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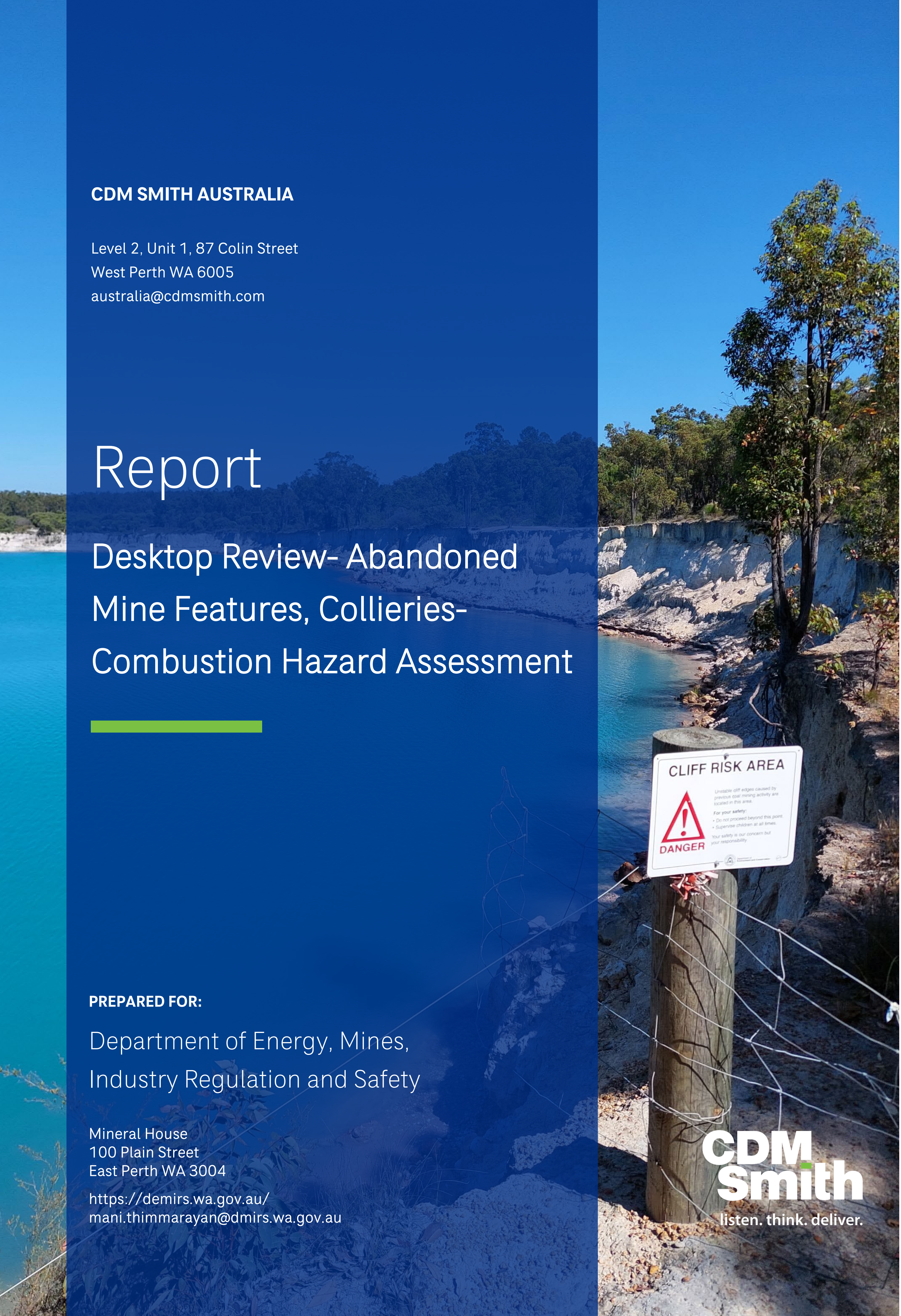
Report

Desktop Review- Abandoned Mine Features, Collieries- Combustion Hazard Assessment



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Executive Summary

The Collie Basin located approximately 160 km south- southeast of Perth in the southwest of Western Australia, has been mined for coal since the late 19th century. Mine waste materials inferred to contain carbonaceous shale and coal have been observed in the region, as a result of mining activities.

Coal and carbonaceous shales are combustible and could have the propensity for self-heating to ignition, in-situ (i.e. within mines), or when exposed at the surface. Historic mining activities could have resulted in the presence of some carbonaceous materials (e.g., carbonaceous shale, coal and coal reject materials) either in stockpiles or spread across the surface. Bushfires in the region have been reported to be difficult to control. The extent to which these mine waste materials present a combustion hazard and or pose an increased fire hazard, is unknown.

The Department of Energy, Mines, Industry Regulation and Safety (DEMIRS) have commissioned CDM Smith Australia Pty Ltd (CDM Smith), as part of the Abandoned Mines Program (AMP), to undertake a two-part investigation process. The first part (separable portion H1A) is to improve the understanding of combustion hazard from abandoned mine waste material and (if practicable) reduce/manage the risk of ignition of fires and potential exacerbation of bushfires from these materials. This is to be followed in part two by a site investigation (separable portion H1B) which involves site investigation, analysis of samples and reporting for three (3) target assessment areas, Moira Colliery, Stockton Colliery and Scottish Colliery. The desktop review and site investigation information will be used to develop a preferred remedial option in collaboration with DEMIRS to mitigate the potential for spontaneous combustion posed by these mine waste material / stockpile areas. This desktop review report forms separable portion H1A.

The objectives of this assessment are to:

- Briefly document the Collie coal mining history in manner that provides context for the possible sources of carbonaceous materials that may exacerbate bushfires in the region.
- Improve the understanding of the physical and chemical characteristics of the mined waste materials that may have been placed at the surface to help understand the propensity of these materials to present a combustion hazard.
- Undertake a preliminary assessment of available information in relation to the distribution of mine waste materials within the area of interest that may contain carbonaceous or reactive carbonaceous materials.
- Support identification of areas for future, targeted site investigation.
- Provide a preliminary summary of options for remediation and hazard reduction of near surface and combustible carbonaceous materials.

Key findings from this desktop assessment are:

- The presence of carbonaceous materials in the natural soils or spread across the surface, may exacerbate fires in the area if they are found to contain reactive pyrite and/or carbonaceous material of sufficient calorific value, mass and extent.
- There was no observed correlation between areas inferred to be ‘hot ash’ and the underlying geology. Anecdotal information suggests the ‘hot ash’ areas are associated with historical mine wastes (dumping/stockpiling).
- No naturally occurring outcrops of carbonaceous material or coal were observed during the preliminary site visit. This is consistent with:
  - the geology which indicates that unconsolidated gravels, sands, silts and clays of the Nakina formation overly the Permian coal and carbonaceous shale units
  - the history which indicates that Collie coal was first identified in the banks of the deeply incised Collie River.

  However, given the significant mining disturbance in the area and intra-basinal faulting of the basin, it is possible that there is outcropping of carbonaceous material and/or coal present within the assessment area. Of note, the depth of mining at Scottish Colliery was as shallow as 5 m and a drilling program conducted by the Minerals and Energy Research Institute of Western Australia identified a 1.5 m thick coal seam at a depth of 8.2m at Moira Colliery.
- Literature suggests that stockpiled coal and carbonaceous shales can have the propensity for self-heating to ignition (i.e. spontaneously combust). This review did not identify evidence to suggest spontaneous combustion of historical mine waste stockpiles has occurred in recent times. However historic records suggest that spontaneous combustion may have occurred during mining operations. Also, evidence of higher ground

temperatures compared to adjacent ground and/or air temperatures were identified at one location each, in the Stockton and Scottish collieries target investigation areas. At Scottish Colliery, the location also indicated the presence of a sulfur-like encrustation. These features are characteristic of thermal heating due to oxidation of reactive pyrite that may occur in coals or carbonaceous shales.

- During the site inspection, the presence of stockpiles or 'hot ash' areas were not found to correlate with higher temperatures compared to surrounding ground and/or air temperatures, however coal and carbonaceous shale like material was observed across several locations.
- The most likely effective remedial options will depend on the pyrite content and calorific value of the material but could include in situ clay capping and revegetation to minimise erosion of the capping, placement in an engineered repository, or blending of carbonaceous material with soils to reduce fuel loads and self-heating potential and in combination with either of the prior options.

These findings supported the conceptual understanding that:

- Due to the long history and reworking of the land, the in-situ waste materials and stockpiles could be highly variable in composition, comprising natural near surface Cretaceous era soils of the Nakina formation, coal fragments and fines, coal rejects, carbonaceous shales and other interburden sediments.
- The Department of Biodiversity, Conservation and Attractions(DBCA) observations that bushfires in 'hot ash' areas appear to burn hotter and longer may be an indication of the presence of carbonaceous shale or mine waste materials containing coal fragments of sufficient calorific to combust in the presence of a bushfires. The review has indicated that:
  - Carbonaceous materials, if present at surface are most likely to be waste materials from the mining activities rather than naturally occurring.
  - The carbonaceous materials could comprise carbonaceous shale from inter-seam sediments, coal fines or other coal containing waste such as coal rejects.
  - The coal or carbonaceous shale could be reactive, i.e., contain pyrite or similar reactive minerals such as marcasite.
- The presence of a coal and carbonaceous material fuel load could also contribute to the increased length of time and temperature at which these materials burn. The spreading of combustion within mine waste stockpiles or in near surface soils, particularly after the above ground fire is extinguished, would also be controlled by the connectivity of materials that have sufficient mass and calorific value. In other words, laterally connected layers of combustible materials could continue to burn and spread in the near surface soils. The more extensive and continuous the combustible carbonaceous materials are in the ground the more capability for the fires to spread in the ground and the greater the difficulty to put out the inground fire.
- Mine waste materials may have been pushed out in layers during mine operations and over time which would increase the potential for this connectivity to occur in the Collie area.
- In addition, if materials with carbonaceous content of sufficient thickness and calorific value become ignited, then the combustion could transmit downward making it more difficult to extinguish and potentially create voids. The presence of crust over the void into which the firefighter fell may relate to the formation of sulfur encrustations or white hydrated irons sulfates at the surface that can occur as a result of subsurface heating or combustion of carbonaceous material.
- The higher temperatures may also be related to the presence of reactive pyrite in the carbonaceous materials which could act as an accelerant. This would be influenced by the dimensions of the carbonaceous waste material, as the volume of material relates to heat production while the area across which the material is spread affects heat loss. Therefore, with sufficient volume, self-heating capacity and presence of reactive pyrite, hotter temperatures may be reached. Some of this material may have the chemical properties and mass within the waste materials such that the material could self-heat to ignition. However, it is important to note that DBCA has not indicated that recent bushfires are a result of this.

Based on this desktop assessment, it is recommended that a field program is undertaken to collect and analyse a selection of mine waste materials in the proximity of the target assessment area. The program would help to develop the understanding of combustibility hazard for areas of mine waste materials or stockpiles containing coal or carbonaceous shale materials. At this stage it is suggested that a targeted field investigation is conducted at first to gather initial information in relation to the composition of mine waste materials in stockpiles or spread across the surface. This program should be focussed on collecting basic characterisation data in relation to the combustibility of the mine waste materials.

This data could then be used in combination with the desktop information to inform future investigations to understand potential extents and volumes of hazardous carbonaceous materials and develop a preferred option for remediation.

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Document history & status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
0	19 December 2024	Dr Hannah Mikkonen	Dr Hannah Mikkonen		DRAFT
1	5 February 2025	Jonathan Medd	Jonathan Medd	5 February 2025	Final
2	4 April 2025	Jonathan Medd	Jonathan Medd	4 April 2025	Final

Distribution of copies

Version	Date issued	Quantity	Electronic	Issued to
0-DRAFT	19 December 2024	1	1	Ludovic Renel (DEMIR)
1-Final	5 February 2025	1	1	Ludovic Renel (DEMIR)
2-Final	4 April 2025	1	1	Ludovic Renel (DEMIR)

Last Saved:	4 April 2025
File Name:	1001872-002-R-Desktop Report-Rev2
Author:	Dr Candan U. Desem / Jonathan Medd
Project Manager:	Haydn Davies
Client:	Department of Energy, Mines, Industry Regulation and Safety
Document Title:	**Desktop Review- Abandoned Mine Features, Collieries-Combustion Hazard Assessment**
Document Version:	2 Final
Project Number:	1001872

Section 1 Introduction

The Collie Basin located approximately 160 km south- southeast of Perth in the southwest of Western Australia, has been mined for coal since the late 19th century. Mine waste materials inferred to contain carbonaceous shale and coal have been observed in the region, as a result of mining activities.

Coal and carbonaceous shales are combustible and can have the propensity for self-heating to ignition, in-situ, (i.e. within mines), or when exposed at the surface (Chalmers et al., 2012; IEA Clean Coal Centre, 2015). Historic mining activities could have resulted in the presence of some carbonaceous materials (e.g., carbonaceous shale, coal and coal reject materials) either in stockpiles or spread across the surface. Bushfires in the region have been reported to be difficult to control (DEMIRS24701 RFQ, August 2024). The extent to which these mine waste materials present a combustion hazard and or pose an increased fire hazard, is unknown.

The Department of Energy, Mines, Industry Regulation and Safety (DEMIRS) have commissioned CDM Smith Australia Pty Ltd (CDM Smith), as part of the Abandoned Mines Program (AMP), to undertake a two-part investigation process in which the first part (separable portion H1A) is to improve the understanding of combustion hazard from abandoned mine waste material and (if practicable) reduce/manage the risk of ignition of fires and potential exacerbation of bushfires. This is to be followed in part two by a site investigation (separable portion H1B) which involves site investigation, analysis of samples and reporting for three (3) target assessment areas, Moira Colliery, Stockton Colliery and Scottish Colliery. The desktop review and site investigation information will be used to develop a preferred remedial option in collaboration with DEMIRS to mitigate the potential for spontaneous combustion posed by these mine waste material / stockpile areas. This desktop review report forms separable portion H1A.

1.1 Definitions

For consistency and clarity throughout the report the following terms have been adopted:

- **Mine waste material** – Soil or rock material resulting from excavation and surface placement of mine overburden, mine inter-seam sediment or other mine waste materials. The mine waste material may contain carbonaceous shale, ash and coal fragments.
- **Carbonaceous materials** – Materials including mine waste materials that contain coal or sedimentary materials such as carbonaceous shales which have a relatively high carbon or 'coal' content.
- **Reactive carbonaceous shale / materials** - Shale rock or other mine waste materials that contain significant amounts of organic carbon and other reactive minerals, such as pyrite. These materials have the potential to self-heat to ignition, also referred to as 'spontaneous combustion'.
- **'Hot ash' locations -** These are locations identified by the Department of Biodiversity, Conservation and Attractions (DBCA) within or near to the investigation area of interest. The nature of mine waste material at the 'hot ash' locations is unclear but may comprise, or have previously comprised, carbonaceous materials or reactive carbonaceous shale.

These terms are used unless required otherwise required when referencing specific literature, emphasising a specific point or summarising information provided through interview of DBCA personnel.

1.2 Background

Since mining commenced, at least 26 documented collieries have ceased operation in the Collie region (MERIWA 1995). Mining methods have included underground and opencut, with many deep and shallow workings of historic mines remaining in the area. Open-cut mining in the Collie basin did not commence until 1943, with the first operation at Stockton. Prior to then, coal mining in the basin was by underground methods (Stedman, 1988). Closure and remediation/rehabilitation of collieries has occurred to varied extent. Prior to the introduction of the Collie Coal Agreement Acts in 1979, no standardised rehabilitation practises were implemented. This potentially resulted in mine waste material being 'dumped' in a manner that may have resulted in carbonaceous materials remaining at or near surface (refer Section 3.1). Subsidence, associated with historical mines, has occurred in the area (Goldsmith et al. 1995).

Areas, colloquially referred to as 'hot ash' locations, have been observed at the ground surface (DEMIRS24701 RFQ, August 2024). It is unclear whether these areas of 'hot ash' are related to the historic mining in the area or are expressions of the natural geology of the region. The extent to which these 'hot ash' materials present an increased combustion hazard is not well understood.

The DBCA have reported that bushfires have occurred in the Collie region that are hotter burning, and more difficult to control when compared to other bushfires. These are understood to be referred to as 'hot ash' fires. The most recent of these fires occurred in the area of the former Moira and Stockton collieries. The fires are also suspected to occur in the shallow subsurface soils and have resulted in injury to firefighting personnel in the region. The most recent reported incident injury was in October 2022 at the Western No. 6 colliery site where a DBCA officer involved in firefighting activities dropped into a pocket of burning material, resulting in injuries requiring hospitalisation. The safety risk associated with these types of fires has caused this issue to be prioritised for investigation by the Abandoned Mines Program (AMP).

Observations from these fire events and incidents have led to the proposition by DBCA that the fires may be associated with reactive carbonaceous shale either naturally occurring at the surface or brought to the surface during mining activities. However, the actual occurrence or description of the material that causes the 'hot ash' fires is not known. This has led to broadening of the desktop review to consider the history of coal mining and include the possibility that waste coal in stockpiles or near surface soils could also be a contributor to the 'difficult to control' bushfires.

1.3 Objective of assessment

The objectives of this desktop assessment are to:

- Briefly document the Collie coal mining history in manner that provides context for the possible sources of carbonaceous materials that may exacerbate bushfires in the region.
- Improve the understanding of the physical and chemical characteristics of the mined waste materials that may have been placed at the surface to help understand the propensity of these materials to present a combustion hazard.
- Undertake a preliminary assessment of available information in relation to the distribution of mine waste materials within the area of interest (as defined in Figure 1-1) that may contain carbonaceous or reactive carbonaceous materials.
- Support identification of areas for future, targeted site investigation.
- Provide a preliminary summary of options for remediation and hazard reduction of near surface and combustible carbonaceous materials.

This desktop assessment is based on an evaluation of applicable literature, publicly available reports, geological mapping, known occurrence of coal deposits, thermal imaging (drone survey), and a site visit.

Subsequent stages of work are proposed to:

- Conduct field investigation assessment of target areas to improve the understanding of the nature of the mine waste materials and their potential for combustion.
- Evaluate and recommend potential remedial/management solutions.

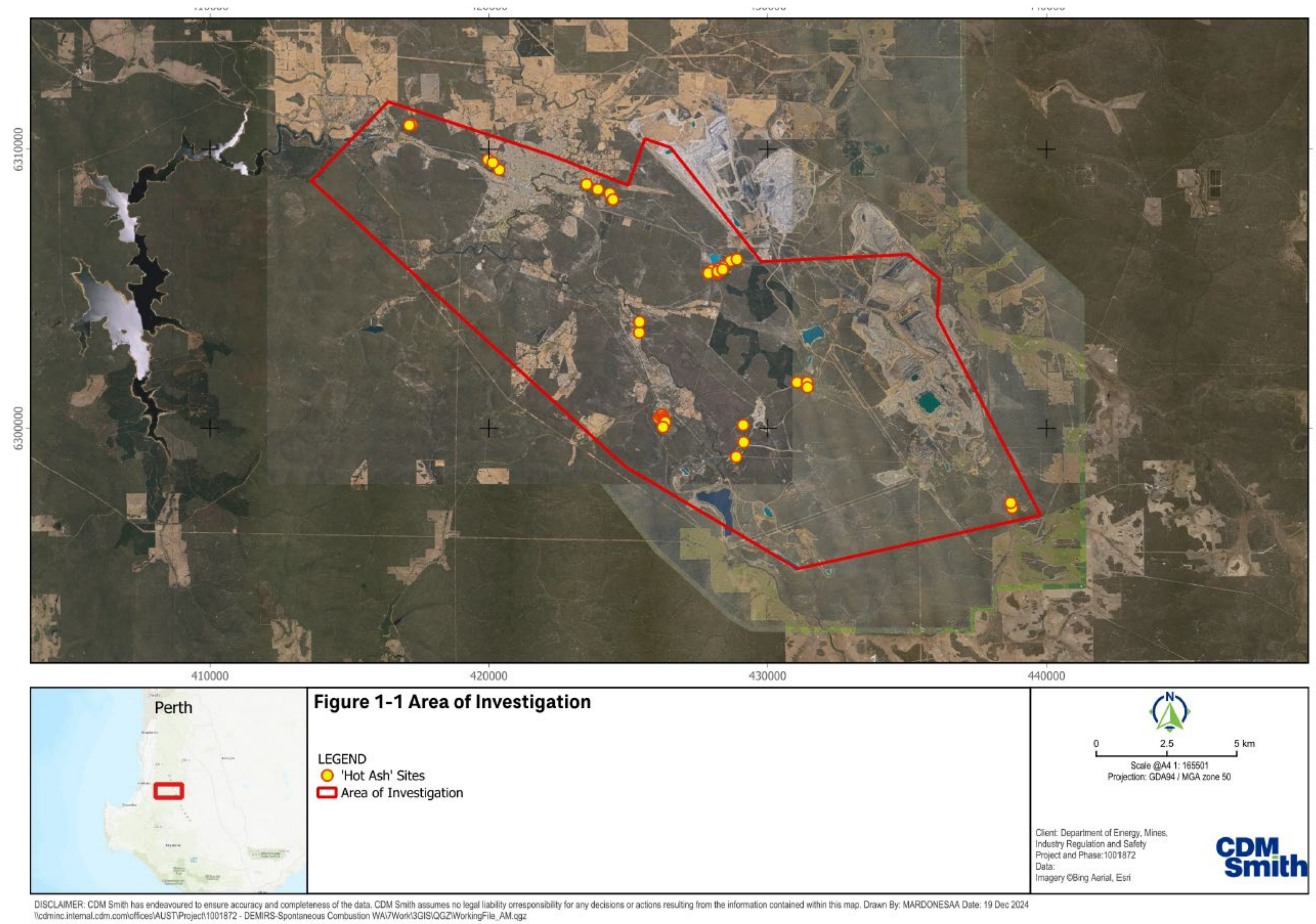

Figure 1-1 – Desktop Area of Interest from DEMIRS24701 RFQ, August 2024, with indicative locations of DBCA reported 'hot ash' sites.

