# APPENDIX F

## ASSESSMENT OF REMEDIATION OPTIONS

# F

Douglas Partners
Geotechnics / Environment / Groundwater

Integrated Practical Solutions

Report on
Assessment of Remediation Options

Proposed Terminal 4 Project
Kooragang Island

Prepared for
Port Waratah Coal Services Limited

Project 49533.02-06
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Douglas Partners
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## Executive Summary

This report presents an assessment of remediation options for existing contaminated land on the proposed Terminal 4 (T4) Project area on Kooragang Island (KI). The work was carried out for Port Waratah Coal Services Limited (PWCS). The report is based on the findings of a contamination assessment and groundwater modelling and assessment, the results of which are detailed in separate reports. The T4 Project site includes the major portion of the Kooragang Island Waste Emplacement Facility (KWIF), formerly used by BHP Billiton for disposal of waste materials from its steelmaking operations. The T4 Project area also includes the Delta EMD waste disposal area and the Fines Disposal Facility (FDF) both currently owned by PWCS, plus wharf areas on both sides of the Hunter River (South Arm), adjacent to Tourle Street bridge. The wharf area on the south bank comprises part of the OneSteel facility, and is assessed in a separate report.

The objectives of the contamination assessments were to assess whether any contamination identified required remedial measures for:

- Protection of the environment; and
- Protection of human health.

The environmental values to be protected are the quality of ground and surface water interacting with receptors that adjoin the site, including the wetlands to the west and north of the site within the Hunter Wetlands National Park and the Hunter River. Protection of human health from identified contamination is required during construction and operation of the T4 Project.

The contamination issues identified at the site and detailed in the Contamination Assessment and Groundwater Assessment are:

- Ponds 5 and 7: Soil and groundwater impact associated with coal tar waste;
- Area K7: Lead dust co-disposed with asbestos could come into contact with groundwater due to settlement under the T4 Project load;
- Site B North: Free phase oil contamination (LNAPL) in the vicinity of Bore B-01;
- Delta EMD: Potential mobilisation of contaminants and adverse groundwater interactions (mainly Easement Pond) during the dredging phase;
- FDF: Potential mobilisation of contaminants (mainly hydrocarbons and metals) associated with settlement under the T4 Project load and a rise in the water table;
- Deep Pond: adverse groundwater impacts on wetlands within the Hunter Wetland National Park during dredging; and
- Management of materials excavated / uncovered during construction activities.

In addition to the above specific issues, the T4 Project area contains widespread general industrial contamination and localised ‘hot spots’. The existing capping strategies for KIWEF and Delta EMD, approved by Office of Environment and Heritage (OEH), are considered to be suitable to manage the risks associated with these areas and an equivalent strategy is proposed for the majority of the T4 Project area. This can be incorporated into the T4 Project design.

The construction of the T4 Project, however, would apply additional loads and constraints that render the existing capping strategy insufficient to manage the risks associated with the specific contamination issues.

The site presents a number of environmental challenges which can be managed by implementing appropriate mitigation measures during staged construction of the T4 Project. This report reviews available remediation technologies and ranks these against set criteria to identify the preferred remediation / management option for each of the contamination issues.

The preferred remediation option for each of the specific contamination issues are:

- Pond 5/7: soil-bentonite barrier wall;
- Lead dust / Asbestos Area: permeable reactive barrier ('funnel and gate' type);
- Site B North free phase oil: dual phase extraction;
- FDF: permeable reactive barrier ('funnel and gate' type);
- Delta EMD: low-permeability capping prior to dredging;
- Deep Pond: low-permeability liner adjacent to railway prior to dredging; and
- Excavations; containment cell construction.

There are a number of remediation technologies available to manage and mitigate the impacts associated with contamination.

The implementation of the proposed remediation and management measures for the T4 Project would protect environmental values, and is expected to improve the long term environmental condition of the T4 Project area and immediate surrounds.

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## Abbreviations

| | |
|---|---|
| **AHD** | Australian Height Datum |
| **ANZECC** | Australian and New Zealand Environmental and Conservation Council |
| **AS** | Australian Standard |
| **ASS** | Acid Sulphate Soil |
| **ASSMAC** | Acid Sulphate Soil Management Advisory Committee |
| **BHP** | Broken Hill Proprietary Company Limited |
| **BHPB** | BHP Billiton Pty Ltd |
| **BTEX** | Benzene, Toluene, Ethylbenzene, total Xylenes (monocyclic aromatic hydrocarbons) |
| **$CaCO_3$** | Calcium Carbonate (agricultural lime) |
| **CWR** | Coal Washery Reject |
| **DECC** | Department of Environment and Climate Change |
| **DECCW** | Department of Environment, Climate Change and Water |
| **DNAPL** | Dense Non-Aqueous Phase Liquid |
| **DP** | Douglas Partners Pty Ltd |
| **EIS** | Environmental Impact Statement |
| **EMD** | Electrolytic Manganese Dioxide |
| **EPA** | Environmental Protection Authority |
| **EPL** | Environment Protection Licence |
| **FDF** | Fines Disposal Facility |
| **GCL** | Geosynthetic Clay Liner |
| **ha** | hectares |
| **$H_2O_2$** | Hydrogen Peroxide |
| **KI** | Kooragang Island |
| **KCT** | Kooragang Coal Terminal |
| **KIEC** | Kooragang Island Emplacement Cell |
| **KIWEF** | Kooragang Island Waste Emplacement Facility |
| **LNAPL** | Light Non-Aqueous Phase Liquid |
| **m** | metres |
| **mg/kg** | milligrams per kilogram (or parts per million) |
| **mg/L** | milligrams per litre (or parts per million |
| **ML** | megalitre (million litres) |
| **Mn** | Manganese |
| **mS/cm** | milli Siemens per cm |
| **NAG** | Net Acid Generation |
| **NAPP** | Net Acid Production Potential |
| **NATA** | National Association of Testing Authorities |

## Abbreviations (continued)

| | |
|---|---|
| **NC** | No Criteria |
| **NCIG** | Newcastle Coal Infrastructure Group |
| **ND (nd)** | Not Detected above the PQL |
| **NEHF** | National Environmental Health Forum |
| **NHTG** | Newcastle Harbour Tide Gauge |
| **$NH_3$** | Ammonia |
| **Ni** | Nickel |
| **NPC** | Newcastle Port Corporation |
| **NSW** | New South Wales |
| **NT** | Not Tested |
| **OEH** | NSW Office of Environment and Heritage |
| **PAH** | Polycyclic Aromatic Hydrocarbons |
| **PASS** | Potential Acid Sulphate Soil |
| **Pb** | Lead |
| **PES** | Prefeasibility Engineering Study |
| **pH** | unit measurement of acidity/alkalinity |
| **$pH_f$** | Soil pH test (1:5 soil/distilled water) |
| **$pH_{fox}$** | Soil peroxide pH test (1:4 soil/distilled water following oxidation of soil with 30% $H_2O_2$) |
| **PID** | Photoionisation Detector |
| **PQL** | Practical Quantitation Limit |
| **PRP** | Pollution Reduction Program |
| **PVC** | Polyvinyl Chloride |
| **PWCS** | Port Waratah Coal Services Limited |
| **QA/QC** | Quality Assurance / Quality Control |
| **QASSIT** | Queensland Acid Sulphate Soil Investigation Team |
| **QASSMAC** | Queensland Acid Sulphate Soil Management Advisory Committee |
| **RL** | Reduced Level |
| **RPD** | Relative Percent Difference |
| **$S\text{-}ANC_{BT}$** | Acid Neutralising Capacity by back titration calculated as equivalent pyrite S% |
| **s-TAA** | Titratable Actual Acidity calculated as equivalent pyrite S% |
| **TPH** | Total Petroleum Hydrocarbons |
| **TRH** | Total Recoverable Hydrocarbons |
| **T4** | Coal Export Terminal 4 |

**Report on Assessment of Remediation Options**
**Proposed Terminal 4 Project**
**Kooragang Island**

# 1. Introduction

## 1.1 Overview

Port Waratah Coal Services Limited (PWCS) proposes to construct and operate a new coal export terminal at the Port of Newcastle, New South Wales (NSW). PWCS owns and operates the Kooragang Coal Terminal (KCT) at Kooragang Island and Carrington Coal Terminal (CCT) at Carrington, both in the Port of Newcastle. The proposal, known as the Terminal 4 Project (T4 Project), is essentially an extension to KCT. The T4 Project would provide additional port capacity required to accommodate the projected future growth in coal exports from the Hunter Valley and broader NSW.

The T4 Project is proposed to include new rail tracks, coal stockyard, conveyors and ancillary facilities on Kooragang Island KI, adjacent to KCT, and wharves, berths, ship loaders and ancillary facilities along the north and south banks will be constructed and operated within the Hunter River South Arm and along its northern and southern banks.

Approval for the T4 Project is being sought under Part 3A of the NSW *Environmental Planning and Assessment Act 1979* (EP&A Act) and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The Commonwealth has accredited the Part 3A process as the appropriate Commonwealth assessment pathway for the T4 Project. An environmental assessment (EA) of the T4 Project is a requirement of the Part 3A approval process. Douglas Partners Pty Ltd (DP) has been engaged by PWCS to undertake components of the EA related to contamination, groundwater and remediation options assessments. This report presents the assessment remediation options to address the relevant Director General's Requirements (DGRs). Table A1 (Appendix A) indicates where each relevant DGR has been addressed.

Investigations of the environmental condition of the T4 Project area and groundwater modelling of the potential impacts of the T4 Project on environmental receptors have been undertaken for KI and are presented in two separate reports:

- Contamination Assessment Report (Ref 21), and
- Groundwater Assessment Report (Ref 22).

The above two reports are included as Appendix C and E respectively in the EA, and a summary of the findings is presented in Section 3.1.

The T4 Project area consists of six parcels of land. Four of these are within the former Kooragang Island Waste Emplacement Facility (KIWEF), designated Sites A, B, C and D (as shown on 6.01). The fifth parcel of land comprises the SP1 (Special Activities) zone (Site E), located to the west and north of the existing railway line, which is 100 m wide. The SP1 zone is essentially low-lying wetlands.

The sixth parcel of land, referred to as Site F, comprises part of the existing OneSteel site adjacent to the Hunter River (South Arm) where Wharves M8 and M9 are proposed. This site is the subject of a separate report that assesses contamination and appropriate mitigation measures.

The contamination issues identified at the T4 KI Project area at KI are:

- Site A Ponds 5 and 7: Soil and groundwater impact associated with coal tar waste;
- Site A Area K7: Lead dust co-disposed with asbestos could come into contact with groundwater due to settlement under the load of the T4 Project infrastructure;
- Site A Deep Pond: adverse groundwater impacts on Office of Environment and Heritage (OEH)[1] wetlands during dredging;
- Site B North: Free phase oil contamination in the vicinity of Bore B-01;
- Site C Delta EMD: Potential mobilisation of contaminants and adverse groundwater interactions (mainly Easement Pond) during the dredging phase; and
- Site D (FDF): Potential mobilisation of contaminants (mainly hydrocarbons and metals) associated with settlement under the load of the T4 Project infrastructure and a rise in the water table.

In addition to the above specific issues, the T4 Project area contains general industrial contamination and localised zones of contamination.

The construction of the T4 Project would apply additional loads and constraints that could render the existing capping strategy insufficient to manage the risks associated with the above specific issues.

This report presents an assessment of remediation options for the T4 Project, required to mitigate and manage the environmental risks identified in the above-mentioned reports. Available remediation technologies and a ranking system were used to identify the preferred remediation options for each specific issue. The T4 Project area is shown on Drawing 6.01 in Appendix C as Sites A, B, C, D, E and F.

The remedial options set out in this report that have been selected to address each of the contamination issues will elaborated on the Remediation Action Plan (RAP) that will be prepared to guide the remediation works on the site.

The contamination assessment report and this remediation options report have been the subject of peer review by Dr Bill Ryall of Ryall of Environmental Pty Ltd.

1 NSW Office of Environment and Heritage (OEH) has replaced the former NSW Department of Environment (DEC), NSW Department of Environment and Climate Change (DECC) and NSW Department of Environment, Climate Change & Water (DECCW). NSW Environment Protection Authority (EPA) is currently part of NSW OEH. NSW EPA, NSW DEC and NSW DECC have each made guidelines endorsed by s.105 of the *Contaminated Land Management Act 1997*.

## 1.2 Proposed Development

The T4 Project is proposed to be located at the Port of Newcastle, in the Newcastle local government area, approximately 6 km north-west of the Newcastle central business district. The T4 project is primarily located on Kooragang Island (Sites A to E), adjacent to KCT and the Newcastle Coal Infrastructure Group (NCIG) coal terminal. Site F (within the OneSteel site) is located on the south bank of the Hunter River South Arm, at Mayfield North and includes a section of the Hunter River bed.

Mayfield North and the southern part of Kooragang Island, where the T4 Project area is located, is dominated by industrial, transport, distribution and port facilities, including KCT and NCIG. To the north and west of the Kooragang Island industrial and port area are estuarine wetlands, mangroves, saltmarsh and pastured and forested lands, subject to agricultural and conservation activities. This includes the Hunter Wetlands National Park, part of which is a Ramsar site. The nearest residential areas are at Fern Bay and Stockton 4.5 km to the east and south-east, and Mayfield and Warabrook 1.7 km to the south and south-west.

The T4 Project area is predominately reclaimed land which has previously been used for disposal of industrial waste and dredge material. It is a largely modified landscape dominated by bare ground, disturbed grassland and artificially constructed drainage depressions and ponds, which now support wetland communities. There is some remnant mangrove and saltmarsh vegetation along the north bank of the Hunter River South Arm, at the locations of the proposed wharves and berths, as well as to the north and west of the existing rail line.

The T4 Project is proposed to be developed progressively over an estimated 10 year timeframe in a nominal three stage program in response to demand for increased coal export capacity. The maximum coal throughput capacity for the T4 Project will increase from 70 million tonnes per annum (Mtpa) in the first stage to a nominal 120 Mtpa at full development. All coal will be received by rail, stockpiled and then shipped to market. The T4 Project components include the following:

- Ground treatments, including pre-loading, to create suitable foundation conditions for development. Sand dredged from the Hunter River South Arm is proposed to be pumped to the proposed stockyard area, to provide pre-load and fill material for the project. This will be supplemented by engineering fill (sand and rock) trucked in from elsewhere;
- Relocation of some existing infrastructure and services, such as electricity transmission lines, gas lines, water lines, fibre optic cable, ship navigation aids, the existing KCT rail tracks and the Ausgrid wind turbine. Minor modification to local roads may also be required;
- Progressive construction and operation of rail receival infrastructure, generally located along the same alignment as the existing rail lines servicing Kooragang Island. At full development there will be up to eight arrival tracks leading up to four dump stations and on to eight departure sidings, which combine into a single departure track around the outside of the existing KCT rail loop;
- Progressive construction and operation of a coal stockyard, including coal stockpiles and yard equipment for stacking and reclaiming coal. At full development there will be up to seven stockpiles;
- Progressive construction and operation of coal conveyors, feeders and transfer stations that extend throughout the stockyard to deliver coal from the dump stations to the stockpiles, and to the wharves to deliver coal to the shiploaders, via buffer bins;

- Progressive construction and operation of wharf and berth facilities on both sides of the Hunter River South Arm, near the Tourle Street Bridge. At full development, up to five berths and four shiploaders are proposed, which accommodate vessels ranging from Handy size to Cape size;
- Development of water and wastewater management infrastructure including drainage works, water management ponds, pump stations and water tanks;
- Ancillary facilities, including electricity supply, dust suppression and fire fighting systems, fencing, amenities, landscaping, internal access roads, car parking areas and potentially, washdown facilities, refuelling facilities, administration and workshop buildings;
- Use of some existing KCT infrastructure, systems and workforce, including administration and maintenance facilities and environmental management and monitoring systems; and
- Habitat creation and enhancement.

