supplied a total of 63 samples, from which 19 samples were selected for spon com testwork following initial screening to determine samples considered more susceptible to spon com. B3 Mining Services (2017) concluded the following from the testwork:

- Carbonaceous overburden rocks from Leigh Creek have a retained fuel load that is related to their Total Organic Carbon Content.

- Reactive pyrite is not present in the Leigh Creek carbonaceous rocks or coal.

- The intrinsic reactivity of the carbonaceous rocks is extremely low with almost all of the samples except one having R_{70} values lower than 0.20°C/h. It would require an external heat source to raise the temperature of the rocks above 100°C for the organic carbon to sustain self-heating.
- The presence of moisture in the samples moderates any self-heating and effectively eliminates any possibility of sustained self-heating at ambient mine temperatures.
- Past spontaneous combustion events in overburden at Leigh Creek have been initiated by the presence of fugitive coal from the mining process that has a high intrinsic reactivity. This feature decreases significantly with time and from the spontaneous combustion testing results obtained, would appear to be negligible after 5 years.

The reason for the significant decrease in spon com propensity over time is due largely to the weathering (or oxidation) of the waste rocks. Materials with a propensity to spontaneously combust are most likely to do so when first exposed through the mining process, as they are suddenly taken from a reducing environment to an oxidising environment through the mining process. Once exposed, all materials begin the weathering process. Hence as time passes, and materials begin to weather, they become less likely to combust or re-self heat.

From a cover perspective, stability is a function of the ability to control erosive forces. In the case of Leigh Creek, management of surface water, particularly at the top of the waste rock slopes is critical. **Plate 8** demonstrates a slope where the water control has not been effective across the entire length of the dump crest, and the erosion gully has formed at the weakest point.

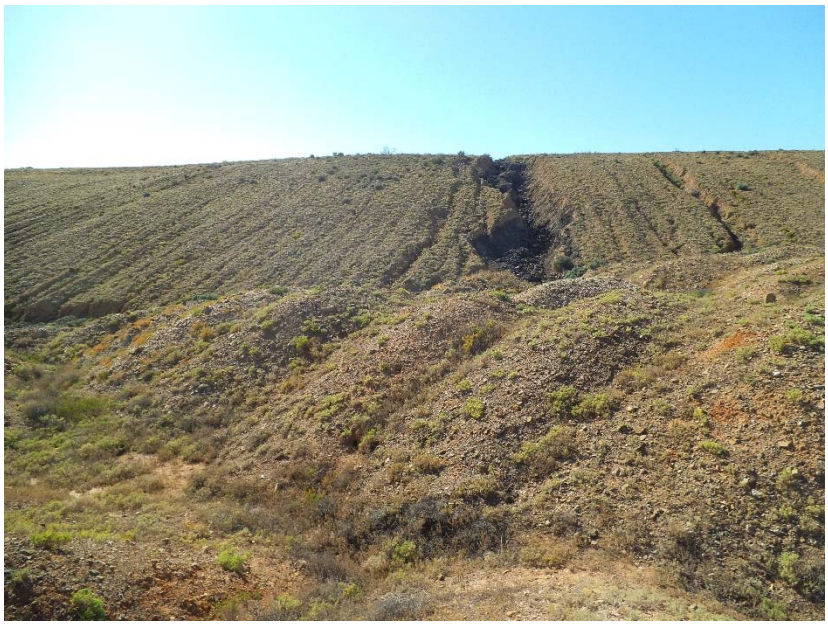

Plate 8. Erosion gully on rehabilitated slope

Plate 9. Covered and uncovered re-profiled waste rock dumps

Plate 10. Good surface water management at the crest of the waste rock dump

Contrast **Plate 8** with **Plate 10** (both surfaces are approximately 10 years old). The key difference is that sufficient surface water control is in place consistently across the entire crest of the dump in **Plate 10**, assisting in the preservation of the dump surface.

In 2011 these slopes were subject to an equivalent "1:100 year" rainfall event (MWH 2016d), providing further confidence that if the correct surface water management practices are implemented, the cover can withstand similar events. To assist in the longer term management and provide confidence on the longevity of a cover (e.g. effect of future 1:100 year events), erosion modelling (using WEPP) was undertaken by MWH (2016g Leigh Creek Erosion Modelling – Letter Report). It should be noted that the WEPP modelling results provide only a simplified prediction of potential sheet erosion from a homogenous surface and do not take into account the potential concentration of surface water and resulting rill / gully erosion. The results from the WEPP modelling concluded that:

- Annual soil loss derived from simplified sheet flow (e.g. cover material) would be in the order of 5 tonnes per hectare per year on a 1:3 slope (refer **Table 1**);
- Basis of modelling:
  - A rainfall event repeat as recorded at Leigh Creek from 1915 to 2015;
  - One metre thickness cover comprised greater than 60% clay and silt content;
  - Cross contour ripping to achieve surface roughness; and
  - Single, planar slope less than 40 metres vertical height.

