MEMO

To: s74

From: s74

CC:

s74

Date: March 2, 2021

Re: Narrabri Gas Project Residual Drilling Materials Land Application Rate Assessment

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Introduction

This memorandum provides an assessment of land application of residual drilling materials (RDMs) to well pads as part of the Narrabri Gas Project (NGP). The assessment compared a range of methods (which align with standard industry practices) that may be employed for the management of RDM including:

- Method 1 – Thin spreading or spraying at surface and use of equipment and/or natural processes to incorporate into the upper 150 millimetres (mm) of the soil profile.
- Method 2 – Spreading and deeper incorporation into the soil profile (up to 0.5 metres [m]) using mechanical processes.
- Method 3 – Mix bury cover with a minimum of 0.5 m of surface cover to eliminate (human health) direct contact and provide native soils for germination and establishment of shallow-rooted vegetation.
- Method 4 – Deep Burial (burial below 1.5 m) where potential ecological exposures to burrowing organisms are eliminated based on the depth of burial.

The assessment process used recent and historical data and assessments of the drilling muds, chemical constituents, and soils relevant to the local area. In terms of the process of drilling and chemicals used in drilling muds, a full Chemical Risk Assessment (EHS Support, 2016) was completed for the drilling mud systems and geogenic constituents contained within the drilling mud. This chemistry is further evaluated below in terms of development of methodologies for management of RDM on the well pad site. This risk assessment should be referenced for Safety Data Sheets (SDSs), chemical dossiers and derived predicted no effect concentrations (PNECs) for soil ($PNEC_{soil}$) for all the chemicals used with the mud system.

In terms of assessment of geogenic constituents within the RDMs, the above referenced chemical risk assessment includes an assessment of historic sampling results; more recent data is discussed and evaluated in the section below using screening levels. In accordance with the approach used in the Chemical Risk Assessment (EHS Support, 2016), the screening was conducted against relevant and applicable national and international screening levels. The following hierarchy was used for screening criteria and, where screening levels were not available in the first referenced source, screening criteria were sourced from subsequent sources:

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- Human Health
  - Australian National Environmental Protection Council (NEPC) Assessment of Site Contamination Human Health Investigation Levels (HILs) and Health Screening Levels (HSLs) for Recreational Land Use (note, if a residential screening level was available for a contaminant; a recreational HIL or HSL was also available) (NEPC, 2013)
  - United States Environmental Protection Agency (USEPA) Regional Screening Levels for Residential Land Use (USEPA, 2020a)
- Ecological
  - NEPC Ecological Screening Criteria for Areas of Ecological Significance and Residential and Open Spaces (NEPC, 2013)
  - Canadian Council of Ministers of the Environment (CCME) Canadian Environmental Quality Guidelines (CEQGs), Soil Screening Guidelines for Agricultural and Residential and Open Spaces (CCME, 2020)
  - USEPA Ecological Soil Screening Levels (USEPA, 2020b)
- Soil Properties for Plant Growth
  - ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality
  - ANZECC & ARMCANZ (2000) Fresh and Marine Water Quality for Protection of Aquatic Ecosystems and Stock Watering (ANZECC & ARMCANZ, 2000)

For the purposes of the assessment of salinity, the local native plants are considered to be tolerant to very tolerant. Salinity studies in the Brigalow Belt have shown that seeds have limited sensitivity to salt, and soils with a salinity below 20 deciSiemens per metre (dS/m) are suitable for regrowth (Arnold et al, 2014). This is consistent with guidance provided in ANZECC 2000 which shows electrical conductivity (EC) of 20 dS/m to not be deleterious to plant yield (**Figure 1**) for species that tolerant.

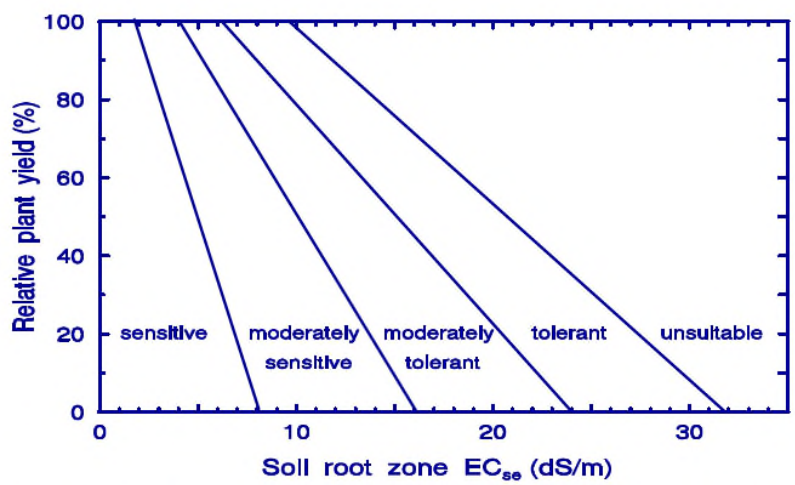

Figure 9.2.4 Relative crop yield in relation to soil salinity (EC_{se}) for plant salt tolerance groupings of Maas and Hoffman (1977). Note that 1 dS/m = 1000 µS/cm.

Figure 1 Relative Crop Yield in Relation to Soil Salinity (Source: ANZECC & ARMCANZ, 2000)

In the context of the land disposal method options described above, a conservative approach has been used where direct contact exposure pathways for human and ecological receptors have been assumed to be complete for Methods 1 through 3. Only for deep burial (Method 4) has the direct contact exposure pathway been eliminated. In the context of the site setting and land use, the ecological exposure pathway is considered the most sensitive. Due to the presence of burrowing organisms, these conservative assumptions are considered appropriate for this screening level assessment.

Consistent with the analytical testing conducted on RDM and the likely geogenic and salt additives contained within the drilling mud, the geogenic assessment of chemicals was only conducted on:

- Metals
- Total petroleum hydrocarbons (TPH)
- Benzene, toluene, ethylbenzene, and xylenes (BTEX)
- Polycyclic aromatic hydrocarbons (PAHs)
- Electrical conductivity (EC)

Chloride is not considered to be a contaminant of concern as the materials will be incorporated into the soil profile (thus no potential for foliar injury) and no crops are being planted on the well pads (no concerns associated with additional cadmium uptake).

Residual Drilling Materials

The following sections present a discussion on RDM data used in this assessment to develop the land application mixing ratios.

Drilling Methods

Consistent with the description of drilling methods contained within the Chemical Risk Assessment (EHS Support, 2016) drilling muds will be recycled and primary drilling cuttings (containing predominantly native materials, including some coal fines) will be applied to land. Based on current methods, residual drilling mud content of the RDM is likely to be less than 10 percent of the total materials (i.e., RDM contains approximately 90 percent cuttings and 10 percent drilling mud). Volumes of RDM generated from drilling are anticipated to be on the order of 200 cubic metres (m^3) per well – 100 m^3 being generated from the vertical, above-seam drill component and 100 m^3 from the horizontal in-seam drill component. The Environmental Impact assessment [EIA] approval does not allow for the management of coal fines from the target coal seams on the well lease, as such only the vertical, above-seam component of the RDM is to be applied to land.

As part of recycling, drilling mud shakers and centrifuges will be used to separate solids from drilling muds with the solids (primarily cuttings) stockpiled for management after completion of well drilling activities. The materials will be stockpiled temporarily and then managed as part of the rehabilitation activities in accordance with one of the aforementioned methods. The rehabilitation of the well pad (establishment of vegetation and habitat) is anticipated to occur over several years; with recolonisation of the area by native fauna not anticipated to occur for one to three years post (commencement of) rehabilitation (M. Sullivan, Eco Logical Australia Pty Ltd personal communication, 22 December 2020). This is important as potential exposures will not occur until conditions are favourable for biological activity (e.g., foraging of the Pilliga mouse).

Chemical Composition of Drilling Muds

The chemical composition of the drilling muds calculated in the risk assessment is presented in **Table 1**, with the exposure point concentration (EPC) in the residual drilling muds reflecting the separation of muds and cuttings as described earlier. RDM contains only about 10 percent drilling mud with the rest made up of cuttings.

The chemical tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione is present in the initially injected material; however, due to rapid degradation, it hydrolyses and/or metabolizes to 100 percent methylisothiocyante (MITC) within three to five days. Therefore, the concentration of tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione within the muds is assumed to be 0 milligram per kilogram (mg/kg).