The conceptual layout of the proposed T4 Project is shown on Drawing 6.04 Appendix C, which is based on drawing *KL 323170_A - Site Overview.dwg*, overlain on a site aerial.

The salient features, which will be refined during detailed design are:

- Up to seven coal stockpiles of up to 1430 m in length;
- Up to eight machinery berms to carry stacker/reclaimers and conveyors;
- T4 railway lines, mainly located in the SP1 zone outside the existing rail lines, except for a section inside Site A at Deep Pond;
- Dump Station located in the SP1 zone, just north of the boundary between FDF Cells 1 and 2; and
- Water treatment ponds located over Deep Pond.

Based on the proposed stockyard levels, which range from RL 6.2 NHTG (5.2 AHD) to RL 11.0 NHTG (10.0 NHTG) the depth of filling would range from zero up to a maximum of about 8.5 m. The proposed depth of cut ranges up to about 3.5 m, mostly occurring in the central northern portion of the site in Area K7. . Accordingly the quantity of cut will be relatively minor compared to the quantity of fill, so that the disturbance of existing contaminated soils is kept to a minimum. It is approximately estimated that the volume of ‘Level 3’ and/or hazardous waste could be in the order of 15,000 $m^3$ to 25,000 $m^3$; Soils that are excavated will be managed as discussed in Section 6.3.

The proposed machinery berms would have a level approximately 5 m above stockyard level. Final levels of the stockyard will be refined during detailed design.

The proposed T4 project development would be undertaken in stages. The initial stage is proposed to include the construction of four coal stockpiles, three berths and associated infrastructure. Subsequent stages would be constructed while the first stage is in operation. Further details on the proposed T4 Project are provided in the EA.

### 1.3 Purposes and Objectives of the Assessment

The contamination assessment was required for the following reasons:

- The proposed T4 Project would be a significant development that would have potential effects on the environment;
- Characterisation of the soil and groundwater contamination at the T4 Project site would be required so that the potential effects could be assessed; and
- Assessment of the appropriate mitigation measures would be required and implemented to effectively manage site contamination and potential off-site groundwater migration.

The proposed development presents an opportunity to reduce the existing environmental risks at the site, which will be achieved by implementing strategies that manage and mitigate risks associated with the presence of contaminants, particularly to on-site and off-site receptors.

The T4 Project site includes the major portion of the Kooragang Island Waste Emplacement Facility (KIWEF), formerly used by BHP Billiton (BHPB) for disposal of waste materials from its steelmaking operations. The T4 Project site also includes the former Delta EMD waste disposal area and the PWCS FDF both currently owned by PWCS. PWCS have entered into an 'Agreement for Lease' with the state government for possible coal terminal development at the site.

Wastes dumped at KIWEF since the early 1970s included coal washery reject, blast furnace slag, granulated slag, coal fines, oil/tarry sludge, clayey silt filter cake, kiln wastes, cell scale (gypsum and manganese dioxide), lime sludge, asbestos, BOS flue dust and building rubble. As a result, various contaminants in soil and groundwater have been identified at elevated concentrations.

The overall objective of the contamination assessment was to aid the environmental assessment of the T4 Project so that it could be constructed and operated in a manner that would:

- Protect the environment; and
- Protect human health.

The specific objectives of the assessment were therefore:

- Identify potential contamination issues arising from the T4 Project whereby the risks may not be adequately managed by the existing capping strategy;
- Assess the appropriate mitigation strategies to manage these issues (remediation and/or management); and
- Ensure the remediation works are undertaken in a sustainable manner that meet the objectives of policies and guidelines endorsed by NSW OEH.

## 1.4 Environmental and Human Health Values

The environmental values that require protection during and following construction of the T4 Project are as follows:

- Wetlands in the Hunter Wetlands National Park located immediately to the north of the T4 Project area, adjacent to and beyond the existing railway line (referred to as the 'OEH Wetlands');
- Hunter Estuary Wetlands Ramsar site located 600 m to the north and 1500 m north-east of the T4 Project area;
- The Hunter River (North Arm) located 1300 m north of the T4 Project area; and
- The Hunter River (South Arm) located 600 m to the south of the main T4 Project area (stockyards) and immediately adjacent the to the proposed T4 Project wharf areas.

The potential risks to these environmental receptors and their ecological attributes are the potential for contaminant migration through groundwater movements and changes to groundwater levels.

The ponds that presently exist on both sides of the existing railway line are man-made, resulting from reclamation activities and construction of the railway embankment. These have since become important habitats that require protection, or where impacted, construction of compensatory habitats.

It is noted that the BHPB Kooragang Island Emplacement Cell (KIEC) is situated directly between the main T4 Project site and the Hunter River (South Arm). This facility comprises engineered fully-lined waste cells constructed to receive treated contaminated sediments from the Hunter River Remediation Project. It is also required that the T4 Project has no adverse impact on KIEC.

Human health would also require protection during construction of the T4 Project and subsequently during operation of the coal terminal. The main modes of protection would be:

- Construction: minimisation of exposure of workers to contaminants ( through implementation of a construction environmental management plan); and
- Operation: prevention of access to contaminants by humans (through capping of the site and implementation of a Long-term Environmental Management Plan).

The protection of these environmental and human health values would be achieved through consideration of the relevant policies and guidelines endorsed by the NSW Office of Environment and Heritage (OEH), by implementation of Data Quality Objectives (DQOs), and with reference to the National Walter Quality Management Strategy *Guidelines for Groundwater Protection in Australia* (NWQMS, September 1995, Ref 5).

### 1.5 Environmental Strategy for the T4 Project

The primary objective of the assessment of remediation options for the T4 Project is to protect from unacceptable impacts the off-site receiving environment including adjacent landholdings, the South Arm of the Hunter River, wetlands of the Hunter Wetlands National Park and the ecological attributes which characterise these areas. A secondary objective is to implement land use options which effectively minimises exacerbation, and reduces the long-term risks posed by the contaminant legacies on the site, minimises the requirement for maintenance to protect environmental values, supports project approvals and minimises PWCS liability.

Development of the T4 Project provides an opportunity for PWCS to contribute to the responsible development of an area of Newcastle which is recognised as a heavily contaminated site which currently has no beneficial use. Understanding the contamination risks, and identifying mitigation measures to prevent or minimise potential impact, facilitate safe use of the T4 Project area and long-term protection of the environment.

The environmental strategies related to soil and groundwater contamination at the T4 Project area are based on the following:

- Existing (or surrendered) Environment Protection Licences (EPLs) for the Site (see Section 4.2);
- OEH approved capping measures for sections of the site (see Section 4.2); and
- Additional measures for specific 'hot spot' areas where capping alone is assessed to be insufficient for meeting the environmental objectives (see Section 5.3).

## 2. T4 Project Area Identification

The T4 Project site consists of six parcels of land, four of which are located within the former Kooragang Island Waste Emplacement Facility (KIWEF), designated Sites A, B, C and D (as shown on Drawing 6.01). The fifth parcel of land comprises the SP1 (Special Activities) zone (Site E), located to the west and north of the existing railway line, which is 100 m wide. The SP1 zone is essentially low-lying wetlands.

Site B is in two parts, which are separated by Cormorant Road. KIWEF is bounded by an existing railway line to the north and west, and the Hunter River (South Arm) to the south.

The sixth parcel of land (Site F) comprises part of the existing OneSteel site adjacent to the Hunter River (South Arm) where Wharves M8 and M9 are proposed. The assessment of contamination at the Site F and mitigation options are presented in a separate report, and this site is not discussed further in this report. The location and extent of these sites are shown on Drawing 6.01, and identified in Table 1.

**Table 1: T4 Project Area Identification**

| Site | Name | Lot and DP | Area (ha) |
|---|---|---|---|
| A | KIWEF (north-west) | Lot 9, Lot 10 and Lot 11 DP 1119752 | 96.7 |
| B | KIWEF (south-east) - River Waterfront / Cormorant Road | Lot 21 DP 1155723 | 37.6 |
| C | Delta EMD Waste Disposal Site | Lot 121 DP 874949 | 25.4 |
| D | PWCS Fines Disposal Facility | Lot 11 DP 841542 | 45.1 |
| E | SP1 Special Activities - Rail and Dump Station | Part Lot 1 DP 126347 | 41.3 |
| F | OneSteel - river waterfront, south bank | Part Lot 222 DP 1013964 | 9.2 |

PWCS have entered into an ‘Agreement for Lease’ with the State government (via Newcastle Ports Corporation) in relation to Sites A and B for possible coal terminal development.

The KIWEF area has historically been split into a number of distinct areas for reference purposes designated K1 to K13. The individual waste disposal cells or ponds were also numbered as they were constructed: called Ponds 1 to 39. These pond numbers are sometimes quoted with a ‘K’ prefix which could lead to confusion between Ponds 1 to 13 and the Areas K1 to K13. In this report the pond numbers are quoted without a prefix. The relationship between the T4 Project, areas and ponds is shown on Drawing 6.01.

Sites A, B North, C and Site D are or were licensed waste disposal facilities. The Environment Protection Licences (EPLs) issued by the NSW Department of Environment, Climate Change and Water (DECCW), now OEH.

# 3. Background

## 3.1 Companion Assessments to this Report

### 3.1.1 Geotechnical Investigation (Geology and Hydrogeology)

A geotechnical investigation was undertaken for the Prefeasibility Engineering Study (PES). The investigation included collation of previous test information and new investigations including boreholes, cone penetration tests, test pits and push cores. The findings are presented in Ref 18.

The results were used to develop geotechnical and hydrogeological models for the T4 Project site. The subsurface conditions at the T4 Project site are broadly represented by the stratigraphic model shown in Table 2.

**Table 2: Geotechnical Model of T4 Project Site**

| Main Unit | Sub-Unit | Description | Depth at Base of Layer (m) | Elevation at Base of Layer (NHTG) |
|---|---|---|---|---|
| 1 | 1.1 | Waste Fill – coal washery reject, slag, coal fines, oil/tarry sludge, clayey silt filter cake, kiln wastes, cell scale (gypsum and manganese dioxide), asbestos, BOS flue dust, lime sludge and various sporadic inclusions | 0.0 / 11.7 | 4.4 / -4.3 |
| | 1.2 | Fill - Dredged Fines (Site D, FDF) clayey silt generated by dredging into sedimentation ponds | 2.2 / 7.3 | 3.6 / -0.1 |
| 2 | - | Silty Clay / Silt with some clayey peat layers - generally soft to firm (natural alluvial clays) | 2.6 / 23.0 | 4.8 / -13.0 |
| 3 | 3.1 | Sand / Silty Sand - loose to medium dense | 16.3 / 30.1 | -15.0 / -32.4 |
| | 3.2 | Sand - medium dense to dense | 23.4 / 37.7 | -6.7 / -36.6 |
| | 3.3 | Sand - very dense, some gravel | 25.3 / 46.5 | -10.2 / -36.6 |
| 4 | 4.1 | Silty Clay - stiff to very stiff | 29.2 / 50.6 | -10.2 / -41.3 |
| | 4.2 | Sandy Clay and Clay - stiff to hard | 14.6 / 78.8 | -15.4 / -71.1 |
| 5 | - | Siltstone - very low to low strength to termination | - | - |

Note to Table 2:
NHTG - Newcastle Harbour Tide Gauge datum

Table 2 indicates a wide range in depths and levels of the main subsurface units. Furthermore there is some overlap because not all units are present at all locations, and Units 3 and 4 are interbedded in many areas.

Groundwater beneath the T4 Project area is known to be present in two principal aquifers: an upper unconfined aquifer within the fill strata (Fill Aquifer), and a semi-confined aquifer within the estuarine sediments (Estuarine Aquifer). The upper soft natural clays (Unit 2) form a ‘leaky’ aquitard that separates these aquifers. The results of the investigation indicate that the Unit 2 aquitard is generally continuous, however, the clay may be absent in localised areas. The main sand layer (Unit 3) is therefore generally confined and forms the Estuarine Aquifer. There are further layers of sand within the stiff estuarine clay (Unit 4), but the data indicate that these layers are hydraulically linked and chemically similar to the Estuarine Aquifer.

Contours of groundwater head were prepared for each aquifer, based on a water level gauging event undertaken on 150 wells, as well as several surface water features, on 25 November 2010, and are included in Refs 21 and 22. These contour plans were used in the development of a hydrogeological model of the T4 Project area and surrounding areas.

The Geotechnical Assessment report (Ref 18) presented estimates of site settlement under the proposed loads associated with the T4 Project, induced by filling the site and proposed infrastructure loads. In the absence of ground improvement measures, estimates of total vertical settlement estimates after 25 years of loading typically ranged from 0.4 m to 2.0 m, but up to 2.4 m in places.

The Geotechnical Assessment report proposed ground improvement measures to reduce post-construction settlements and avoid foundation failures. The preferred ground improvement technique for the majority of the site is preload with deep soil mixing in specific locations. These are proven techniques that have been applied successfully at the neighbouring KCT and NCIG coal terminals. The proposed soil improvement measures would provide a suitable foundation for construction of the T4 Project Infrastructure.

### 3.1.2 Contamination Assessment

#### 3.1.2.1 General

A contamination assessment of the T4 Project area was undertaken to determine the type and degree of soil and groundwater contamination. The assessment included collation and review of previous geo-chemical testing and new investigations including boreholes, installation of groundwater monitoring wells and test pits. Soil, groundwater and surface water samples were collected for chemical laboratory testing. The results are presented in Ref 21.

Due to differing historical filling practices and usage between the five sites (A to E), the contamination assessment findings were presented in terms of these areas, although not in isolation. The interactions between these areas were also considered, particularly in regard to groundwater quality and movements.

A summary of these areas is provided in the following sub-sections.

#### 3.1.2.2 Site A (North-West KIWEF)

The waste disposal ponds in Site A were constructed by BHPB in the early 1970s as the land was reclaimed. The ponds were progressively filled with various waste materials until BHP Steelworks closed in 1999. Areas adjoining the ponds also received ‘general refuse’ progressively dumped, while an asbestos burial area was set up in Area K7 in the 1980s.

Site A predominantly contains coarse coal washery reject and slag. These materials are associated with and have resulted in an alkaline pH and elevated concentrations of metals (most notably manganese, copper and zinc). Site A also contains a number of soil contamination ’hot spots’, most notably Pond 5 containing tar residues.

The historical information relating to groundwater and surface water contaminant concentrations is mainly derived from approximately 20 years of monitoring data from sampling groundwater wells and surface water bodies. These data are augmented by various studies by consultants for specific parts of the site for specific purposes, and by new sampling as part of the current assessment for the T4 project.

Contaminant concentrations exceeding ANZECC Trigger Levels for Slightly to Moderately Disturbed Ecosystems (Ref 4) have been recorded at many locations. Contaminants in groundwater include heavy metals, polycyclic aromatic hydrocarbons (PAHs), phenols, ammonia and elevated pH.