1.4 Scope

This desktop review included the following.

- Literature review including:
  - Historical reports and data made available by DEMIRS (DBCA_HotAshSite.shp, Goldsmith et al., 1995; historic_collieries_gsd.shp).
  - Publicly available reports relating to the collieries and reactive carbonaceous shale fire issues in the Collie Basin (Carras et al., 2005; Chalmers et al., 2012; DNRM, 2015; Sasaki et al., 2014; Sloss, 2015; Smith, 1993; Stedman, 1988).
  - The Australian National Hydrocarbon Geochemistry Data Collection under Organic Geochemistry in the Geoscience Australia Portal, along with the Organic Geochemistry Database. Relevant data types include TOC (Total Organic Carbon), Rock-Eval pyrolysis, and organic matter reflectance, which are useful for identifying similar rock types, such as carbonaceous shales.
  - Review of geological data available from the Western Australia Geological Survey.
  - Australian Coal Association Research Program (ACARP).
  - Premier Coal publicly available data.
  - Historical data from other areas of carbonaceous shales/coal deposits within Australia (as provided by B3 Mining services).
  - Publicly available surface temperature data available from Landsat 8 data (30m resolution) from NASA Landsat Science.
- Site visit
  - Site visits were conducted on the 28th of November and 12th of December 2024 of areas outlined as targeted assessment sites to support the desktop observations.
  - The purpose of the site walkover was to plan for the field assessment including gaining an understanding of access, safety and logistics for performance of the site investigation. During the field inspection a handheld infrared thermometer was used to provide a preliminary indication of potential areas of increased heat/reactivity.
- Interview with personnel from the Department of Biodiversity, Conservation and Attractions (DBCA) on 14th November 2024 and 12th December 2024. The purpose of the interviews was to discuss DBCA's experience attending to fires at inferred 'hot ash' locations and where possible gather additional information relating to location, suspected extent of hazardous material as well as the fire temperature, duration, amount of water and whether additives were used.
- Drone Survey. A drone survey was conducted on the 28 – 29th November 2024. The drone survey included collection of thermal and digital elevation modelling (DEM) imaging information from three target assessment areas (based on assessment areas provided by DEMIRS, refer Section 1.5).

1.5 Targeted Assessment Areas for further investigation

The target assessment areas defined by DEMIRS are described below.

1.5.1 Moira Colliery

The Moira Colliery is located approximately 400 metres northwest of Collie and is the closest colliery to the town of Collie. The Moira Colliery ceased operations in 1901 due to it becoming unprofitable. Exploration continued however only areas adjacent to the exploration became exploited. It was not until another fifty years later that renewed interest and exploration of the Moira Colliery returned (Smith, G.L.B., 1993).

The target assessment area and proximal location of known ‘hot ash’, site is illustrated in Figure 1-2.

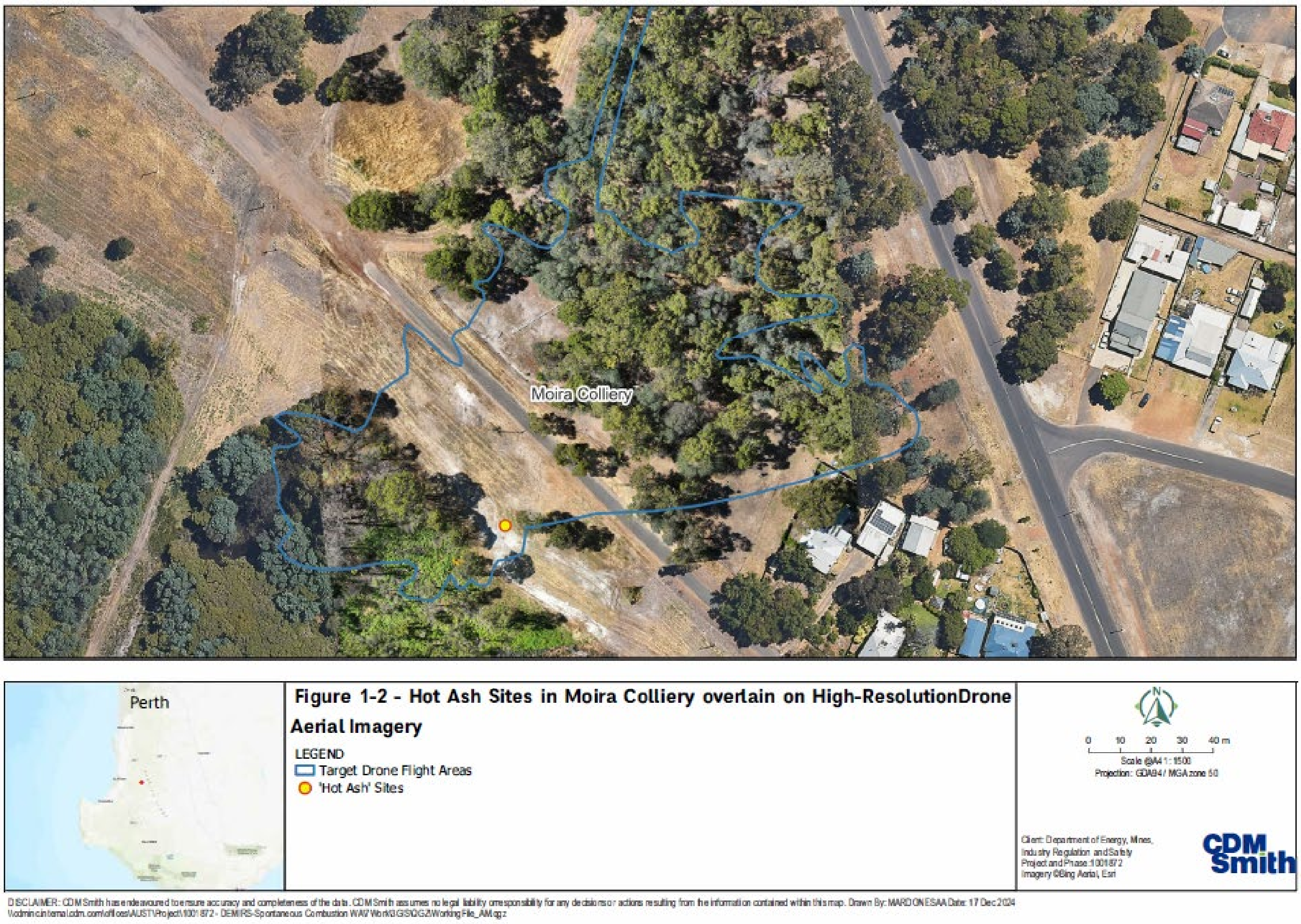

Figure 1-2 – ‘Hot ash’ locations at Moira Colliery overlain on high-resolution drone aerial imagery

1.5.2 Scottish Colliery

Located approximately 5.5 kilometres southeast of Collie, the Scottish Colliery (Collie Burn) opened in 1903. A fire in 1905 destroyed the mine, but it was finally brought under control without any serious effect on production. Water flooded the mine in 1915, which caused a shut down for several months. In 1916, operations were again suspended due to further uncontrollable water inflows and breakdowns of pumping equipment. The company resumed work by opening a new entry; however, the roof and floor of the seam were unstable. Recoverable coal was limited from this tunnel, and the mine finally closed in 1920 when it was taken over by Amalgamated Collieries (Stedman, 1988). During its history the mine produced 513,109 tons of coal.

The target assessment area and proximal location of known 'hot ash' sites is illustrated in Figure 1-3.

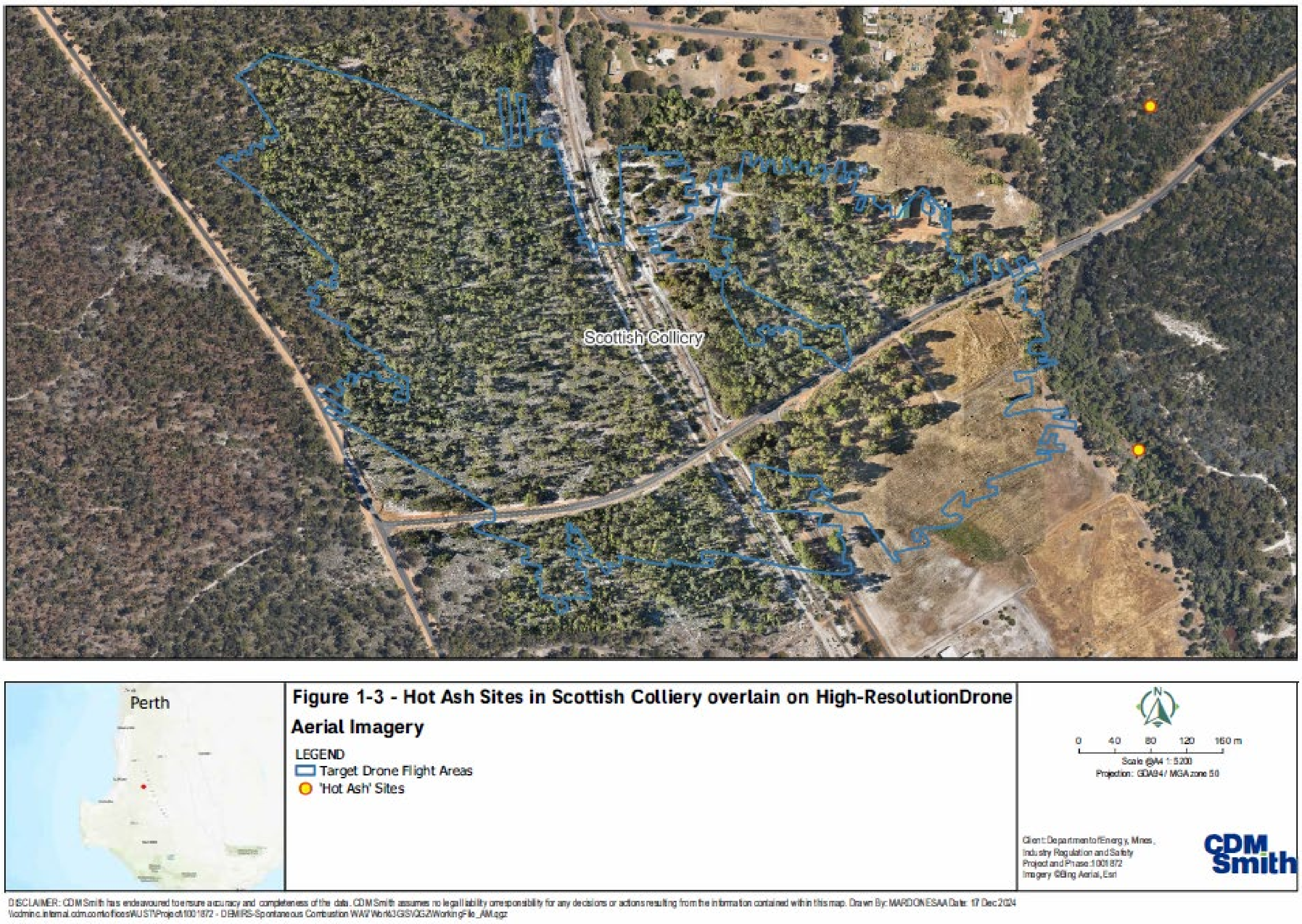

Figure 1-3 – 'Hot ash' location at Scottish Colliery overlain on high-resolution drone aerial imagery

1.5.3 Stockton Colliery

Stockton Colliery opened in 1927. The original tunnels to enter the coal seam were hand worked by pick and shovel well before the development of modern earth-moving equipment. A pit pony provided the power for haulage of coal to the surface. Ventilation shafts were sunk by windlass and lined with local timber. The mine continued as a reliable producer during the depression and into the war years. Water problems were not as serious to what was encountered at most other mines. The mine continued to operate until closure in 1960. It produced 2,750,806 tons of coal. The Stockton open-cut operation commenced from 1943. During the later years of the mine's operation, underground workers entered the mine through the worked open-cut area as a means to reduce travel time (Stedman, 1988).

The target assessment area and proximal location of known 'hot ash' sites are illustrated in Figure 1-4.

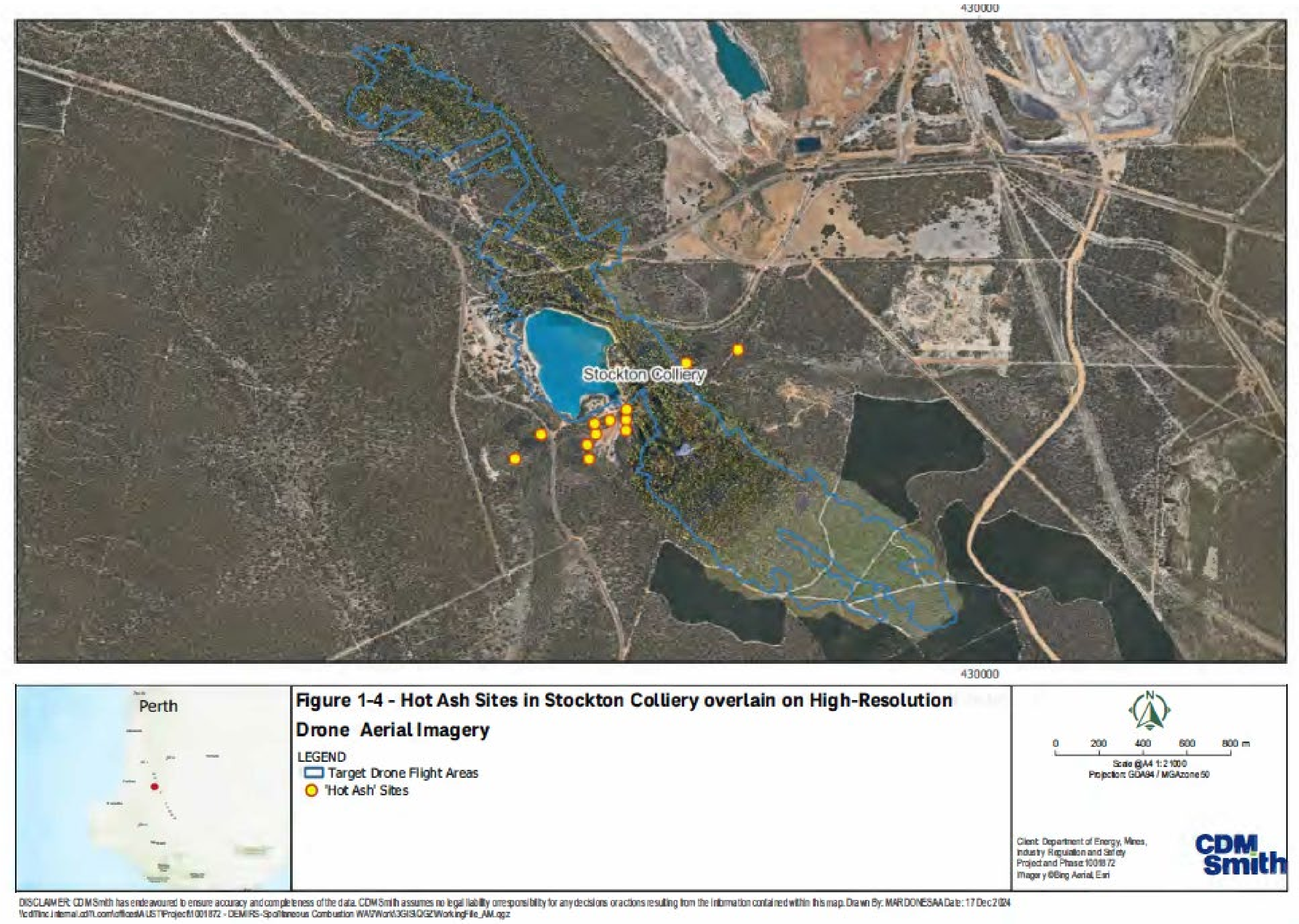

Figure 1-4 – 'Hot ash' locations at Stockton Colliery overlain on high-resolution drone aerial imagery

Section 2 Setting

The environmental setting is described in the table below.

Table 2-1 Desktop Area of Interest - Details Summary

Item	Description
Desktop Area of Interest Location	Collie Basin is located in Western Australia, approximately 160 km south of Perth and 60 km east of Bunbury. The desktop assessment area *(Figure 1.1) is approximately 25,353 Ha.
Municipality	Shire of Collie
Local Scheme Reserves and/or Zones (see Figure 2-1)	Local Scheme Reserves: - State Forest - Public Open Space - Environmental Conservation Zone Local Scheme Zones: - Rural - Rural Residential - Residential
General Site Description and Land Use (see Figure 2-1)	The area of interest has mixed land uses including: - Residential - Commercial - Industrial - Mining - State Forest - Rural - Agriculture - Recreational

The environmental setting at and surrounding the site is outlined below in Table 2-2.