Table 1 Summary of Vendor Chemicals In Residual Drilling Materials

Constituent Name	CAS No.	Estimated Vendor Chemical Concentration In Drilling Muds (mg/kg)	Exposure Point Concentration in Residual Drilling Materials (10% of mud concentration) (mg/kg)
Copolymer of acrylamide and sodium acrylate	25085-02-3	702	70
Ethylene oxide/propylene oxide copolymer	9003-11-6	24	2.4
Glyoxal	107-22-2	31	3.1
Methanol	67-56-1	3	0.30
Methylisothiocyanate (MITC)	556-61-6	30	3.0
Pentanedial / Glutaraldehyde	111-30-8	300	30
Polyalkylene	9038-95-3	22,260	2,226
Polypropylene glycol	25322-69-4	48	4.8
Potassium chloride	7447-40-7	41,520	4,152
Silicic acid, potassium salt	1312-76-1	22,200	2,220
Sodium carbonate	497-19-8	78	7.8
Sodium carboxymethyl cellulose	9004-32-4	3,117	312
Sodium chloride	7647-14-5	45,600	4,560
Sodium hydroxide	1310-73-2	300	30
Sodium polyacrylate	9003-04-7	1,092	109
Starch	9005-25-8	3,058	306
Tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione	533-74-4	0	0.0
Xanthan gum	11138-66-2	3,060	306

Notes:
CAS = chemical abstract service
mg/kg = milligram per kilogram
% = percent

The EPCs presented in **Table 1** do not include degradation after being stockpiled adjacent to the drilling site or the degradation that will occur over time and before sufficient rehabilitation has occurred (greater than one year), at which time the area will be conducive for recolonisation by fauna. Should a chemical exceed the $PNEC_{soil}$, an application rate has been developed that accounts for stockpiling potential and rehabilitation timeframes. The likely timeframe at which habitat establishment and potential continuous exposures could occur to sensitive receptors is considered to be two years from the date of well drilling. This time frame reflects the total time expended from the date of drilling through well completion, well work-over and establishment of surface infrastructure, physical rehabilitation activities and the natural process of revegetation and ultimately fauna recolonisation.

A comparison of sulphate-based and chloride-based drilling muds was proposed. Since sulphate is a macronutrient and chloride is not a constituent of concern (as noted above) no further assessment was required. The chemical composition of the drilling mud assessed is chloride-based and the geogenic assessment is based on a sulphate-based mud system that contains the same organic constituents as the chloride-based mud.

Analytical Testing of Residual Drilling Materials and Background Soils

Analytical testing of RDM and background soils has been completed at the site as part of historical activities. Cuttings data was collected from December 2013 to December 2015 from the following wells within the project area: DWH24, DWH8A, DWH22, DWH23, DWH25, DWH26, DWH27, DWH27DW, DWH27DW1, DWHYDW2, DWH27DW2, DWH28 and DWH29.

The statistical summary of analytical (geogenic) results for RDM is provided as **Attachment A**, **Table A-1**. For the data evaluation, an assessment has been completed against the screening levels as described earlier.

A summary of background soil data within the NGP is provided in **Attachment A**, **Table A-2**. For a number of constituents, the background concentrations provided are higher than the screening levels. The salinity of soils in the area has been shown to be variable but generally low with a medium EC less than 50 microSiemens per centimetre (µS/cm). In this context, simple blending calculations have been conducted assuming no salt inputs from the native soil (as this is not material to the final soil salinity).

Evaluation Process

This RDM assessment was conducted in multiple phases. First, a screening level evaluation was conducted to identify chemicals of potential concern (COPCs) and develop blending and application ratios to satisfy applicable criteria. Next, to further refine the COPCs identified for geogenic constituents, an evaluation of historic RDM data was completed to address the presence of coal materials which cannot be managed on-site. This involved assessment of geologic information and calculation of coal fine content and associated hydrocarbon content in the RDM materials that can be applied on the well lease. Using the theoretical and empirical data, an evaluation of potential land application rates for the various management methods was developed. It should be noted that additional sampling of RDM materials is anticipated (specifically to evaluate petroleum hydrocarbon) to validate the calculations and assessment provided in this document.

Screening Level Evaluation

The baseline evaluation was partitioned into three steps to develop application rates and mixing ratios. The following sections present each step in the process and the application rates and mixing ratios based on the conservative EPCs.

Step 1 – Preliminary Screening and Selection of Chemicals of Potential Concern

Preliminary screening was conducted to determine COPCs and included comparison of empirical geogenic composition data of the RDM and theoretical chemical constituents of additives from drilling muds within the RDM against screening levels. For the purposes of the assessment, the drilling mud content (and associated chemicals) of RDM was assumed to be 10 percent (consistent with field observations). Only those chemicals which exceeded the screening level or chemical-specific $PNEC_{soil}$ were retained for further evaluation.

Attachment A, **Table A-1** presents the comparison of the empirical geogenic data to the human health and ecological screening levels discussed previously. **Attachment A**, **Table A-3** presents the comparison of the theoretical concentrations of the residual drilling chemicals in RDM compared to the $PNEC_{soil}$ derived in the Chemical Risk Assessment (EHS Support, 2016). Based on this evaluation of the data the following were selected as COPCs:

- Geogenic data:
  - EC
  - Cadmium
  - Nickel
  - >C10-C16 Fraction minus Naphthalene (F2)
  - >C16 – C34 Fraction
  - Benzo(b)fluoranthene
  - Benzo(b+j) fluoranthene
  - Benzo(k)fluoranthene
  - Benzo(b) & Benzo(k)fluoranthene
  - Benz(a)anthracene
  - Chrysene
  - Pyrene
- Residual drilling chemicals
  - Methylisothiocyante (MITC)
  - Pentanedial/glutaraldehyde
  - Polypropylene glycol
  - Sodium polyacrylate

Step 2 – Assessment of Blending Ratios to Achieve Criteria

For each COPC identified in Step 1, an assessment of blending ratios with native soils was conducted for each of the methodologies provided above. The blending ratio was estimated as the proportion predicted (chemical in drilling muds) or measured median/maximum concentrations (geogenic constituents) exceeding the respective screening criteria. The estimated blending ratios for all COPCs identified in Step 1 are provided in **Attachment A**, **Table A-4** and **Table A-5** for each of the screening levels for the geogenic chemicals and residual drilling chemicals, respectively.

Step 3 – Assessment of Application Ratios to Achieve Blending Criteria and Acceptance Criteria.

In terms of the methods that are described above, the application rate was calculated based on the volumes provided in **Table 2**. For Methods 1 and 2, the application rates have been developed based on a standard unit of 1 hectare (ha). Where smaller areas (and associated volumes of soil) are available, the calculated application rates in **Table 3** and **Table 4** (described further below) should be adjusted accordingly (for example if only 0.5 ha is available, the values should be multiplied by 0.5 ha). The development of application rates based on a standard area enables easy calculation of application rates based on the specific area available for land application at each well pad.

Table 2 Summary of Land Application Methods

Method	Criteria that Apply	Volume of Soil Used for Blending	Estimated Application Rate
Method 1 – Surface application and mixing into soils in top 150 mm of soil column	Human Health (Direct Contact) Ecological Plant Growth	1 ha and 150 mm soil column = 1,500 m^3	1,500 m^3/required blending ratio for constituent. Lowest application rate retained as criteria.
Method 2 – Surface application and mixing into soils in top 0.5 m of soil column	Human Health (Direct Contact) Ecological Plant Growth	1 ha and 0.5 m soil column = 5,000 m^3	5,000 m^3/required blending ratio for constituent. Lowest application rate retained as criteria.
Method 3 – Mixed with soils and then buried with a minimum of 0.5 m of soil cover	Ecological Plant Growth	Mixing ratio only in materials such that criteria is met	Mixing ratio with volume of soil needed determined by volume of RDM
Method 4 - Mixed with soils and then buried with a minimum of 1.5 m of soil cover	Plant Growth	Mixing ratio only in materials such that criteria is met	Mixing ratio with volume of soil needed determined by volume of RDM

Notes:
ha = hectare
m = metre
m^3 = cubic metre
mm = millimetre
RDM = residual drilling material

As described above, a comparison of sulphate-based and chloride-based drilling muds was proposed but based on sulphate being a macronutrient and chloride not being a constituent of concern (as noted above) no further assessment was warranted.