#### 3.1.2.3 Site B (South-East KIWEF)

The background information relating to contamination of Site B North is sourced mainly from historical filling records and limited groundwater monitoring. These data are augmented by various studies by consultants for specific parts of the site for specific purposes, and new sampling for the current assessment.

The principal area of soil contamination in Site B North is the waste disposal area comprising Ponds 13 to 19, 21, 23 and 25 which contain PAH contamination. Pond 25 also contains BOS flue dust.

Site B South, located between Cormorant Road and Hunter River, comprises minor filling and undisturbed mangroves. The potential for contamination is therefore considered to be low.

Limited groundwater monitoring data are available from three monitoring wells in the vicinity of Cormorant Road. These wells have provided approximately 10 years of data and the results indicate slightly elevated ammonia and cyanide, with other parameters typically below the relevant criteria. One well (K12/1W) has recorded occasional spikes in PAH in the past, the last being in 2005.

#### 3.1.2.4 Site C (Delta EMD Waste Site)

The former Delta EMD site originally comprised BHPB waste disposal Ponds 33 to 36, constructed in the late 1970s in the same manner as Ponds 1 to 12 on Site A. The information for soil contamination within Site C is derived from a large number of previous geotechnical and contamination investigation reports, plus waste disposal records from Delta EMD who owned and operated the facility between 1998 and 2009. These data have been augmented by new sampling and testing.

The background information on groundwater and surface water contaminant concentrations is mainly derived from approximately 20 years of monitoring data from sampling groundwater wells and surface water bodies. The monitoring was required by the EPL for the site and was undertaken by Delta EMD until PWCS purchased the site in 2009.

The source of potential contaminants for soils within Site C includes:

- Alluvial sediments dredged from the Hunter River: iron, manganese, zinc and PAHs (ie from reclamation activities in the 1960s and 1970s);
- BHP Steelworks waste: pH, iron, manganese, PAHs, total petroleum hydrocarbons (TPH) and benzene, toluene, ethylbenzene and xylenes (BTEX, (i.e. from BHP disposal activities from 1979 to 1988); and
- EMD waste: pH, iron, manganese, sulphur, potassium.

The soil results indicate exceedances of the NSW EPA Commercial and Industrial Landuse (NEHF F) criteria (Ref 40), including elevated levels of PAH, benzo(a)pyrene, TPH and manganese.

Groundwater contaminant concentrations exceeding ANZECC Trigger Levels (Ref 4) have been recorded at many locations. Contaminants include TRH, PAH, BTEX, ammonia, sulphate, cyanide, heavy metals (particularly manganese) and elevated pH.

#### 3.1.2.5 Site D (Fines Disposal Facility)

The FDF cells were constructed in 1993-1994 to receive and treat fines dredged from the Hunter River during Stage 2A works for KCT.

Dredged river sediments deposited in the FDF have been found to contain some elevated concentrations of contaminants including PAHs, TPH and heavy metals (chromium, copper, lead, manganese, mercury and zinc).

In 2009 an agreement between PWCS and BHPB was made to allow cement-modified sediment, dredged from the river for the Hunter River Remediation Project, to be transported to the FDF following classification as 'General Solid Waste' in accordance with NSW EPA waste classification guidelines (Ref 32). It is understood that the dredged material was blended with 5% to 10% cement (by wet weight) at the BHPB Mayfield site to render it manageable for handling and transport.

Under EPL 5022 regular groundwater monitoring has been undertaken at the FDF from a series of wells installed in both the Fill Aquifer and the Estuarine Aquifer. Minor exceedances of the ANZECC 2000 guidelines (Ref 4) were recorded for ammonia, aluminium, cadmium, copper, molybdenum, zinc and TRH. In addition, pH was outside the ANZECC range in all but two samples, which is common on Kooragang Island generally.

#### 3.1.2.6 SP1 Area

The SP1 (Special Activities) zone comprises low-lying wetlands, with only minor amounts of fill materials associated with access tracks, and hence the likelihood of soil contamination is low.

The available surface water chemistry data indicate some elevated concentrations of ammonia, nitrogen oxides, manganese and cyanide. The mean values of these parameters are higher than then adjacent Sites A and D and therefore do not appear to be related to KIWEF or FDF.

The records for other parameters in surface water and groundwater indicate that the concentrations of most contaminants of interest (metals, PAH, TRH, BTEX) are typically below the relevant criteria.

#### 3.1.2.7 Overall Findings of Contamination Assessment

The background data, combined with the Contamination Assessment for the T4 Project (Ref 21), allowed specific contamination issues to be identified. As the construction of the T4 Project would apply additional load to the ground surface, it was assessed that measures in addition to the existing approved capping strategy would be required to manage the risks associated with the specific contamination issues. These issues are:

- Soil and groundwater impact associated with tar waste in Ponds 5 and Pond 7;
- Lead dust co-disposed with asbestos that could come into contact with groundwater due to settlement under the T4 Project load;

- Free phase oil contamination in Site B North;
- Potential mobilisation of contaminants (mainly hydrocarbons and metals) at the FDF associated with settlement under the T4 Project load and a rise in the water table;
- Potential mobilisation of contaminants and groundwater interactions at the former Delta EMD site during the dredging phase; and
- Potential salinity impacts both on and off-site due to dredging, particularly at Deep Pond and Easement Pond.

In addition to the above specific issues, the site contains general widespread industrial contamination and localised ‘hot spots’.

### 3.1.3 Groundwater Assessment and Modelling

The groundwater assessment and modelling was undertaken in five stages as follows:

- Stage 1: data collection and collation, including a site walkover by a senior groundwater engineer, measurement of water levels in 150 existing wells on the one day to provide a ‘snapshot’ of water levels, installation of water level loggers in key surface water bodies, testing of soil for Total Organic Carbon and development of a conceptual flow model for the site;
- Stage 2: steady state numerical flow model, calibrated using the ‘snapshot’ groundwater level data and average annual climatic data;
- Stage 3: transient numerical flow model, calibrated to rainfall, evapotranspiration and tide data using the logged groundwater and surface water levels collected in the Stage 1. The model was used to assess potential development impacts to the wetland sites of ecological significance;
- Stage 4: contaminant transport models to assess the potential movement of contaminants, for the current site condition continuing, and for various development options, to estimate the net impacts of the proposed development; and
- Stage 5: modelling of mitigation measures, such as pond liners, capping the site and barriers, to assess the benefit of mitigation measures to the development of the site.

The groundwater assessment and numerical modelling identified a number of groundwater related matters which would require management / mitigation during staged construction and operation of the T4 Project. The following groundwater issues were identified:

- Potential salinity impacts both on and off-site due to dredging, particularly at Deep Pond and Easement Pond;
- Potential mobilisation of contaminants and groundwater interactions at the former Delta EMD site during the dredging phase;
- Changes to water levels in the wetlands west and north of the T4 Project area;
- Changes to water levels and flow rates due to filling, preloading and subsequent capping the site;
- Potential groundwater impact associated with tar waste in Pond 5;
- Lead dust co-disposed with asbestos could come into contact with groundwater due to settlement under the T4 Project load;

- Free phase oil contamination at Bore B-01 in Site B;
- Potential mobilisation of contaminants (mainly hydrocarbons and metals) at the FDF associated with settlement under the T4 Project load and a rise in the water table; and
- Groundwater interactions and potential contaminant pathways where the clay aquitard is penetrated by development.

The groundwater model and report was peer reviewed by Dr Noel Merrick, former Acting Director, National Centre for Groundwater Management, University of Technology, Sydney.

## 3.2 Environmental Condition of the Site

### 3.2.1 Ponds 5 and 7 Tar Waste

Ponds 5 and 7 in Site A contain large volumes of non-aqueous phase liquid (NAPL) tar waste to depths of approximately 8 m. The tar waste is generally in the form of a viscous sludge. Groundwater impact has also been recorded above ANZECC criteria (Ref 3) in wells immediately surrounding Ponds 5 and 7. The groundwater impact is primarily within the Fill Aquifer, with some elevated concentrations also recorded in the underlying Estuarine Aquifer.

Drawing 6.06 in Appendix C shows the estimated plan extent of identified tar-impacted soil that exceeds the landuse criteria (NEHF ‘F’) by more than 2.5 times, and the assessed extent of significant groundwater impact.

The ponds have been constructed with permeable slag bund perimeter walls and no side or base lining system. Pond 5 has a coal washery reject surface cap and a geosynthetic clay liner (GCL) at about 0.8 m depth. The cap does not extend over Pond 7, however.

The current approved capping strategy for Pond 5 is to extend the GCL cap by 20 m around the perimeter of Pond 5. This does not cover the identified tar waste in the adjacent Pond 7, and does not consider effects of loading associated with the T4 Project.

It has been assessed that the T4 Project would pose some risk to off-site receptors if remedial measures were not implemented, as follows:

- Groundwater modelling indicates that the ‘squeezing’ effect of T4 Project loading would lead to a temporary increased flow of contaminants towards receptors including Deep Pond, BHPB KIEC (Blue Billed Duck Pond), OEH Wetland 2 and Easement Pond;
- Contaminant transport modelling indicates that contaminant flow rates would be increased during dredging and preloading, up to twice for naphthalene, compared to the no development case;
- There is potential for long term off-site migration with or without the T4 Project, however the risks are higher during dredging and preloading stages; and
- Following development over the Pond 5 area (ie continuation of the proposed coal stockyard), it may not be practical to implement mitigation measures, should off-site impacts become evident.

Accordingly, it is recommended that mitigation measures be implemented prior to construction of the stockyard over Ponds 5 and 7.

### 3.2.2 Lead Dust / Asbestos Area

The asbestos burial pits are known to contain lead dust, co-disposed with the asbestos in polyethylene bags. The designated asbestos disposal area and the location of known burial pits are shown on Drawing 6.08 in Appendix C.

It is assessed that elevated concentrations of lead could potentially reach the wetlands to the north of the disposal area, for the following reasons:

- The site is close to the northern boundary of the T4 Project area and the groundwater flow direction in this part of the site is to the north;
- At least 50 % of the asbestos and lead dust burial pits are expected to come into permanent or frequent contact with groundwater following settlement induced by preloading and subsequent T4 Project loads;
- The long-term integrity of bags containing lead dust cannot be guaranteed (i.e. potential for existing bags to be damaged, or become damaged due to loading and settlement, or degradation over time); and
- The lead dust is expected to be highly leachable when in contact with groundwater.

Adoption of the ‘precautionary principle’ would indicate that mitigation measures should be put in place or allowed for in the future to manage the potential risk.

### 3.2.3 LNAPL Contamination Site B North

Free-phase hydrocarbon impact, comprising Light Non-aqueous Phase Liquid (LNAPL), was encountered in groundwater collected from the Fill Aquifer monitoring well B-01-U. The apparent thickness of floating product in Bore B-01-U was found to be 2.15 m, when dipped in June 2011. Fingerprint analysis of the free product found that the sample was degraded mineral lubricating oil with trace amounts of diesel. The report concluded that the oil was not a recent release and may have been used in diesel engines.

The additional bores drilled in the vicinity of B-01 did not encounter free-phase product but hydrocarbon odours and sheen were noted in groundwater samples, and subsequent testing confirmed hydrocarbon impact in these waters. The degree of impact generally diminished with distance from B-01, indicating that the extent of free product is relatively localised. The assessed extent of significant soil and groundwater contamination is shown on 6.05 and 6.07 (Appendix C).

Groundwater samples collected from the Estuarine Aquifer wells recorded minor hydrocarbon impact in the vicinity of free phase impact.

OEH policy is that the LNAPL contamination should be removed or treated to the extent practicable.

### 3.2.4 Fines Disposal Facility

It is known that groundwater levels within the FDF are artificially low due to the existing leachate collection system – generally about RL 1.8 to 2.0 NHTG. This is approximately the same level as the base of the dredged spoil placed in the FDF, hence to date materials with elevated contaminant levels have been essentially above the water table. Regular annual monitoring of groundwater wells in and around the FDF has shown no firm evidence of off-site migration to date.

Groundwater levels would be elevated during dredging and preload stages. The existing leachate collection system is expected to continue functioning during dredging. Following dredging, however, the elevated head of water in the sand fill (now overlying the FDF) would increase vertical infiltration through the dredge spoil and potentially mobilise contaminants.

Preload and site development are expected to induce significant settlements which are likely to impact on the leachate collection system at the FDF. The base of the emplaced dredge spoil would settle to around RL 1.5 to 2.0 based on the estimated settlements. The capping of the site is expected to result in a typical long-term water table level of approximately RL 3.0 NHTG (Ref 22). This would mean that the lower 1.5 to 2.0 m of dredge spoil within the FDF would remain below the water table in the long term.

Groundwater modelling using measured leachable levels of contaminants within the FDF has indicated a risk of metals and PAH contamination migrating off-site to OEH Wetlands 3, at concentrations exceeding ANZECC criteria (Ref 3). Mitigations measures should therefore be implemented to manage this risk.

### 3.2.5 Delta EMD Site

The former Delta EMD site contains principally manganese waste and localised hydrocarbon contamination. The Contamination Assessment reported exceedances of the landuse criteria and *Waste Classification Guidelines* for metals, TRH and PAH.

A proposed capping strategy (Ref 25) was approved by DECCW (now OEH) comprising a GCL of permeability k of $3 \times 10^{-11}$ m/s over a regraded landform.

The groundwater study identified that the main risk associated with the Delta EMD site would be vertical infiltration of saline water during dredging due to the presence of a thinner and more permeable Unit 2 aquitard below fill materials compared to elsewhere on site. This presents a risk of migration of contamination into the Estuarine Aquifer, and increased groundwater effects on nearby surface water bodies. Groundwater modelling predicts a salinity level exceeding 10,000 ppm in Easement Pond during dredging.

It is considered that mitigation measures would be required to control and manage the saline waters deposited on the Delta site during dredging. Following dredging, the approved capping strategy or equivalent is considered to be adequate to manage contamination at this site.

# 4. Remediation Goals

## 4.1 Guidelines, Regulation and Policy

### 4.1.1 Guideline Documents

The remediation options have been developed based on the findings of the contamination and groundwater assessments, which were undertaken with reference to relevant parts of the following NSW OEH (EPA) recommended guidelines:

- ANZECC (2000) *"Australian and New Zealand Guidelines for Fresh and Marine Water Quality"* (Ref 4);
- ARMCANZ / ANZECC (1995) *"National Water Quality Management Strategy Guidelines for Groundwater Protection in Australia"* (Ref 5);
- NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination* (Ref 34);
- NSW DECC (2008) "*Waste Classification Guidelines, Part 1: Classifying Waste"*, April 2008 (Ref 36);
- NSW EPA (1994) "*Guidelines for Assessing Service Station Sites"*, December 1994 (Ref 37);
- NSW EPA (1996) *"Environmental Guidelines, Solid Waste Landfills"*, January 1996 (Ref 38);
- NSW EPA (2000) *"Guidelines for Consultants Reporting on Contaminated Sites"* (Ref 39); and
- NSW DEC (2006) "*Guidelines for the NSW Site Auditor Scheme, 2nd edition"* (Ref 40), which contain National Environmental Health Forum (NEHF) levels for various beneficial use scenarios including: low density residential (A), high density residential (D), recreational (E) and commercial/industrial (F). These criteria are applicable where aesthetic and ecological concerns are not an issue.