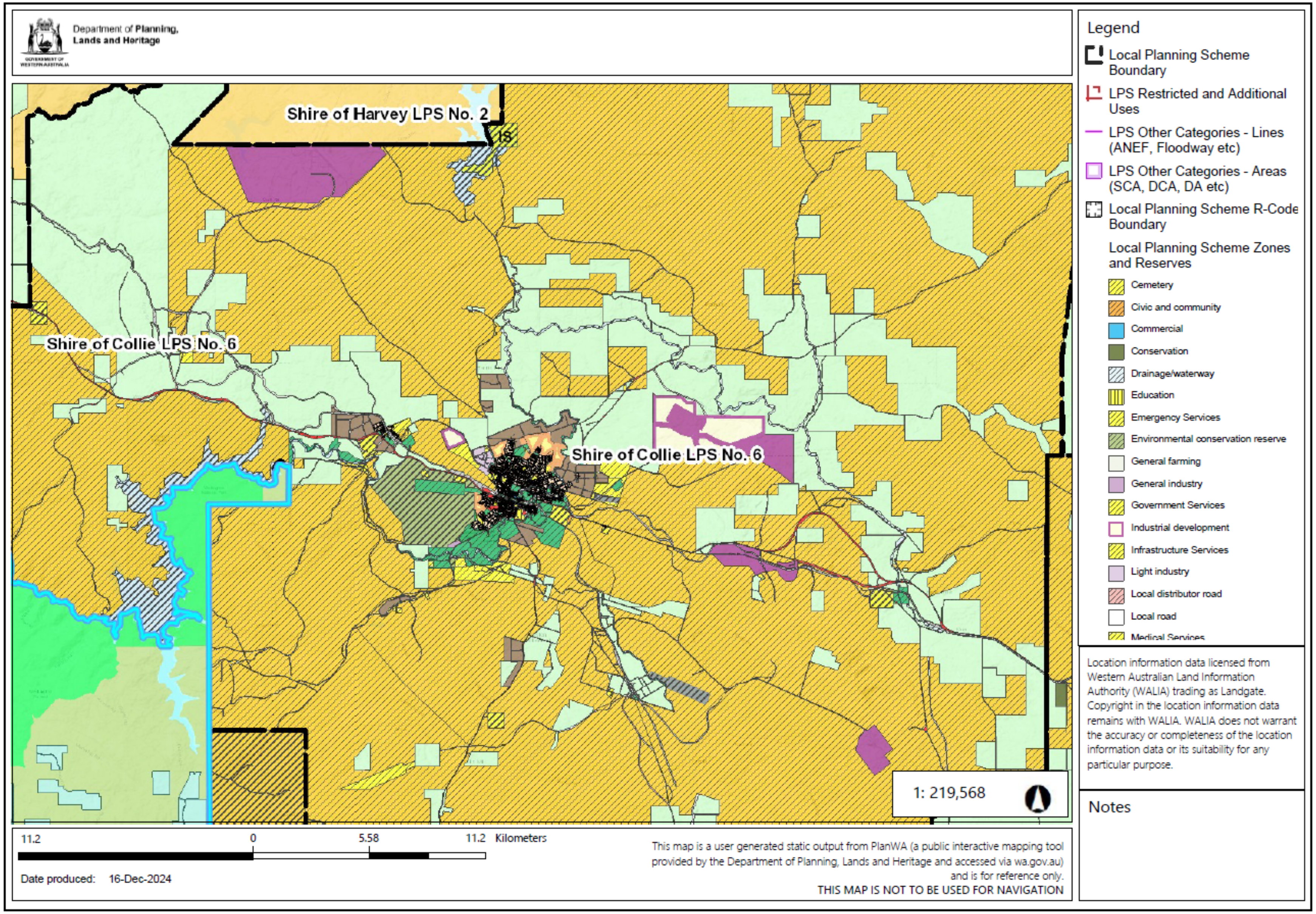

Figure 2-1 - Planning scheme zones and reserves

Table 2-2 Environmental Site Setting Summary

Summary Information	Details
Climate	The climate in Collie is generally characterised by hot summers and wet winters. The mean annual rainfall is 618 mm with October to April being the driest months (data sourced from http://www.bom.gov.au/climate/data-services/station-data.shtml).
Topography	Collie is situated within a north-westerly trending valley in the Darling Plateau. The average elevation is around 210 metres above sea level and ranges between 174 to 286 metres. The area includes various physical features such as hills, valleys, and water bodies.
Surface water	The Collie Basin is drained by the northwest flowing Collie River which has two major tributaries, Collie River East Branch and the Collie River South Branch. There are numerous unnamed creeks that traverse the basin which discharge to either the South Branch or the East Branch of the Collie River.
Regional Geology	The Collie Basin is a fault-bounded basin which formed post deposition through tensional forces whereby overlapping faulting caused sinking of the geologic units to form a basin. The basin comprises two principal grabens that strike northwest, with south westerly dipping Permian siliciclastic formed as a result of right-lateral shear in a trans tensional setting. The coal bearing sequence in the basin reaches a maximum thickness of 900 metres. The sediments overly the crystalline basement rocks of the Archaean Yilgarn Craton. The bulk of the rocks in the Collie Basin are Archaean granitic units from the southern extension of a major plutonic complex, the Darling Range Batholith and metamorphic rocks consist of ortho- and paragneiss metasediments and some mafic and ultramafic intrusion of the Balingup Metamorphic Belt. Younger mafic dykes of late Precambrian age are tholeiitic quartz dolerite intrusives which have a north westerly trend. There are several intrabasinal faults running parallel to the graben axial trend which transect low-amplitude folds, making the determination of mineable areas in the basin, complicated. Coal was initially discovered in the Collie River which resulted in the discovery of the basin and subsequent coalfield. More specifically the Collie Group comprises the: - Muja Coal Measures - Premier Coal Measures - Allanson Sandstone - Ewington Coal - Westralia Sandstone Further detail on geology is presented in Section 3.1.
Regional Hydrogeology	The Collie Group contains a regional groundwater flow system in which groundwater is unconfined in the upper part and confined at depth. There is recharge from rainfall and recharge from small streams into the basin. There is also some leakage from the Collie River South Branch in the southern Cardiff Sub-basin. The groundwater elevation is highest around the basin margins and in the northern Premier Sub-basin and flow is towards the Collie River and its tributaries, where discharge occurs. Groundwater abstraction at open cuts and underground mines, has depressed the watertable over an area of approximately 100 km^2. Groundwater flow at depth has been modified due to

Summary Information	Details
	mining processes over the years, and therefore remains uncertain. The depression of the watertable is not evenly distributed and may extend beyond the basin boundary. Groundwater salinity in the Collie Basin is predominantly recorded as below 1000 mg/L TDS (total dissolved solids) and much of the groundwater is lower than 500 mg/L TDS. TDS is largely attributed to sodium chloride and the groundwater is considered acidic as a result of its contact with sulfide-bearing sedimentary rocks as well as the presence of carbon dioxide (DNRM, 2015). Groundwater in the region is also considered corrosive due to its acidity, carbon dioxide, hydrogen sulfide and chloride hydrogeochemistry.
Coal Resources	Figure 2-2 of the coal resources of the Collie Basin, illustrates the widespread presence of coal in the basin. Petrography of coal in the Collie Basin is determined by the original types of peat forming vegetal debris, environments of accumulation, degree of organic maturation (rank), and mineralisation. Carbonaceous shale is often found interbedded with coal. Carbonaceous shale and coal differ in their chemical composition as well as their classification as sedimentary rocks. Coal is made up of complex organic matter, including aromatic and aliphatic structures and organic-containing functional groups. Whereas carbonaceous shale is a sedimentary rock that is mainly made up of clay minerals and quartz, but due to its high carbon content (i.e., from organic matter), it is classified as a carbonaceous shale. Shales can also be classified as either siliceous or calcareous depending on their silicon and calcium contents respectively.
Vegetation	The region features a mix of open forests and low open woodlands. Common tree species include jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*). Tall shrublands are also prevalent, with species such as banksias and hakeas. Low sedgelands are found in wetter areas, supporting species like the blue lechenaultia (*Lechenaultia biloba*) and the running postman (*Kennedia prostrata*) (Western Australian Department of Agriculture, 1974)

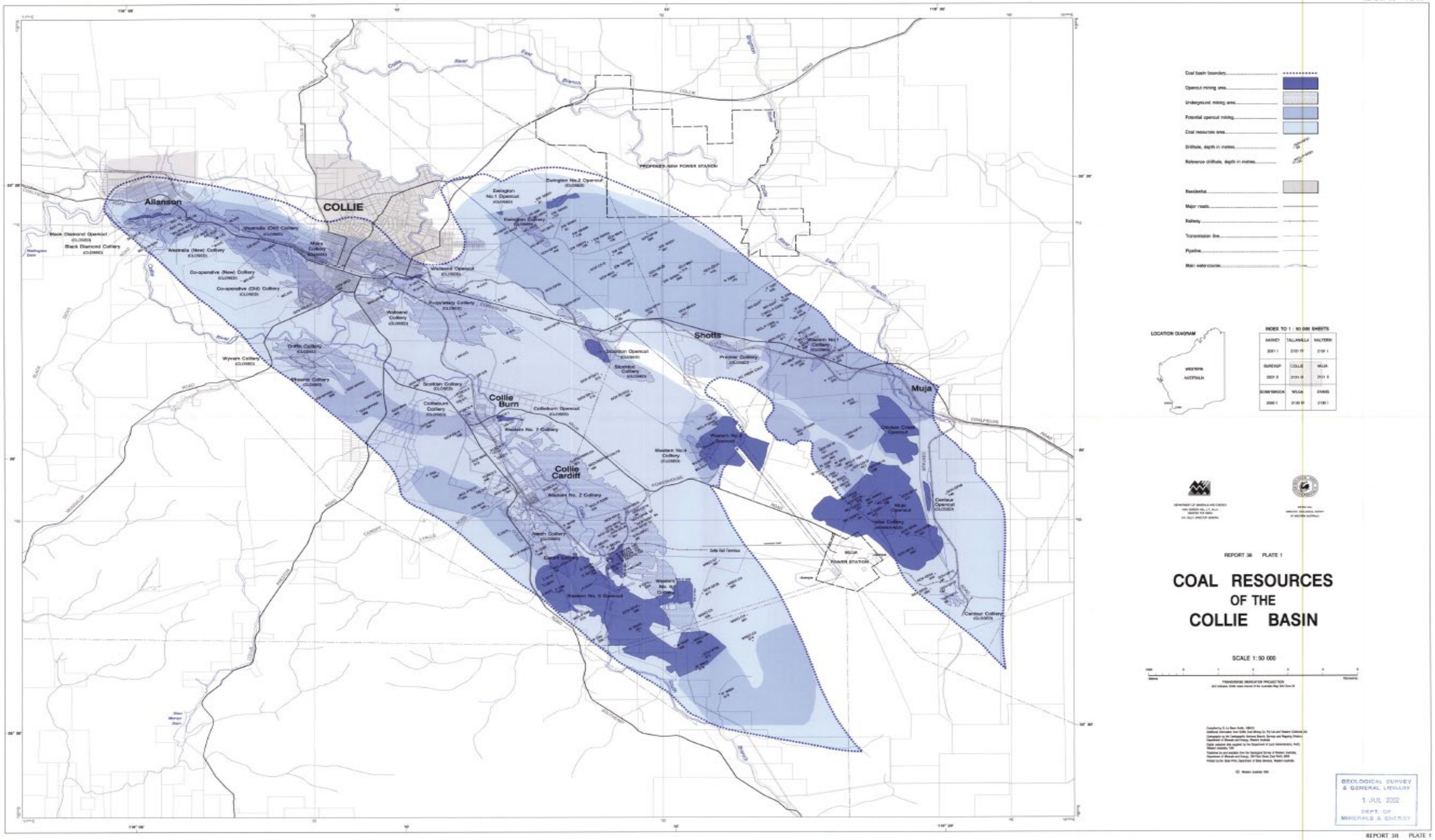

Figure 2-2 - Coal Resources of the Collie Basin (sourced from Smith, G.L.B., 1993)

Section 3 Mining and Geochemical Setting

3.1 Relevant history of coal mining in the Collie region

Coal was first discovered in the Collie Basin in 1883 (Goldsmith et al., 1995) and coal is reported to have first been identified in the banks of the deeply incised Collie River, west of the town of Collie (Davy & Wilson, 1989).

The following relevance historic points have been obtained from two key references as follows:

- '100 Years of Collie Coal' (Stedman 1998) indicates that:
  - Until 1943 coal mining in the basin was by underground methods.
  - Open cut mining practice that commenced after this saw overburden being 'dumped' out of the pit. As mines increased in size, back filling became more common. The backfilling inverted the original soil profile such that deeper strata ended up near or at the surface.
  - In 1966, the then Forest Department began tree planting on 'spoil dumps' starting with the Diamond and Collie mines.
  - In 1975, Western Collieries implemented a rehabilitation programme which involved stockpiling of topsoil and commencement of rehabilitation. This led to rehabilitation of 55 hectares of re-vegetated mined land using vegetative species panted in topsoil covering the dumps.
  - In the early history of the mines, high market demand for lump coal meant that coal fines were 'dumped in the bush'. It is reported that much of this material was later recovered but that this left a residue that was 'prone to ignite during spells of hot weather or as a result of Forestry Department burns. The timing of these transitions does not appear to be documented however it is noted that:
    - Moira commenced in 1900 to 1901 and the larger Old Co-operative Colliery surrounding the immediate east, south and west sides of Moira was mined from 1902 to 1918.
    - Scottish colliery opened in 1903.
    - Stockton opened in 1927.

    Hence, it is possible that coal fines are present in mine waste materials at each of these mines.
  - The coal was known to be prone to 'spontaneous combustion' and stockpile fires had been 'troublesome feature throughout the history of the industry'. As time progressed, stockpiling methods were developed to mitigate the potential for stockpile fires (refer Section 3.4).
- 'An Investigation of the Controls on Shallow Subsidence in the Collie basis 100 Years of Collie Coal' (Goldsmith et. al. 1995)
  - 26 collieries were operated and abandoned prior to closure of the Western Collieries in the mid-1990s. 24 were underground mine (Stedman 1998).
  - Coal from the Wallsend "Old Proprietary' Colliery was mined from the Ewington coal seam. Roof falls and coal dust in the mine resulted in 'ideal conditions for spontaneous combustion to occur'. This led to fires that eventually closed part of the underground mine. The Wallsend Colliery was located to the south of the Collie township between the Moira, Scottish and Stockton collieries.

In summary, there is documented history that suggests that mine waste material was deposited at the surface. In the early history of mine development the history suggests that these are more likely to have been left at the surface rather than placed back within the mine workings. Of note, are the coal fines that were placed in the bush and that are indicated to have been prone to combustion. There is also indication that mine materials such as the coal fines may have been prone to spontaneous combustion. The progressive improvements in rehabilitation activities starting around the mid-1970s may mean that mines abandoned after this time may have less potential for carbonaceous materials to be present in near surface soils.

3.2 Geology and Geochemistry of Collie carbonaceous shale

3.2.1 Geology

The Collie Basin is a fault-bounded basin, which formed post deposition through tensional forces whereby overlapping faulting, such as en echelon faults, caused sinking of the geologic units to form a basin.

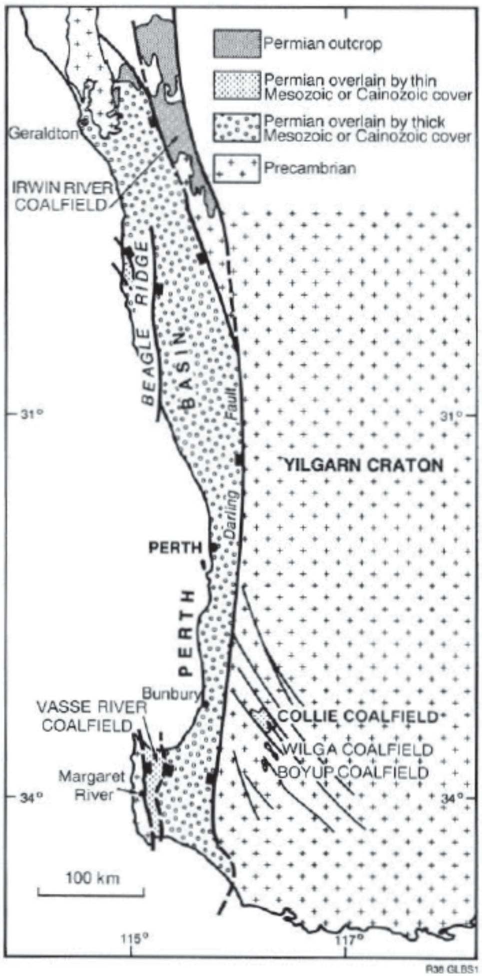

Figure 3-1 Location map of Collie Basin and Permian sediments at shallow depth in southwestern Western Australia (sourced from Smith, G.L.B., 1993)

The basin comprises of two principal grabens that strike northwest, with south-westerly dipping Permian siliciclastics formed from right-lateral shear in a transtensional setting. The coal bearing sequence in the basin reaches a maximum thickness of approximately 900 m (Smith, G.L.B., 1993). The sediments overly the crystalline basement rocks of the Archaean Yilgarn Craton. The basin contains numerous intra-basinal faults such that determination of mineable areas in the basin as a function of the complex structural geology has been difficult. It was in the Collie River that coal was first discovered associated with the basin.

The Collie Group is the main geological unit that hosts the coals and carbonaceous shales in the region. More specifically the Collie Group (from oldest to youngest) comprises the Westralia Sandstone, Ewington Coal Measures, Allanson Sandstone, Premier Coal Measures and Muja Coal Measures. These lithological units contain coal seams and inter-seam sediments including carbonaceous shales. The Westralia Sandstone is largely a sandstone succession with some laminated siltstones that are thinly capped by carbonaceous shales. The Ewington Coal Measures are the oldest coal-bearing unit in the Collie Basin which contains sandstone, carbonaceous shale, clast-supported conglomerate and coal. The Allanson Sandstone which overlies the Ewington Coal Measures, has substantial coal present in numerous seams, and contains carbonaceous shale. The Premier Coal Measures consist of sandstone, carbonaceous shales, a clast-supported small pebble conglomerate and coal. The youngest unit of the Collie Group, the Muja Coal Measures is made up of an interbedded poorly sorted feldspathic sandstone, carbonaceous shale, clast-supported small pebble conglomerate, and coal. This brief geological summary of the main Collie Group is provided to demonstrate the main lithological units contain both coal and carbonaceous sediments including shales.

The Cretaceous Nakina Formation unconformably overlies the Permian Collie Group to a thickness of up to 20 metres (Goldsmith et. al. 1995). The formation consists mainly of unconsolidated gravel, sand, silt and clay and is derived from the reworking of the Permian sediments and erosion of the surrounding granitic rock. The Nakina Formation is subsequently overlain by the younger Tertiary age laterite. There are geochemical differences which distinguish the laterite in the coalfields compared to the adjacent basin areas, through lower alumina and iron contents in the laterite overlying the coalfield (Smith, G.L.B., 1993).

Figure 3-2 demonstrates the stratigraphic log of the units as well as the identified coal seams in the basin.

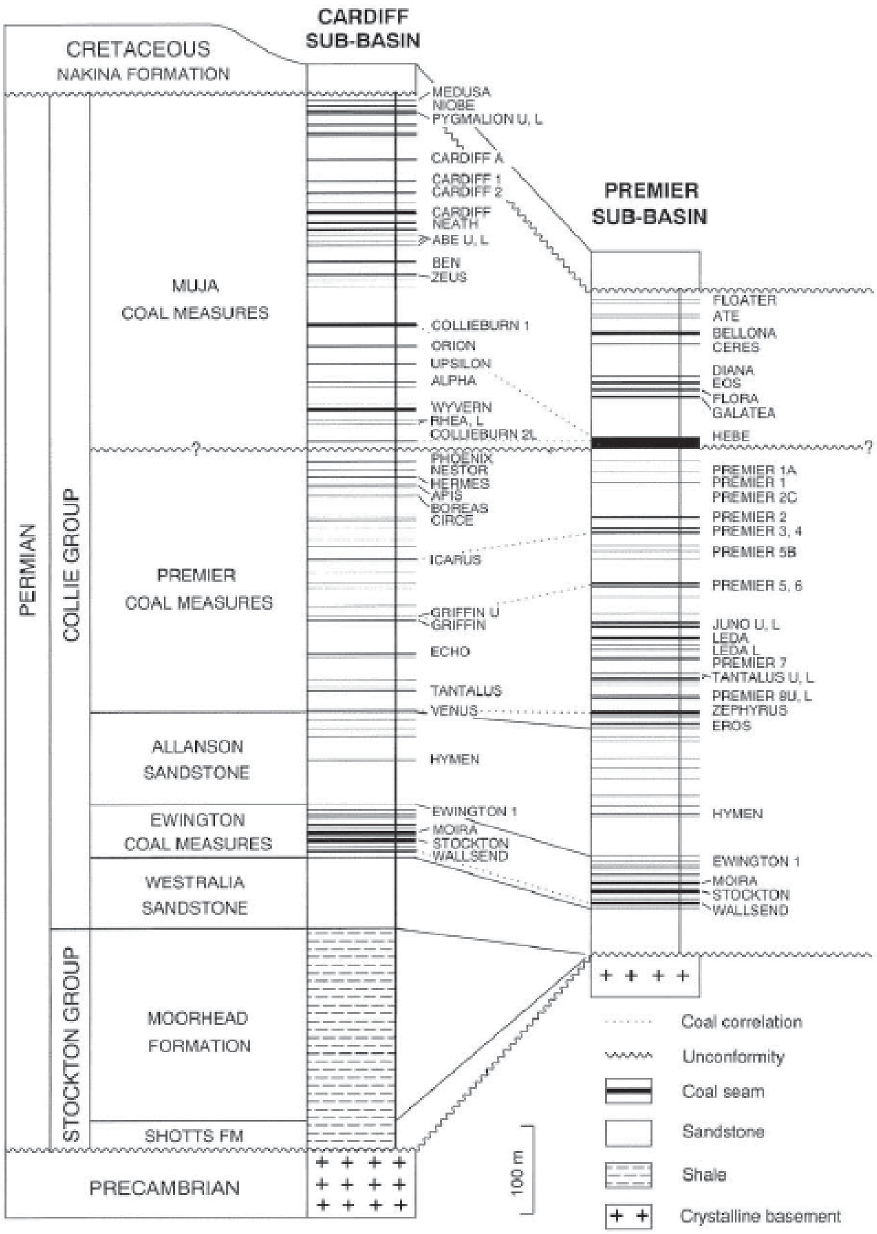

Figure 3-2 - Geology and Permian Coal Resources of the Collie Basin, Western Australia, sourced from Smith, G.L.B., 1993, Report 38.