Screening Level Evaluation and Mixing Ratios

Using the evaluation process discussed in the previous section, the proposed application and mixing ratios were calculated. **Attachment A**, **Table A-6** and **Attachment A**, **Table A-7** present the mixing ratios calculated for each method presented above for each COPC. **Table 3** presents a summary of the mixing ratios based on the median chemical concentrations from the geogenic chemicals and the residual drilling chemicals COPCs with a period of two years elapsing before recolonisation and potential exposure occurs. **Table 4** presents a summary of the mixing ratios based on the maximum chemical concentrations from geogenic chemicals and the residual drilling chemicals COPCs with an identical two-year period.

As described above, the application rates for Methods 1 and 2 have been developed for a standard unit of 1 ha. In the context of physical application in the field, areas less than 1 ha will be available and these numbers should be multiplied by the available area (for example multiply application rate by 0.5 if 0.5 ha is the available area for application) to define application rates. Where specific risk driving chemicals (as noted in **Table 3** and **Table 4**) are not present, then higher application rates can be supported. The technical appendices should be referenced to determine these higher application rates.

Table 3 Summary of Application Rates/Mixing Ratios Based on Median Concentrations in RDM and Theoretical Chemical Concentrations from Drilling Mud

Mud Mixing Ratio	Application rate (m^3/ha)	Assumptions
Method 1 – Surface application and mixing into soils in top 150 mm of soil column	101	Materials will be temporarily stockpiled prior to application as part of rehabilitation activities. Management will involve mixing of the RDM into the top 150 mm of soil across the well pad (1 ha area). Two years will lapse between drilling commencement and rehabilitation/recolonization. Risk driver is >C10- C16 Fraction minus Naphthalene (F2) in sulphate-based mud geogenic data. **Note: driven by historical data which has elevated concentrations.**
Method 2 – Surface application and mixing into soils in top 0.5 m of soil column	338	Materials will be temporarily stockpiled and ultimately placed as part of the rehabilitation activities. Management will involve mixing of the RDM into the top 0.5 m of soil across the well pad (1-ha area). Two years will lapse between drilling commencement and rehabilitation/recolonization. Risk driver is >C10- C16 Fraction minus Naphthalene (F2) in sulphate-based mud geogenic data. **Note: driven by historical data which has elevated concentrations.**
Method 3 – Mixed with soils and then buried with a minimum of 0.5 m of soil cover	6.4:1 Mixing Ratio (Native soils to RDM)	Materials buried below ecological criteria and buried below 0.5 m. Covered by native soils. Risk driver is EC.
Method 4 – Mixed with soils and then buried with a minimum of 1.5 m of soil cover	6.4:1 Mixing Ratio (Native soils to RDM)	Materials buried greater than 1.5 m; therefore, no completed human or ecological pathways. Deep-rooted vegetation could be affected by EC. Risk driver is EC.

Notes:
EC = electrical conductivity
ha = hectare
m = metre
m^3/ha = cubic metres per hectare
mm = millimetre
RDM = residual drilling material

Table 4 Summary of Application Rates/Mixing Ratios Based on Maximum Concentrations in RDM and Theoretical Chemical Concentrations from Drilling Mud

Mud Mixing Ratio	Application rate (m^3/ha)	Assumptions
Method 1 – Surface application and mixing into soils in top 150 mm of soil column	35	Materials will be temporarily stockpiled and ultimately placed as part of rehabilitation activities. Management will involve mixing the RDM into the top 150 mm of soil across the well pad (1-ha area). Two years will lapse between drilling commencement and rehabilitation/recolonization. Risk driver is pyrene in sulphate-based mud geogenic data. **Note: driven by historical data which has elevated concentrations.**
Method 2 – Surface application and mixing into soils in top 0.5 m of soil column	116	Materials will be temporarily stockpiled and ultimately placed as part of rehabilitation activities. Management will involve mixing the RDM into the top 0.5 m of soil across the well pad (1-ha area). Two years will lapse between drilling commencement and rehabilitation/recolonization. Risk driver is pyrene in sulphate-based mud geogenic data. **Note: driven by historical data which has elevated concentrations.**
Method 3 – Mixed with soils and then buried with a minimum of 0.5 m of soil cover	10.2:1 Mixing Ratio (Native soil to RDM)	Materials buried below ecological criteria and buried below 0.5 m. Covered by native soils. Risk driver is EC.
Method 4 – Mixed with soils and then buried with a minimum of 1.5 m of soil cover	10.2:1 Mixing Ratio (Native soil to RDM)	Material buried greater than 1.5 m; therefore, no completed human or ecological pathways. Deep-rooted vegetation could be affected by EC. Risk driver is EC.

Notes:
EC = electrical conductivity
ha = hectare
m = metre
m^3/ha = cubic metres per hectare
mm = millimetre
RDM = residual drilling material

Refinement of Geogenic COPCs

In accordance with the commitments contained within the EIA for the project and regulatory approvals, Santos has committed to off-site disposal of all drilling cuttings from the target coal sequences. This includes materials from in-seam as well as the vertical well within the target zone.

Historical analysis of RDM sampling has been conducted on materials contained within the target coal sequences and, as a consequence, hydrocarbon content of the RDM is biased high. To further facilitate evaluation of potential risks and assessment of land application rates for above-seam (or Non-Target) material, an evaluation was conducted using boring log data (e.g., Dewhurst 8A) and compositional analysis data for the coals.

To facilitate the long-term management of materials it is proposed that the RDM materials be split into two functional groups based on the EIA commitments:

- Group 1 – Upper (Non-Target) Materials – These comprise materials within the upper 850 metres (m) of the formations encountered through drilling of the upper sections of the vertical section of the wells. The materials are primarily within non-hydrocarbon containing sandstones, claystones and siltstones with some fine interspersed (non-target) coal sequences. Review of the boring logs for wells in the area indicate thin seams which, in aggregate, do not exceed 16 m over the 850 m vertical sequence (in many cases significantly less than 16 m).
- Group 2 – Target Coal Sequences – This comprises the vertical interval between 850 m and 980 m where the target coal sequence is encountered. These comprise thicker seams of coal that can be targeted for in-seam placement of laterals (i.e., horizontal wells) which can be encountered at varying depths within this unit. The coal sequences are similarly contained within a sandstone and claystone dominant formation and, in aggregate, these coals make up 18 m of the 130 m vertical sequence.

In terms of this later grouping (i.e., Group 2), all of these materials (coal seams and overlying and underlying sandstone and mudstones) are to be transported off-site for disposal in accordance with EIA commitments and regulatory approvals. However further segregation may be considered whereby sandstones/claystones/siltstones from these materials are separated from the coal fines and also retained, tested and managed on-site.

Based on the compositional analysis of the sandstone/siltstone/claystones (which are non-hydrocarbon containing) and the chemical analysis of coal sequences, as well as other RDM materials, the relative ratios of hydrocarbon constituents in the Group 1 materials have been determined. Key assumptions and inputs are as follows:

- Group 1 coal content of RDM materials is 2 percent (rounded up from 1.885 based on 16 m of coal in 850 m of formation).
- Hydrocarbon composition of coals based on the RDM testing and maximum constituent concentrations results are presented in **Table 5**.

Table 5 Summary of Hydrocarbon Composition of Coals

Constituent with corresponding ESL	RDM no Silica Gel Cleanup (% of Total Hydrocarbons)	RDM with Silica Gel Cleanup (% of Total Hydrocarbons)
>C10 - C16 Extractable Hydrocarbons (no naphthalene)	8.5 %	1.39 %
> C16 - C34 Extractable Hydrocarbons	65.4 %	9.34 %
> C34 - C40 Extractable Hydrocarbons	6.3 %	2.40 %
PAHs that failed preliminary screening of PAHs		
Benzo(a)anthracene	0.018 %	NA
Benzo (b) fluoroanthene	0.019 %	NA
Benzo (b+j) fluoroanthene	0.009 %	NA
Pyrene	0.041 %	NA
Chrysene	0.058 %	NA

Notes:
% = percent
ESL = ecological screening level
NA = not applicable
PAHs = polycyclic aromatic hydrocarbons
RDM = residual drilling materials

On the basis of the above, the potential concentration in RDM can be estimated as a composite of mixing non-hydrocarbon containing sandstone/siltstone/claystone and the coals. **Table 6** presents the estimated concentrations for Group 1 materials.