Table 1 provides a summary of outcomes for WEPP modelling results from Angle of Repose, slope angle at constant 1:3 and slope angle at constant 1:4.5. The basic modelling results predict that if slopes are constructed as designed then the amount of cover loss derived from sheet flow over a 20 year period (using average rainfall inputs only) would be less than one metre.

Table 1: WEPP annual average erosion rates for three slope design scenarios

WEPP output	Scenario		
	Angle of Repose	1:3	1:4.5
Average annual precipitation (mm)	186	186	186
Average annual rainfall runoff (mm)	12.82	9.99	8.04
Average annual soil loss (kg/m^2)	0.50	0.49	0.32
Average annual sediment yield (t/ha)	5.03	4.87	3.20

As outlined in Sections 2 and 3, a substantial amount of data and information is available to FP for the successful mitigation of spon com post mining at Leigh Creek Lobe B. **Table 2** provides a summary of the key aspects applicable to mine closure planning of Lobe B.

Table 2: Summary of Key Aspects related to spon com for Leigh Creek mine closure

ASPECT / ISSUE	KNOWLEDGE	REFERENCE
Can waste rock located in the waste rock dumps spontaneously combust?	Rocks containing organic carbon and/or high sulphide content may possibly spon com, depending on a range of factors. Testwork has determined that low ranking coal present at Lobe B has a propensity for spon com. Testwork completed in 2016 determined that it was extremely unlikely that carbonaceous shale could spon com. B3 Mining Services determined that the most likely cause of spon com in waste rock dumps was fugitive coal that has a high intrinsic reactivity. As such, spon com occurring within the waste rock dump is likely to be isolated to these discrete areas.	B3 Mining Services 2014 & 2017
Does the orientation of the outer slope of a waste rock dump affect the potential for spon com?	Yes. The steeper the outer slope, the more likely that spon com can occur. Lower profile outer dump surfaces (ie. less than 20^0) are unlikely to allow spon com to occur as oxygen ingress is more difficult with a lower profile and less particle size segregation.	Carras et al (1994)
What cover (if any) should be placed over the waste rock dumps to prevent spon com? What type and thickness?	A cover of inert waste rock will significantly reduce the ability for spon com to occur. Fine, clay rich material is the most suitable as it will reduce the ability for oxygen and moisture ingress. By using a combination of reduced final waste dump slope angles (ie. less than 20^0) and fine, clay rich inert cover material (average combined clay and silt content greater than 60%), the thickness of cover recommended is 1 metre (compacted by placement). This approach is confirmed by field observations, where previous areas of spon com have been covered with waste material of a nominal 1 metre thickness. In every case this has been successful in extinguishing fires and preventing	Carras et al (2005) Cliff et al (2014) MWH (2016f) MWH (2017) Supported by field observations and data

	their re-occurrence.	
Could the exposed rocks in the pit high walls spontaneously combust post mining?	Highly unlikely. Whilst there is likely exposures of coal in the high walls (nominally far east and far west of main and lower series) the surface area exposed is extremely low and these materials have already been exposed for some years without evidence of spon com.	B3 Mining Services (2014) Supported by field observations and data
Can rainfall affect / re-ignite a burning area or create spon com?	Possible if untreated. A key variable of spon com is moisture content. Where controls are not in place (eg. covers) then rainfall can trigger spon com in freshly mined material. Recent testwork indicates that the propensity for spon com is greatly reduced after 5 years. Hence the ability for rainfall to trigger spon com in older materials is negligible.	FPP (2016) B3 Mining Services (2017) Supported by field observations and data
Does spon com potential reduce over time once as material has been mined?	Yes. It is known generally that once materials are exposed by the mining process they quickly begin to oxidise (weather). The oxidation process reduces the propensity for spon com. Recent testwork indicates that the propensity for spon com is greatly reduced after 5 years for Leigh Creek samples tested.	B3 Mining Services (2017) Supported by field observations and data
Can temperature changes (re)ignite waste rock material?	Unlikely. For materials with a high propensity for spon com, high, persistent temperatures have been suspected to trigger spon com. Testwork on Leigh Creek samples demonstrates that these materials are far less reactive than at other mines. There is no field observations to support that observed spon com may have from excessive solar heating.	Carras et al (1994) B3 Mining Services Supported by field observations and data
What is the best method to extinguish any fires?	The current procedures for employed at Leigh Creek LCC-HSSE-PHMP-008 Spontaneous Combustion Principal Hazard Management Plan have been extremely successful in extinguishing all spon com events and preventing re-ignition.	FPP (2016) Supported by field observations and data
How long will a cover last?	WEPP modelling indicates that a 1 metre cover (clay rich, compacted by placement) could last at least 20 years, depending on construction and based on average rainfall events. Field observations of waste rock dumps at Leigh Creek	MWH (2016g) Supported by field observations and data