3.2.2 Geochemistry

A study of coal composition in the Collie coal measures was carried out by Davey and Wilson's (1989). Chemical data for all coals sampled was derived and demonstrated an average range in ash contents of the 312 coal samples of between 1.5 – 19.3%, with a mean of 6.0% and sulfur contents between 400 – 50,000 ppm with a mean of 5,010 ppm (approximately 0.5%) (refer Table 3-1).

Table 3-1 Summary of sulfur composition data for relevant Collie coal measures

Coal Bearing Member	Range (sulfur ppm)	Mean (sulfur ppm)	Geometric Mean (sulfur ppm)
Cardiff Member (n = 75)	650 – 25,400	3,350	2,880
Collieburn Member (n = 34)	2,190 – 18,500	6,920	6,060
'Ben' (n = 7)	2,130 – 4,080	2,981	2,917

In addition to the analysis of coal samples, some limited information is available in the literature relating to inter-seam sediments. These are sediments derived from detritus that were originally comprised of quartz, feldspar and mica. These minerals have over time largely weathered into clays and cover lithologies defined as carbonaceous shales. While there are elemental similarities of these inter-seam sediments to their overlying or underlying seams, some key differences identified are the absence of aluminium hydroxide and sulphate minerals. The inter-seam sediments have reported values of alkaline earth oxides, in particular SiO_2 and Al_2O_3 considerably higher than in nearby coals. Other elements typically higher in the weathered clay bearing inter-seam sediments compare to the coal are As, B, Cr, Li, Nb, Rb, Th, U V, Zr and possibly Pb. Although the Davey and Wilson (1989) study indicated that analysis of inter-seam sediments was undertaken, the results are not documented. However, the study does state that "*the value of a few elements, Co, Ni, and S are commonly lower in the claystones than in the coal*". This could infer that the carbonaceous shales have a low sulfur content which would reduce the potential for them to self-heat to ignition. This would require confirmation though site investigation and sample analysis.

3.3 Relationship between geology and known, inferred 'hot ash' stockpiles

Figure 3-3 indicates the stratigraphy and structure of the Collie Basin in the proximity of the collieries and 'hot ash' locations. It is evident from the figure, that the collieries span across different stratigraphic units whereby the Scottish Colliery is largely underlain by the Muja Coal Measures. The Moira Colliery is largely underlain by the Ewington Coal Measures and Westralia Sandstone. Whilst the Stockton Colliery is underlain by the Ewington Coal Measures, Westralia Sandstone and Moorhead Formation.

The stratigraphic units listed for each of the collieries are logged as containing carbonaceous shales however the distribution of reported 'hot ash' sites are spread across the Collie Basin with no visible correlation or systematic pattern with respect to geology of the coal or carbonaceous shale bearing units.

Further, the Cretaceous Nakina Formation unconformably overlies these Permian coal and carbonaceous shale bearing units. The Nakina Formation is subsequently overlain by a laterite, which in most areas of the Collie Basin acts as a further lithological layer separating the Permian coal and carbonaceous shale bearing units from the surface. Davy and Wilson (1989) report that '*nowadays there are no natural exposures of the Permian rocks*'. This suggests that the presence of carbonaceous material at the surface, i.e., first 1 to 2 metres, is more likely to be a result of historic mining operations and less likely to be naturally occurring. These observations are consistent with the first discovery of coal in the deeply incised Collie River valley (Davy & Wilson, 1989).

However, it is important to consider that due to the presence of intra-basinal faulting as described Section 3.1, the potential for the Collie Group to be exposed at or near to the surface in some areas of the Collie Basin cannot be excluded. For example, a drilling program identified a 1.5 m thick coal seam at a depth of 8.2m at the Moira Colliery and the depth of mining at Scottish Colliery was as shallow as 5 metres (Goldsmith et. al., 1995).

The regolith (natural soil deposits and weather rock) mapping of the area from the 500K WA Regolith Geology dataset, demonstrates that the Moira, Stockton and Scottish collieries regolith is made up of a predominantly residual or relict unit, “YPP”, for which the material is described as transported duricrust; cemented sand, gravel, cobbles and boulders in alluvial/colluvial deposits or colluvial unit described as colluvium derived from different rock types including gravel, sand and silt. The regolith map is presented for each colliery in Figure 3-4, Figure 3-5 and Figure 3-6 below.

It is difficult to establish whether the residual unit, i.e., predominantly duricrust, contains reworked coal or carbonaceous shale materials (during regolith formation) that are now expressed at the surface.

Overall, from review of the geological information of the area, the presence of ‘hot ash’ material at the surface may not be controlled by geology at the regional scale but there may be the potential near surface or outcropping of coal and carbonaceous shale units at a local scale due to localised faulting and mining related changes to the topography. The observed distribution suggests that the general presence of ‘hot ash’ material across the assessment area is more likely to be associated with the presence of mine waste materials from the historic mining operations.

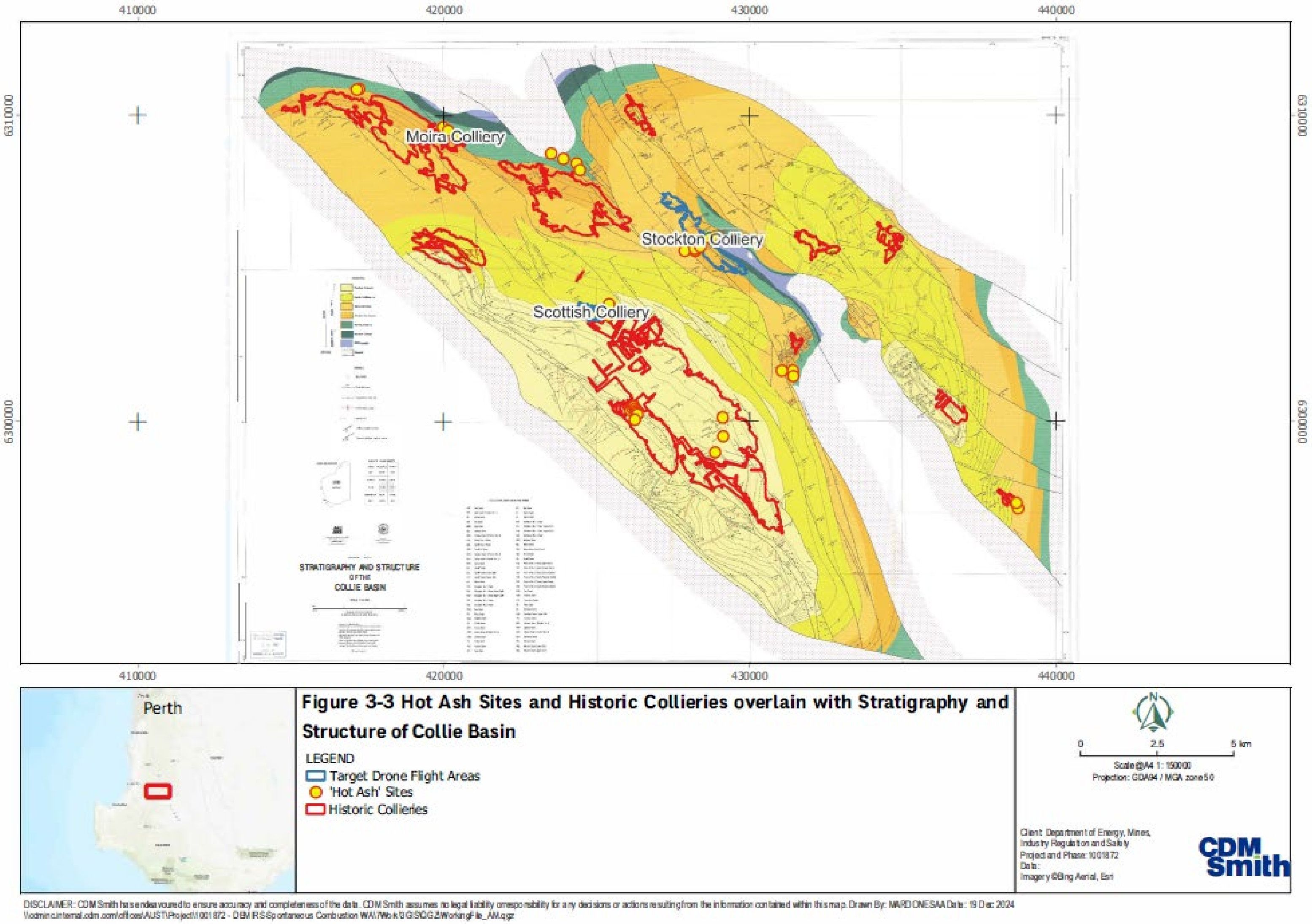

Figure 3-3 – 'Hot ash' locations and historic collieries overlain on geological units of the Collie Basin

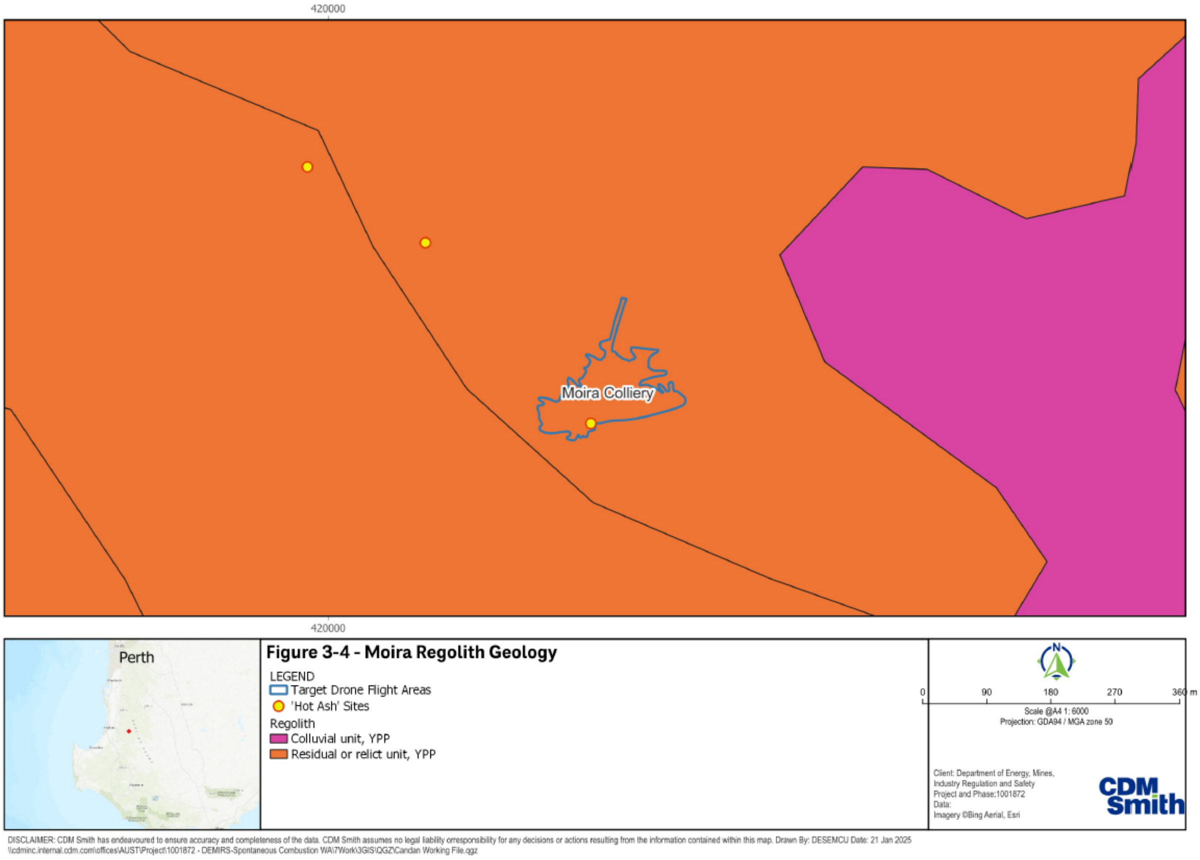

Figure 3-4 - Moira regolith geology

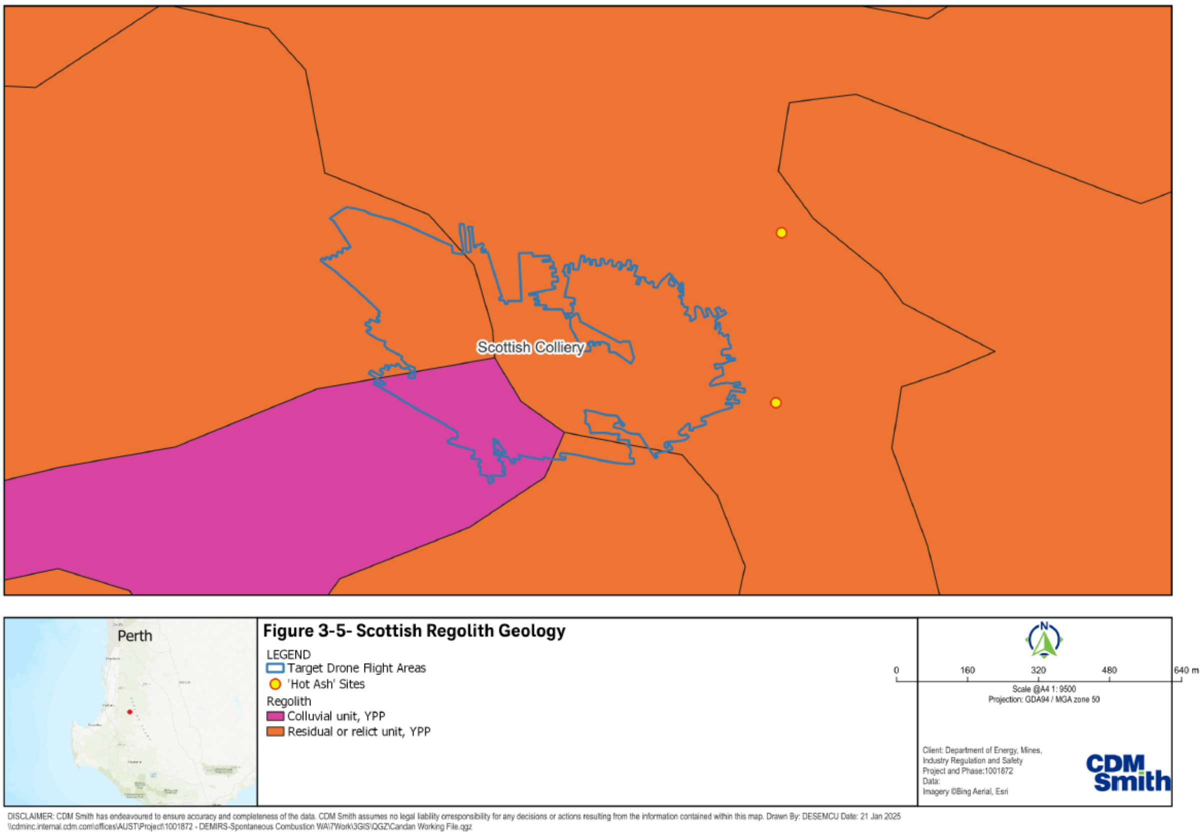

Figure 3-5 - Scottish regolith geology

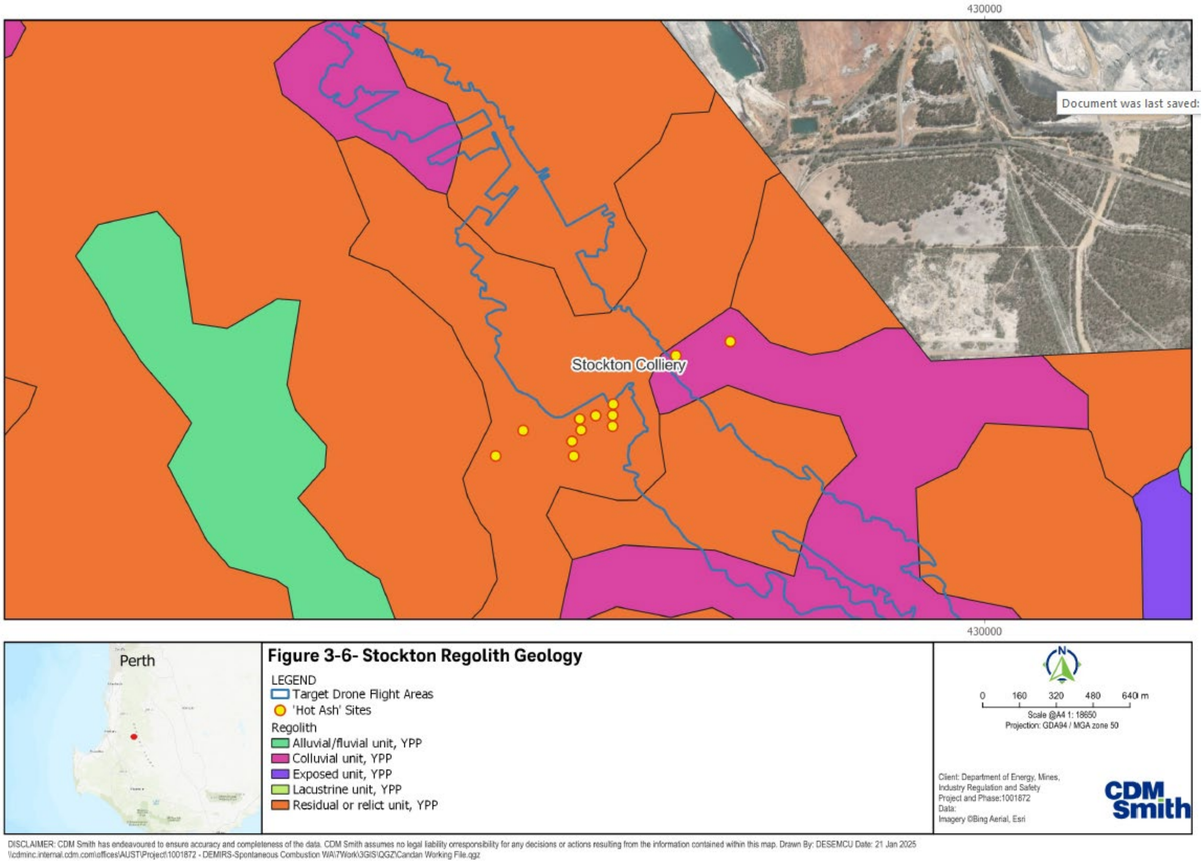

Figure 3-6 - Stockton regolith geology

3.4 Combustibility hazard for coals and carbonaceous shales

Mine waste materials containing carbonaceous waste rock, which includes coal and carbonaceous shales of the abovementioned units, are known to exist in the coalfield. Both coal and carbonaceous shales can have the propensity for self-heating to ignition and are often found associated with each other due to the depositional environment in which coals form. It has been suggested that coals that are classed as lower rank coals, have a higher propensity for self-heating to ignition (Sloss, 2015).

The potential for spontaneous combustion (self-heating to ignition) of Collie coal stockpiles during mining activity is a matter that has been managed since 1979 with the introduction of the Collie Coal Agreement Acts. The Acts provided standards for the management of coal stockpiles. Coal was required to be stockpiled in a specially prepared area adjacent to Power Stations. The critical aspect of stockpile construction was to ensure air could not reach the interior. The stockpile was designed to allow for coal to be well compacted with gently sloping sides which would direct wind over the surface. A high level of compaction was achieved by stockpiling only crushed open-cut and shot fired coal and machine-cut underground mined coal. The relatively small lumps and fines in the coal pack closely together when compacted with a vibrating roller, excluding air from the interior of the pile. Continual monitoring of coal temperature, quality, size and stockpile density demonstrated that stockpiles were chemically and physically stable and could be maintained for many years without significant loss of quality (Stedman, 1988).