Table 6 Estimated Concentration in RDM

Chemical Component	Ecological Criteria	Estimated Chemical Concentration in RDM (% coal multiplied by Constituent Concentration in Coals)	
		RDM no Silica Gel Cleanup (mg/kg)	RDM with Silica Gel Cleanup (mg/kg)
Group 1 (0 to 850 m)			
>C10 - C16 (no naphthalene)	25	16.92	2.8
> C16 - C34	300	130.81	18.7
> C34 - C40	2800	12.63	4.8
Benzo(a)anthracene	0.1	0.035354	NA
Benzo (b) fluoroanthene	0.1	0.037879	NA
Benzo (b+j) fluoroanthene	0.1	0.017677	NA
Pyrene	0.1	0.08586	NA
Chrysene	1.1	0.116162	NA

Notes:
% = percent
m = metres
mg/kg = milligrams per kilogram
NA = not applicable
RDM = residual drilling material

In the context of the mass calculations provided above, petroleum hydrocarbon concentrations (including PAHs) can be eliminated as COPCs for Group 1 materials. This assumption is further supported as the ecological screening levels (ESLs) and Eco-Tox generic screening values used in this assessment were highly conservative (i.e., are not site-specific/receptor specific).

Group 1 Application and Mixing Ratios

Using the evaluation process discussed in the Screening Level Evaluation and Mixing Ratio section, the proposed application and mixing ratios were calculated for the refined Group 1 COPCs. **Attachment A**, **Table A-8** and **Attachment A**, **Table A-9** present the mixing ratios calculated for Method 1 and Method 2 for the refined Group 1 COPCs. **Table 7** presents a summary of the mixing ratios based on the median chemical concentrations from the geogenic chemical, the calculated hydrocarbon content after exclusion of materials from the target coal seams and the residual drilling chemical COPCs, allowing for biodecay over the time period required for rehabilitation/recolonisation. Calculated application rates using the maximum geogenic concentrations were the same as those calculated based on the median concentrations. Additionally, as EC is the risk driver for Method 3 and Method 4, a new mixing ratio was not calculated for the Group 1 COPCs.

As described above, the application rates for Methods 1 and 2 were developed for a standard unit of 1 ha. In the context of physical application in the field, areas smaller than 1 ha will be available and these numbers should be multiplied by the available area (for example multiply application rate by 0.5 if 0.5 ha is the available area for application) to define application rates. Where specific risk driving chemicals (as noted in **Table 7**) below are not present, then higher application rates can be supported. The technical appendices should be referenced to determine these higher application rates.

Table 7 Summary of Application Rates/Mixing Ratios For Group 1 COPCs

Mud Mixing Ratio	Application rate (m^3/ha)	Assumptions
Method 1 – Surface application and mixing into soils in top 150 mm of soil column	234	Materials will be temporarily stockpiled and ultimately placed as part of rehabilitation activities. Two years will lapse between drilling commencement and rehabilitation/ recolonization. Management will involve mixing of RDM into the top 150 mm of soil across the well pad (1 ha area). Risk driver is EC.
Method 2 – Surface application and mixing into soils in top 0.5 m of soil column	781	Materials will be temporarily stockpiled and ultimately placed as part of the rehabilitation activities. Management will involve mixing the RDM into the top 0.5 m of soil across the well pad (1-ha area). Two years will lapse between drilling commencement and rehabilitation/ recolonization. Risk driver is EC.

Notes:
EC = electrical conductivity
ha = hectare
m = metre
m^3/ha = cubic metres per hectare
mm = millimetre
RDM = residual drilling material

Target concentrations for the RDM were calculated using dilution ratios for Methods 1 and 2 and are included in **Attachment A**, **Table A-10.** This table presents the target RDM COPC concentrations developed for Method 1 and Method 2 for application rates of 200 m^3/ha, 225 m^3/ha and 250 m^3/ha. The values provided in the table are for RDM prior to mixing.

References

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Attachment A Tables

Table A-1

Summary Statistics of Geogenic Data
Narrabri Gas Project

			Statistical Summaries						Human Health Evaluation		Ecological Evaluation	
METHOD	Chemicals	Units	Minimum	Maximum	Mean	Median	Stadard Deviation	Detection Frequency	Human Health Screening Level	Maximum Detection Exceed Human Health SL?	Ecological Screening Level	Maximum Detection Exceed Ecological SLs
APHA_2510_B_1:5	Electrical Conductivity @ 25°C	µS/cm	383	7250	3948.1304	4570	1994.00389	23 / 23	NSL	NO	50 Site-specific	Yes
APHA_3112_CV_FIMS	Mercury	mg/kg	< 0.1	0.2	NR	NR	NR	1 / 27	80 HIL	NO	6.6 CEQG	No
USEPA_3060A	Hexavalent Chromium	mg/kg	< 0.5	< 0.5	NR	NR	NR	0 / 5	300 HIL	NO	0.4 CEQG	No
USEPA_6010	Arsenic	mg/kg	< 5	7	6.33	6	0.47	3 / 12	300 HIL	NO	40 EIL/ESL	No
USEPA_6010	Beryllium	mg/kg	< 1	< 1	NR	NR	NR	0 / 5	90 HIL	NO	4 CEQG	No
USEPA_6010	Cadmium	mg/kg	< 0.4	< 0.4	NR	NR	NR	0 / 6	90 HIL	NO	1.4 CEQG	No
USEPA_6010	Cadmium	mg/kg	< 1	< 1	NR	NR	NR	0 / 6	90 HIL	NO	1.4 CEQG	No
USEPA_6010	Chromium	mg/kg	10	16	13	12	2.20	7 / 7	300 HIL	NO	140 EIL/ESL	No
USEPA_6010	Copper	mg/kg	8	52	28	29	12.67	7 / 7	17000 HIL	NO	85 EIL/ESL	No
USEPA_6010	Lead	mg/kg	7	17	12	12.5	3.61	10 / 12	600 HIL	NO	470 EIL/ESL	No
USEPA_6010	Molybdenum	mg/kg	< 2	< 2	NR	NR	NR	0 / 5	390 RSL	NO	5 CEQG	No
USEPA_6010	Nickel	mg/kg	3	31	13.64	8	9.49	11 / 12	1200 HIL	NO	50 EIL/ESL	No
USEPA_6010	Selenium	mg/kg	< 5	0	NR	NR	NR	0 / 5	700 HIL	NO	1 CEQG	No
USEPA_6010	Silver	mg/kg	< 2	0	NR	NR	NR	0 / 5	390 RSL	NO	20 CEQG	No
USEPA_6010	Zinc	mg/kg	15	72	41.71	49	20.80	7 / 7	30000 HIL	NO	230 EIL/ESL	No
USEPA_6020	Arsenic	mg/kg	< 5	26	9.25	6	6.57	8 / 21	300 HIL	NO	40 EIL/ESL	No
USEPA_6020	Cadmium	mg/kg	< 0.4	2.4	NR	NR	NR	1 / 21	90 HIL	NO	1.4 CEQG	Yes
USEPA_6020	Chromium	mg/kg	4	74	19.38	14	16.89	21 / 21	300 HIL	NO	140 EIL/ESL	No
USEPA_6020	Copper	mg/kg	5	56	29.43	27	15.25	21 / 21	17000 HIL	NO	85 EIL/ESL	No
USEPA_6020	Lead	mg/kg	< 5	22	12.44	12	4.87	18 / 21	600 HIL	NO	470 EIL/ESL	No
USEPA_6020	Nickel	mg/kg	3	71	20.71	16	17.79	21 / 21	1200 HIL	NO	45 CEQG	Yes
USEPA_6020	Zinc	mg/kg	6	109	48.67	57	26.67	21 / 21	30000 HIL	NO	230 EIL/ESL	No
USEPA_8015	>C10 - C16 Fraction	mg/kg	< 50	2240	409	180	518	19 / 24	3800 HSL	NO	NSL	No
USEPA_8015	>C10 - C16 Fraction minus Naphthalene (F2)	mg/kg	50	670	363	370	253	3 / 3	NSL	NO	25 EIL/ESL	Yes
USEPA_8015	>C10 - C40 Fraction (sum)	mg/kg	< 50	5910	1745	1130	1691	22 / 24	NSL	NO	NSL	No
USEPA_8015	>C16 - C34 Fraction	mg/kg	< 100	5180	1429	1005	1291	20 / 24	5300 HSL	NO	300 EIL/ESL	Yes
USEPA_8015	>C34 - C40 Fraction	mg/kg	< 100	500	255	230	123	8 / 24	7400 HSL	NO	2800 EIL/ESL	No
USEPA_8015	C10 - C14 Fraction	mg/kg	< 50	650	211	145	190	12 / 24	NSL	NO	NSL	No
USEPA_8015	C10 - C36 Fraction (sum)	mg/kg	< 50	5680	1705	1035	1638	22 / 24	NSL	NO	NSL	No
USEPA_8015	C15 - C28 Fraction	mg/kg	< 100	4770	1379	775	1368	22 / 24	NSL	NO	NSL	No
USEPA_8015	C29 - C36 Fraction	mg/kg	< 100	740	331	220	203	14 / 24	NSL	NO	NSL	No
USEPA_8015_SG	>C10 - C16 Fraction	mg/kg	< 50	110	NR	NR	NR	1 / 5	3800 HSL	NO	NSL	No
USEPA_8015_SG	>C10 - C40 Fraction (sum)	mg/kg	< 50	1040	657	690	327	3 / 5	NSL	NO	NSL	No
USEPA_8015_SG	>C16 - C34 Fraction	mg/kg	< 100	740	557	690	225	3 / 5	5300 HSL	NO	300 EIL/ESL	Yes
USEPA_8015_SG	>C34 - C40 Fraction	mg/kg	< 100	190	NR	NR	NR	1 / 5	7400 HSL	NO	2800 EIL/ESL	No
USEPA_8015_SG	C10 - C14 Fraction	mg/kg	< 50	< 50	NR	NR	NR	0 / 5	NSL	NO	NSL	No
USEPA_8015_SG	C10 - C36 Fraction (sum)	mg/kg	< 50	890	657	800	269	3 / 5	NSL	NO	NSL	No
USEPA_8015_SG	C15 - C28 Fraction	mg/kg	< 100	570	417	550	203	3 / 5	NSL	NO	NSL	No
USEPA_8015_SG	C29 - C36 Fraction	mg/kg	< 100	340	240	230	77.89	3 / 5	NSL	NO	NSL	No
USEPA_8260	Benzene	mg/kg	< 0.2	0.3	NR	NR	NR	1 / 24	120 HSL	NO	8 EIL/ESL	No
USEPA_8260	C6 - C10 Fraction	mg/kg	< 10	67	30	23	18.81	7 / 13	5100 HSL	NO	NSL	No
USEPA_8260	C6 - C10 Fraction minus BTEX (F1)	mg/kg	< 10	66	34.4	23	19.37	5 / 8	NSL	NO	125 EIL/ESL	No
USEPA_8260	C6 - C9 Fraction	mg/kg	< 10	19	14.75	14.5	3.34	4 / 13	NSL	NO	NSL	No
USEPA_8260	Ethylbenzene	mg/kg	< 0.5	0	NR	NR	NR	0 / 24	5300 HSL	NO	1.5 EIL/ESL	No
USEPA_8260	meta- & para-Xylene	mg/kg	< 0.5	1	NR	NR	NR	1 / 24	550 RSL	NO	NSL	No
USEPA_8260	Naphthalene	mg/kg	< 1	< 1	NR	NR	NR	0 / 8	1900 HSL	NO	10 EIL/ESL	No
USEPA_8260	ortho-Xylene	mg/kg	< 0.5	< 0.5	NR	NR	NR	0 / 24	650 RSL	NO	NSL	No
USEPA_8260	Sum of BTEX	mg/kg	< 0.2	3.3	1.14	0.6	1.08	5 / 24	NSL	NO	NSL	No
USEPA_8260	Toluene	mg/kg	< 0.5	2	0.88	0.6	0.56	5 / 24	18000 HSL	NO	10.5 EIL/ESL	No
USEPA_8260	Total Xylenes	mg/kg	< 0.5	1	NR	NR	NR	1 / 24	17000 HSL	NO	10 EIL/ESL	No
USEPA_8260_VOC	Benzene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 5	120 HSL	NO	8 EIL/ESL	No
USEPA_8260_VOC	Ethylbenzene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 5	5300 HSL	NO	1.5 EIL/ESL	No