	support this prediction, with the key threat to retention of cover integrity being the control of surface water runoff over slopes. This can be largely mitigated through effective bunding structures to minimise excess water flow onto slopes.	

4 Recommendations for Planning / Execution of Closure Activities

Both the Australian Coal Association Research Program (Day 2008) and the South African CoalTech Research Association (Phillips 2011) have undertaken recent updates to the best practices for spon com management in open cut coal mines. Additionally, the New South Wales Department of Industry and Investment in 2011 released an updated Mine Design Guideline (NSW 2011) that contains a comprehensive technical reference guide. These best practices have been developed through a combination of fundamental research undertaken to understand what causes spon com in coal mines and what methods are effective in managing and extinguishing spon com. Summarising key industry practices:

- In all cases, extinguishing a coal fire, spon com or hot spot can safely be effected in all cases by smothering with inert, fine material. The more extensive the smothering, the more effective the extinguishment. Correct application will vary from site to site, depending on the type of spon com and where it is located but generally consists of:
  - Placing inert material over the hotspot in order to reduce oxygen penetrating into the burning area. Minimum thickness is 1-2 metres for hot spots when a fine, clay rich inert material is used. Where inert, coarse material is to be used (e.g. sandstone) the cover thickness may need to be up to 10 metres.
  - The most effective method is to import the material into the area and doze up over the exposed outer face containing the heated area; as this will block off the oxygen pathways within the waste dump.
  - Ensure that the entire area (vertically and laterally) is covered. The more extensive the cover the more effective it will be in extinguishing the fire and prevention re-occurrence.
  - Extinguishing a sponcom fire using water should only be undertaken where there are exposed flames. Water is a catalyst to the chemical reactions occurring during sponcom hence the addition of water is more likely to prolong the burning period. Hence this practice can be hazardous and ineffective.

- Digging out a sponcom hot spot or fire can be an effective way of dispersing and cooling a heated area. However there is a greater risk in this technique that “opening up” a hot spot will increase the amount of oxygen available to the area and will most likely result in a “flare up” of the area. Again this practice creates a hazardous health and safety risk to machine operators and as such should only be undertaken where necessary and where there is no better access alternatives.
- Fires and hot-spots should be contained and extinguished as soon as detected in order to prevent the risk of re-occurrence.
- For spoil dumps, tip heads should be low to minimise the opportunity for particle size distribution down the rill slope as the material is emplaced. Tip heads should advance quickly to minimise the exposure of material on the outer surface. Dumps should be covered with inert material, outer wall angles should be reduced to the final angle and rehabilitation commence as soon as possible to reduce the risk of hot spots developing within completed dumps.
- Monitoring techniques such as thermal camera monitoring should be used routinely to detect for potential hotspots and to monitor the effectiveness of extinguished hotspots to determine that they have not re-heated.
- Spon com management plans, including specific operating procedures and full risk assessments should be developed for each site and updated for each situation (e.g. LCC-HSSE-PHMP-008). In some States this is now a statutory requirement for operation (e.g. NSW).