Coal forms from the deposition and consolidation of organic matter i.e., vegetation, between other rock strata via processes of microbial action, pressure and heat, over geologic time scales. Coal is largely composed of carbon but also contains lower amounts of hydrogen, oxygen, nitrogen and sulfur amongst other elements. Carbonaceous shales also contain high amounts of organic matter and are often found to be deposited between layers of coal. However, carbonaceous shales differ in that they are predominantly made up of clay minerals and quartz. Spontaneous combustion of carbonaceous materials is a function of the oxidation of these units through exposure to air (Chalmers et al., 2012; IEA Clean Coal Centre, 2015). The ideal conditions under which spontaneous combustion occurs is where there is a sufficient supply of air and insufficient airflow to remove heat. Subsequently, factors that affect the propensity for material to self-heat to ignition are the porosity of the material, the presence of reactive pyrites), moisture content and petrology, such as the presence of total sulfur and total organic carbon (Chalmers et al., 2012). Pyrites can often be observed as nodules or bands and the abundance of pyrite mean that the carbonaceous shales can contain more than 10% total sulfur. In addition, the ability for material to self-heat is dependent on low air velocities, moderate differential pressures, broken coal surfaces and mining methods (Chalmers et al., 2012). Where there is enough waste rock material that has a continuous supply of oxygen and minimal heat dissipation, reactive pyrite can act as an accelerant to cause the material to heat to ignition.

The controls on spontaneous combustion and the factors which affect the propensity for material to ignite are discussed below, with the purpose of identifying indicators that can be used to aid in understanding the potential for carbonaceous material to self-heat to ignition. For reference, below is a Figure 3-7 sourced from Sasaki et al. (2014), which demonstrates the process of self-heating within a stockpile. Through the movement of oxygen and air over the surface, oxidation takes place which heats up the coal. Heat is then transferred both inwards and outwards. It is heat travelling inwards that can lead to a temperature hotspot which continues to spread until it reaches a point on the surface. Once at the surface, it will interact with oxygen in the air that can lead to glowing embers and subsequent ignition of the coal pile. Coal that are classified as low rank coals as opposed to high rank coals, are more likely to spontaneously combust (Sasaki et al., 2014; IEA Clean Coal Centre, 2015). In the case of carbonaceous shales, it is a possible hypothesis that a similar mechanism for self-heating occurs within a stockpile of carbonaceous shales.

Physical indicators that can be used to demonstrate the propensity of material to ignite include:

- thermal venting through the recording of higher ground temperatures than air temperatures as well as through visible cracks in the ground surface
- sulfur encrustations or the presence of white hydrated iron sulfates around ground cracks.

In addition to this self-heating process described the emission of gases from coal containing stockpiles is another factor which contributes to the propensity for the stockpile to ignite. The Department of Natural Resources and Mines (DNRM) of the Queensland Government (DNRM, 2015) has identified a series of flammable and toxic gases that are released from open cut coal mines. These are methane, hydrogen sulfide, carbon monoxide, carbon dioxide, sulfur dioxide and nitrogen dioxide. Subsequent research has found that hydrogen is also emitted during coal oxidation. The presence of methane in particular around coal mining activities has been identified as a significant contributor to the incidence of explosions (IEA Clean Coal Centre, 2015).

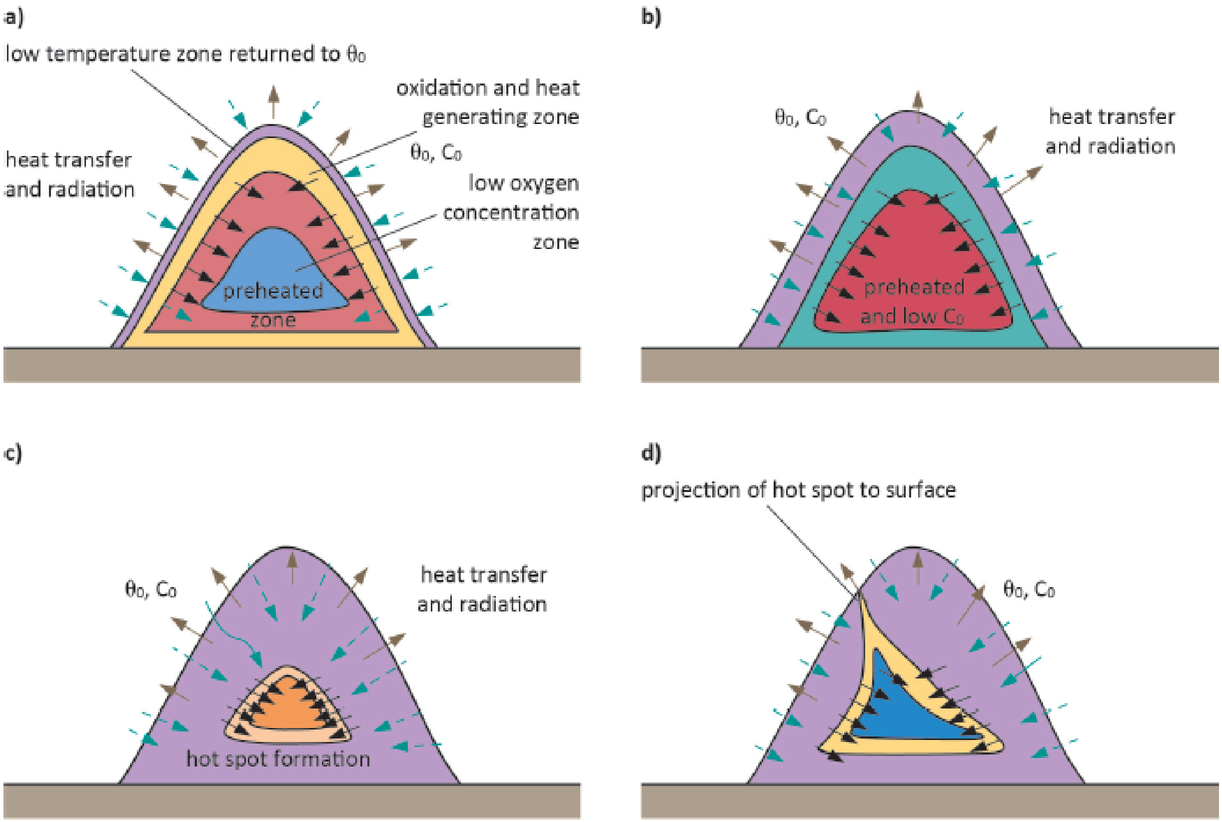

Figure 3-7 - Schematic showing the self-ignition process of a coal stockpile (sourced from Sasaki and others, 2014)

Section 4 Aerial Image and Digital Elevation Model review

4.1 Aerial imagery

Aerial imagery and mapped information was used to assess if there is correlation between the inferred ‘hot ash’ sites and visible features. Figure 4-1presents the areas of historic and current collieries, known coal deposits and inferred ‘hot ash’ on publicly available aerial imagery.

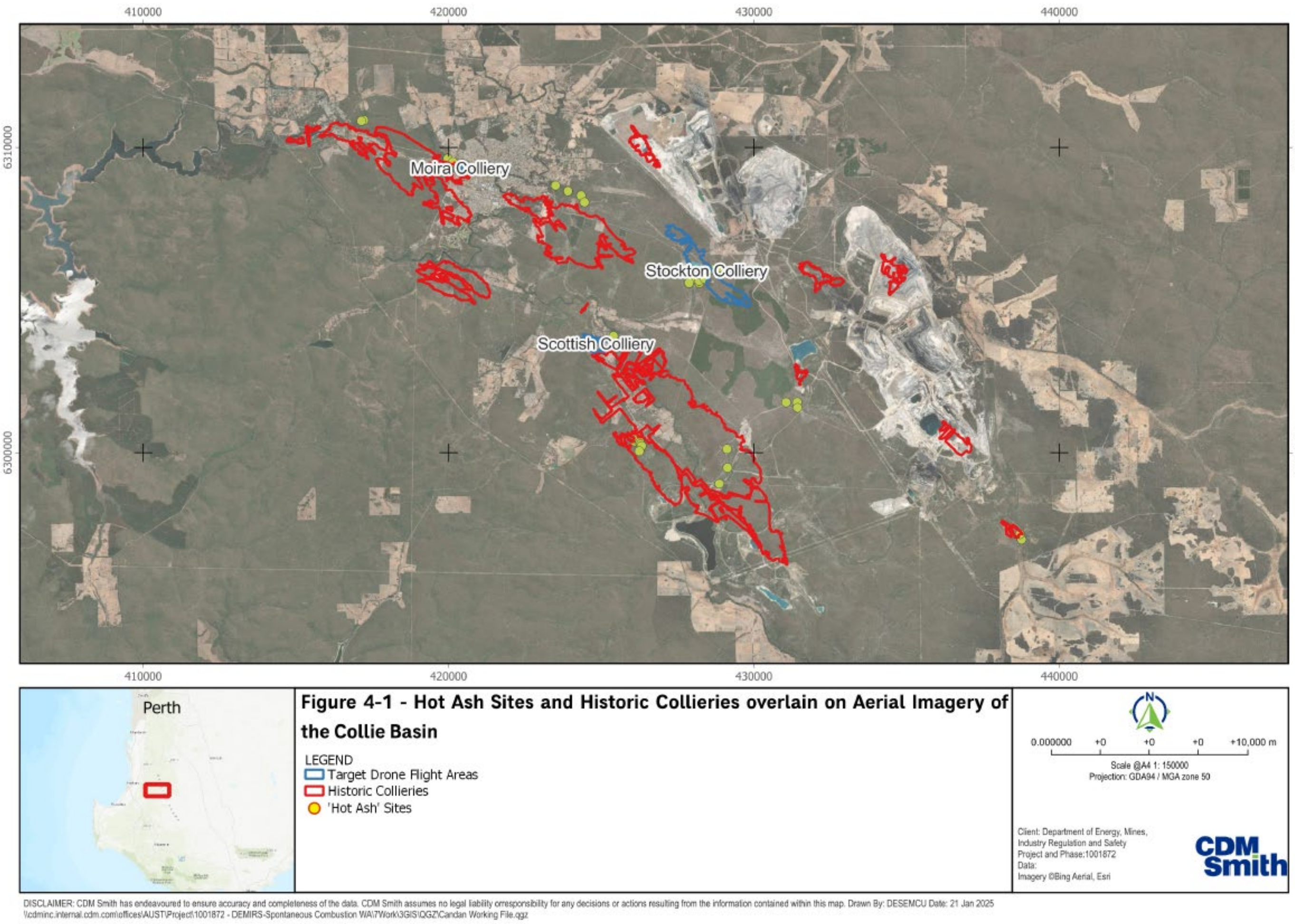

Figure 4-1 – ‘Hot ash’ locations and historic collieries in the Collie Basin

High-resolution aerial imagery data was also obtained during the drone survey (refer Figure 1-2, Figure 1-3 and Figure 1-4) and have been used to make the following observations:

- In the Stockton Colliery area, the inferred ‘hot ash’ locations surround what is likely to be the historic open cut mine (Stockton Lake) that is now filled with surface water. Some locations are situated in vegetated areas while other are located in cleared areas.
- At the Moira Colliery area, ‘hot ash’ locations are not readily distinguishable from the surrounding area, however some areas of darker material can be seen to correlate with stockpiles of material that are dark grey to black in colour; possibly waste rock made up of coal and/or carbonaceous shales or soil containing residual ash following a bushfire.
- At the Scottish Colliery, there are areas of land clearing visible from aerial imagery, however inferred ‘hot ash’ locations are observed in vegetated areas. The identification of ‘hot ash’ locations in vegetated areas is

possibly due to the identification of these sites 'hot ash' sites post fires. The trees have likely acted as a fuel source during the bushfires, concentrating the identification of these sites to vegetated areas once burnt.

4.2 Digital Elevation Model

Digital elevation information was also obtained for each targeted assessment area during the drone survey. These images were used to develop a digital elevation model (DEM). The DEM imagery can then be converted to LiDAR to inspect terrain variation in the absence of trees. These images were inspected using QGIS to establish whether there were observable correlations between the areas of know 'hot ash' to terrain elevation features. This was only able to be carried out for the Moira targeted assessment area, as this is the only area where known inferred 'hot ash' locations occurred within the assessment area (refer Figure 4-2). The DEM or LiDAR imagery does not indicate that the 'hot ash' location is discernible from the background topography.

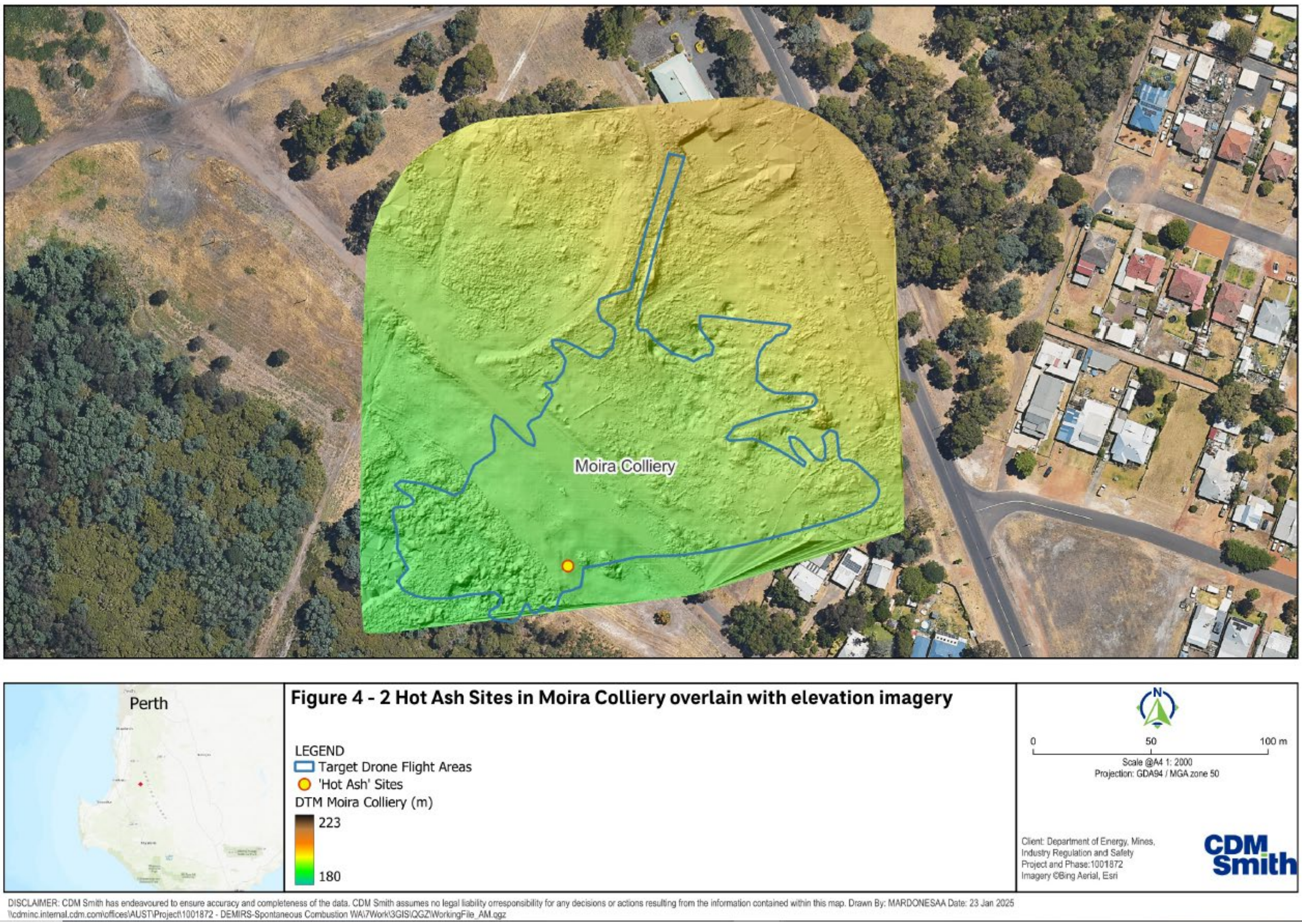

Figure 4-2 – 'Hot Ash' location at Moira Colliery overlain with elevation imagery

Section 5 Site visit and Interviews

5.1 Objective

An experienced environmental scientist from CDM Smith accessed the targeted assessment areas on 28th November 2024 and 12th December 2024.

The objective of the site visits was to assess access to areas for potential future sampling, assess general ground conditions and potential visible indicators of increased combustible hazard likelihood due to the presence/absence of in coals/shales. In addition, the site visit was to support with the site access for the drone survey of the targeted assessment areas (refer Section 6 as well as Figure 1-2, Figure 1-3 and Figure 1-4).

5.2 Scope and Methodology

At each location visual observations were made of access, ground surface and absence/presence of indicators of mine wastes, in the areas visited. Support was also provided to the drone survey team. A handheld thermometer was used in the field to provide an indication of potential hot spots at the ground surface, compared to background conditions.

The site visit was not an exhaustive inspection of the targeted assessment areas. The aim of the site inspection was to cover as much of the target assessment area as possible that was safe to do so, looking for stockpiles and comparing stockpile temperatures to adjacent ground and atmospheric temperatures, to assess whether there was evidence of a relative difference in temperature. If there were anomalous land features such as the organic pile identified at Scottish (refer to photograph and location SCO3 in Section 5.3.4), their temperature was also measured. The area covered also varied based on the size and land ownership in each of the target areas. The Moira target area was easily accessible and most of the area was covered. Stockton contained restrictions due to land subsidence in the area as well as being the largest of the target areas. For this reason, it was not feasible to inspect the whole area. The Scottish target area had areas of private property and so the inspection focussed on publicly accessible areas.

5.3 Site Inspection Findings

5.3.1 Summary

Field observations made during the site visits are presented in the sections below. These observations are preliminary only, and assessment was limited to inspection of locations of expected ‘hot ash’ and suitable drone launching areas within the targeted assessment areas. Field observations included observation of stockpiles and carbonaceous materials.

Only one of the ‘hot ash’ sites falls within the target assessment areas, and that is in the Moira target assessment area. This location was inspected, and photographs taken with no noticeable elevated temperatures compared to surrounding ground. In addition, there were no other obvious signs of physical land features suggesting the presence of material that may contain the propensity for self-heating to ignition.

In the case of the Stockton target area, while no ‘hot ash’ locations fall within the target area, nearby ‘hot ash’ locations were inspected. At these locations, visible features such as the presence of sulfur encrustations and rotten egg odour (possible H_2S or SO_2) and visible coal fragments, were observed.

In the Scottish targeted assessment area, one location was identified as having a higher temperature, approximately 15 to 20°C greater than surrounding ground temperatures. This location was not in a known ‘hot ash’ location. Features of elevated ground temperatures, sulfur encrustations, hydrogen sulfide odours, moisture and stockpiles of coal/carbonaceous materials may suggest a site of thermal venting associated with reactive carbonaceous materials.

Sections 5.3.2, 5.3.3 and 5.3.4 provide a summary of the site inspection observations for each of the accessible portions of the targeted assessment area that were able to be visited.

5.3.2 Moira Colliery

Summary Information	Details
Site Infrastructure	▪ Road ▪ Powerlines
Site Surface	Majority of area is easily accessible off a public road and is predominately cleared land. Some of the area is over private property. Topography is flat to slightly undulating.
Vegetation	Site is heavily vegetated in the southern section of the target area but is cleared along the road easement and the rail line to the south.
Evidence of Staining / Vegetation Stress	Vegetation in southern section of area recently burnt in bushfire.
Water features	No water features in area.
Mine Waste (surface stockpiles, other)	No mounded mine waste materials were observed within the targeted assessment area but in situ surface soil did contain coal fragments. No elevated temperature readings above background were observed. One known 'hot ash' location was situated in the Moira target area. This location was inspected, and photographs taken with no noticeable elevated temperatures compared to surrounding ground or other physical land features suggesting the presence of material that may contain the propensity for self-heating to ignition. Two known 'hot ash' locations were situated 200m and 500m west of the target area with warning signage recommending caution. The area contained stockpile mounds that were heavily overgrown with vegetation.