### 4.1.2 Soil

The policy adopted by OEH for the remediation of soil follows the policy adopted by ANZECC/NHMRC (1992) and is set out in section 4.3.2, 4.3.3 and 4.3.4 of the NSW DEC (2006) *Guidelines for the NSW Site Auditor Scheme (2nd edition)* (Ref 40). Although this guideline addresses actions site auditors must follow, it is understood that the actions represent the policy of OEH that would be expected to be applied to remediation works at the site. The parts of the guideline considered relevant to remediation of contamination at the site are as follows:

The site remediation policy (Section 4.3.2 of Ref 40) states that:

*"…soil remediation and management is implemented in the following preferred order:*

- *On-site treatment of the soil so that the contaminant is either destroyed or the associated hazard is reduced to an acceptable level;*
- *Off-site treatment of the excavated soil so that the contaminant is either destroyed or the associated hazard is reduced to an acceptable level, after which the soil is returned to the site;*

- *Removal of contaminated soil to an approved site or facility, followed where necessary by replacement with clean fill;*
- *Consolidation and isolation of the soil on-site by containment within a properly designed barrier.*

*If remediation is likely to cause a greater adverse effect than leaving the site undisturbed, remediation should not proceed"*.

The policy regarding on-site containment and capping (Section 4.3.3 of Ref 40) states:

"…*such options should be considered only where other preferred approaches from the ANZECC/NHMRC remediation hierarchy, outlined in Section 4.3.2, are not applicable.*

*The capping and/or containment strategy must be appropriate for the contaminants of concern. Before endorsing any capping and/or containment proposal site auditors must check that it:*

- *Maximises the long-term stability of the capping and/or containment system(s) and any proposed structures above it (from an engineering perspective) and, where applicable, minimises the potential for leachate formation and/or volatilization;*
- *Does not include the erection of structures on the capped and/or contained area that may result in a risk of harm to public health or the environment;*
- *Recommends a notification mechanism to ensure that the capped and/or contained areas are protected from any unintentional or uncontrolled disturbance that could breach the integrity of the physical barrier, such as recommending placing a notation or covenant on the property title or a notation on a s.149 certificate or issuing a notice or placing a covenant on the title to land under the CLM Act to require maintenance of remediation action under the Act*".

Section 4.3.4 of Ref 40 deals with contamination at depth, and states that as a general principle, contamination at a site must be remediated to meet the appropriate clean-up criteria through the full depth of contamination and that:

"*Clean-up criteria for contaminated soils at depth may differ from the criteria for shallow soils due to differences in exposure opportunities. However, the inhalation of volatile contaminants and the need to protect groundwater require consideration, irrespective of depth. Where clean-up criteria for contaminated soils at depth are different from those for shallower soils, an auditor must consider, in the site audit report, the need for any ongoing management of the contamination at depth in addition to any requirements for managing shallow soil contamination. An auditor must document in their report the rationale supporting the conclusion on this issue*".

Irrespective of the depth of contamination, it is undesirable to leave contamination that may pose an unacceptable human health or environmental risk *in situ* unless the following issues are satisfactorily addressed:

- Investigation has demonstrated that the remaining contamination would not affect the groundwater quality and that any contaminant vapours would not migrate to the surface and pose a risk to human health;

- An environmental management plan has been developed, would be implemented, and can be enforced under relevant laws to ensure that, if the contaminated soil is disturbed, it would be handled in an appropriate manner to avoid any increase in potential risks to human health or the environment;
- The local planning authority is notified that contamination remains at depth on the site, together with its location, nature and extent, details of the environmental management plan and any other regulatory requirements that relate to the contamination, thus allowing the local authority to record this information, as it considers appropriate, in its property information system for the site, such as S.149 certificates".

### 4.1.3 Groundwater

The framework for managing groundwater in NSW is summarised in NSW DEC (2007) *Guidelines for the Assessment and Management of Groundwater Contamination* (Ref 34). The sections of these guidelines that are considered to apply to the contamination at the Site are discussed below.

*Section 1.3 Framework for groundwater management in NSW:*

> "*Legislation and published policies in NSW have articulated key principles for assessing and managing groundwater contamination. These include the principles of ecologically sustainable development, which require the effective integration of economic, social and environmental considerations in decision-making. This can be achieved by implementing:*
>
> - *The precautionary principle;*
> - *Intergenerational equity;*
> - *Conservation of biological diversity and ecological integrity;*
> - *Improved valuation, pricing and incentive mechanisms for; and*
> - *Environmental factors (including the concept of 'polluter pays').*
>
> *The groundwater policies set out in 1.3.3 encourage ecologically sustainable development to:*
>
> - *Slow and halt, or reverse, any degradation of groundwater resources;*
> - *Ensure long-term sustainability of the ecological support;*
> - *Characteristics of groundwater systems;*
> - *Maintain the full range of beneficial uses of these systems; and*
> - *Maximise economic benefit to the region, state and nation.*
>
> *The policies set out basic principles that should guide the management of groundwater in NSW. In relation to groundwater contamination, these include:*
>
> - *Preventing groundwater pollution so future remediation is not required;*
> - *Managing all groundwater systems so their most sensitive identified beneficial use (or environmental value) is maintained;*
> - *Recognising the cumulative impacts of human activities on groundwater quality;*

- *Replacing processes and practices that degrade groundwater systems, either directly or indirectly, with ecologically sustainable alternatives;*
- *Requiring developments to minimise adverse impacts on the environment by preventing pollution of, or changes in, groundwater quality;*
- *Applying the precautionary principle to protect groundwater dependent ecosystems where scientific knowledge is lacking;*
- *Affording town water supplies special protection against contamination;*
- *Rehabilitating degraded groundwater systems, where practical, to minimise the impacts of contamination on groundwater dependent ecosystems, and to restore the ecosystem support; and*
- *Characteristics of groundwater systems.*

*DEC would consider the above principles of ecologically sustainable development when exercising functions under the CLM Act, and others managing contaminated groundwater must also implement these principles. These guidelines establish a decision-making framework for addressing groundwater contamination that is consistent with these principles*".

Section 3.5.1 "*Non-aqueous Phase Liquids*" of the Groundwater Guidelines addresses the presence and remediation of these compounds as follows:

"*Non-aqueous phase liquids (NAPLs) in the subsurface provide an ongoing source of contamination. NAPLs that are in contact with groundwater constitute groundwater contamination. Where light NAPLs (LNAPLs) or dense NAPLs (DNAPLs) are present in the subsurface, they must be removed or treated as much as practicable. Particular care, however, is required in the assessment and clean-up of DNAPL contamination to prevent mobilisation or an increased rate of dissolution.*

*Where complete removal or treatment of the NAPL is impracticable, as may be the case with some DNAPLs in complex geological media, ongoing monitoring and management of the contamination is required as a minimum for as long as necessary, to ensure the protection of human and ecological health. Sources and plumes would need to be contained to the maximum extent practicable, and remediation to address the dissolved-phase contaminants may also be required.*

*A strategy for controlling NAPL contamination should have the following objectives:*

- *To ensure the protection of human and ecological health;*
- *To control further migration of contaminants from subsurface NAPLs to the surrounding groundwater (source control);*
- *To reduce NAPL mass to the extent practicable (source removal or treatment).*

> *It is recognised that clean-up of NAPL contamination can be difficult. For instance, there can be high costs and uncertain benefits in aggressive source zone treatment of some NAPLs. Therefore, the remedial objective for some sites with recalcitrant sources of NAPL may be to contain the source material and prevent or minimise further contaminant migration. Nonetheless, presumptions about the practicability of source zone remediation must keep pace with emergent technology; it should not automatically be assumed that source zone remediation is not feasible. Any assessment that source removal of NAPL contaminants is impracticable should be clearly documented*".

Section 3.6 "*Plume containment*" of the Groundwater Guidelines addresses the requirement to contain plumes of contaminated groundwater as follows:

> "*In responding to groundwater contamination, one goal is to contain the extent of the contaminant plume, that is, to prevent or minimise further plume migration while other management actions are taking place. Plume containment, as the sole long-term response to groundwater contamination, is generally only acceptable when cleaning up contaminated groundwater is not practicable.*
>
> *Proponents of long-term containment must demonstrate they have adequately considered all risks posed by the groundwater contamination. Systems must be developed to monitor the effectiveness of the containment in the long term, and contingency plans must be developed if monitoring data shows that the containment is not effective. In this context, the responsibilities for, and resourcing of, long-term management and contingency plans need to be addressed*".

Section 4.3 "*Clean-up to the extent practicable*" of the Groundwater Guidelines considers the situation where it is considered impracticable to remediate groundwater to restore the protection of all environmental values, which is required to be demonstrated to OEH. Section 4.3 addresses the situation where restoring environmental values is impracticable, which is termed "clean-up to the extent practicable" (CUTEP) as follows:

> "*Where DEC has decided to regulate the management of contaminated groundwater under Part 3 of the CLM Act, DEC must be satisfied with any remediation plan or proposal for a voluntary remediation agreement. In this context, DEC would consider what is practicable and may seek independent expert verification of any supporting claims. In some cases, it may not be practicable to continue cleaning up the groundwater to the point where all its environmental values are restored. In such instances, when regulating the remediation, DEC may consider proposed interim clean-up goals in consultation with stakeholders.*
>
> *4.3.1 Demonstrating restoring environmental values is impracticable*
>
> *If a proponent considers that clean-up to restore the protection of environmental values is impracticable in the future, this must be clearly demonstrated to DEC. The evaluation of practicability should be documented against each factor listed below:*
>
> - *Technical capability to achieve the clean-up;*
> - *Clean-up costs;*
> - *The value of the groundwater resource;*
> - *Threats the contamination poses to human or ecological health.*

*Proposed clean-up measures should correlate with the value of the groundwater resource and the severity of the contamination. Further, any proposal for the clean-up that argues impracticability must include an acknowledgement that the long-term objective is to restore the protection of all relevant environmental values, and ultimately achieve natural background quality. In such cases, ongoing management and monitoring of the groundwater may be required to ensure the protection of human and ecological health.*

*In considering the nature of the remediation required for a site, DEC may consider what actions are practicable. If it is impracticable to clean up groundwater to a concentration needed to restore the protection of environmental values, DEC may accept that clean-up to the extent practicable has occurred and that, subject to appropriate ongoing management of exposures to the contaminants and periodic review, further clean-up is not required. However, acute risks from the contamination, such as risks from short-term exposure or a risk of explosion from the accumulation of vapours, must be resolved without delay.*

*In all cases where clean-up to restore environmental values cannot be achieved:*

- *It is still necessary to clean up to the extent practicable, to minimise the impact on environmental values;*
- *Human and ecological health must be protected;*
- *Plume containment should be implemented to prevent the plume from spreading;*
- *Ongoing groundwater monitoring may be required;*
- *The possibility of cleaning up the groundwater contamination should be periodically reassessed to account for emerging technologies;*
- *Provisions are required for long-term resourcing and responsibility for any ongoing management strategy;*
- *Information must be recorded and disseminated.*

*In considering the practicability of cleaning up the groundwater contamination, DEC would take into account technical, logistical and financial considerations.*

*Before DEC agrees to the proposal, it may seek input from DNR on the current and realistic future uses of the groundwater and the implications that residual contamination may have for groundwater resource management. DNR would consider the information provided in a groundwater management plan where long-term restrictions on groundwater use are required.*

*Where DEC agrees that clean-up to the extent practicable has occurred, this does not remove the proponent's responsibility for ongoing management of the residual contamination. The remediation proposal should be accompanied by:*

- *A commitment to ongoing monitoring and re-evaluation of the practicability of clean-up. A satisfactory monitoring and reporting program must be implemented to continually evaluate the contamination;*
- *A groundwater management plan (GMP) that specifies measures which would be implemented to mitigate risks to human and ecological health (see 5.3.2);*

- *Acknowledgement that future management including cleanup action may be required by the government to ensure the protection of human and ecological health;*
- *Provision for long-term resourcing and responsibility for any ongoing management strategy;*

*Any ongoing management actions may be enforceable through statutory means such as a regulatory instrument issued under the CLM or POEO Act*".

It is likely that OEH would expect that remediation of contamination that is acting or has potential to act as a source of contamination of groundwater and surface water would be remediated or managed so that contamination of groundwater does not occur. Remediation or management is required to be in accordance with the policy and guidelines referred to above.

It is expected that NAPLs, both LNAPLs and Dense Non-aqueous Phase Liquids (DNAPLs), would be required to be managed or remediated so that they do not pose a potential to contaminate groundwater or surface water and so that they do not pose an unacceptable risk to human health from generation of vapours and/or from fire or explosion, as appropriate.

It is also expected that substances that have a high potential to contaminate groundwater, such as leaded dust, aqueous sludges, oil sludges, tar waste, waste oil, acid sludges, lime sludges, manganese sludges and the like, would be expected to be managed and/or remediated as part of the T4 Project. Each of these potential contaminants, if present at the T4 Project site are required to be addressed in the groundwater assessment program if they pose a potential risk to the quality of groundwater or surface water.

### 4.1.4 Ecologically Sustainable Development

The Contaminated Land Management Act (CLM Act) sets out the principles of ecologically sustainable development (ESD), which have been considered when assessing remediation or management options for the Site. The main features of ESD are:

- Precautionary principle – the lack of scientific certainty should not preclude the application of measures to prevent environmental degradation;
- Inter-generational equity – the health, diversity and productivity of the environment should be maintained for future generations;
- Conservation of biological diversity and ecological integrity; and
- Inclusion of environmental factors in the valuation of assets and services.

In assessing the sustainability of a particular remediation or management option for implementation on the T4 Project area, environmental sustainability has also be considered, such as the residual waste generated, and the required use of energy and resources to implement the remedial action and to manage the remediated site into the future remediation.

## 4.2 Environment Protection Licences

Sites A and B North were the subject of an EPL issued by the EPA (now part of the OEH) until the surrender of the licence in December 2010. Sites C and D are currently subject to EPLs and have not yet been surrendered.

These licences prescribed the permitted waste disposal activities, environmental monitoring and reporting requirements. Table 3 lists the relevant licences, permitted waste and number of water monitoring locations for each site.