The Leigh Creek mine site has very similar settings to other coal mines worldwide in relation to spon com. Research work undertaken on Leigh Creek material (ETSA 1994, Beamish 2014, B3 Mining Services 2017) confirms that the self-heating properties of some of the Leigh Creek formations are analogous to the reactions and properties experienced at other sub-bituminous open cut coal mines elsewhere in Australia and globally. Comparing the current operational practices for managing spon com that are applied at Leigh Creek (Alinta Energy 2015) to industry practices (summarised in Section 4), there is good correlation; specifically that extinguishing hot spots with inert material is the most effective long term measure for extinguishing fires and cooling hot spots. Summarising the practices for Leigh Creek:

For pit walls:

- Mine the broken material back to hard face / limits and remove all this material for the pit. Mine out any excess broken material. Do not use carbonaceous material for building windrows, dividers or other earthen structures around the mine.
- To minimise a smouldering patch in the wall, firstly doze out the material to spread and cool the area. Remove broken material. Then track-roll the area to compact and cover with fine fraction material (ideally with high clay content) to minimise the ingress of oxygen. Track-roll the material again to increase compaction, then build up a mound of material over the area.

For waste dumps:

- Coal and carbonaceous material should be contained within the waste dump and covered as soon as possible to minimise oxidation potential.
- Build waste dumps in low lifts to minimise the segregation of material particle size that occurs on the tipping face.
- For existing dumps, batter down the slopes to their final angle as soon as practical – this will reduce the potential for convection pathways to be created within the dumps. Cover with material as soon as possible – ideally a fines dominated cover that contains clay. Waste dumps should be fully encapsulated.

Moisture / water control:

- Either totally saturated or totally dry conditions are best. Spon com is promoted where potentially combustible material is subject to constant wetting and drying.
- Ideally, storm water movement will be controlled in order to minimise erosion and gullying.
- Water movement over the batters of waste dumps or low-walls on pit voids should not be promoted, as this has the potential to create erosion and gullying.
- Bunds and other water control features should be placed on the crests of all batters and slopes (pit and dumps).
- Water should only be used on burning areas where flames are present.

4.1 Proposed Design Parameters – Waste Dumps (in-pit and external)

The parameters outlined in **Figure 4** consider coal industry leading practice for spon com management and the current Leigh Creek operations. Some of the key features are:

- As the Leigh Creek mine site has been prematurely closed, the ability for active waste dumps to be built with closure in mind is not available. Unexpected mine closure creates landforms that are partially built and, as such, considerable effort is required to achieve satisfactory outcomes and compromises are required.
- Reducing the angle of the dump batters reduces the ability for convection cells to be created within the dump. Convection cells can readily draw oxygen deep into the dump through the high angle of repose combined with the void spaces in the lower part of the dump.

- Re-battering by dozing from the top pushes finer material from the upper lift of the dump to the bottom, hence partially closing up void space in the part of the tip-head.
- Dumps higher than 40 metres are difficult to re-batter by dozing alone, and they also have a higher chance of creating convection cells through material segregation. Creating a lower lift "buttress" allows material to be trucked in and dumped, improving the quality of the cover spread and required thickness. Water control is also a key, hence an appropriate sized berm (nominal to contain a 1:100 year event) at this point will help to manage water movement, reduce erosion across the entire face and promote stability.
- The height of bunds should consistently be at least 1.5 metres to cater for high intensity rainfall events that will cause erosion.