Table A-1

Summary Statistics of Geogenic Data
Narrabri Gas Project

			Statistical Summaries						Human Health Evaluation		Ecological Evaluation	
METHOD	Chemicals	Units	Minimum	Maximum	Mean	Median	Stadard Deviation	Detection Frequency	Human Health Screening Level	Maximum Detection Exceed Human Health SL?	Ecological Screening Level	Maximum Detection Exceed Ecological SLs
USEPA_8260_VOC	meta- & para-Xylene	mg/kg	< 0.5	0.6	0.55	0.55	0.05	2 / 5	17000 HSL	NO	10 EIL/ESL	No
USEPA_8260_VOC	ortho-Xylene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 5	17000 HSL	NO	10 EIL/ESL	No
USEPA_8270B_PAH	Acenaphthene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 25	Screen Sum of PAH	NO	29 ECO-SSL	No
USEPA_8270B_PAH	Acenaphthylene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 25	Screen Sum of PAH	NO	29 ECO-SSL	No
USEPA_8270B_PAH	Anthracene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 25	Screen Sum of PAH	NO	2.5 CEQG	No
USEPA_8270B_PAH	Benz(a)anthracene	mg/kg	< 0.5	1.4	1	0.8	0.28	3 / 25	Screen Sum of PAH	NO	0.1 CEQG	Yes
USEPA_8270B_PAH	Benzo(a)pyrene	mg/kg	< 0.5	0.7	0.63	0.6	0.05	3 / 25	3 HIL	NO	0.7 EIL/ESL	No
USEPA_8270B_PAH	Benzo(a)pyrene TEQ (Half LOR)	mg/kg	0.6	1.1	0.85	0.85	0.25	2 / 2	3 HIL	NO	NSL	No
USEPA_8270B_PAH	Benzo(a)pyrene TEQ (LOR)	mg/kg	1.2	1.4	1.3	1.3	0.1	2 / 2	3 HIL	NO	NSL	No
USEPA_8270B_PAH	Benzo(a)pyrene TEQ (zero)	mg/kg	< 0.5	1	0.87	0.8	0.09	3 / 25	3 HIL	NO	NSL	No
USEPA_8270B_PAH	Benzo(b)fluoranthene	mg/kg	< 0.5	1.5	1.45	1.45	0.05	2 / 23	Screen Sum of PAH	NO	0.1 CEQG	Yes
USEPA_8270B_PAH	Benzo(b+j)fluoranthene	mg/kg	< 0.5	0.7	NR	NR	NR	1 / 2	Screen Sum of PAH	NO	0.1 CEQG	Yes
USEPA_8270B_PAH	Benzo(g.h.i)perylene	mg/kg	< 0.5	1	0.8	0.8	0.16	3 / 25	Screen Sum of PAH	NO	1.1 ECO-SSL	No
USEPA_8270B_PAH	Benzo(k)fluoranthene	mg/kg	< 0.5	0.6	0.55	0.55	0.05	2 / 25	Screen Sum of PAH	NO	0.1 CEQG	Yes
USEPA_8270B_PAH	Chrysene	mg/kg	< 0.5	2.3	1.83	1.8	0.37	3 / 25	Screen Sum of PAH	NO	1.1 ECO-SSL	Yes
USEPA_8270B_PAH	Dibenz(a.h)anthracene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 25	Screen Sum of PAH	NO	0.1 CEQG	No
USEPA_8270B_PAH	Fluoranthene	mg/kg	< 0.5	2.1	1.47	1.4	0.49	3 / 25	Screen Sum of PAH	NO	50 CEQG	No
USEPA_8270B_PAH	Fluorene	mg/kg	< 0.5	3.6	2.43	2.1	0.85	3 / 25	Screen Sum of PAH	NO	29 ECO-SSL	No
USEPA_8270B_PAH	Indeno(1.2.3.cd)pyrene	mg/kg	< 0.5	< 0.5	NR	NR	NR	0 / 25	Screen Sum of PAH	NO	0.1 CEQG	No
USEPA_8270B_PAH	Naphthalene	mg/kg	0.6	2.5	1.0571429	0.6	0.65	7 / 25	Screen Sum of PAH	NO	10 EIL/ESL	No
USEPA_8270B_PAH	Pentachlorophenol	mg/kg	< 2	< 2	NR	NR	NR	0 / 2	120 HIL	NO	7.6 CEQG	No
USEPA_8270B_PAH	Phenanthrene	mg/kg	< 0.5	5.7	2.7	2.9	1.85	5 / 25	Screen Sum of PAH	NO	29 ECO-SSL	No
USEPA_8270B_PAH	Pyrene	mg/kg	< 0.5	2.1	1.33	1.3	0.55	4 / 25	Screen Sum of PAH	NO	0.1 CEQG	Yes
USEPA_8270B_PAH	Sum of polycyclic aromatic hydrocarbons (PAHs)	mg/kg	< 0.5	21.2	6.16	1.1	7.79	9 / 25	300 HIL	NO	NSL	No
USEPA_8270D	Acenaphthene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 3	Screen Sum of PAH	NO	29 ECO-SSL	No
USEPA_8270D	Acenaphthylene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 3	Screen Sum of PAH	NO	29 ECO-SSL	No
USEPA_8270D	Anthracene	mg/kg	< 0.5	0.6	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	2.5 CEQG	No
USEPA_8270D	Benz(a)anthracene	mg/kg	< 0.5	2.1	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	0.1 CEQG	Yes
USEPA_8270D	Benzo(a)pyrene	mg/kg	< 0.50	< 0.50	NR	NR	NR	0 / 3	3 HIL	NO	0.7 EIL/ESL	No
USEPA_8270D	Benzo(b) & Benzo(k)fluoranthene	mg/kg	< 0.5	1	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	0.1 CEQG	Yes
USEPA_8270D	Benzo(g.h.i)perylene	mg/kg	< 0.5	1.1	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	1.1 ECO-SSL	No
USEPA_8270D	Chrysene	mg/kg	< 0.5	4.6	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	1.1 ECO-SSL	Yes
USEPA_8270D	Dibenz(a.h)anthracene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 3	Screen Sum of PAH	NO	0.1 CEQG	No
USEPA_8270D	Fluoranthene	mg/kg	< 0.5	3.7	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	50 CEQG	No
USEPA_8270D	Fluorene	mg/kg	< 0.5	7.2	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	29 ECO-SSL	No
USEPA_8270D	Indeno(1.2.3.cd)pyrene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 3	Screen Sum of PAH	NO	0.1 CEQG	No
USEPA_8270D	Naphthalene	mg/kg	< 0.5	1.9	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	10 EIL/ESL	No
USEPA_8270D	Phenanthrene	mg/kg	< 0.5	9.8	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	29 ECO-SSL	No
USEPA_8270D	Pyrene	mg/kg	< 0.5	4.3	NR	NR	NR	1 / 3	Screen Sum of PAH	NO	0.1 CEQG	Yes