**Table 3: Environment Protection Licences**

<table>
<tr><th>Site</th><th>EPL No.</th><th>Licensee</th><th>Date of Most Recent Variation</th><th>Permitted Waste</th><th>Number of Water Monitoring Locations</th></tr>
<tr><td>A</td><td>6437[1]</td><td>Hunter Development Corporation</td><td>23-07-2009<br>(surrendered)</td><td>General Solid Waste<br>Asbestos waste<br>Waste tyres</td><td rowspan="2">47 Groundwater<br>7 Surface Water<br>(A and B combined)</td></tr>
<tr><td>B North</td><td>6437[1]</td><td>Hunter Development Corporation</td><td>23-07-2009</td><td>General Solid Waste</td></tr>
<tr><td>C</td><td>7675</td><td>Port Waratah Coal Services Limited</td><td>02-07-2010</td><td>General Solid Waste<br>Stabilised asbestos<br>Filter cake<br>Thickener underflow<br>Kiln and pond sludge</td><td>26 Groundwater<br>5 Surface Water</td></tr>
<tr><td>D</td><td>5022</td><td>Port Waratah Coal Services Limited</td><td>17-04-2009</td><td>Dredge Spoil arising from expansion of KCT<br>General Solid Waste[2]</td><td>15 Groundwater<br>2 Surface Water</td></tr>
</table>

Notes to Table 3:
1. This licence was surrendered on 8 December 2010; waste disposal no longer permitted
2. General Solid Waste added in Draft Licence Variation 1104137, July 2009

Sites A and B North were subject to EPL 6437. Since commencing the current investigation, DECCW issued an “Approval of the Surrender of Licence No. 6437”, dated 8 December 2010. The approval included specific conditions relating to final capping (to be implemented by 28 March 2013), materials management, environmental monitoring and reporting, which would have an impact on the T4 Project development. The capping strategy is discussed further in Section 6 below. The main features of the capping strategy are as follows:

- 0.5 m cap comprising Coal Washery Reject (CWR) compacted to achieve a permeability of $1x10^{7}$ m/s;
- Surface grades of not less than 1%;

- Pond 5 – maintain existing GCL cap, minor re-contouring; extend cap nominally 20 m past the boundary of Pond 5 and compact to achieve a permeability of $1x10^{-8}$ m/s;
- Minimise disturbance to the asbestos dump area (the existing cap over this area is considered to be sufficient); and
- General earthworks (cut/fill) for regrading, capping and final landform preparation. Any cut material that is significantly contaminated as defined in the materials management plan would be disposed off-site or relocated to a nominated containment cell area.

Further details of the proposed cap over Sites A and B North are provided in Ref 28.

Site C (Delta EMD waste disposal site) operates under EPL 7675. The licence has recently been revised to reflect the new approved capping strategy (Licence Variation dated 23 July 2009), however the monitoring requirements remain unaltered. The main features of the capping strategy for Delta EMD are as follows:

- Seal bearing surface – regrading of in-situ materials;
- Sealing layer – Geosynthetic Clay Liner (CGL); and
- Hardstand surface (pavement material).

Further details of the proposed Delta EMD cap are provided in Ref 25.

Site D (FDF) operates under EPL 5022 and PWCS proposes to submit a closure plan that ties in with the T4 Project construction.

# 5. Assessment of Remediation

## 5.1 Review of Available Options

A review of available remediation and management technologies was undertaken prior to assessing the preferred options for each of the contamination issues identified. Of the many remediation technologies available, only well-established, proven technologies were considered for the T4 Project. Relevant OEH guidelines and policies were also considered when determining preferred options for remediation and management. Table 4, below, presents a summary of the remediation technologies reviewed.

The remediation technologies considered the most appropriate for the identified issues are discussed further in the following sub-sections. Alternative and emerging technologies were also briefly reviewed but discounted due to lack of experience and uncertain effectiveness; these included electrochemical remediation technologies (ECRT), supercritical fluid technology (SCF) and nanotechnology (in particular the use of nanoscale zero-valent iron (nZVI).

The *in situ* technologies are those that do not require excavation or removal of the contaminated soil and/or water to remediation the area, although there may be some excavation associated with installation of the remedial option elements (e.g. barrier wall). The *ex situ* technologies require the contaminated soil or water to be removed from the ground for treatment, which can either occur on- or off-site.

**Table 4: Summary of Remediation Technologies Reviewed**

| Category | Technique | S/W[1] | Place | General Comments |
|---|---|---|---|---|
| Physical/ Chemical | Soil washing | S | ex situ | best suits coarse grained soils |
| | Soil vapour extraction | S | in situ | only suits volatile organics |
| | Dual phase extraction (includes bioslurping) | W | in situ/ ex situ | pumping of free phase; with soil vapour extraction |
| | Chemical oxidation | S/W | in situ | oxidants added to convert contaminants into harmless substances; usually circulated by pumping and reinjection. |
| | Pump and treat | W | ex situ | pumping of contaminated water or free phase for on-site or off-site treatment |
| | Solidification/stabilisation | S | in situ | deep soil mixing in situ with cementitious binder |
| | Air sparging | W | in situ | air injected via wells to vaporise contaminants; unsuitable for free phase; inhibited by stratified soils |
| | Permeable reactive barrier | W | in situ | zero-valent metals, chelators, sorbents, microbes, etc used to treat organics or inorganics |
| | Excavate to on-site cell or dispose off-site | S | ex situ | relocate to on-site lined cell or off-site treatment/disposal |
| Biological | Bioventing | S | in situ | uses nutrient injection wells; best suits volatile organics |
| | Biopiles | S | ex situ | aerobic landfarming in controlled cells; best suits volatile organics |
| | Enhanced bioremediation | S/W | in situ | can be slow for PAHs |
| | Phytoremediation | S/W | in situ | uses natural plant processes; limited to shallow soils |
| | Biosparging | W | in situ | unsuitable if free phase present |
| | Monitored Natural Attenuation | W | in-situ | relies on natural biological processes |
| Thermal | Thermal Treatment | S/W | in situ | heat introduced via electrodes, steam injection, radio frequency; needs abstraction wells |
| | Vitrification | S | in situ | soil is melted by electric current then solidifies |
| | Thermal desorption | S | ex situ | organic contaminants are volatilised by heat then extracted |
| | Incineration | S | ex situ | contaminants are destroyed at very high temperatures |
| Containment | Barrier wall | W | in situ | soil-bentonite or cement-bentonite wall constructed in a slurry supported trench |
| | Capping | W | in situ | reduces vertical infiltration only |

Note to Table 4:

1. S = soil; W = water

## 5.2 Method of Ranking Remediation Options

The remediation options for each contamination issue were evaluated against the following attributes and weightings:

- **Technical Effectiveness (20%):** the suitability of the method to treat or manage the contaminant(s) of concern, also considering geotechnical impacts (beneficial or adverse);
- **Track Record in Australia (5%):** whether the method has been successfully used in Australia;
- **Availability (5%):** the number of contractors who have the expertise and equipment to implement the method; can include international contractors who could bring the technology into Australia;
- **Ease of Implementation (10%):** consideration of site constraints, regulatory hurdles and logistics;
- **Verification (5%):** effectiveness of construction quality control and ability to verify that specifications have been achieved;
- **Sustainability (10%):** the principles of ESD and the use of resources, energy inputs, waste generation, on-going management and maintenance;
- **Stakeholder Acceptance (5%):** the likely degree of satisfaction of regulators, owner, neighbours and the community with the remediation option;
- **Risk of off-site Migration (10%):** effectiveness of the method to inhibit contaminant transport;
- **Cost (20%):** including trials, design, construction and operation; and
- **Time to Implement (10%):** trials, design and construction.

The number in brackets represents the weight assigned for each attribute, indicating the relative importance of each attribute, with the total of weightings equalling 100 %.

The attributes were each scored from 0 to 5 based on a combination of quantitative and qualitative inputs. The scoring system is shown in Table 5. The total score was calculated as:

$\Sigma S_i W_i$ where $S_i$ = score for attribute i, and $W_i$ = weighting for attribute i.

**Table 5: Remediation Option Scoring**

| Attribute | Score | | | | | |
|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 |
| Technical Effectiveness | Not Effective | Very Poor | Poor | Satisfactory | Good | Very Good |
| Track Record in Australia | Never Used | Very Poor | Poor | Satisfactory | Good | Very Good |
| Availability | Not Available | 1 Contractor | 2 Contractors | 3 - 5 Contractors | 6 – 10 Contractors | >10 Contractors |
| Ease of Implementation | Not Possible | Very Difficult | Difficult | Medium | Easy | Very Easy |
| Verification | Not Possible | Very Difficult | Difficult | Medium | Easy | Very Easy |
| Sustainability | NA | Very Poor | Poor | Satisfactory | Good | Very Good |
| Stakeholder Acceptance | Not Acceptable | Very Low | Low | Moderate | High | Very High |
| Risk of Off-site Migration | NA | Very High | High | Moderate | Low | Very Low |
| Cost | >$100M | $50 -$100M | $20 - $50M | $10 - $20M | $5 - $10M | <$5M |
| Time to Implement | > 5 years | 4 - 5 years | 3 - 4 years | 2 - 3 years | 1 - 2 years | <1 year |

Note to Table 5:
1. NA - not applicable

The remediation ranking score sheets for the identified contamination issues are presented in Appendix A. The individual scores were assessed after taking into account preliminary advice provided by remediation contractors, particularly in relation to availability of the method, technical effectiveness, ease of implementation, cost and time to construct.

In each case the remediation option with the highest score is highlighted green on the ranking sheet and represents the option assessed to be the most appropriate. The preferred options are discussed in more detail below.

It is customary to include a “Do Nothing” option in remediation assessments. In the case of the T4 Project, the site would be capped as a minimum and a monitoring network set up for groundwater and surface water (see Section 6.1). The “Do Nothing” option is therefore effectively the Cap and Monitor option.

## 5.3 Preferred Remediation Options

The preferred remediation options for each of the identified contamination issues are summarised in Table 6 below.

**Table 6: Summary of Preferred Remediation Options**

| Contamination Issue | Preferred Remediation Option | Second Ranked Option | Third Ranked Option |
|---|---|---|---|
| Pond 5/7 tar waste | Barrier Wall (soil bentonite) | Permeable Reactive Barrier (1) | Extend Cap and Monitor |
| Lead Dust / Asbestos | Permeable Reactive Barrier (1) | Barrier Wall (soil bentonite) | NA (3) |
| Site B LNAPL | Dual Phase Extraction | Pump and Treat (2) | Barrier Wall (soil bentonite) |
| FDF | Permeable Reactive Barrier (1) | Cap and Monitor | Interception Drain and Monitor |
| Delta EMD (Dredging Phase) | Liner / Cap prior to dredging | Barrier Wall (soil bentonite) | Interception Drain and Monitor |
| Deep Pond (Dredging Phase) | Low permeability liner before dredging | NA (3) | NA (3) |

Notes to Table 6:

1. Includes possible variants such as "funnel and gate" arrangements
2. Includes combinations with related technologies, such as air sparging
3. NA - Not applicable

Further details are shown in Table A2 in Appendix A, and the preferred remediation option for each site is discussed below.

**Ponds 5 and 7**

The proposed barrier wall is a form of containment, and although this method ranks fourth in the OEH preferred order of soil remediation (see Section 4.1.2), intrusive remediation options are considered likely to result in an increased risk of environmental harm due to exposure of the tar which is in the form of a viscous sludge (NAPL). The Groundwater Guidelines recognise that containment of this type of contamination may be the most appropriate option (see Section 4.1.3). Options that require excavation and dewatering of the ponds are not practical and are prohibitively costly.

A barrier wall could be effectively installed to the natural soft clay stratum at about 10 m below current surface levels (i.e. intercepting the Fill Aquifer containing the raw tar materials), which is easily achievable with readily available equipment and expertise.

It is anticipated that the upper few metres of the soil profile at Ponds 5 and 7 will also be stabilised using deep soil mixing techniques, primarily to provide a geotechnically suitable working platform for the remediation activities.

The design of the wall should take into account the hydraulic conditions of the contained volume under initial loading (especially preload), which would be a one-off event during construction. The design should consider requirements for internal drainage measures the relieve water pressures and collect leachate, which could be re-infiltrated within the confines of the barrier wall or alternatively collected, treated and disposed.

**Lead Dust / Asbestos**

The 'precautionary principle' as outlined in the Principles of ESD (Section 4.1.4) and the Groundwater Guidelines (Section 4.1.3) has been applied to the potential risk resulting from this class of contamination.

The permeable reactive barrier (PRB) would be designed to maintain northerly groundwater flows while 'treating' lead leachate in the event that lead dust comes into contact with the groundwater.

There are several design options for a PRB, however, the most likely type would be a 'funnel and gate' arrangement, comprising 'gates' of reactive medium with intervening panels of impermeable barrier wall. This system allows for more convenient maintenance and, if needed, replenishment of the reactive media. The Long-term Environmental Management Plan will be required to incorporate regular monitoring and maintenance of the reactive media.

The founding level of the PRB would be around RL 0.0 to 0.5 m NHTG within the clay aquitard (subject to detail design).

Monitoring wells would be required on both sides of the PRB to monitor water quality, and would form part of the groundwater monitoring network for the T4 Project, as will be set out in the Long-term Environmental Management Plan.

For access during construction, maintenance and monitoring, a corridor of at least 5 m width (preferably 8 m) would be required to be maintained between the northern machinery berm and the railway lines, which should be incorporated into the design of the T4 Project.

**Site B LNAPL**

The Groundwater Guidelines and OEH policy dictate that free-phase floating product should be removed or treated to the extent practicable.

Dual Phase Extraction is an in-situ technology that uses pumps to remove various combinations of contaminated groundwater, free-phase petroleum product and hydrocarbon vapours from the subsurface. Extracted liquids and vapours are treated and collected for disposal, or re-injected to the subsurface (where permissible). Dual-phase extraction systems are therefore aimed at reducing concentrations of petroleum hydrocarbons in both the saturated and unsaturated zones of the subsurface. Dual-phase extraction systems are typically designed to maximise extraction rates; however, the technology can also stimulate biodegradation of petroleum constituents in the unsaturated zone by increasing the supply of oxygen, in a manner similar to bioventing.

**Fines Disposal Facility**

The PRB would be designed to maintain northerly groundwater flows while 'treating' leachate potentially generated by the FDF sediments coming into contact with the groundwater. As the FDF would be capped as part of the T4 Project development, future generation of leachate should be minimal.

There are several design options for a PRB, however, the most likely type would be a 'funnel and gate' arrangement, comprising 'gates' of reactive media with intervening panels of impermeable barrier wall. This system allows for more convenient maintenance and, if needed, replenishment of the reactive media. The Long-term Environmental Management Plan will incorporate regular monitoring and maintenance of the reactive media.

The reactive media would be designed to 'treat' the primary leachable contaminants within the FDF sediments: PAHs, TPH and metals (aluminium, chromium, copper, lead, mercury and zinc).

The founding level of the PRB would be around RL 0.0 to 0.5 m NHTG within the clay aquitard (subject to detail design).

Monitoring wells would be required on both sides of the PRB to monitor water quality, and would form part of the groundwater monitoring network for the T4 Project, as will be set out in the Long-term Environmental Management Plan.

For construction, maintenance and monitoring purposes, a corridor of at least 5 m width (preferably 8 m) would be required between the northern machinery berm and the railway lines, which should be incorporated into the T4 design.

**Delta EMD**

The former Delta EMD site principally contains stabilised manganese waste and localised hydrocarbon contamination. The Contamination Assessment reported exceedances of the landuse criteria for metals (mainly manganese), TRH and PAH. Furthermore, high salinity waters from dredging represent a risk to sensitive habitats adjacent to this site. The risk of highly saline water entering Easement Pond and other water bodies during dredging could be managed by the installation of a low-permeability 'cap' prior to dredging. After dredging, this 'cap' becomes sacrificial as the construction of T4 Project infrastructure at a higher level will form a new cap.

OEH has approved a capping strategy comprising a GCL of permeability (k) of $3 \times 10^{-11}$ m/s over a regraded landform. A similar measure comprising a low-permeability layer could be implemented as the mitigation strategy for this site during the dredging phase, but it would not necessarily have to be a GCL. Surface water and groundwater monitoring measures would be required to confirm the effectiveness of the cap during dredging, as will be set out in the Long-term Environmental Management Plan.