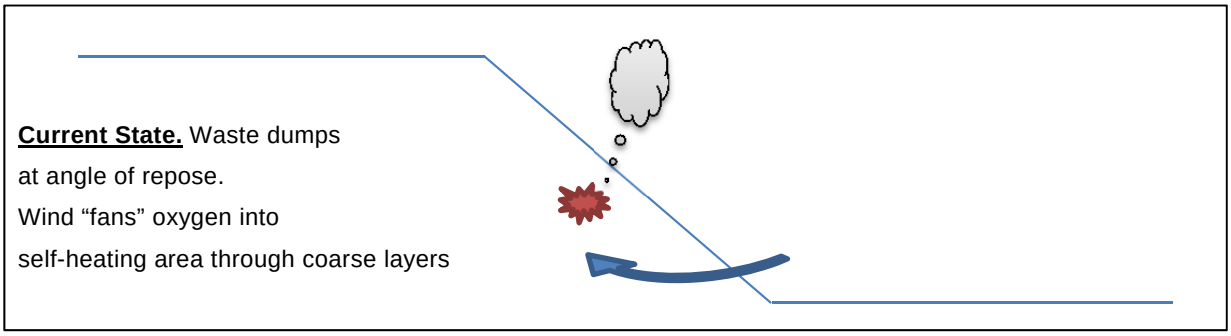

Figure 3: Schematic of how sponcom can form in waste dumps

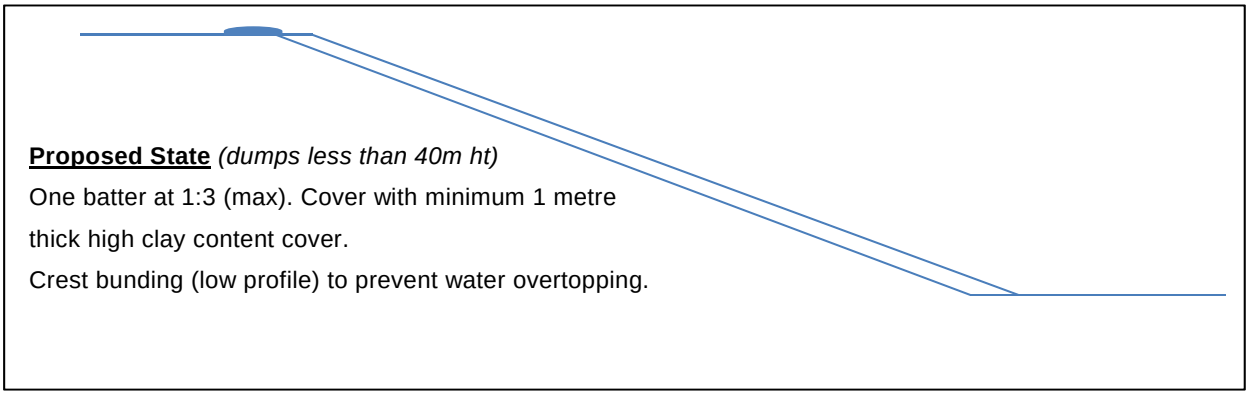

Figure 4: Conceptual Design Parameters for Leigh Creek waste dump sponcom management

A key question for mitigation of spon com post mining at Leigh Creek is the need for a cover on the outer waste dump slopes. Several key factors drive the determination of proposed thickness of a cover:

- Degree of reactivity of the inherent material within the dump. Hence, where there is no risk of spon com within a waste dump, then there is no need for a cover.
- Available material type: Coarse, blocky material is less suitable; finer, clay rich material is preferred.
- Angle of the dump outer slope: Where the angle is flatter, the purpose of a cover is more to manage moisture infiltration. For steeper slopes, the cover must minimise both oxygen and moisture infiltration. Hence for flatter slopes, a cover can be thinner.

The "ideal" cover material is loosely defined in public literature as "clay rich soils with high water retention characteristics" perform best (Carras et al (2005) and Cliff et al (2014)). Analysis of material characterisation results from Leigh Creek (MWH 2016f, MWH 2017) determined that "ideal fine, clay rich material" can be conservatively defined as material that:

- Is characterised as non-acid forming (NAF);
- Soil pH >6;
- Average of clay and silt fractions (minimum five samples) content greater than 60%; and
- Average of sand and coarser fractions (minimum five samples) content less than 40%.

Material satisfying this criteria can be used as a cover to a minimum thickness of one metre (post placement/compaction), refer **Table 2**. This is supported by field observations (MWH 2016b) where there are no observed areas of spon com at Leigh Creek where a cover of inert material has been placed on waste dumps.

Where material tested in the field is PAF, then this material shall not be used as a cover.

Based on previous and ongoing testwork, the material contained in "main series dragline" and "lower series dragline" stockpiles best meet this criteria. Volume calculations (Leigh Creek Mine Closure Plan, October 2016) have determined that there is sufficient volume of suitable cover stockpiled in the Main Series Dragline waste dumps alone to provide a one metre cover across the entire surface area of dumps to be rehabilitated. Based on the PSD analysis from the various spoil dumps available, presented in **Figure 5**, topsoil alone as a cover material would require a thicker application due to the higher sand content.

Recent and ongoing field and laboratory testing (MWH, 2017) of the materials being sourced for the purposes of covering the outer dump slopes is confirming the high clay content of the Main Series Dragline stockpile, making this material the most suitable available for use as an effective cover.

Importantly, there is the occasional occurrence of "black shale" within these stockpiles (**Plate 11**), that field testing has shown is potentially acid forming (PAF). Hence these easily observed "black shales" are not to be used for cover material.

Finally, for the cover to be most effective in aiding to mitigate spontaneous combustion, cover material should be placed as soon as possible after re-profiling. If topsoil is to be applied to the cover, this also should be done as soon as practicable after re-profiling. Track rolling (with a dozer) along the contour after these activities is encouraged to reduce the preferential flow of water down the slope of the outer dump surface.