Notes:

< = less than
°C = degrees Celsius
µS/cm = microSiemens per centimetre
BTEX = benzene, toluene, ethylbenzene, and xylene
CEQG = Canadian Environmental Quality Guidelines
ECO-SSL = ecological soil screening level
EIL = Ecological Investigation Level
ESL = Ecological Screening Level
HIL = Health Investigation Level
HSL = health Screening Level

LOR = limit of reporting
mg/kg = milligrams per kilogram
PAH = polycyclic aromatic hydrocarbon
NA = not applicable
NR = not reported
NSL = no screening level
RSL = regional screening level
TEQ = toxic equivalence quotient

Refer to text for sources of screening levels.

Table A-2

Summary of Background Soils Data within New South Wales
Narrabri Gas Project

CHEMICAL	UNITS	Min	Max	Mean	Median	Standard Deviation	Detection Frequency	Human Health Evaluation			Ecological Evaluation		
								Human Health Screening Level		Maximum Detection Exceed Human Health SL?	Ecological Screening Level		Maximum Detection Exceed Ecological SLs
Electrical Conductivity @ 25°C	µS/cm	7	1420	137.3	37.5	319.6	28 / 28	NSL		NO	50	CEQG	Yes
Mercury	mg/kg	<0.1	<0.1	NR	NR	NR	0 / 18	80	HIL	NO	6.6	CEQG	No
Arsenic	mg/kg	<5	<5	NR	NR	NR	0 / 18	300	HIL	NO	40	ESL	No
Cadmium	mg/kg	<0.4	<0.4	NR	NR	NR	0 / 18	90	HIL	NO	1.4	CEQG	No
Chromium	mg/kg	5	16	8.625	7.5	3.60	8 / 18	300	HIL	NO	140	ESL	No
Copper	mg/kg	6	41	25.4	35	15.55	5 / 18	17000	HIL	NO	85	ESL	No
Lead	mg/kg	5	8	6	6	0.87	8 / 18	600	HIL	NO	470	ESL	No
Nickel	mg/kg	2	36	9.07	3	12.06	15 / 18	1200	HIL	NO	50	ESL	No
Zinc	mg/kg	5	52	26	25.5	19.66	6 / 18	30000	HIL	NO	230	ESL	No
>C10 - C16 Fraction	mg/kg	<50	<50	NR	NR	NR	0 / 18	3800	HSL	NO	NSL		No
>C10 - C40 Fraction (sum)	mg/kg	130	320	197.5	170	75.62	4 / 18	NSL		NO	NSL		No
>C16 - C34 Fraction	mg/kg	130	320	197.5	170	75.62	4 / 18	5300	HSL	NO	300	ESL	Yes
>C34 - C40 Fraction	mg/kg	<100	<100	NR	NR	NR	0 / 18	7400	HSL	NO	2800	ESL	No
C10 - C14 Fraction	mg/kg	<50	<50	NR	NR	NR	0 / 18	NSL		NO	NSL		No
C10 - C36 Fraction (sum)	mg/kg	100	360	177.5	125	107.3	4 / 18	NSL		NO	NSL		No
C15 - C28 Fraction	mg/kg	100	230	160	150	53.54	3 / 18	NSL		NO	NSL		No
C29 - C36 Fraction	mg/kg	100	130	115	115	15	2 / 18	NSL		NO	NSL		No
Benzene	mg/kg	<0.2	<0.2	NR	NR	NR	0 / 18	120	HSL	NO	8	ESL	No
Ethylbenzene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	5300	HSL	NO	1.5	ESL	No
meta- & para-Xylene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	550	RSL	NO	NSL		No
ortho-Xylene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	650	RSL	NO	NSL		No
Sum of BTEX	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	NSL		NO	NSL		No
Toluene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	18000	HSL	NO	10.5	ESL	No
Total Xylenes	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	17000	HSL	NO	10	ESL	No
Acenaphthene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	29	ECO-SSL	No
Acenaphthylene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	29	ECO-SSL	No
Anthracene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	2.5	CEQG	No
Benz(a)anthracene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	0.1	CEQG	No
Benzo(a)pyrene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	3	HIL	NO	0.7	ESL	No
Benzo(a)pyrene TEQ (Half LOR)	mg/kg	0.6	0.6	0.6	0.6	0.00	8 / 8	3	HIL	NO	NSL		No
Benzo(a)pyrene TEQ (LOR)	mg/kg	1.2	1.2	1.2	1.2	0.00	8 / 8	3	HIL	NO	NSL		No
Benzo(a)pyrene TEQ (zero)	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	3	HIL	NO	NSL		No
Benzo(b+j)fluoranthene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 8	Screen Sum of PAH		NO	0.1	CEQG	No
Benzo(g.h.i)perylene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	18	ECO-SSL	No
Benzo(k)fluoranthene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	0.1	CEQG	No
Chrysene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	18	ECO-SSL	No
Dibenz(a.h)anthracene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	0.1	CEQG	No
Fluoranthene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	50	CEQG	No
Fluorene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	29	ECO-SSL	No
Indeno(1.2.3.cd)pyrene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	0.1	CEQG	No
Naphthalene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	10	ESL	No
Phenanthrene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	29	ECO-SSL	No
Pyrene	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	Screen Sum of PAH		NO	0.1	CEQG	No
Sum of polycyclic aromatic hydrocarbons (PAHs)	mg/kg	<0.5	<0.5	NR	NR	NR	0 / 18	300	HIL	NO	NSL		No

Notes:
Refer to text for sources of screening levels.
< = less than
°C = degrees Celsius
µS/cm = microSiemens per centimetre
BTEX = benzene, toluene, ethylbenzene, and xylene
CEQG = Canadian Environmental Quality Guidelines
ECO-SSL = ecological soil screening level
ESL = Ecological Screening Level
HIL = Health Investigation Level
HSL = health Screening Level
LOR = limit of reporting
mg/kg = milligrams per kilogram
NA = not applicable
NR = not reported
NSL = no screening level
PAH = polycyclic aromatic hydrocarbon
RSL = regional screening level
TEQ = toxic equivalence quotient