**Deep Pond**

The proposed low-permeability liner adjacent to the railway embankment within Deep Pond would be required to keep high salinity dredge waters from seeping through the rail embankment into OEH Wetlands 1 and 2.

The use of a liner allows for a larger portion of Deep Pond to be used to manage dredge waters.

# 6. Landfill Closure, Site Capping and Containment Cell

## 6.1 Landfill Guidelines

The NSW EPA *Environmental Guidelines, Solid Waste Landfills* (Ref 38) outlines the requirements for capping and monitoring of landfills after closure. The sections relevant to closure and site capping are Benchmark 28 and Benchmark 29 and are discussed below.

**Benchmark 28 – Site Capping and Revegetation**

Benchmark 28 requires the final landfill capping to comprise the following five parts (in order from lowest part to top):

- A seal-bearing surface – a properly designed and engineered layer of material;
- A gas drainage layer – minimum thickness 30 cm, with no more than 10% $CaCO_3$ content;
- A sealing layer – clay at least 50 cm thick and permeability < $10^{-8}$ m/s;
- A drainage layer – at least 30 cm of material with permeability ≥ $10^{-5}$ m/s; and
- A revegetation layer – at least 100 cm of topsoil; plants to have root systems that do not penetrate into or block the drainage layer beneath.

The final profile of the seal-bearing surface after settlement should leave a gradient of greater than 5 % to defined drainage points. If the sealing layer is left for more than seven days before being covered by the revegetation layer, it should be covered by a flexible membrane liner for protection.

The OEH has already approved capping strategies for Sites A, B North (KIWEF) and C (Delta EMD) that vary from the above requirements due to the history of the site and specific nature of the contamination. The approvals were based on the provision of capping that met the intent of Benchmark 28. In particular the approved strategies omit the gas drainage layer because the landfills were used for non-putrescible waste, hence the risk of gas generation was considered to be low. The approved strategies also omit the upper drainage and revegetation layers on the basis that the site would be used for industrial development. Ultimately both strategies consist only of a seal-bearing surface and a low permeability sealing layer (as described in Section 4.2).

The constructed T4 Project would provide equivalent or superior capping to that already approved for KIWEF and Delta EMD. The components would be:

- Stockyard machinery berms – low permeability cement-stabilised sand;

- Stockyard coal pads – base layer of low permeability sand-cement-bentonite mix or equivalent;
- Water management ponds – low permeability liners to prevent loss of water; and
- Elsewhere – surface paving or a low permeability cap equivalent to the approved capping.

The design of the T4 Project development should be such that the above components effectively form a sealing layer with hydraulic performance equivalent to a 50 cm clay layer of permeability < $10^{-8}$ m/s.

**Benchmark 29 – Landfill Closure and Post-Closure Monitoring and Maintenance**

Benchmark 29 requires a post-closure monitoring and maintenance programme which "ensures the long-term integrity of the landfill". The details are to be set out in a written Closure Plan submitted to the OEH for approval. The required features of the Closure Plan are:

- Specify the steps to be taken to 'stabilise' the landfill and the timeframe required;
- Monitoring and reporting procedures to a standard equivalent to that required during operation of the landfill;
- Advise neighbouring residents details of contact persons for complaints (e.g. odour) and maintaining a record of complaints; and
- Ensure that waste materials are no longer received at the facility.

The monitoring and maintenance is required until the landfill no longer poses a threat to the environment. Construction and operation of the T4 Project would conform to the requirements of Benchmark 29. This would include a groundwater and surface water monitoring programme, as will be set out in the Long-term Environmental Management Plan.

## 6.2 Status of Landfills within the T4 Project Area

Landfill closure and surface capping plans have been developed for Site A, Site B North and Site C. These plans are typically required by the OEH upon the impending closure of a landfill, however the status and specifics vary with each site as reflected in the relevant EPLs as shown in Table 7.

**Table 7: Environment Protection Licence Closure/Capping Status**

| Site | Licence No. | Clauses | Closure /Capping Status |
|---|---|---|---|
| A and B North | 6437 | O4.1<br>U1.1<br>U1.2<br>U1.3 | • Closure Plan submitted to OEH;<br>• Materials Management Plan for Area K10 submitted to OEH;<br>• Boundary Monitoring Network to be expanded to fill gaps in network; OEH intends to include these in future ongoing monitoring programme;<br>• Surrender of Licence was approved on 8 December 2010;<br>• Capping to be completed by 28 March 2013. |
| C | 7675 | O6.1<br>O6.2<br>O6.3<br>O6.4 | • Construct and install final cap in accordance with Ref 25;<br>• Implement construction in accordance with Ref 25;<br>• Construction to be supervised by suitably qualified engineer;<br>• Provide construction verification report within two months of completion (completion date has not yet been set). |
| D | 5022 | O10[1] | No capping/closure requirement in current version, but a Draft Variation by OEH[1] requires a Closure Plan be submitted within three months prior to the last load of waste. |

Note to Table 7:

1. DECCW Draft Variation Notice 1104137, July 2009

## 6.3 Containment Cell

The bulk earthworks for T4 Project would include some excavation of existing fill, mainly within Area K7 and to a lesser extent within Area K5. Excavated fill materials would contain varying degrees of contaminated soil and deleterious materials. These would be suitably managed through implementation of a Materials Management Plan (MMP), which would be part of the Construction Environmental Management Plan (CEMP). Waste materials that cannot be re-used as general fill would be placed in a purpose-built containment cell within the T4 Project area.

Based on similar previous projects the MMP would likely nominate three categories of excavated fill materials:

- Level 1: Unrestricted Re-use on the T4 Project area;
- Level 2: Restricted Re-use on the T4 Project area;
- Level 3: Cannot be Re-used (typically NAPLs and Asbestos); possible requirement to notify OEH.

A preliminary assessment was undertaken of suitable cell locations for a containment cell within the T4 Project area. Further detail is included in the Contamination Assessment Report. Comments on potential locations, cell size and expected usage are provided below:

**Location Considerations**

- Cell should be sited as far as practical from sensitive receptors;
- Base level should be at least 1.5 m above highest expected water level;
- If under a proposed stockyard area, the cell should be designed to withstand subsequent pre-loading and project loads; and geotechnically unsuitable material would have to be segregated and placed in non-loaded areas or improved/stabilised (e.g. soft/wet materials);
- If preloading was undertaken first, the cell area would be susceptible to settlement under the stockyard loads unless the material was compacted or stabilised (e.g. cement treated) to engineering specifications when placed;
- The location and design should allow for the size of the cell to be adjusted (increased) if necessary during construction works (for reasons discussed below);
- The cell is likely to require perimeter groundwater monitoring wells that would need to be accessed during construction and (possibly) terminal operation. The cell location should not restrict access to monitoring wells; and
- The location cannot be within the footprint of a transfer house, buffer bin, conveyor or other piled structure, as the piles would have to penetrate the cell and lining system.

**Size Considerations**

- The final volume of 'Level 3' contaminated material is not yet accurately known; a preliminary estimate based on available information is that the volume of 'Level 3' and/or hazardous waste could be in the order of 15,000 $m^3$ to 25,000 $m^3$;
- The final volume will depend on adopted bulk earthworks level – proposed lowering would increase the risk of encountering Level 3, and the potential amount of Level 3 and/or unsuitable materials;
- A more accurate estimate of type and quantity of waste (and Level 3 materials) from cut areas will be obtained following further investigation and finalisation of the bulk earthworks levels; and
- Design to be flexible in regard to layout and size (e.g. series of sub-cells) so that capacity can be adjusted (increased) during the works if required. A total capacity in the order of 30,000 $m^3$ is envisaged.

**Cell Usage**

- It is expected the cell would primarily be used for 'Level 3' type materials – those impacted by free-phase contaminants (NAPLs), with significant staining or odours, and Asbestos; and
- Some geotechnically unsuitable material may also have to go in the cell if its contaminant levels preclude off-site removal.

It is assessed that suitable potential locations for an on-site containment cell would include:

1. North-west corner of Delta EMD (former Pond 34 area), designed to accommodate the subsequent preloading / loading effects on the cell; this area is also conveniently close to where most of the contaminated material would be found (i.e. Area K7 and Area K5).
2. South-west corner of Delta EMD (triangular area) where it is beyond the footprint of the stockyards and hence would not be loaded.
3. Site B North, possibly involving excavating into the coal washery reject cap and re-using this material for bunds or surface capping of cells.

The site selection and design process would include mapping the areas and depths of proposed cut, assessment of the likely composition of the materials to be excavated, sizing of the cell, design of the lining system and preparation of construction procedures.

# 7. Conclusions

## 7.1 Remediation

The T4 Project area presents a number of environmental challenges associated with contamination and groundwater which could be managed effectively by implementing appropriate, readily available and robust mitigation measures during staged construction of the T4 Project. The following soil and groundwater contamination issues were identified:

- Site A Ponds 5 and 7: Soil and groundwater impact associated with coal tar waste;
- Site A Area K7: Lead dust co-disposed with asbestos could come into contact with groundwater due to settlement under the load of the T4 Project infrastructure;
- Site A Deep Pond: adverse groundwater impacts on OEH wetlands during dredging;
- Site B North: Free phase oil contamination (LNAPL) in the vicinity of Bore B-01;
- Site C Delta EMD: Potential mobilisation of contaminants and adverse groundwater interactions (mainly Easement Pond) during the dredging phase; and
- Site D Fines Disposal Facility: Potential mobilisation of contaminants (mainly hydrocarbons and metals) associated with settlement under the load of the T4 Project infrastructure and a rise in the water table.

Drawing 6.09 in Appendix C indicates the main areas of contamination in relation to the proposed development. In addition to the specific contamination issues identified, the remainder of the site contains general industrial contamination and localised ‘hot spots’ that require management through the capping strategies already approved by OEH for Sites A, B North and C, or equivalent. Maintenance of the capping layer will be implemented by actions that will be set out in the Long-term Environmental Management Plan.

The remediation and management measures would require detailed assessment, trials, design and pricing prior to implementation. Accordingly the preferred options may be varied or refined during this process, or a combination of methods may be developed.

The implementation of the proposed remediation and management measures for the T4 Project would protect environmental values, and is expected to improve the long term environmental condition of the T4 Project site and immediate surrounds. The impacts of the T4 Project are considered reasonably well known within the normal limitations of investigation and modelling techniques. An element of uncertainty always exists due to the inherent variability of soil and groundwater conditions, but is manageable through engineering design and monitoring practices.

### 7.2 Environmental Management Plans

Environmental management plans (EMPs) should be prepared for both the construction activities and the operation of the completed stages of the T4 Project. The plans would include, but not necessarily be limited to, the following:

- Over-arching Environmental Management Plan for construction activities for the T4 Project, setting standards, objectives and criteria;
- Individual Construction Environmental Management Plans (CEMP) for each major component of construction, including individual mitigation measures. This would include environmental monitoring during construction and occupational health and safety matters;
- Construction Groundwater and Surface Water Monitoring Plan, establishing a suitable monitoring network of groundwater wells and surface water locations for construction; and
- Long-term Environmental Management Plan for terminal operation, including groundwater and surface water monitoring and incorporating as far as practicable monitoring stations established for the construction activities.

Further details on the contents of the above plans are given in the document outlining the Remediation Action Plan (RAP), including an outline of the CEMP for each mitigation measure. The Groundwater and Surface Water Monitoring Plan for baseline and construction monitoring is currently being developed and is expected to be implemented in February 2012.

The Long-term Environmental Management Plan for the T4 Project would be an important element of the adopted remediation options. The development and implementation of this plan would ensure the remediation works are maintained properly, the effectiveness of the remediation works are monitored, maintenance, as required, is undertaken and any intrusive works are undertaken to ensure protection of the remedial measures.

The requirements for the Long-term Environmental Management Plan will be set out in the Remediation Action Plan and the Plan will be developed following completion of the remediation works.

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## 9. Limitations

DP has prepared this report for the T4 Project at Kooragang Island in accordance with DP's proposal NCL100317 Rev 1 dated 26 July 2010 and Consultancy Agreement with PWCS dated 4 August 2010. The report is provided for the exclusive use of PWCS for this project only and for the purpose(s) described in the report. It should not be used for other projects or by a third party. In preparing this report DP has necessarily relied upon information provided by the client and/or their agents.

The results provided in the report are indicative of the sub-surface conditions only at the specific sampling or testing locations, and then only to the depths investigated and at the time the work was carried out. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of anthropogenic influences. Such changes may occur after DP's field testing has been completed.

DP's advice is based upon the conditions encountered during this investigation. The accuracy of the advice provided by DP in this report may be limited by undetected variations in soil conditions between sampling locations. The advice may also be limited by constraints imposed by others or by site accessibility.

This report must be read in conjunction with all of the attached notes and should be kept in its entirety without separation of individual pages or sections. DP cannot be held responsible for interpretations or conclusions made by others unless they are supported by an expressed statement, interpretation, outcome or conclusion given in this report.

**Douglas Partners Pty Ltd**

# Appendix A

About this Report

Table A1 Director General's Requirements (Soils and Contamination, Water Quality and Hydrological Impacts)

Table A2 Environmental Issues and Mitigation Measures

## Introduction

These notes have been provided to amplify DP's report in regard to classification methods, field procedures and the comments section. Not all are necessarily relevant to all reports.

DP's reports are based on information gained from limited subsurface excavations and sampling, supplemented by knowledge of local geology and experience. For this reason, they must be regarded as interpretive rather than factual documents, limited to some extent by the scope of information on which they rely.

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This report is the property of Douglas Partners Pty Ltd. The report may only be used for the purpose for which it was commissioned and in accordance with the Conditions of Engagement for the commission supplied at the time of proposal. Unauthorised use of this report in any form whatsoever is prohibited.

## Borehole and Test Pit Logs

The borehole and test pit logs presented in this report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on frequency of sampling and the method of drilling or excavation. Ideally, continuous undisturbed sampling or core drilling will provide the most reliable assessment, but this is not always practicable or possible to justify on economic grounds. In any case the boreholes and test pits represent only a very small sample of the total subsurface profile.

Interpretation of the information and its application to design and construction should therefore take into account the spacing of boreholes or pits, the frequency of sampling, and the possibility of other than 'straight line' variations between the test locations.

## Groundwater

Where groundwater levels are measured in boreholes there are several potential problems, namely:

- In low permeability soils groundwater may enter the hole very slowly or perhaps not at all during the time the hole is left open;
- A localised, perched water table may lead to an erroneous indication of the true water table;
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report; and
- The use of water or mud as a drilling fluid will mask any groundwater inflow. Water has to be blown out of the hole and drilling mud must first be washed out of the hole if water measurements are to be made.

More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be advisable in low permeability soils or where there may be interference from a perched water table.

## Reports

The report has been prepared by qualified personnel, is based on the information obtained from field and laboratory testing, and has been undertaken to current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal, the information and interpretation may not be relevant if the design proposal is changed. If this happens, DP will be pleased to review the report and the sufficiency of the investigation work.

Every care is taken with the report as it relates to interpretation of subsurface conditions, discussion of geotechnical and environmental aspects, and recommendations or suggestions for design and construction. However, DP cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions. The potential for this will depend partly on borehole or pit spacing and sampling frequency;
- Changes in policy or interpretations of policy by statutory authorities; or
- The actions of contractors responding to commercial pressures.