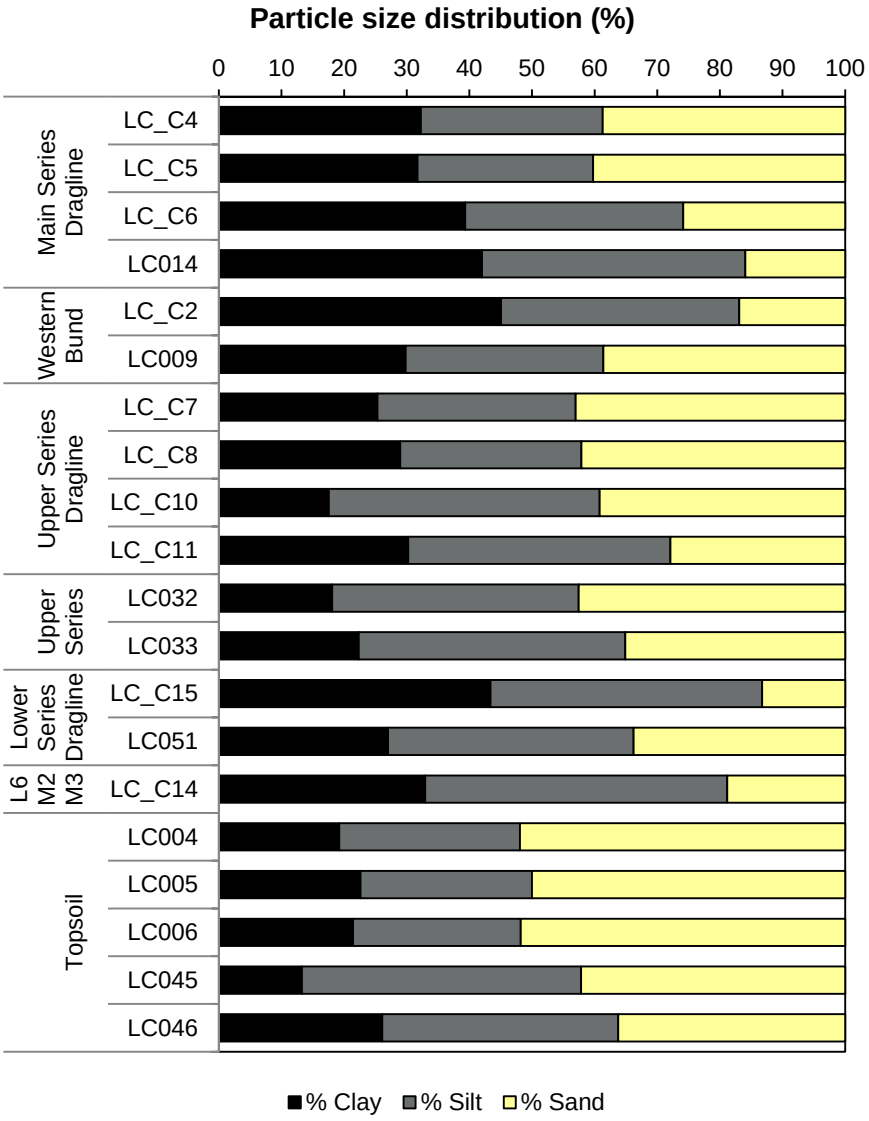

Figure 5: Particle size distribution of soil-sized fraction (<2 mm) of soil and waste samples (source: MWH 2016f)

Plate 11 – Main Series Dragline stockpile. Note black "stringer" of black shale in the face.

4.2 Design Implementation – In Pit Waste Dumps

4.2.1 Main Series Pit

There are two main areas for reshaping in the main pit; Terrace 21 and Terrace 15. Both of these areas contain partially completed infill dumping with slopes at angle of repose, hence they require dozing of the current slopes and emplacement of inert cover material.

Terrace 21 contains a deep area surrounded by fill and the south highwall. The height of the rill face is 80 metres. Based on the design parameters in Section 4, a mid-slope berm would be required. However there are two reasons to consider an alternative design:

- The toe of the rill slope is close to the south highwall, and
- It would be impractical to truck in fill onto a mid slope toe as the strike length of the area is less than 500 metres and would not provide space for a ramp.