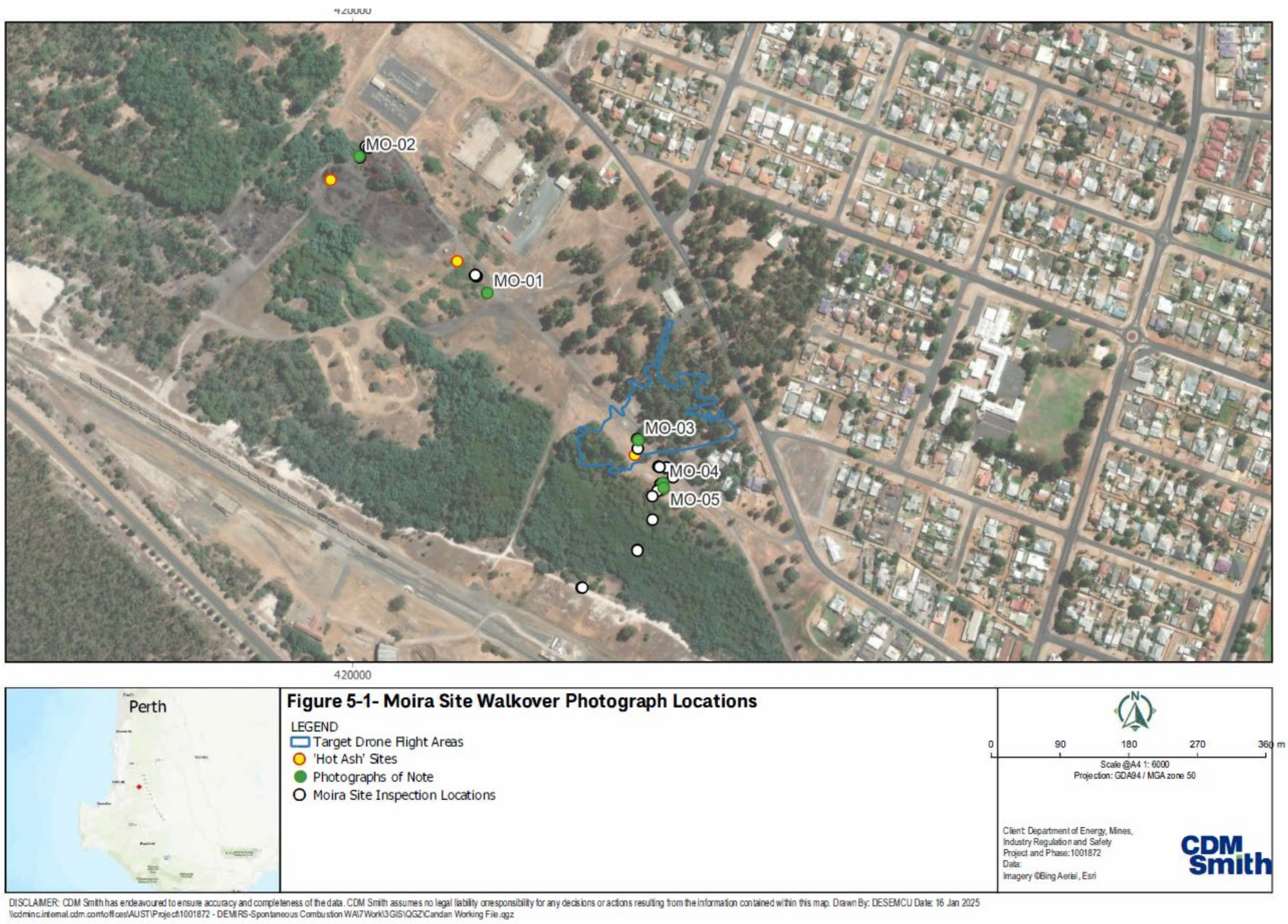

Figure 5-1 Location of site walkover photographs for Moira targeted assessment area

Moira site walkover photographs of note

MO01 - Hot ash warning signage near Moira assessment area.

MO02 – looking southwest to inferred 'hot ash" location north of targeted assessment area.

MO03 Moira assessment area near 'hot ash' location.

MO04 - Inferred waste material to southeast of targeted assessment area. Temperature not dissimilar to background.

MO05 - Inferred waste material to southeast of targeted assessment area. Temperature not dissimilar to background.

5.3.3 Stockton Lake

Summary Information	Details
Site Infrastructure	▪ Access tracks ▪ Collie – Lake King Rd ▪ Public ablutions (Stockton Lake) ▪ Railway line
Site Surface	Topography is flat to undulating. Areas of significant subsidence are present east and south of Stockton Lake from historical mine workings. Areas of subsidence observed to range from approximately 0.5 to 6 metres deep.
Vegetation	▪ Native vegetation covers 80% of area (State Forest) ▪ Pine plantation in southern end of area (State Forest)
Evidence of Staining / Vegetation Stress	Some vegetation stress visible around an area of mine waste materials located 200m south Stockton Lake.
Water features	Stockton Lake (surface area approximately 1.2km^2)
Mine Waste (surface stockpiles, other)	▪ Coal stockpiles located approximately 200m south of Stockton Lake recreational area. These are located outside the area of assessment. ▪ The known 'hot ash' locations (as mapped on Figure 5-2) are located approximately 200 metres to the south of assessment area. These locations contained extensive mine waste materials which appeared to contain a high percent of crushed coal material mixed with shales and sand. ▪ Very slight inferred sulfur dioxide odour in areas where sulfur encrustation on the surface and boulders was observed. ▪ No elevated readings of stockpiles compared to surrounding ground temperature were detected with the handheld thermometer. ▪ No mine waste material stockpiles were observed in the northern section of the target area (north of Coalfields Rd) that were accessible during the site walkover noting that the entirety of the area was not able to be investigated during the site inspection. ▪ No mine waste material stockpiles were observed in the southern section of the target area (south of known 'hot ash' location) that were accessible during the site walkover noting that the entirety of the area was not able to be investigated during the site inspection.

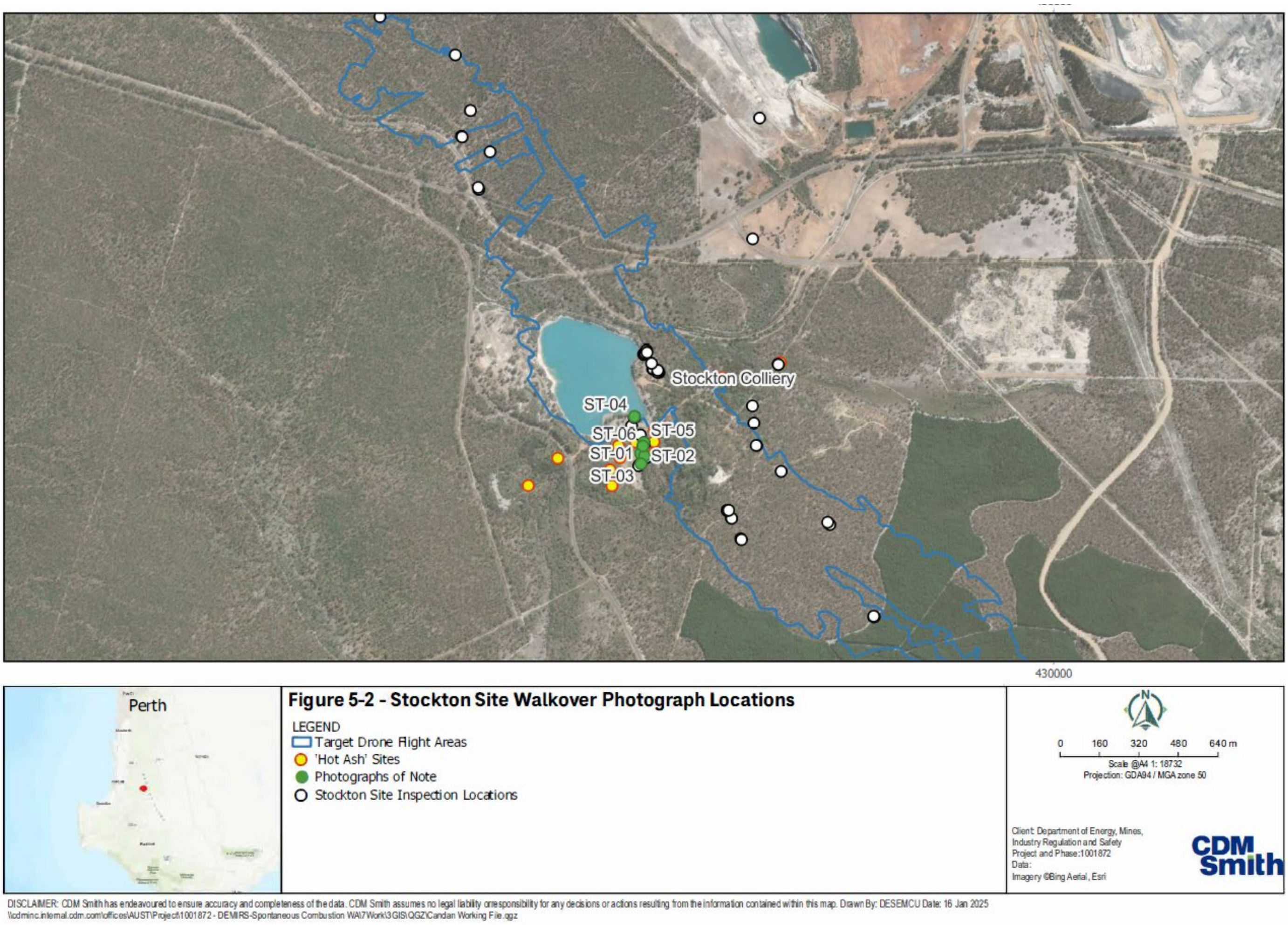

Figure 5-2 Location of site walkover photographs for Stockton targeted assessment area

Stockton site walkover photographs of note		
ST01 – Rail infrastructure from historic mining. Rotten egg odour noted at this location. 	ST02 – Close up of material at surface at known 'hot ash' location 200 metres south of Stockton Lake. 	ST03 - Known 'hot ash' location 200m south of Stockton Lake with sulfur encrustations on boulder. 
ST04 – Fragments of coal noted. 	ST05 - Rail infrastructure from historic mining. Rotten egg odour noted at this location. 	ST06 – Known 'hot ash' location 200 metres south of Stockton Lake. Darker material at surface anticipated to be ash, coal and/or carbonaceous shales. 

5.3.4 Scottish Colliery

Summary Information	Details
Site Infrastructure	▪ Roads ▪ Private Properties ▪ Railway line
Site Surface	Topography is flat to undulating.
Vegetation	Native vegetation (State Forest) Areas of cleared land
Evidence of Staining / Vegetation Stress	Signs of localised areas of vegetation stress throughout area.
Water features	No water features in assessment area
Mine Waste (surface stockpiles, other)	▪ Observed two locations that had elevated temperatures above background levels of 70 to 75°C when compared to adjacent areas of 50 to 55°C. Readings were taken around midday. Areas were small, approximately 30 cm in diameter and appeared to contain organic material, most likely plant roots. The area is located in a forested area with no mine waste material stockpiles identified. ▪ A known 'hot ash' location to the east of the target area was surveyed. The area contained numerous small mine waste material mounds approximately 1 m to 2 m high. Minor elevated readings above background temperatures, approximately 10°C higher than background, were observed at one location.

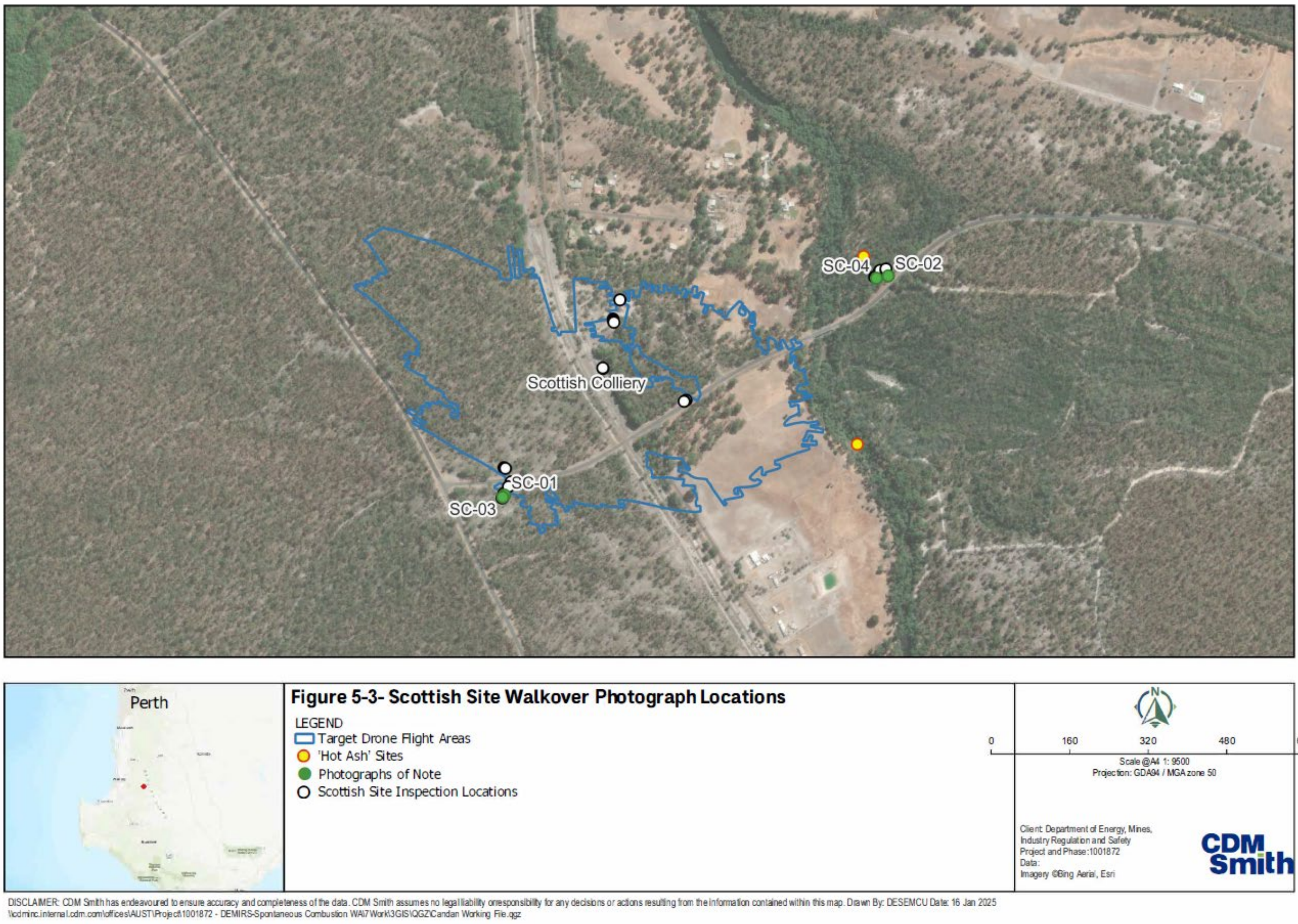

Figure 5-3 - Location of site walkover photographs for Scottish targeted assessment area

Scottish site walkover photographs of note	
SC01 – High surface temperature reading in organic matter. 	SC02 – Historical stockpile surrounded by vegetation. 
SC03 - High surface temperature reading in organic matter. 	SC04 - Historical stockpile surrounded by vegetation. 

5.4 Interviews with DBCA representatives

CDM Smith met with representatives from the DBCA on 14th November 2024 and 12th December 2024. The purpose of the meeting was to understand the experience from DBCA personnel who had attended to fires at inferred 'hot ash' locations. Key information provided during these emails and follow up correspondence is summarised below:

- The fires inferred to involve carbonaceous shale, or 'hot ash' areas are understood to have been started from bushfires or deliberately lit fires and have needed an ignition source that is slow and long burning such as tree branches, roots or fallen trees. For example:
  - A recent fire at an inferred 'hot ash' area was located near the town centre of Collie at the old Moira Colliery (BF 094). It is understood that the fire has a high likelihood of being deliberately lit. DBCA indicated that the fire area had a combination of peat and carbonaceous shale. The fire was approximately 15ha in size of which approximately 4 to 5 ha had hot hash present and remained active for approximately 3.5 months. DBCA indicated that a fire of this size in non-'hot ash' areas will take approximately 10 days from initial attack to shut closure on our Bushfire Reporting System. This includes mopping up and ensuring that the fire is either extinguished fully, or safe. Approximately 150,000 L of water was applied for approximately 30 days.
  - Another fire in an area of inferred carbonaceous shale was at a large stockpile approximately 8 m high, southeast of Collie. The fire had been burning for several months and it was thought winter rainfall would extinguish the fire but despite high winter rainfall, the fire was not extinguished. To extinguish the fire, the soil had to be carefully excavated, and thousands of litres of water applied (e.g., the Stockton Fire across from the Stockton Lake entrance needed 450,000 L of water, which contained 1% sodium carbonate as a wetter). The temperature of fire was reported to be 850°C and climbing using a K-type thermocouple probe. Brown coloured steam was observed when water was applied.
  - Other 'hot ash' fires in the district have resulted from prescribed burns or bushfires igniting the material.
- Crust that had formed at surface in an area, currently identified as a 'hot ash' location had appeared solid but once stepped on, collapsed into the 'hot ash'. As a result, a firefighter was seriously burnt at Western Deep 6, south of Muja power station, when stepping on crust of 'hot ash'. DBCA believed that the heat caused the topsoil (clay) to form a crust, similar to a baking process.
- The DBCA representatives also noted:
  - Peat fires tend to produce a dark coloured steam while carbonaceous shale fires produce a brown coloured steam.
  - They are not aware of evidence that inferred carbonaceous shale fires at the surface, had resulted from spontaneous combustion of mine waste materials.
  - They are not aware of evidence that inferred carbonaceous shale fires at the surface have ignited from spontaneous combustion of naturally occurring outcrops of shales.
  - The fires in the areas of inferred coal and carbonaceous shale materials appear to burn hotter and longer.
  - Handheld heat measuring probe, handheld thermal camera, and aerial thermal camera techniques have been used by DBCA to identify heat sources.
- With regards to fire management techniques, DBCA indicated that:
  - Class A firefighting foam known as Phos-Chek is also used to fight the fires. Flood 'mop up' with water and Phos-Chek in 'hot ash' areas has proven to be the only effective combatting method.
  - An excavator mounted penetrating rod with water spray was used at the WD06 'hot ash' fire. However, this technique relies on the excavator being able to safely access the site due to the limited reach of machine. The Stockton fire involved large volumes of water and DBCA indicated that attempting to jet water into the 'coal spoil' resulted in ignition of material.

The above information is not able to be confirmed without detailed documentation, photographs and the opportunity to have inspected the areas identified immediately after the occurrence of the fire. However, the information helps to improve the understanding with respect to the potential cause of the observed, 'hot ash' or exacerbated bushfires in the Collie area.

Section 6 Thermal Drone Survey

6.1 Objective

A thermal drone survey was conducted to capture relative ground temperatures across the Moira, Stockton and Scottish investigation areas.

The objectives of the thermal drone survey were to:

- where possible identify the presence of areas of elevated ground surface temperatures that might be additional target sites for the site investigation forming Part 2 of the project.
- examine whether this method has the potential for ongoing use to identify areas of elevated temperature and inferred elevated potential risk of spontaneous combustion.

6.2 Method

In choosing the thermal drone survey method it was understood from discussions with DEMIRS that some of the stockpiles or mounds of coal and carbonaceous materials could be small in extent, i.e., a few metres in diameter. The field visit and literature review also indicated that elevated temperatures may also be small in extent, for example elevated ground temperatures due to features such as thermal venting. As such, a thermal camera, model DJI ZH20T, was used and flown at a survey height of approximately 100 metres to capture a relatively high resolution.

The drone and thermal camera were operated by National Drones and used to survey for elevated ground temperatures within the three targeted assessment areas: Moira Colliery, Stockton Colliery and Scottish Colliery. The survey was carried out between the hours of 1 am and 4.30 am on the 29th November 2024. In additional, high-resolution imagery and digital elevation survey was carried out during the daytime. The thermal survey flight paths for each site are presented in Figure 6-1, Figure 6-2 and Figure 6-3.`

Each image captured an area of approximately 60 metres by 80 metres with each image pixel representing an area of approximately 8 cm to 10 cm. Each image captures the relative temperature range within each image, not absolute temperature.