If these occur, DP will be pleased to assist with investigations or advice to resolve the matter.

## Site Anomalies

In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, DP requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather than at some later stage, well after the event.

## Information for Contractual Purposes

Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a specially edited document. DP would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

## Site Inspection

The company will always be pleased to provide engineering inspection services for geotechnical and environmental aspects of work to which this report is related. This could range from a site visit to confirm that conditions exposed are as expected, to full time engineering presence on site.

**Table A1: Director General's Requirements (Soils and Contamination, Water Quality and Hydrological Impacts)**

| Director General's Requirements (14 March 2011) | Report Reference | Report Title | Section(s) where DGR Addressed |
|---|---|---|---|
| **Soils and Contamination Impacts** | | | |
| • Soil and geotechnical assessment (geotechnical and groundwater models); | 49533.02-02 | Contamination Assessment | Section 6 |
| • Risks and impacts of exposure and mobilisation of contaminants; | 49533.02-02 | Contamination Assessment | Section 10 |
| | 49533.02-05 | Groundwater Assessment | Section 11.3, 12 |
| • Risk of further migration of contaminants; | 49533.02-05 | Groundwater Assessment | Section 11.3 |
| • Risk and impacts associated with acid sulphate soils; | 49533.02-02 | Contamination Assessment | Section 8.5, Section 8.6 |
| • Potential for fill settling under load; | 49533.02-05 | Groundwater Assessment | Section 8.4.4, Drawing 5.23 |
| | 49533.02-06 | Assessment of Remediation Options | Section 3.1.1 |
| • Interaction of project components with site capping, including implications for piling and design of foundations; | 49533.02-02 | Contamination Assessment | Section 10.10.3 |
| • Invasive land and groundwater contamination investigation; | 49533.02-02 | Contamination Assessment | Section 5, Section 8 |
| • Remediation requirements and mitigation measures. | 49533.02-06 | Assessment of Remediation Options | Section 5 |
| **Water Quality and Hydrological Impacts** | | | |
| • Changes to groundwater recharges and flow regimes, impacts to surface and groundwater flow regimes, including the Kooragang Wetland and groundwater users. | 49533.02-05 | Groundwater Assessment | Sections 9.2, Section 11.3, Section 12 |
| **Supplementary Director General's Requirements (21 September 2011)** | **Report Ref** | **Report Title** | **Section(s) where DGR Addressed** |
| **Soils and Contamination, Water Quality and Hydrological Impacts** | | | |
| • A detailed assessment of the nature and extent of the likely short term and long term relevant impacts; | 49533.02-02 | Contamination Assessment | Section 9, Section 10 |
| | 49533.02-05 | Groundwater Assessment | Section 11.3, Section 12 |
| • A statement whether any relevant impacts are likely to be unknown, unpredictable or irreversible; | 49533.02-06 | Assessment of Remediation Options | Section 7.1 |
| • A description, and an assessment of the expected or predicted effectiveness of, the mitigation measures; | 49533.02-05<br>49533.02-06 | Groundwater Assessment<br>Assessment of Remediation Options | Section 11.3, Section 12<br>Section 5.3 |
| • Any statutory or policy basis for the mitigation measures. | 49533.02-06 | Assessment of Remediation Options | Section 4.1 |
| **Director General's Requirements (14 March 2011)** | **Report Reference** | **Report Title** | **Section(s) where DGR Addressed** |
| • An outline of an environmental management plan that sets out the framework for continuing management, mitigation and monitoring programs for the relevant impacts of the action. | 49533.02-06 | Assessment of Remediation Options | Section 7.2 |
| **Water Quality and Hydrological Impact** | | | |
| • Assess impacts to the Hunter Estuary Wetland (HEW) Ramsar site as a result of reduction in water quality and hydrological changes; | 49533.02-05 | Groundwater Assessment | Section 9.2, Sections 11.3, 12.2 to 12.4 |
| • Assess the potential impacts to groundwater recharge or discharge, and any consequences to the HEW Ramsar site; | 49533.02-05 | Groundwater Assessment | Section 9.2, Sections 11.3, 12.2 to 12.4 |
| • Include a description and maps of all surface water and groundwater sources relevant to the project, and their associated NWQMS environmental values; | 49533.02-05 | Groundwater Assessment | Section 1.4, Section 9.1, Drawings 5.07 & 5.08 |
| | 49533.02-06 | Assessment of Remediation Options | Section 1.4, Section 3.1.3 |
| • Include baseline data on current water quality including reference and test site data; | 49533.02-02 | Contamination Assessment | Section 8.3, Sections 9.3 and 9.4 |
| • Discuss water quality issues, including planning monitoring and management informed by the NWQMS. | 49533.02-05 | Groundwater Assessment | Section 1.3, Section 1.4 |
| | 49533.02-06 | Assessment of Remediation Options | Section 1.4, Section 7.2 |

**Table A2: Environmental Issues and Mitigation Measures**

| Location | Issue | Potential Implications | Mitigation and Management Strategies / Comments |
|---|---|---|---|
| Pond 5 and 7 | Soil contamination within Pond 5 and part of Pond 7 (metals, TRH, BTEX, PAH).<br>Groundwater contamination in wells surrounding Pond 5 (metals, TRH, BTEX, PAH, phenols, pH, ammonia) suggesting lateral migration.<br>Free-phase (NAPL) hydrocarbons (tar waste) in soil and groundwater (in and around Pond 5 and part of Pond 7).<br>Detectable concentrations of TRH and PAH in Estuarine Aquifer wells surrounding Pond 5 indicating some vertical migration.<br>Potential for leaching of contaminants and impact on groundwater. | Potential for further migration of contamination via groundwater beyond Pond 5.<br>Potential migration of contamination to the Estuarine Aquifers.<br>The dredging and preloading would create a temporary increase in groundwater flow due to consolidation (squeezing). This would cause faster transport of contaminants towards receptors, with higher concentrations (Naphthalene up to twice as high) compared to no development.<br>Impact on the staging and design of future development over Pond 5 and surrounds.<br>Potential for loading of Pond 5 to compromise the integrity of the existing GCL cap (due to settlement/deformation).<br>Requirement for management during construction if excavation proposed (if bulk earthworks levels are lowered from the current planned levels). | The current approved management strategy for Pond 5, approved by NSW OEH, is to extend the existing cap a further 20 m beyond the Pond 5 footprint, compacted to achieve k $\leq$ 1 x$10^{-8}$ m/s. The investigation has shown that NAPL tar contamination extends into Pond 7, indicating that any cap would need to extend much further than 20 m.<br>Groundwater modelling indicates that the 'squeezing' effect of T4 loading would lead to a temporary increased flow of contaminants towards receptors including Deep Pond, BHPB KIEC (Blue Billed Duck Pond), OEH Wetland 2 and Easement Pond. Although there is a potential for long term off-site migration with or without the T4 development, the presence of NAPL, the higher risks during dredging and preloading, plus the difficulty of implementing mitigation measures after Pond 5 is built over, implementation of mitigation is recommended.<br>The preferred mitigation options in order are:<br>• Barrier wall around Pond 5 and part Pond 7 to about 10 m depth, to contain the source contamination;<br>• Permeable Reactive Barrier around Pond 5 and part Pond 7 to about 9 m depth, to treat water moving out of the contamination source; and<br>• Extend the GCL cap (or equivalent) and monitor (does not mitigate the risk, however, and further measures may be needed at a later date if the risk is realised). |
| Lead Dust Disposal in Area K7 | Lead dust disposed in plastic bags above the water table are expected to settle to below the water table, with potential for rupture of bags and leaching into groundwater. | Waste dust with high concentrations of lead could come in contact with groundwater. The groundwater flow direction is to the north.<br>Potential for on-going impacts on surface water and groundwater quality due to leaching of lead close to the northern boundary of the T4 site. | The 'precautionary principle" should be applied, even though there is currently no confirmed impact:<br>The preferred mitigation options in order are:<br>• Permeable Reactive Barrier along northern boundary, to treat water moving off-site; and<br>• Barrier wall to about 8 m depth along the southern side of the burial pits to divert water around the area. |
| Site B LNAPL, in the vicinity of Well B-01 | Free-phase hydrocarbons (degraded lubrication oil) in the Fill Aquifer groundwater.<br>Detectable concentrations of PAHs in the Estuarine Aquifer well B-01-L suggesting possible vertical migration. | Possible migration of contamination and impacts on surface water and groundwater quality.<br>Soils with elevated contaminant concentrations and "hot spots" would require management. | The presence of free-phase (LNAPL) hydrocarbon contamination is notifiable to OEH (EPA) under the CLM Act, and policy requires that it be remediated (i.e. the approved capping strategy would not be enough). The area around B-01 would not be directly impacted by T4 structures, but maybe required for ancillary works.<br>The preferred mitigation options in order are:<br>• Dual Phase Extraction of the oil and treatment of groundwater;<br>• Pump and Treat, removal of the free-phase plus ancillary technologies, such as air sparging to treat dissolved contaminants in the groundwater; and<br>• Barrier wall to about 10 m depth, to contain the source contamination.<br>The approved capping strategy approved by NSW OEH is considered appropriate for the remainder of Site B (north). |

**Table A2: Environmental Issues and Mitigation Measures (continued)**

| Location | Issue | Potential Implications | Mitigation and Management Strategies / Comments |
|---|---|---|---|
| Delta EMD | Salinity impacts on adjacent Easement Pond during dredging.<br>Exceedances of Landuse Criteria and Waste Disposal Guidelines across Site C (metals, primarily Mn, TRH and PAH) – possible "hot spots".<br>Potential leaching of contaminants and impact on surface water and groundwater. | The soil profile at Delta is more permeable than elsewhere on site allowing infiltration. Salinity exceeding 10,000 ppm is predicted for Easement Pond during dredging.<br>Possible migration of contamination into the Estuarine Aquifer, particularly during dredging. Possible migration of contamination and impacts on surface water and groundwater quality. | Groundwater modelling indicates the greatest risk to the environment is during dredging.<br>The preferred mitigation options in order are:<br>• Install a low-permeability liner over the existing site prior to dredging nominally 0.5 m thick, $k \leq 1 \times 10^{-8}$ m/s, to prevent saline water from infiltrating the soil profile or reaching nearby water bodies;<br>• Barrier wall to about 6 m depth between Delta and Easement Pond, to redirect the infiltrated saline water; and<br>• Install a drainage interception trench along the southern side of Delta to collect the infiltrated dredge water. |
| Fines Disposal Facility (FDF) | Exceedances of Landuse Criteria and Waste Disposal Guidelines across Site D (metals, TRH and PAH) – localised "hot spots".<br>Leachable levels of PAH and metals exceeding ANZECC and impact on surface water and groundwater.<br>Settlement and decommissioning of leachate collection system would lead to rise in groundwater levels. | Soils with elevated contaminants would come in contact with groundwater and potentially leach. The groundwater flow direction is to the north.<br>Potential for on-going impacts to surface water and groundwater quality of off-site receptors. | Groundwater modelling indicates potential leaching of groundwater with elevated PAH and metals concentrations towards OEH Wetland 3 to the north.<br>The preferred mitigation options in order are:<br>• Permeable Reactive Barrier along northern boundary, to treat water moving off-site;<br>• Cap and monitor. Early capping after completion of dredging advisable (the existing leachate collection system is expected to function during dredging), nominally 0.5 m thick, $k \leq 1 \times 10^{-7}$ m/s; and<br>• Install a drainage interception trench along the northern side of FDF to replicated the leachate collection drainage (keep water levels low) following T4 loading and development, and intercept any leachate.<br>A landfill closure plan should be prepared and submitted to OEH to seek approval for the surrender the environmental protection licence. |
| Deep Pond | Exceedances of Waste Classification Guidelines in the Pond sediment (Ni, Pb).<br>Altered groundwater regime due to ground improvement measures, rail embankment construction and associated consolidation. | Soils exceeding criteria would require management.<br>Potential for on-going impact on surface water and groundwater quality. Exceedances were generally minor.<br>Possible groundwater effects on northern and western side of existing railway. | Installation of a low-permeability liner for dredging to provide a barrier between the saline dredge water and the wetlands to the west/north-west.<br>Lining of water management ponds constructed as part of T4 development.<br>Monitoring of surface water quality (Note - current monitoring generally indicates the absence of significant impact on water quality from pond sediments). |
| General site filling (not containing free phase hydrocarbon impact) | Exceedances of Landuse Criteria and Waste Classification Guidelines across Sites A - D (metals, primarily Mn).<br>Potential leaching of contaminants and impact on surface water and groundwater. | Soils exceeding landuse criteria would require management.<br>Potential for on-going impacts on surface water and groundwater quality due to leaching.<br>Where earthworks and excavation disturb these soils there would be a requirement for management during construction. | The current OEH approved management strategy for KIWEF (including former Delta Site) is for a 0.5 m thick cap with $k \leq 1$ x10-7 m/s and annual monitoring of groundwater and surface water. This is appropriate for the majority of the T4 Project area.<br>The proposed T4 development is compatible with the management strategy (i.e. capping with low permeability layer to reduce surface infiltration).<br>Earthworks and excavations to be conducted in accordance with a Materials Management Plan. |

**Table A2: Environmental Issues and Mitigation Measures (continued)**

| Location | Issue | Potential Implications | Mitigation and Management Strategies / Comments |
|---|---|---|---|
| Various identified contamination "hot spots" on site | Soil: Concentrations of PAH / TRH greater than 2.5 times Landuse Criteria at A-21, A-28, A-29, A-30, A-39, A-41, C-02, D-01, D-10, E23, E26, K7/1, PB1.<br><br>Groundwater: Concentrations of PAH /TRH greater than 10 times ANZECC at A-04, A-05, K7/2N, K3/1E, K10/5E. | Potential for migration of contamination beyond "hot spots".<br><br>Potential for temporary increase in groundwater flow due to consolidation (squeezing) as a result of loading from future development.<br><br>Soils with elevated contaminant concentrations and "hot spots" would require management.<br><br>Potential for on-going impacts on surface water and groundwater quality. | The current OEH approved management strategy for KIWEF is for a 0.5 m thick cap with k $\leq$ 1 x10-7 m/s material and annual monitoring of groundwater and surface water. This is appropriate for the majority of the T4 site including localised 'hot spots'.<br><br>The proposed T4 development is compatible with the management strategy (i.e. capping with low permeability layer to reduce surface infiltration). |
| Various identified contamination "hot spots" off site | Soil: Concentrations of PAH / TRH greater than 2.5 times Landuse Criteria at Ponds 24, 26, 31, 32 (NCIG rail loop).<br><br>Groundwater: Concentrations of PAH /TRH greater than 10 times ANZECC at BHe23D, BHe26D, BHe29D, BHe52S, BHe60S, BHe67L, Ponds 24, 26, 31, 32 (NCIG rail loop). | Extent of "hot spots" unknown.<br><br>Potential for migration of contamination from off-site "hot spots" to T4.<br><br>Potential for on-going impacts on surface water and groundwater quality. | Monitoring of surface and groundwater quality to assess if contamination is entering the T4 site from adjacent sites, to provide early warning and protection of T4. |
| Acid generating soils | Presence of Acid Sulphate Soils (ASS) in natural clays or potential acid generating materials (such as coal rejects). | Generation of sulphuric acid upon oxidation, potentially entering surface waters or groundwater and lowering pH. | An Acid Sulphate Soil Management Plan would be required for any possible disturbance of potential acid generating materials or acid sulphate soils. |