Given these constraints, an alternate design is proposed. Summarising, the alternate design proposes that the northern, eastern and western faces are re-profiled flatter by dozing, then covered with inert, fine, clay rick oxide material sourced from one of the oxide dragline spoil dumps located north of the Main Series pit as indicated in **Figure 6**.

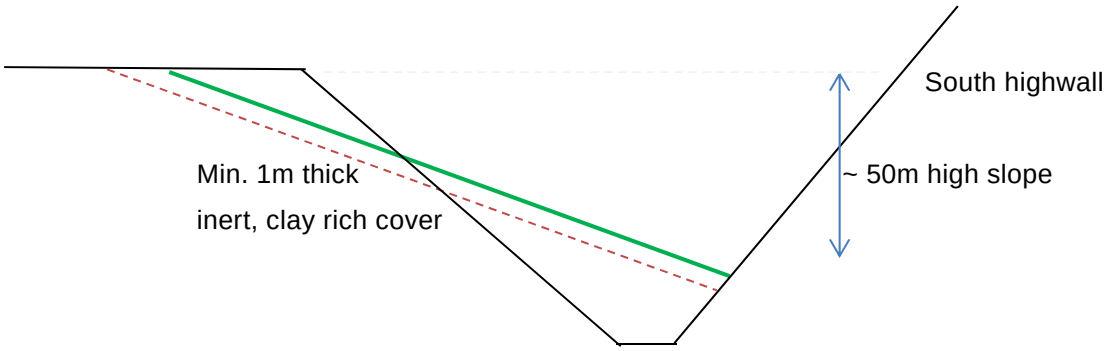

Figure 6: Terrace 21 concept rehabilitation

For Terrace 15, a more complex design may be required. **Figure 7** shows how the same modified design parameters used for Terrace 21 would be applied at Terrace 15. An 80 metre high face will be present on the eastern and western batter slopes, with the inert cover reaching a maximum thickness of 30 metres; this is would require nearly 5 million cubic metres of inert fill.

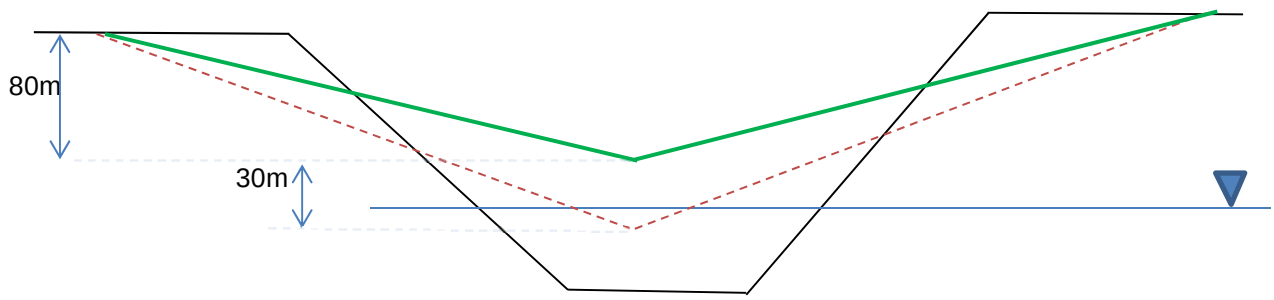

Figure 7: Design considerations as applied to Terrace 15

Consideration of the current pit lake is also required, as the design outlined in **Figure 7** would result in the final surface being approximately 20 metres above the current pit lake level. It is likely that the pit lake level will rise initially as fill material is dozed to the pit void, but to what RL is unknown.

In consultation with Leigh Creek Operations personnel, several alternate designs for Terrace 15 have been considered. A key design issue at this location involves the hazards associated with implementing a viable solution including:

- potentially battering down dump faces that have contained known hot spots for many months. This would create extremely hazardous conditions and ultimately slow the rehabilitation project down;
- extensive downhill haulage of waste fill material with DC type haul trucks is likely to lead to brake failure as these trucks are not designed to be used for hauling loads downhill; and
- tipping material and exposed working faces with a pit lake immediately below. This creates instability issues with the toe of the dump resulting in slumping.

Leigh Creek planning and operational staff have incorporated these design criteria into design plans that were submitted as part of the Leigh Creek Mine Closure Plan (FP 2016).

4.2.2 All other in-pit waste dumps

Modification of all other in-pit waste dumps (regardless of height) should be implemented as per the parameters outlined in Section 4.1.