The thermal images were then manually reviewed by CDM Smith personnel to look for areas of potentially elevated temperatures using a visualisation software interface provided by National Drones.

The number of images captures for each targeted area are:

- Moira – 44 images
- Scottish – 559 images
- Stockton – 2295 images

Figure 6-1 - Moira flight path and imagery locations (red diamonds)

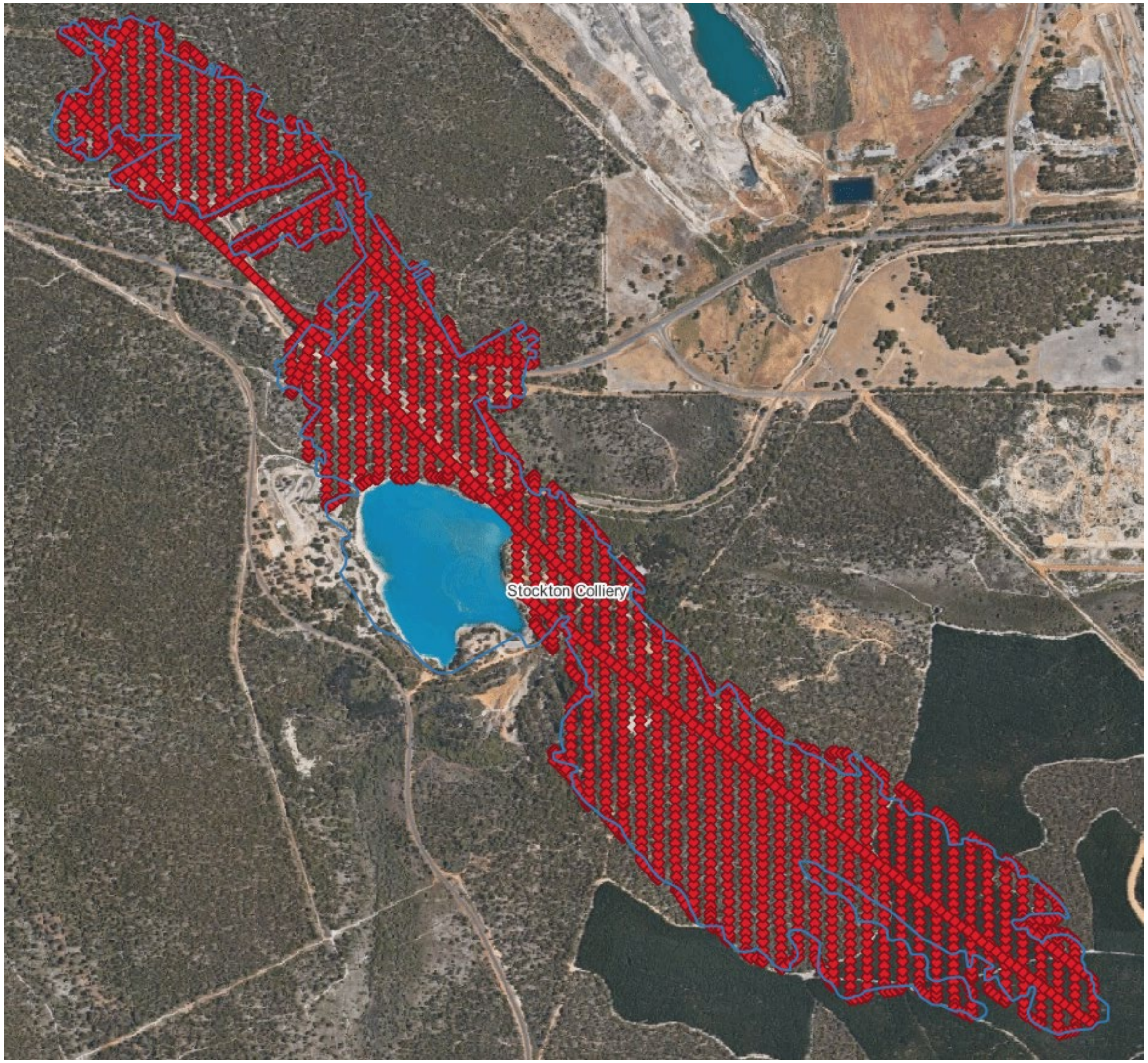

Figure 6-2 - Stockton flight path and imagery locations (red diamonds)

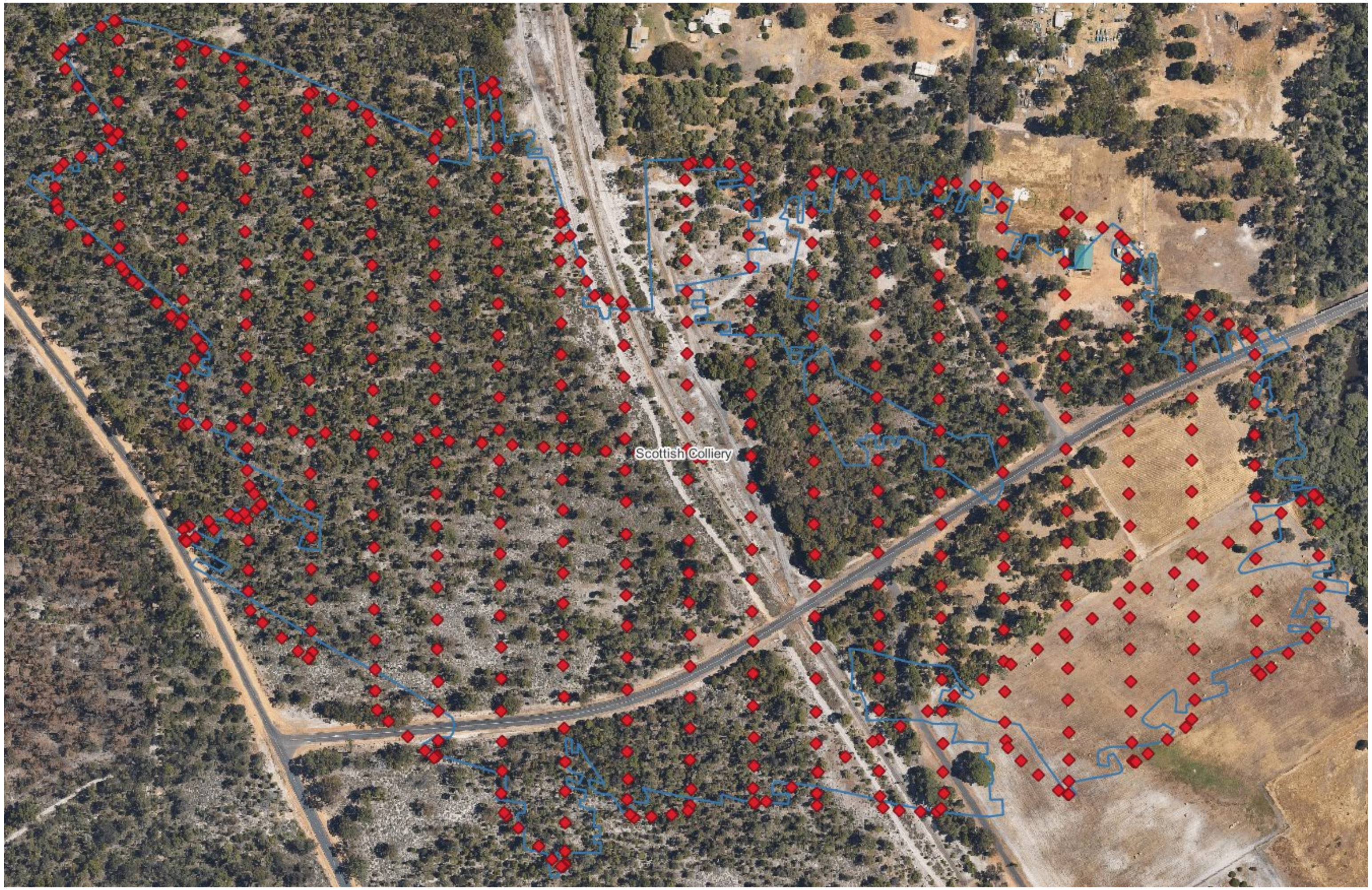

Figure 6-3 - Scottish flight path and imagery locations (red diamonds)

6.3 Results - thermal imaging

The typical temperature ranges were between 2°C to 6°C (refer Figures Figure 6-4Figure 6-5). Features such as roads and exposed earth often returned slightly elevated temperature, presumably due to heat retention from the previous day.

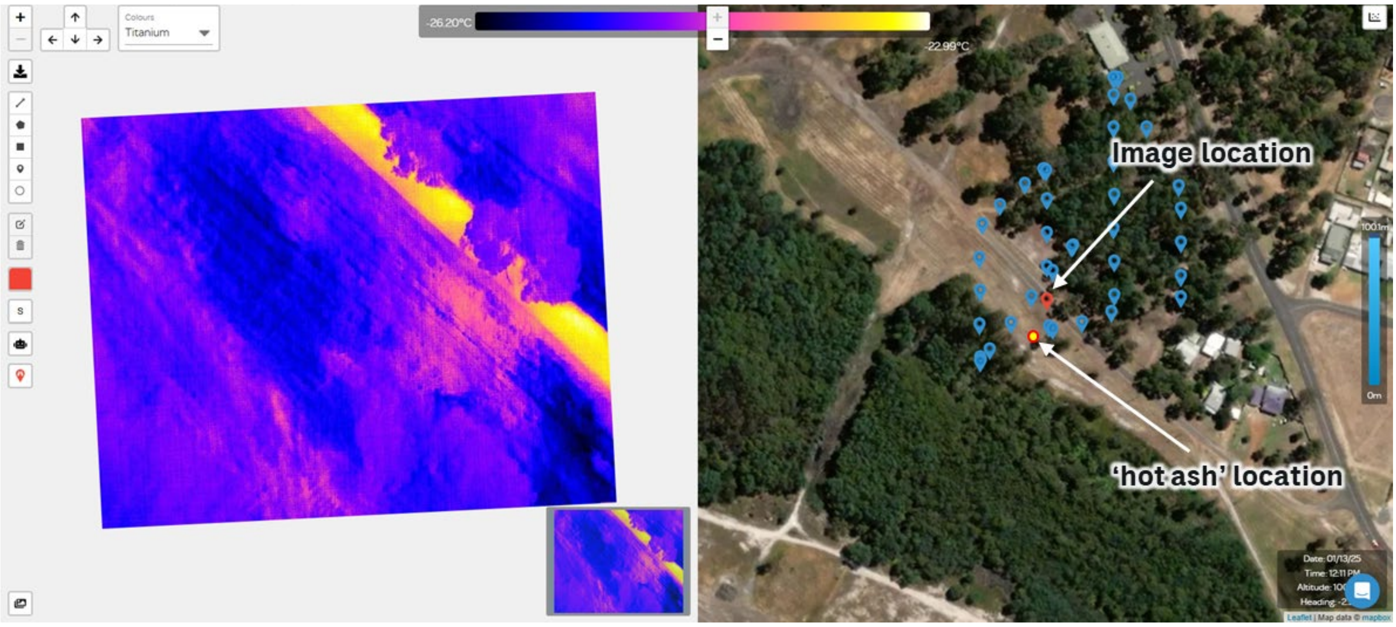

Figure 6-4 Typical thermal image for the Moria targeted area in the proximity of a previously identified 'hot ash' location.

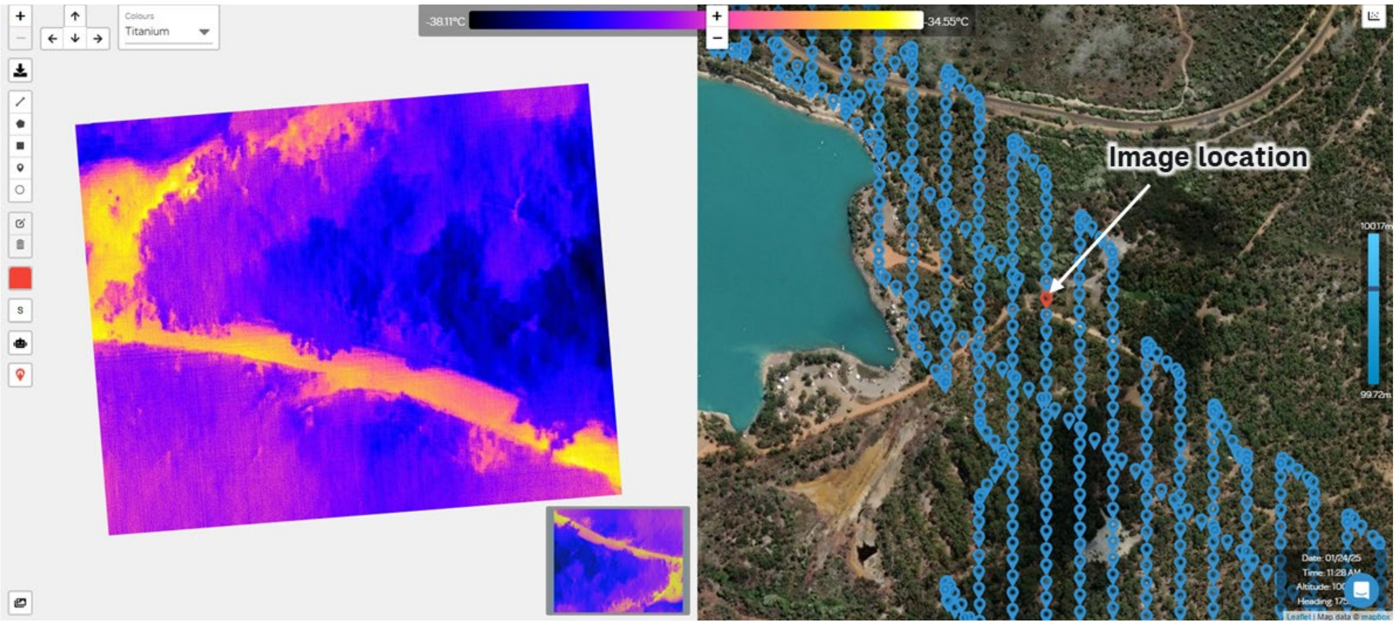

Figure 6-5 Typical thermal image for the Stockton targeted area.

The largest temperature range recorded was 35°C, located on the edge of a 'hot spot' area to the west of Stockton Lake (Figure 6-6).

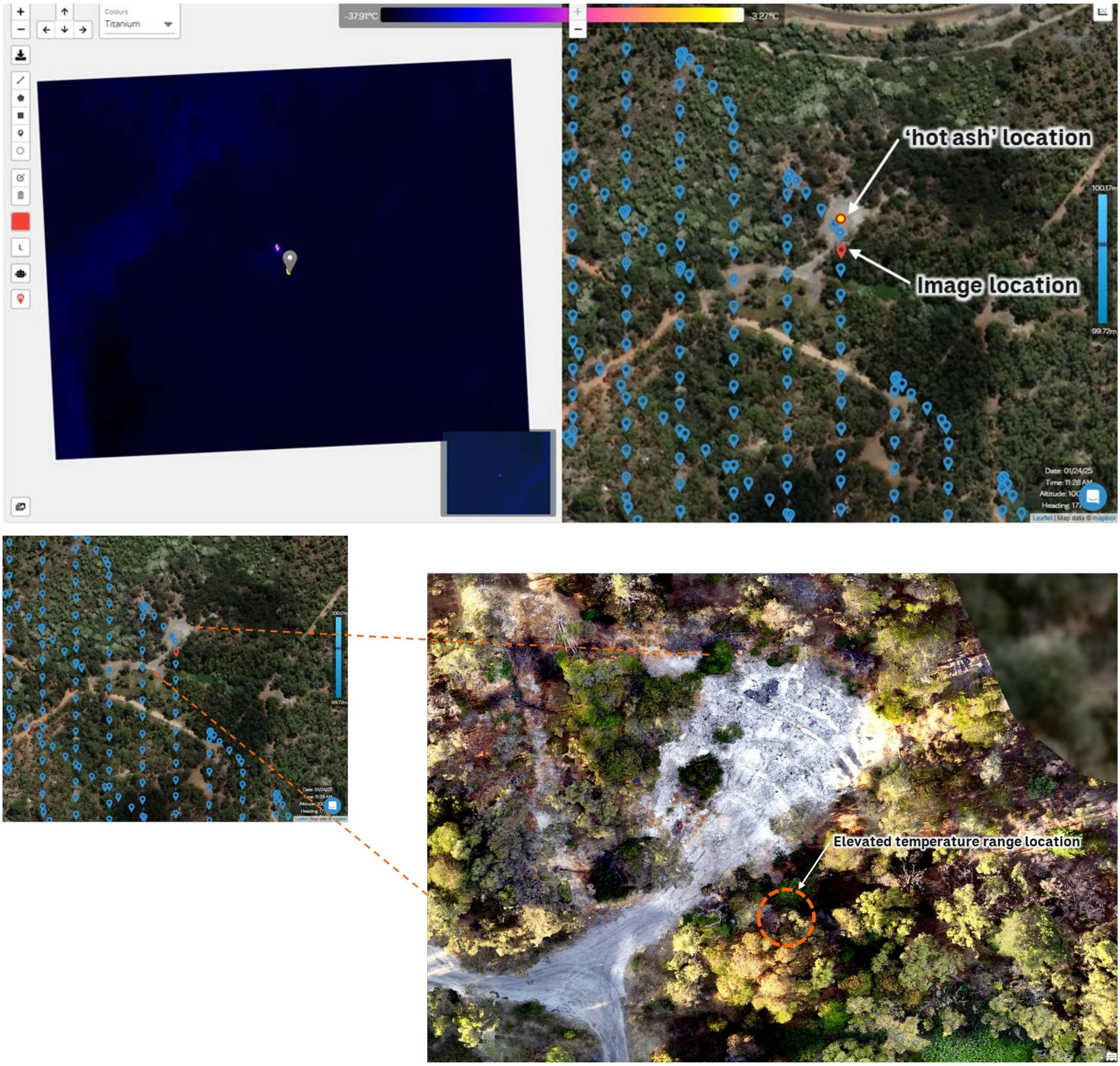

Figure 6-6 Location of elevated temperature range immediately adjacent to the Stockton targeted assessment area.

No other areas of elevated temperature range were identified. Much of the survey area has a relatively dense tree canopy coverage which limits the ability of the thermal camera to measure the ground temperature. As such, there may be areas within the targeted survey areas where elevated temperatures are present that were not detected. In addition, many of the 'hot ash' locations are not within the targeted assessment areas and were therefore not surveyed. One 'hot ash' location was situated within the Moira targeted assessment area and did not indicate the presence of an elevated temperature range (Figure 6-4). However, there remains the possibility that other 'hot ash' locations may return elevated temperature ranges similar to that observed for Stockton.

6.4 Summary

The thermal drone survey generated 2,908 images across the three targeted assessment areas: Moira, Scottish and Stockton. The typical temperature ranges were between 2°C to 6°C and only one elevated temperature location was identified on the edge of the Stockton targeted assessment area.

Overall, the thermal imagery survey approach may be a useful additional tool to assess other known and exposed 'hot ash' or reactive mine waste material / stockpile locations. However, its use in densely treed areas may be limited.

Section 7 Preliminary Remediation Option Considerations

Options for remediation or hazard reduction of potentially combustible coal or carbonaceous shale including spontaneously combustible materials in the targeted investigation areas, largely centre around mitigation of one element of the 'fire triangle':

- oxygen (limit exposure of material to air, to reduce combustion potential).
- ignition source (remove opportunity for exposure to ignition source or heat build-up), and
- fuel (remove fuel source or isolate potentially combustible materials from oxygen and ignition sources).

Factors which influence selection of management or remediation options include:

- Technical considerations. Remediation options are generally screened for their technical ability to manage or remediate, before further considerations are made.
- Economic considerations. Preferred technical solutions may not be considered economically viable or may not be commercially available in the works area.
- Logistical considerations. The ability of the management or remediation measure to be implemented may be restricted due to logistical constraints such as access, availability of utility services, size of area, impracticability of application, environmental considerations, availability of trained personnel to perform works and so on.

Further, the nature and spatial distribution of potentially combustible materials to be managed influences potential management and remediation options. It may be that following assessment and delineation works, one or more remediation approaches are considered to be required based on risks and the aforementioned factors.