# Appendix B

Remediation Option Ranking Sheets

Douglas Partners
Geotechnics • Environment • Groundwater

**TERMINAL 4 PROJECT** **ASSESSMENT OF REMEDIATION OPTIONS**

**Issue:** **Pond 5 / 7**

| Category | Remediaton Option | Technical Effectiveness | Track Record in Australia | Availability | Ease of Implementaiton | Verification | Sustainability | Stakeholder Acceptance | Off-site Migration Risk | Cost | Time to Implement | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight | 20% | 5% | 5% | 10% | 5% | 10% | 5% | 10% | 20% | 10% | 100% |
| Physical / Chemical | Soil Washing | 1 | 1 | 3 | 1 | 4 | 2 | 3 | 3 | 0 | 4 | **1.75** |
| | Soil Vapour Extraction | 1 | 2 | 3 | 1 | 3 | 2 | 3 | 2 | 0 | 2 | **1.45** |
| | Dual Phase Extraction | 2 | 2 | 3 | 1 | 3 | 2 | 3 | 3 | 0 | 2 | **1.75** |
| | Chemical Oxidation | 2 | 1 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 4 | **2.30** |
| | Pump and Treat | 0 | 3 | 4 | 2 | 3 | 2 | 2 | 2 | 2 | 4 | **2.00** |
| | Soil Mixing/Solidification | 4 | 2 | 3 | 3 | 3 | 3 | 4 | 3 | 1 | 4 | **2.90** |
| | Air Sparging | 1 | 2 | 3 | 2 | 3 | 1 | 3 | 2 | 3 | 3 | **2.15** |
| | Permeable Reactive Barrier | 3 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 4 | 5 | **3.55** |
| | Interception Drain and Monitor | 1 | 3 | 4 | 4 | 5 | 3 | 1 | 2 | 5 | 5 | **3.25** |
| | Excavate to on-site cell | 4 | 4 | 4 | 1 | 4 | 2 | 3 | 4 | 0 | 3 | **2.55** |
| Biological | Bioventing | 1 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 3 | **2.35** |
| | Biopiles | 1 | 3 | 3 | 1 | 3 | 4 | 1 | 1 | 0 | 3 | **1.60** |
| | Enhanced Bioremediation | 2 | 2 | 3 | 1 | 3 | 3 | 1 | 2 | 2 | 4 | **2.25** |
| | Phytoremedation | 0 | 1 | 2 | 1 | 3 | 3 | 1 | 1 | 2 | 0 | **1.25** |
| | Biosparging | 1 | 2 | 3 | 1 | 3 | 2 | 1 | 2 | 2 | 4 | **1.95** |
| | Monitored Natural Attenuation | 1 | 4 | 5 | 5 | 4 | 4 | 2 | 1 | 4 | 5 | **3.25** |
| Thermal | Thermal Treatment in Situ | 2 | 0 | 1 | 2 | 2 | 1 | 2 | 3 | 0 | 4 | **1.65** |
| | Vitrification | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 3 | 0 | 4 | **1.30** |
| | Thermal Desorption | 3 | 3 | 3 | 1 | 4 | 1 | 2 | 4 | 0 | 4 | **2.20** |
| | Incineration | 4 | 1 | 1 | 1 | 4 | 2 | 2 | 4 | 0 | 5 | **2.40** |
| Containment | Barrier Wall | 4 | 4 | 3 | 4 | 4 | 3 | 4 | 4 | 4 | 5 | **3.95** |
| | Cap and Monitor | 1 | 4 | 5 | 4 | 4 | 4 | 3 | 2 | 5 | 5 | **3.50** |

**TERMINAL 4 PROJECT** **ASSESSMENT OF REMEDIATION OPTIONS**

## Issue: Lead Dust - K7 Asbestos Area

| Category | Remediaton Option | Technical Effectiveness | Track Record in Australia | Availability | Ease of Implementaiton | Verification | Sustainability | Stakeholder Acceptance | Off-site Migration Risk | Cost | Time to Implement | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Attributes / Weight | 20% | 5% | 5% | 10% | 5% | 10% | 5% | 10% | 20% | 10% | 100% |
| Physical / Chemical | Soil Washing | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | **0.80** |
| | Soil Vapour Extraction | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | **0.45** |
| | Dual Phase Extraction | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | **0.45** |
| | Chemical Oxidation | 0 | 1 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | **1.00** |
| | Pump and Treat | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | **1.15** |
| | Soil Mixing/Solidification | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 4 | 1 | 4 | **2.65** |
| | Air Sparging | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | **1.35** |
| | Permeable Reactive Barrier | 4 | 3 | 3 | 4 | 4 | 3 | 4 | 3 | 5 | 5 | **4.00** |
| | Interception Drain and Monitor | 3 | 3 | 4 | 4 | 4 | 2 | 2 | 3 | 5 | 5 | **3.65** |
| | Excavate to on-site cell | 5 | 4 | 4 | 2 | 4 | 2 | 4 | 4 | 0 | 3 | **2.90** |
| Biological | Bioventing | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 3 | **1.15** |
| | Biopiles | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | **0.80** |
| | Enhanced Bioremediation | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 4 | **1.05** |
| | Phytoremedation | 1 | 1 | 2 | 1 | 1 | 1 | 1 | 1 | 3 | 1 | **1.45** |
| | Biosparging | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | **1.25** |
| | Monitored Natural Attenuation | 2 | 4 | 5 | 5 | 5 | 4 | 2 | 1 | 4 | 5 | **3.50** |
| Thermal | Thermal Treatment in Situ | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | **0.65** |
| | Vitrification | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 1 | 0 | 4 | **1.10** |
| | Thermal Desorption | 0 | 3 | 3 | 0 | 0 | 0 | 0 | 4 | 1 | 4 | **1.30** |
| | Incineration | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | **0.80** |
| Containment | Barrier Wall | 3 | 4 | 3 | 4 | 4 | 3 | 3 | 4 | 5 | 5 | **3.90** |
| | Cap and Monitor | 2 | 4 | 5 | 5 | 5 | 4 | 2 | 1 | 5 | 5 | **3.70** |

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**TERMINAL 4 PROJECT** **ASSESSMENT OF REMEDIATION OPTIONS**

**Issue:** **Site B LNAPL**

| Category | Remediaton Option | Attributes | Technical Effectiveness | Track Record in Australia | Availability | Ease of Implementaiton | Verification | Sustainability | Stakeholder Acceptance | Off-site Migration Risk | Cost | Time to Implement | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Weight | 20% | 5% | 5% | 10% | 5% | 10% | 5% | 10% | 20% | 10% | 100% |
| Physical / Chemical | Soil Washing | | 1 | 1 | 3 | 2 | 4 | 2 | 2 | 4 | 4 | 5 | **2.80** |
| | Soil Vapour Extraction | | 2 | 2 | 3 | 4 | 3 | 2 | 4 | 3 | 5 | 5 | **3.40** |
| | Dual Phase Extraction | | 4 | 4 | 3 | 4 | 3 | 2 | 4 | 4 | 5 | 5 | **4.00** |
| | Chemical Oxidation | | 3 | 1 | 3 | 2 | 3 | 2 | 3 | 3 | 5 | 5 | **3.30** |
| | Pump and Treat | | 3 | 4 | 4 | 3 | 3 | 2 | 4 | 4 | 5 | 5 | **3.75** |
| | Soil Mixing/Solidification | | 3 | 2 | 3 | 3 | 3 | 3 | 4 | 3 | 5 | 5 | **3.60** |
| | Air Sparging | | 3 | 2 | 3 | 3 | 3 | 1 | 4 | 4 | 5 | 5 | **3.50** |
| | Permeable Reactive Barrier | | 2 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 5 | 5 | **3.45** |
| | Interception Drain and Monitor | | 2 | 3 | 4 | 4 | 4 | 3 | 2 | 2 | 5 | 5 | **3.45** |
| | Excavate to on-site cell | | 2 | 4 | 4 | 2 | 4 | 2 | 3 | 3 | 4 | 4 | **3.05** |
| Biological | Bioventing | | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 4 | 5 | 4 | **3.45** |
| | Biopiles | | 2 | 3 | 3 | 2 | 3 | 4 | 2 | 3 | 5 | 4 | **3.25** |
| | Enhanced Bioremediation | | 3 | 2 | 3 | 2 | 3 | 3 | 2 | 3 | 5 | 4 | **3.30** |
| | Phytoremedation | | 1 | 1 | 2 | 1 | 3 | 3 | 1 | 1 | 5 | 1 | **2.15** |
| | Biosparging | | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 3 | 5 | 5 | **3.40** |
| | Monitored Natural Attenuation | | 2 | 4 | 5 | 5 | 4 | 4 | 2 | 2 | 4 | 5 | **3.55** |
| Thermal | Thermal Treatment in Situ | | 2 | 0 | 1 | 2 | 2 | 1 | 2 | 4 | 5 | 4 | **2.75** |
| | Vitrification | | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 3 | 5 | 4 | **2.30** |
| | Thermal Desorption | | 3 | 3 | 3 | 2 | 4 | 1 | 2 | 3 | 5 | 4 | **3.20** |
| | Incineration | | 4 | 1 | 1 | 2 | 4 | 2 | 2 | 4 | 5 | 5 | **3.50** |
| Containment | Barrier Wall | | 3 | 4 | 3 | 3 | 4 | 3 | 2 | 4 | 5 | 5 | **3.75** |
| | Cap and Monitor | | 1 | 4 | 5 | 4 | 4 | 4 | 1 | 2 | 5 | 5 | **3.40** |

**TERMINAL 4 PROJECT** **ASSESSMENT OF REMEDIATION OPTIONS**

## Issue: Fines Disposal Facility

| Category | Remediaton Option | Attributes | Technical Effectiveness | Track Record in Australia | Availability | Ease of Implementaiton | Verification | Sustainability | Stakeholder Acceptance | Off-site Migration Risk | Cost | Time to Implement | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Weight | 20% | 5% | 5% | 10% | 5% | 10% | 5% | 10% | 20% | 10% | 100% |
| Physical / Chemical | Soil Washing | | 1 | 1 | 3 | 2 | 4 | 2 | 1 | 3 | 0 | 0 | **1.35** |
| | Soil Vapour Extraction | | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0.25** |
| | Dual Phase Extraction | | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0.25** |
| | Chemical Oxidation | | 2 | 1 | 3 | 2 | 3 | 2 | 2 | 4 | 0 | 0 | **1.65** |
| | Pump and Treat | | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0.35** |
| | Soil Mixing/Solidification | | 4 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 0 | 1 | **2.50** |
| | Air Sparging | | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 5 | **0.95** |
| | Permeable Reactive Barrier | | 4 | 3 | 3 | 4 | 4 | 3 | 4 | 3 | 4 | 5 | **3.80** |
| | Interception Drain and Monitor | | 3 | 3 | 4 | 4 | 4 | 3 | 2 | 2 | 5 | 5 | **3.65** |
| | Excavate to on-site cell | | 5 | 4 | 4 | 4 | 4 | 2 | 3 | 4 | 0 | 1 | **2.85** |
| Biological | Bioventing | | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 4 | 1 | 1 | **2.35** |
| | Biopiles | | 2 | 3 | 3 | 2 | 3 | 4 | 2 | 3 | 0 | 1 | **1.95** |
| | Enhanced Bioremediation | | 3 | 2 | 3 | 2 | 3 | 3 | 2 | 3 | 0 | 0 | **1.90** |
| | Phytoremedation | | 1 | 1 | 2 | 1 | 3 | 3 | 1 | 1 | 0 | 0 | **1.05** |
| | Biosparging | | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 3 | 0 | 2 | **2.10** |
| | Monitored Natural Attenuation | | 3 | 3 | 5 | 5 | 4 | 4 | 2 | 2 | 4 | 5 | **3.70** |
| Thermal | Thermal Treatment in Situ | | 2 | 0 | 1 | 2 | 2 | 1 | 2 | 4 | 0 | 4 | **1.75** |
| | Vitrification | | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 3 | 0 | 1 | **1.00** |
| | Thermal Desorption | | 3 | 3 | 3 | 2 | 4 | 1 | 1 | 4 | 0 | 2 | **2.05** |
| | Incineration | | 4 | 1 | 1 | 2 | 4 | 2 | 1 | 3 | 0 | 4 | **2.25** |
| Containment | Barrier Wall | | 4 | 4 | 3 | 4 | 4 | 2 | 2 | 4 | 4 | 4 | **3.65** |
| | Cap and Monitor | | 3 | 4 | 4 | 4 | 4 | 4 | 2 | 1 | 5 | 5 | **3.70** |

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**TERMINAL 4 PROJECT** **ASSESSMENT OF REMEDIATION OPTIONS**

**Issue:** **Delta EMD (Dredging Phase)**

| Category | Remediaton Option | Technical Effectiveness | Track Record in Australia | Availability | Ease of Implementaiton | Verification | Sustainability | Stakeholder Acceptance | Off-site Migration Risk | Cost | Time to Implement | Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Attributes / Weight | 20% | 5% | 5% | 10% | 5% | 10% | 5% | 10% | 20% | 10% | 100% |
| Physical / Chemical | Soil Washing | 3 | 1 | 3 | 2 | 2 | 2 | 3 | 4 | 1 | 0 | **2.05** |
| | Soil Vapour Extraction | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **0.45** |
| | Dual Phase Extraction | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | **0.45** |
| | Chemical Oxidation | 0 | 1 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | **0.40** |
| | Pump and Treat | 0 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | **0.95** |
| | Soil Mixing/Solidification | 4 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 2 | 1 | **2.90** |
| | Air Sparging | 0 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 4 | 5 | **1.55** |
| | Permeable Reactive Barrier | 2 | 3 | 3 | 4 | 4 | 3 | 3 | 3 | 4 | 5 | **3.35** |
| | Interception Drain and Monitor | 2 | 3 | 4 | 4 | 4 | 3 | 2 | 2 | 5 | 5 | **3.45** |
| | Excavate to on-site cell / dispose | 4 | 4 | 4 | 4 | 4 | 2 | 3 | 3 | 1 | 1 | **2.75** |
| Biological | Bioventing | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 4 | 1 | **1.35** |
| | Biopiles | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | **0.80** |
| | Enhanced Bioremediation | 0 | 2 | 3 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | **0.85** |
| | Phytoremedation | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 1 | 3 | 0 | **1.55** |
| | Biosparging | 0 | 2 | 3 | 3 | 0 | 0 | 0 | 0 | 3 | 2 | **1.35** |
| | Monitored Natural Attenuation | 1 | 4 | 5 | 5 | 5 | 4 | 2 | 2 | 4 | 5 | **3.40** |
| Thermal | Thermal Treatment in Situ | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 4 | **0.85** |
| | Vitrification | 1 | 0 | 1 | 1 | 2 | 1 | 1 | 3 | 0 | 1 | **1.00** |
| | Thermal Desorption | 0 | 3 | 3 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | **0.90** |
| | Incineration | 0 | 1 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 4 | **0.90** |
| Containment | Barrier Wall | 4 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 4 | 4 | **3.70** |
| | Liner / Cap | 5 | 4 | 5 | 4 | 5 | 4 | 4 | 4 | 4 | 5 | **4.40** |