EHS Support

Table A-3

Comparison of Residiual Driling Chemicals to $PNEC_{soil}$
Narrabri Gas Project

Constituent Name	CAS No.	EPC (10% of mud concentration) (mg/kg)	$PNEC_{soil}$ (mg/kg)	EPC drilling muds >$PNEC_{soil}$?
Copolymer of acrylamide and sodium acrylate	25085-02-3	70	ND	NO
Ethylene oxide/propylene oxide copolymer	9003-11-6	2.4	ND	NO
Glyoxal	107-22-2	3.1	4.1E+00	NO
Methanol	67-56-1	0.30	1.0E+02	NO
Methylisothiocyanate (MITC)	556-61-6	3.0	2.8E-03	YES
Pentanedial / Glutaraldehyde	111-30-8	30	2.0E-02	YES
Polyalkylene	9038-95-3	2226	ND	NO
Polypropylene glycol	25322-69-4	4.8	5.0E-02	YES
Potassium chloride	7447-40-7	4152	ND	NO
Silicic acid, potassium salt	1312-76-1	2220	ND	NO
Sodium carbonate	497-19-8	7.8	ND	NO
Sodium carboxymethyl cellulose	9004-32-4	312	ND	NO
Sodium chloride	7647-14-5	4560	ND	NO
Sodium hydroxide	1310-73-2	30	ND	NO
Sodium polyacrylate	9003-04-7	109	2.5E+01	YES
Starch	9005-25-8	306	ND	NO
Tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione [a]	533-74-4	0.0	4.0E-03	NO
Xanthan gum	11138-66-2	306	ND	NO

Notes:
a/ Tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione hydrolizes/metabilizes to 100% MITC after 3-5 days based on degredation. Therefore, mass of Tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione in muds will be assumed to be 0 mg/kg.
CAS = Chemical Abstracts Service
EPC = exposure point concentration
mg/kg = milligrams per kilogram
ND = not derived
PNEC = predicted no effects concentration

Table A-4

Development of Blending Ratios Based on Geogenic COPCs
Narrabri Gas Project

METHOD	Constituent Name	Units	Statistical Summaries: Maximum	Statistical Summaries: Median	Ecological Evaluation: Ecological Screening Level		Blending Ratio: Based on Maximum Detection	Blending Ratio: Based on Median Detection
APHA_2510_B_1:5	Electrical Conductivity @ 25°C	µS/cm	7250	4570	50	Site-specific	10.2	6.4
USEPA_6020	Cadmium	mg/kg	2.4	NR	1.4	CEQG	1.7	NA
USEPA_6020	Nickel	mg/kg	71	16	45	CEQG	1.6	0.4
USEPA_8015	>C10 - C16 Fraction minus Naphthalene (F2)	mg/kg	670	370	25	EIL/ESL	26.8	14.8
USEPA_8015	>C16 - C34 Fraction	mg/kg	5180	1005	300	EIL/ESL	17.3	3.4
USEPA_8270B_PAH	Benzo(b)fluoranthene	mg/kg	1.5	1.45	0.1	CEQG	15.0	14.5
USEPA_8270B_PAH	Benzo(b+j)fluoranthene	mg/kg	0.7	NR	0.1	CEQG	7.0	NA
USEPA_8270B_PAH	Benzo(k)fluoranthene	mg/kg	0.6	0.55	0.1	CEQG	6.0	5.5
USEPA_8270D	Benz(a)anthracene	mg/kg	2.1	NR	0.1	CEQG	21.0	NA
USEPA_8270D	Benzo(b) & Benzo(k)fluoranthene	mg/kg	1	NR	0.1	CEQG	10.0	NA
USEPA_8270D	Chrysene	mg/kg	4.6	NR	1.1	ECO-SSL	4.2	NA
USEPA_8270D	Pyrene	mg/kg	4.3	NR	0.1	CEQG	43	NA

Notes:
°C = degrees Celsius
µS/cm = microSiemens per centimetre
CEQG = Canadian Environmental Quality Guidelines
ECO-SSL = ecological screening level
EIL = Ecological Investigation Level
ESL = Ecological Screening Level
mg/kg = milligrams per kilogram
NA = not applicable
NR = not reported
PAH = polycyclic aromatic hydrocarbon
Refer to text for sources of screening levels.

EHS Support

Table A-5

Development of Blending Ratios Based on Residual Drilling Chemical COPCs
Narrabri Gas Project

Constituent Name	CAS Number	EPC (10% of mud concentration) (mg/kg)	Soil Half-life (days)	EPC in Rehabiliated Well Pad soils after 2 years (mg/kg)[1]	Blending Ratio[1]
Methylisothiocyanate (MITC)	556-61-6	3.0	5 to 14	1.5E-149	5.4E-147
Pentanedial / Glutaraldehyde	111-30-8	30	1.7	0.0E+00	0.0E+00
Polypropylene glycol	25322-69-4	4.8	15	2.2E-139	4.3E-138
Sodium polyacrylate	9003-04-7	109	NA	109	4.4

Notes:
CAS = Chemical Abstracts Service
EPC = exposure point concentration
mg/kg = milligrams per kilogram
NA = not applicable
1/ Calculated EPC for pentanedial/gultaraldehyde degreaded to infinitesimally small concentration.
Therefore, EPC effectively 0 mg/kg and no blending required to satisfy screening level after 2 years.

Table A-6

Calculation of Land Application Ratios for Residual Drilling Material
(Median Geogenic Concentrations)
Narrabri Gas Project

GEOGENIC					
		METHOD 1 (m^3/ha)	METHOD 2 (m^3/ha)	METHOD 3 (m^3/ha)	Method 4 (m^3/ha)
Constituent Name	Dilution Ratio to Achieve Risk-Based Criterion	Volume that can be spread and naturally incorporated into top 150 mm of soil over 1 ha	Volume that can be mixed into 0.5 m column of soil and buried over 1 ha	Volume of soil to mix with residual drilling material, then bury with minimum of 0.5 m of soil cover	Volume of soil to mix with residual drilling material, then bury with minimum of 1.5 m of soil cover
Electrical Conductivity @ 25°C	6.4	234	781	6.40	6.40
Cadmium	NA	NA	NA	NA	NA
Nickel	0.4	4219	14063	NA	NA
>C10 - C16 Fraction minus Naphthalene (F2)	14.8	101	338	NA	NA
>C16 - C34 Fraction	3.4	448	1493	NA	NA
Benz(a)anthracene	8.0	188	625	NA	NA
Benzo(b)fluoranthene	14.5	103	345	NA	NA
Benzo(b+j)fluoranthene	NA	NA	NA	NA	NA
Benzo(k)fluoranthene	5.5	273	909	NA	NA
Chrysene	1.6	917	3056	NA	NA
Pyrene	13.0	115	385	NA	NA
Benzo(b) & Benzo(k)fluoranthene	NA	NA	NA	NA	NA
	GEOGENIC MIX/BLEND RATIO	101	338	6.4	6.4
CHLORIDE-BASED MUDS					
Methylisothiocyanate (MITC)	0	731416	2438052	2.1E-03	NA
Pentanedial / Glutaraldehyde	0.000	7.31E+47	2.4E+48	2.1E-45	NA
Polypropylene glycol	0.000366211	4096000	13653333	3.7E-04	NA
Sodium polyacrylate	4.4	343	1145	4.4	NA
	CHLORIDE-BASED MUDS MIX/BLEND RATIO	343	1145	4.4	NA
	FINAL RATIOS	101	338	6.4	6.4

Notes:
°C = degrees Celsius
ha = hectare
m = metre
m^3/ha = cubic metres per hectare
mm = millimetre
NA = not applicable

Table A-7

Calculation of Land Application Ratios for Residual Drilling Material
(Maximum Geogenic Concentrations)
Narrabri Gas Project