For potentially combustible coal or carbonaceous materials, including spontaneously combustible carbonaceous materials, industry knowledge is largely drawn from mitigation of combustion potential within coal industries and mining operations. Options for remediation and management may also be considered as potential 'short-term' controls or 'longer-term' controls, where:

- Short-term controls may be initially very effective at mitigating potential combustion including spontaneous combustion, however, would not be viable to be maintained for longer term management. Short-term approaches may be utilised to reduce risks of combustion whilst long-term controls are being established.
- Long-term controls may ultimately be more passive in nature, however, may require significant design and construction works to be established and may require use of short-term controls during their establishment.

Options that have been identified to date include:

- Excavation and removal of potentially combustible materials from the area. Centralisation of the materials at a specifically designed long-term holding area with appropriate utility services available to reduce fire risks.
- Placement of cover, such as a compacted clay, over potentially spontaneously combustible / combustible materials to limit exposure to oxygen and other ignition or heat sources. This could occur in a centralised location through the use of a purposely designed and operated repository facility to improve long term management outcomes.
- Moisture control to maintain moisture and limit oxygen levels such that potential for spontaneous combustion is reduced. This could include flooding of materials.
- Should areas of larger potentially spontaneous combustible materials be identified, use of thermal venting to reduce potential for build-up of heat through management of potential fuel load and / or ventilation in each area. This may be achieved through creation of smaller covered piles of material, spaced apart to reduce potential for heat transfer.
- Use of gels or foams to limit oxygen exposure, however, this approach may not have long term viability.

Potential remediation and management options will be further assessed at a future stage once the additional investigation data is available. Notwithstanding, our experience is that remedial options are likely to include isolation of fuel loads from interaction with bushfires either through:

1. in situ clay capping and revegetation to minimise erosion of the capping, or
2. removal of the coal and carbonaceous material fuel load to a repository prior to clay capping and revegetation.

For materials with low pyrite content and low fuel load the former remedial strategy may be appropriate whereas for material with high pyrite content and substantial fuel load the latter remedial strategy may need to be considered. A third option could involve option (1) and/or (2) coupled with blending of natural soil/clay materials with carbonaceous materials that poses elevated fuel loads to reduce the propensity for blended materials to combust or self-heat to ignition.

Section 8 Summary of Desktop Review

8.1 Overview

The Collie basin hosts numerous geological units that contain coal and carbonaceous shales. These coal and carbonaceous shales have been mined in the basin since the late 19th century. As a result of its extensive mining history, 'stockpiles' of mine waste materials and overburden associated with legacy coal mining have been observed in areas surrounding historic mining operations, as evidenced during the site visit.

The mine waste materials may contain carbonaceous materials and pyrite which may present a hazard due to its potential to present a combustion hazard and to increase the intensity and duration of bushfires in the area.

A desktop review was therefore undertaken to:

- Briefly document the Collie coal mining history in manner that provides context for the possible sources of carbonaceous materials that may exacerbate bushfires in the region.
- Improve the understanding of the physical and chemical characteristics of the mined waste materials that may have been placed at the surface to help understand the propensity of these materials to present a combustion hazard.
- Undertake a preliminary assessment of available information in relation to the distribution of mine waste materials within the area of interest that may contain carbonaceous or reactive carbonaceous materials.
- Support identification of areas for future, targeted site investigation.
- Provide a preliminary summary of options for remediation and hazard reduction of near surface and combustible carbonaceous materials.

Key findings from this desktop assessment are:

- The presence of carbonaceous materials in the regolith or spread across the surface, may exacerbate fires in the area if they are found to contain reactive pyrite and/or carbonaceous material of sufficient calorific value, mass and extent.
- There was no observed correlation between areas inferred to be 'hot ash' and the underlying geology. Anecdotal information suggests the 'hot ash' areas are associated with historical mine wastes (dumping/stockpiling).
- No naturally occurring outcrops of carbonaceous material or coal were observed during the preliminary site visit. This is consistent with:
  - the geology which indicates that unconsolidated gravels, sands, silts and clays of the Nakina formation overly the Permian coal and carbonaceous shale units
  - the history which indicates that Collie coal was first identified in the banks of the deeply incised Collie River.

  However, given the significant mining disturbance in the area and intra-basinal faulting of the basin, it is possible that there is outcropping of carbonaceous material and/or coal present within the assessment area. Of note, the depth of mining at Scottish Colliery was as shallow as 5 m and a drilling program conducted by the Minerals and Energy Research Institute of Western Australia identified a 1.5 m thick coal seam at a depth of 8.2m at Moira Colliery.
- Literature suggests that stockpiled coal and carbonaceous shales can have the propensity for self-heating to ignition (i.e. spontaneously combust). This review did not identify evidence to suggest spontaneous combustion of historical mine waste stockpiles has occurred in recent times. However historic records suggest that spontaneous combustion may have occurred during mining operations. Also, evidence of higher ground temperatures compared to adjacent ground and/or air temperatures were identified at one location each, in the Stockton and Scottish collieries target investigation areas. At Scottish Colliery the location also indicated the presence of a sulfur-like encrustation. These features are characteristic of thermal heating due to oxidation of reactive pyrite that may occur in coals or carbonaceous shales.

- During the site inspection, the presence of stockpiles or 'hot ash' areas were not found to correlate with higher temperatures compared to surrounding ground and/or air temperatures, however coal and carbonaceous shale like material was observed across several locations.
- The most likely effective remedial options will depend on the pyrite content and calorific value of the material but could include in situ clay capping and revegetation to minimise erosion of the capping, placement in an engineered repository, or blending of carbonaceous material with soils to reduce fuel loads and self-heating potential and in combination with either of the prior options.

8.2 Conceptual understanding

Due to the long history and reworking of the land, the in-situ waste materials and stockpiles could be highly variable in composition, comprising natural near surface Cretaceous era soils of the Nakina formation, coal fragments and fines, coal rejects, carbonaceous shales and other interburden sediments.

The DBCA observations that bushfires in 'hot ash' areas appear to burn hotter and longer may be an indication of the presence of carbonaceous shale or mine waste materials containing coal fragments of sufficient calorific to combust in the presence of a bushfires. The review has indicated that:

- Carbonaceous materials, if present at surface are most likely to be waste materials from the mining activities rather than naturally occurring.
- The carbonaceous materials could comprise carbonaceous shale from inter-seam sediments, coal fines or other coal containing waste such as coal rejects.
- The coal or carbonaceous shale could be reactive, i.e., contain pyrite or similar reactive minerals such as marcasite.

The presence of a coal and carbonaceous material fuel load could also contribute to the increased length of time and temperature at which these materials burn. The spreading of combustion within mine waste stockpiles or in near surface soils, particularly after the above ground fire is extinguished, would also be controlled by the connectivity of materials that have sufficient mass and calorific value. In other words, laterally connected layers of combustible materials could continue to burn and spread in the near surface soils. The more extensive and continuous the combustible carbonaceous materials are in the ground the more capability for the fires to spread in the ground and the greater the difficulty to put out the inground fire. Mine waste materials may have been pushed out in layers during mine operations and over time which would increase the potential for this connectivity to occur in the Collie area.

In addition, if materials with carbonaceous content of sufficient thickness and calorific value become ignited, then the combustion could transmit downward making it more difficult to extinguish and potentially create voids. The presence of crust over the void into which the firefighter fell may relate to the formation of sulfur encrustations or white hydrated irons sulfates at the surface that can occur as a result of subsurface heating or combustion of carbonaceous material (refer Section 3.4).

The higher temperatures may also be related to the presence of reactive pyrite in the carbonaceous materials which could act as an accelerant. This would be influenced by the dimensions of the carbonaceous waste material, as the volume of material relates to heat production while the area across which the material is spread affects heat loss (Restuccia et al., 2017). Therefore, with sufficient volume, self-heating capacity and presence of reactive pyrite, hotter temperatures may be reached. Some of this material may have the chemical properties and mass within the waste materials such that the material could self-heat to ignition. However, it is important to note that DBCA has not indicated that recent bushfires are a result of this.

The above concepts are based on our understanding of carbonaceous material combustion processes but are not able to be confirmed without detailed documentation, photographs and the opportunity to have inspected the areas identified immediately after the occurrence of the bushfire.

Table 8-1 outlines this conceptual understanding in further detail in relation to, issue of concern, source of the problem, location of problematic mine waste materials, composition of the 'hot ash' material, combustibility and reactivity of the mine waste materials.

The table also indicates key identified gaps in our understanding and provides potential approaches to build on the current knowledge.

Table 8-1 Summary of conceptual understanding, information gaps and potential approaches to build on the current knowledge

What we conceptually understand?	Identified gaps in the understanding	Potential approaches to build on the current knowledge
Issue		
▪ Bushfires have occurred in the Collie coal region that are hotter and more difficult to control when compared to other bushfires. ▪ Some bushfires have resulted in subsurface voids containing hot embers / ashes into which firefighters have fallen and been seriously injured. ▪ This presents an increased safety risk to both firefighters and the public.		
Source of the problem		
▪ The review indicates that the source which is referred to by DBCA as 'hot ash' or carbonaceous shales is likely to be associated with mine waste materials left near the surface (i.e. 1 to 2 metres depth) during historic mining activities. ▪ There is a potential for coal or carbonaceous shale seams to be present at relatively shallow depth (i.e. around 5 metres). ▪ DBCA observations relating to the cause of ignition of recent bushfires have not suggested that they are a result or spontaneous combustion of reactive carbonaceous materials. ▪ The observation that the bushfires burn hotter and longer may be a general indication of the presence of carbonaceous materials, not just reactive carbonaceous materials, of overall sufficient calorific value, mass and extent to combust and spread. ▪ The more extensive and continuous the carbonaceous material are in the ground, the more capability for the fires to spread and the greater the difficulty to put out the inground fire. ▪ The thermal drone survey identified a 'hot spot' in the Stockton area which is adjacent to a former 'hot ash' fire which may indicate the actual presence of reactive carbonaceous material or ongoing combustion of carbonaceous material in the ground.	▪ The location and characteristics of hazardous, i.e. combustible and/or reactive carbonaceous mine waste material is not well understood. ▪ Refer to rows below for further detail.	▪ The 'hot spot' at Stockton should be inspected as soon as practicable.

What we conceptually understand?	Identified gaps in the understanding	Potential approaches to build on the current knowledge
Location of problematic mine waste materials		
▪ There are: – existing stockpiles at Moira, Stockton and Scottish collieries that may contain mine waste materials – areas identified as 'hot ash' locations ▪ Historic practice could also have resulted in the placement and spreading of wastes across the surface followed by revegetation. This would make these mine waste materials hard to identify.	The location of the mine waste materials that are inferred to exacerbate the bushfires is not known: ▪ The locations of all mine waste stockpiles have not yet been identified ▪ The location and extent of all bushfires with exacerbated temperature and duration characteristic is not defined.	▪ Conduct a detailed site history assessment to attempt to: – understand locations and extent of former open cut and now backfilled abandoned mines – locate former mine stockpile or mine waste material placement areas – locate underground mine entrance shafts with the inference that a waste stockpile may have been nearby. ▪ Obtain improved history of fires from DBCA and map location and extent of exacerbated fires ▪ Conduct visual survey of area. ▪ Conduct LiDAR survey supported by digital analysis to identify potential stockpiles or filled/mounded areas followed by visual verification. ▪ Examine available historic aerial photographs to identify cleared areas or recent regrowth areas.
Composition of the 'hot ash' material		
▪ Due to the long history and reworking of the land, the in-situ waste materials and stockpiles could be highly variable in physical and chemical composition. ▪ The mine waste materials could be comprised of: – carbonaceous shales – remnant coal fragments – coal fines – non carbonaceous overburden or inter-seam sediments – coal rejects – a mixture of the above.	▪ The physical and chemical composition of the mine waste materials is not well understood. ▪ There is limited available information on the physical and chemical composition of the inter-seam sediments, in particular the carbonaceous shales at Collie.	▪ Consider an initial field investigation to obtain an indicative characterisation of mine waste materials, chemical composition and extent. ▪ Consider targeting: – waste stockpiles – exacerbated bushfire areas, in particular the margins which may not have been subject combustion – potentially disturbed ground if present near to these areas. ▪ Work with DBCA to help inform target locations.

What we conceptually understand?	Identified gaps in the understanding	Potential approaches to build on the current knowledge
Combustibility of the mine waste materials		
▪ The potential for carbonaceous mine waste material to combust in situ and also continue to exacerbate bushfires would be influenced by the calorific value of the material and the lateral continuity of these materials which would enable near surface material to continue to burn once the above ground fuel is depleted.	▪ The in situ distribution and continuity of the materials is not well understood.	▪ To the extent possible use the initial investigation to help understand the distribution and extent of carbonaceous and potential combustible materials. ▪ Composition testing to include analyses to understand carbon and pyrite content. ▪ Consider calorific value analyses once the insitu distribution and composition is better understood at a specific location.
Reactivity of the mine waste materials		
▪ DBCA observations relating to the cause of ignition of recent bushfires have not suggested that they are a result or spontaneous combustion of reactive carbonaceous materials. ▪ Available data suggests that the sulfur content of Collie coal and the inter-seam sediments could be which would reduce the potential for sufficient pyrite or similar reactive minerals to self-heat to ignition. ▪ There may be localised increases in the amount of pyrite in coal cleats or fissures within inter-seam sediments. ▪ Historic information suggests occurrence of mine fires related to spontaneous combustion of coal fines or carbonaceous shales.	▪ The reactivity of the mine waste materials and their capacity to self-heat to ignition is not known.	▪ Consider additional testing for material reactivity and capacity to self-heat to ignition once initial indicative characterisation of mine waste materials is completed and the composition better understood.

8.3 Approaches for identifying hazardous combustible materials

8.3.1 Desktop findings

The desktop assessment indicated the following findings in relation to potential methods to identify the presence of carbonaceous materials and reactive carbonaceous materials:

- There was limited capacity to evaluate whether surface topography could be a useful tool to assist with identifying 'hot ash' containing waste stockpiles. Only one 'hot ash' location occurred within the targeted assessment areas and its presence was not discernible from the surrounding topography. However, it is possible that more extensive LiDAR survey data in combination with digital analysis techniques could help to identify areas of disturbed ground that are not consistent with the natural topography and hence provide future targets for investigation.
- The thermal drone survey generated 2,908 images across the three targeted assessment areas: Moira, Scottish and Stockton. The typical temperature ranges were between 2°C to 6°C and only one location of elevated temperature was identified on the edge of the Stockton targeted assessment area. Overall, the thermal imagery survey approach may be a useful additional tool to assess other known and exposed 'hot ash' or reactive mine waste material / stockpile locations. However, its use in densely treed areas may be limited.
- The use of a handheld temperature gauge provided an indication of potential hotspots at one location. This indicates that this could be a useful screening tool to assist in identifying active hot spots that may indicate the presence of subsurface reactive materials, and which can then be targeted for further investigation and or rehabilitation.
- Visual and olfactory observations of the presence of carbonaceous materials and indicators of reactive carbonaceous materials are also useful tools.

8.3.2 Useful field indicators

The desktop review has identified that the following field indicators may be useful field tools to identify hazardous combustible materials for further assessment:

- Presence of coal material as fragment or dust and/or carbonaceous shales.
- Visible cracking in soils or stockpiles which may indicate thermal venting.
- Presence of moisture near cracking in soils or stockpiles i.e., as wet patches from steam generate by subsurface heating.
- Sulfur encrustations or white hydrated iron sulfates appearing as white fibrous crystalline material near surfaces of cracks.
- Presence of carbon monoxide in atmosphere (can be measure through a gas monitoring device).
- Presence of SO_2 or H_2S (can also be measured through a gas monitor but the rotten egg smell may also indicate the presence of these gases without a gas monitoring device).
- Elevated ground temperatures relative to air temperatures.

8.3.3 Laboratory methods

Laboratory analytical methods can be used to further evaluate the potential for material to present a combustion hazard, act as a fuel that might exacerbate a bushfire or be reactive and self-heat to ignition through characterisation of one or more of the following:

- General geochemical composition of the material including but not limited to:
  - total sulfur and chromium reducible sulfur suite to support assessment of oxidisable sulfides (pyrites)
  - total organic carbon and moisture content

  - volatile matter and ash content (analysis methods may be limited by shale properties and suitability).
- Reactivity of the coal/carbonaceous material.
- The incubation period for self-heating under different conditions.
- The effect of temperature, humidity and moisture on the incubation period.

At this stage, the desktop assessment suggests that the combustibility of the mine waste materials should be the focus for initial intrusive site investigation to develop an initial understanding of material composition and extent. Laboratory testing methods that can be used to assess this include:

- Total sulfur and chromium reducible sulfur suite to support assessment of oxidisable sulfides (pyrites).
- Proximate analysis to assess volatile matter, ash content and carbon content (analysis methods may be limited by shale properties and suitability).
- Total organic carbon and moisture content.
- Calorific value analysis

Should field investigations or initial laboratory analyses suggest the presence of reactive carbonaceous materials then the potential for these materials to self-heat to ignition can be assessed by the following methods:

- eR70 Test which is an adiabatic heating test which is used to measure the intrinsic reactivity of coal to oxygen. Reference to an extensive database of R70 results from locations around the world, enable a direct comparison to be made between coals/materials of similar spontaneous combustion propensity.
- Tailored adiabatic oven incubation test procedure – designed to replicate self-heating behaviour from low ambient temperatures, starting at normal in-mine temperatures, with conditions that minimise heat dissipation and ensure sufficient oxygen supply. Compared to the R70 test, there is a larger sample mass used with lower oxygen flow rate. Further, test samples are analysed with their as-received moisture content, which can reveal prolonged temperature increases leading to thermal runaway.
- Incubation period analysis procedure – this test compares the self-heating behaviour of coal or carbonaceous strata from the incubation test against samples with known spontaneous combustion histories. The key indicator being, the time taken for the sample temperature to reach 120°C (tTR), which is converted from laboratory hours to site days, expressed as a range, to account for real-world variability in loosely piled materials.

These laboratory methods enable a better understanding of the likelihood of material to self-heat to ignition and have the potential to be combined with the basic geochemistry data to provide and develop a potential hazard ranking matrix. Once sufficiently developed, this matrix type approach could be used to enable screening of basic geochemistry data from waste materials to understand whether there is increased combustion potential and whether further testing or remedial action should be considered.

8.4 Recommendations and future works

This desktop assessment has provided multiple lines of evidence to support the selection of targeted locations for further investigation to understand the nature and extent of carbonaceous materials and potential combustion hazard in stockpiles and near surface soils.

The intention of the field program and laboratory testing would be to characterise materials from these investigation locations to:

- Help build toward an understanding of whether there are materials that have the potential to present a combustion hazard through understanding material composition and extent.
- If necessary, use the information to further develop an understanding of the chemical factors that can be more readily analysed in the field or standard laboratory analyses to help identify surface materials that have the potential for spontaneous combustion or that may act as an additional fuel in a bushfire.
- Assist in informing the remediation options available to DEMIRS to manage and ultimately reduce risk associated with bushfires.

The site investigation is to be developed in consultation with DEMIRS and it is suggested that this includes input from DBCA to capture their knowledge of the area to help focus the investigation.

At this stage it is suggested that a targeted field investigation is conducted at first to gather initial information in relation to the composition of mine waste materials in stockpiles or spread across the surface. This program should be focussed on collecting basic characterisation data in relation to the combustibility of the materials using the analyses outlined in Section 8.3.3.

Once more information is gathered, or the site investigation indicate the likely presence of reactive carbonaceous materials then more advance characterisation methods can be considered.

Key considerations when selecting areas for further investigation are:

- Presence of coal material or potentially carbonaceous shales at the surface.
- Proximity to identified 'hot ash' location or 'hot ash' stockpiles.
- Proximity to a known, exacerbated bushfire, ideally at the edges where mine waste materials may occur that have not burnt.
- Observations from the site visit or future visits, including physical indicators such as:
  - elevated ground temperatures
  - visible cracking in soils or stockpiles
  - sulfur residues or white hydrated iron sulfates appearing as white fibrous crystalline material
  - presence of rotten egg smell (hydrogen sulfide indicator)
  - visual observations of iron sulfides.
- Areas showing evidence of reworking or anomalous vegetation or surface workings.
- Proximity to known collieries as an indicator of the potential for mine waste material or stockpiles to be present in the area.
- Land use and proximity to human activities or resources as indicator of elevated risk in the event of a fire.

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