4.3 Design Parameters – Pit Walls

There are two aspects to pit wall treatment for spon com at Leigh Creek, how to treat exposed pit walls at the western and eastern ends of the pits (where a high wall of "across-dip" exposure will be left) and how to treat current (and future) hot spots on pit walls.

Plate 12: Across strike, Upper Series

Plate 13: Upper Series Low wall (right)

4.3.1 Across Strike Exposures

The recommended approach for the treatment of spon com in across strike exposures is to:

- Dig out all free / loose material on berms and batters.
- Monitor the temperature of the faces with the thermal camera. Prepare remedial action if temperatures rise above 70^{0}C, implement remedial action if temperature exceeds 75^{0}C.
- Eliminate water flowing over the surface from the crest of these faces by controlling the water at the top of the wall.

4.3.2 Other Exposed Final Pit Walls

Spon com historically occurs on the low-wall exposures of both Main Series Pit and Upper Series Pit for a number of reasons including:

- Clean-up of loose material has not been undertaken, resulting in susceptible material being exposed beyond critical mass limits and subsequent spon com.

- Batter-scale wall failures (mostly in Main Series Pit) results in cracking and breakup of low-wall material. This allows moisture and oxygen to enter, resulting in spon com.
- Erosion, gullying of the low wall due to rainfall and subsequent runoff. This not only generates fresh exposures of potentially combustible material but the wetting and drying process also promotes combustion.

Recommended practices for minimising spon com on the low walls (both main and upper series pits) include:

- Dig out all free / loose material on berms and batters.
- Monitor walls with thermal imaging camera.
- Eliminate water flowing over the surface from the crest of these faces by controlling the water at the top of the wall.
- In the event of a suspected hot-spot, implement existing practices as per LCC-HSSE-PHMP-008.

4.4 Water Control

The movement of water promotes erosion, the potential for AMD and offsite discharges. The wetting and drying of material susceptible to combustion is a known catalyst of spon com. Hence the objective for mine closure at Leigh Creek mine site should be to minimise uncontrolled water movement.

The climate at Leigh Creek is semi-arid with less than 200 mm annual average rainfall and over 3,000 mm of evaporation annually. It is well documented that for locations where evaporation exceeds rainfall by a factor of 10, then “store and release” water control techniques work particularly well. These include:

- “Paddock dumping” out flat, sloping areas that are no longer in use. Where flat, compacted surfaces are tightly covered with paddock dumped, inert material the resulting cover will act as a “sponge”. Rainfall will hit the loosely dumped material and be consumed within the pore space. Water will then be evaporated before being able to migrate further to the point of creating runoff. This practice has been well researched in the Pilbara since the mid-1990s and successfully tested in 1:100 year flood events. Paddock dumping with inert material should be undertaken on pit haul ramps and consideration given to using this on the batter side of ramps to reduce the surface area of flows.
- Bunding and cross bunding. For very extensive flat areas such as the top of waste dumps, paddock dumping can be prohibitive. An alternative is to use substantial bunds around all crests (including berms) and cross bunds. An example of effective surface bunding is shown in **Plate 14**.

Plate 14: Example of effective bund configuration on top of waste landform

5 Further Work and Monitoring

Thermal temperature monitoring that has been ongoing at Leigh Creek is critical to the ongoing monitoring of suspected areas of self-heating to determine effectiveness.

Currently FP is proposing to undertake regular monitoring of rehabilitation performance using drone-based LiDAR equipment. MWH is familiar with adopting LiDAR methodology for monitoring the performance, stability and erodibility of surfaces such as waste rock dump slopes and encourages this technique as it will provide a comprehensive, 3-D coverage over entire dump slopes, as opposed to point measurements (1 dimensional) that can be achieved from pin measurements.

MWH also supports the concept of a trial area dedicated to instrumentation to demonstrate the effectiveness of the cover. An area “western bund” is agreed to be the ideal location for this monitoring to be established and should include temperature, oxygen and moisture monitoring points. The details of this instrumentation installation are the subject of another study commissioned by FP.

MWH is aware that the following work continues to be undertaken that will further assist and support the rehabilitation efforts at Leigh Creek including:

- Compaction and permeability testing to be undertaken by Coffey Consulting;
- Further assessment of existing erosion parameters of waste landforms on site; and
- Ongoing, regular field testing of materials for use in covers to determine their suitability.

The availability of this information will be valuable information to further support the current rehabilitation approaches to Leigh Creek as described in the Leigh Creek Mine Closure Plan (FP, October 2016).

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