GEOGENIC					
		METHOD 1 (m^3/ha)	METHOD 2 (m^3/ha)	METHOD 3 (m^3/ha)	Method 4 (m^3/ha)
Constituent Name	Dilution Ratio to Achieve Risk Based Criteria	Volume that can be spread and naturally incorporated into top 150 mm of soil over 1 ha	Volume that can be mixed into 0.5 m column of soil and buried over 1 ha	Volume of soil to mix with residual drilling material, then bury with minimum of 0.5 m of soil cover	Volume of soil to mix with residual drilling material, then bury with minimum of 1.5 m of soil cover
Electrical Conductivity @ 25°C	10.2	148	493	10.2	10.2
Cadmium	1.71	875	2917	NA	NA
Nickel	1.58	951	3169	NA	NA
>C10 - C16 Fraction minus Naphthalene (F2)	26.80	56	187	NA	NA
>C16 - C34 Fraction	17.27	87	290	NA	NA
Benzo(b)fluoranthene	15.0	100	333	NA	NA
Benzo(b+j)fluoranthene	7.0	214	714	NA	NA
Benzo(k)fluoranthene	6.0	250	833	NA	NA
Benz(a)anthracene	21.0	71	238	NA	NA
Benzo(b) & Benzo(k)fluoranthene	10.0	150	500	NA	NA
Chrysene	4.2	359	1196	NA	NA
Pyrene	43.0	35	116	NA	NA
	GEOGENIC MIX/BLEND RATIO	35	116	10.2	10.2
Chloride based mud					
Methylisothiocyanate (MITC)	0.0	731416	2438052	0.0	NA
Pentanedial / Glutaraldehyde	0.000	7.31E+47	2.44E+48	0.0	NA
Polypropylene glycol	0.0	4096000	13653333	0	NA
Sodium polyacrylate	4.4	343	1145	4	NA
CHLORIDE-BASED MUDS MIX/BLEND RATIO		343	1145	4	NA
	FINAL RATIOS	35	116	10	10.2

Notes:
*C = degrees Celsius
ha = hectare
m = metre
m^3/ha = cubic metres per hectare
mm = millimetres
NA = not applicable

Table A-8

Calculation of Land Application Ratios for Residual Drilling Material for Group 1 Materials
(Median Geogenic Concentrations)
Narrabri Gas Project

GEOGENIC			
		METHOD 1 (m^3/ha)	METHOD 2 (m^3/ha)
Constituent Name	Calculate Median/ Screening Level	Volume that can be spread and naturally incorporated into top 150 mm of soil over 1 ha	Volume that can be mixed into 0.5 m column of soil and buried over 1 ha
Electrical Conductivity @ 25°C	6.4	234	781
Cadmium	NA	NA	NA
Nickel	0.4	4219	14063
GEOGENIC MIX/BLEND RATIO		234	781
CHLORIDE-BASED MUDS			
Methylisothiocyanate (MITC)	2.1E-03	731416	2438052
Pentanedial / Glutaraldehyde	2.1E-45	7.3E+47	2.4E+48
Polypropylene glycol	3.7E-04	4096000	13653333
Sodium polyacrylate	4.4	343	1145
CHLORIDE-BASED MUDS MIX/BLEND RATIO		343	1145
	FINAL RATIOS	234	781

Notes:
°C = degrees Celsius
ha = hectare
m = metre
m^3/ha = cubic metres per hectare
mm = millimetre
NA = not applicable

Table A-9

Calculation of Land Application Ratios for Residual Drilling Material
(Maximum Geogenic Concentrations)
Narrabri Gas Project

GEOGENIC			
		METHOD 1 (m^3/ha)	METHOD 2 (m^3/ha)
Constituent Name	Dilution Ratio to Achieve Risk Based Criteria	Volume that can be spread and naturally incorporated into top 150 mm of soil over 1 ha	Volume that can be mixed into 0.5 m column of soil and buried over 1 ha
Electrical Conductivity @ 25°C	10.2	148	493
Cadmium	1.71	875	2917
Nickel	1.58	951	3169
	GEOGENIC MIX/BLEND RATIO	148	493
Chloride based mud			
Methylisothiocyanate (MITC)	2.1E-03	731416	2438052
Pentanedial / Glutaraldehyde	2.1E-45	7.3E+47	2.4E+48
Polypropylene glycol	3.7E-04	4096000	13653333
Sodium polyacrylate	4.4	343	1145
CHLORIDE-BASED MUDS MIX/BLEND RATIO		343	1145
	FINAL RATIOS	148	493

Notes:
*C = degrees Celsius
ha = hectare
m = metre
m^3/ha = cubic metres per hectare
mm = millimetres
NA = not applicable

Table A-10

Calculation of Target Chemical Concentrations for Residutal Drillnig Material

Narrabri Gas Project

Constituent Name	Applciation Rate of 200 m3/ha — METHOD 1 (m^3/ha): Target Chemical Concentration that can be spread and naturally incorporated into top 150 mm of soil over 1 ha soil (mg/kg)	METHOD 2 (mg/kg): Target Chemical Concentration that can be mixed into 0.5 m column of soil and buried over 1 ha (mg/kg)
GEOGENIC		
Electrical Conductivity @ 25°C	375	1250
Cadmium	11	35
Nickel	338	1125
>C10 - C16 Fraction minus Naphthalene (F2)	188	625
>C16 - C34 Fraction	2250	7500
Benz(a)anthracene	0.75	2.5
Benzo(b)fluoranthene	0.75	2.5
Benzo(b+j)fluoranthene	0.75	2.5
Benzo(k)fluoranthene	0.75	2.5
Chrysene	8.25	28
Pyrene	0.75	2.5
Benzo(b) & Benzo(k)fluoranthene	0.75	2.5
CHLORIDE-BASED MUDS		
Methylisothiocyanate (MITC)	4.2E+147	1.4E+148
Pentanedial / Glutaraldehyde	NA	NA
Polypropylene glycol	8.4E+138	2.8E+139
Sodium polyacrylate	187.50	625

Constituent Name	Applciation Rate of 225 m3/ha — METHOD 1 (mg/kg): Target Chemical Concentration that can be spread and naturally incorporated into top 150 mm of soil over 1 ha soil (mg/kg)	METHOD 2 (mg/kg): Target Chemical Concentration that can be mixed into 0.5 m column of soil and buried over 1 ha (mg/kg)
GEOGENIC		
Electrical Conductivity @ 25°C	333	1111
Cadmium	9.3	31
Nickel	300	1000
>C10 - C16 Fraction minus Naphthalene (F2)	167	556
>C16 - C34 Fraction	2000	6667
>C16 - C34 Fraction	2000	6667
Benz(a)anthracene	0.67	2.2
Benzo(b)fluoranthene	0.67	2.2
Benzo(b+j)fluoranthene	0.67	2.2
Benzo(k)fluoranthene	0.67	2.2
Chrysene	7.3	24.4
Pyrene	0.67	2.2
Benz(a)anthracene	0.67	2.2
Benzo(b) & Benzo(k)fluoranthene	0.67	2.2
CHLORIDE-BASED MUDS		
Methylisothiocyanate (MITC)	3.7E+147	1.2E+148
Pentanedial / Glutaraldehyde	NA	NA
Polypropylene glycol	7.4E+138	2.5E+139
Sodium polyacrylate	1.7E+02	5.6E+02

Table A-10

Calculation of Target Chemical Concentrations for Residutal Drillnig Material

Narrabri Gas Project

Applciation Rate of 250 m3/ha		
	METHOD 1 (mg/kg)	METHOD 2 (mg/kg)
Constituent Name	Target Chemical Concentration that can be spread and naturally incorporated into top 150 mm of soil over 1 ha soil (mg/kg)	Target Chemical Concentration that can be mixed into 0.5 m column of soil and buried over 1 ha (mg/kg)
GEOGENIC		
Electrical Conductivity @ 25°C	300	1000
Cadmium	8.4	28
Nickel	270	900
>C10 - C16 Fraction minus Naphthalene (F2)	150	500
>C16 - C34 Fraction	1800	6000
>C16 - C34 Fraction	1800	6000
Benz(a)anthracene	0.6	2.0
Benzo(b)fluoranthene	0.6	2.0
Benzo(b+j)fluoranthene	0.6	2.0
Benzo(k)fluoranthene	0.6	2.0
Chrysene	6.6	22
Pyrene	0.6	2.0
Benz(a)anthracene	0.6	2.0
Benzo(b) & Benzo(k)fluoranthene	0.6	2.0
CHLORIDE-BASED MUDS		
Methylisothiocyanate (MITC)	3.4E+147	1.1E+148
Pentanedial / Glutaraldehyde	NA	NA
Polypropylene glycol	6.7E+138	2.2E+139
Sodium polyacrylate	150	500

Notes:
°C = degrees Celsius
ha = hectare
m = metre
m^3/ha = cubic metres per hectare
mg/kg = milligram per kilogram
mm = millimetre
NA = not applicable