Geo-environmental challenges of a major coal terminal development in Australia

Défis géo-environnementaux du développement d'un terminal majeur de charbon en Australie

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ABSTRACT: This paper describes the integration of geotechnical, environmental and groundwater investigations for the Terminal 4 Project in Newcastle, Australia, aimed at identifying appropriate remediation measures to protect human health and environmental values. The site presented a series of complex challenges due to its geological setting, previous uses for waste disposal and adjacent environmentally sensitive areas. Past industrial wastes have caused contamination of soil and groundwater. The site and adjoining wetlands form habitats for protected flora and fauna species. Without mitigation measures, the proposed coal terminal development would have the potential to increase the mobilisation and flow of contaminants off site into the wetlands and other environmental receptors. Geotechnical and groundwater modelling was undertaken, resulting in a series of remediation and mitigation measures for specific identified risks. The implementation of the proposed remediation and mitigation measures for the project will protect environmental values, and is expected to improve the long-term environmental condition of the project area and immediate surrounds.

RÉSUMÉ : Ce document décrit l'intégration des études géotechniques, environnementales et de sondages des eaux souterraines du Projet Terminal 4, afin que des mesures d'assainissement appropriées puissent être mises en œuvre pour protéger la santé humaine et l'environnement. Le site présente plusieurs défis complexes en raison de son contexte géologique, de son utilisation historique pour déposer des déchets et de sa proximité avec des zones à caractère environnemental sensible. Les déchets industriels ont entraîné la contamination des sols et des nappes souterraines. Le site forme avec les marécages adjacents des habitats pour des espèces protégées de la flore et de la faune. Le développement proposé du terminal de charbon a le potentiel d'accroître la mobilisation et la circulation des contaminants hors du site, et par là-même de contaminer les marécages adjacents ainsi que d'autres récepteurs de l'environnement. Les résultats des modélisations géotechniques et d'écoulement des eaux souterraines ont entraînés une série de mesures d'atténuation des risques identifiés. La mise en œuvre du projet d'assainissement et des mesures d'atténuation pour le projet protégera les valeurs environnementales, et devrait permettre d'améliorer sur le long terme l'état de l'environnement.

KEYWORDS: coal export, landfill, soil and water contamination, barrier wall, permeable reactive barrier, multi-phase extraction.

1 INTRODUCTION

Kooragang Coal Terminal on Kooragang island near Newcastle, Australia is the world's largest coal export facility with an export capacity of 120 Mtpa. It is planned to substantially increase the size of the facility by construction of a new adjoining terminal, known as Terminal 4. The location of the site is shown in Figure 1.

The site has a total area of 246 ha and comprises reclaimed land over soft alluvial soils. For 40 years the site was used for dumping of various industrial wastes, leading to significant soil and groundwater contamination.

Industrial landfill cells were constructed in the 1970s and 80s by pushing out slag bund walls and filling in between; no base or side liners were installed. It is proposed to fill and level the site by dredging approximately 5 million m^3 of sand from the nearby Hunter River. The development will impose significant loads to the ground and the sand will also be used as surcharge material for ground improvement purposes.

The groundwater system comprises dual aquifers connected to the adjacent Hunter Estuary Wetlands that support endangered flora and fauna. These sensitive wetlands are a national park and listed by the Ramsar Convention as having international importance. The wetlands and two arms of the nearby Hunter River represent the environmental receptors requiring protection.

The complex conditions presented many geotechnical and environmental challenges to the project. The project is unique to Australia, and relatively unusual worldwide, whereby multiple remediation technologies will be implemented on a large scale. Some of the proposed remediation measures have had only limited previous application in Australia.

The work included extensive field investigations, laboratory testing, water level monitoring, groundwater flow modelling and contaminant transport modelling.

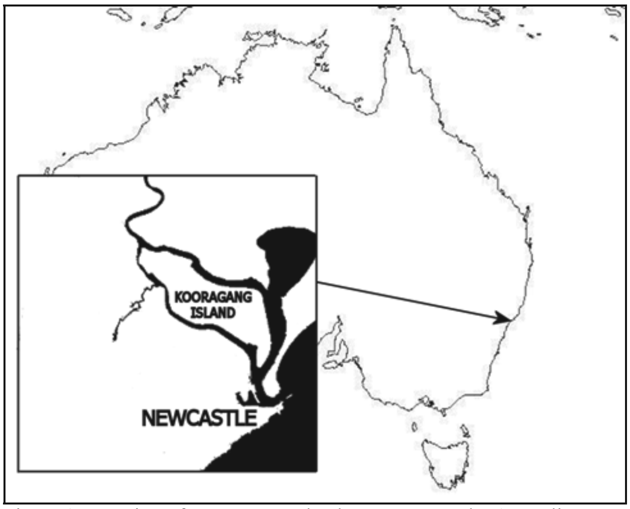

Figure 1. Location of Kooragang Island, near Newcastle, Australia.

2 GEOLOGY AND HYDROGEOLOGY*Geology*

Kooragang Island is located on the lower reaches of the Hunter River and is about 10 km long by 3 km wide. The island was formed by the reclamation of a number of former islands, channels and mudflats using dredged sandy materials from the river. The geology at the site comprises Permian aged Tomago Coal Measures overlain by Quaternary alluvium. The Tomago Coal Measures consist of shale, siltstone, sandstone, conglomerate and coal. The depth to rock ranges from 30 m to more than 70 m.

The overlying alluvium comprises fine to medium grained estuarine sediments with some gravel zones, overlain by fluvial sands with further fine grained estuarine deposits at the top of the natural profile including soft silty clays up to 14 m thick.

The natural profile is overlain by significant fill materials resulting from the former disposal of waste from steel making and dredging activities. The fill is up to 12 m in thickness and comprises a wide range of materials, including coal washery reject, slag, coal fines, oil/tarry sludge, clayey silt filter cake, kiln wastes, cell scale (gypsum and manganese dioxide), asbestos, steel-making flue dust, lime sludge, timber dunnage and various sporadic inclusions. The consistency of the fill ranges from very soft to very dense/cemented.

2.2 Hydrogeology

Groundwater beneath the site is known to be present in two principal aquifers: an upper unconfined aquifer within the fill strata (Fill Aquifer), and a deeper confined aquifer within the estuarine sediments (Estuarine Aquifer). The upper soft natural clays form a slightly 'leaky' aquitard that separates these aquifers. Figure 2 shows a conceptual groundwater model.

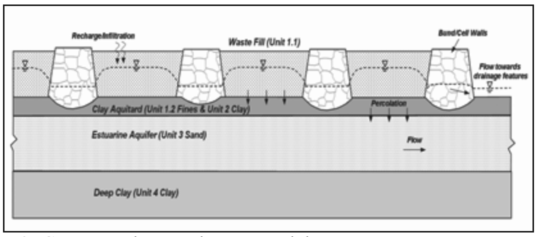

Figure 2. Conceptual groundwater model.

As the degree of contamination in the Fill Aquifer is considerably worse than the Estuarine Aquifer, the continuity and integrity of the clay aquitard is of important to the hydraulic and environmental performance of the site.

3 INTEGRATED INVESTIGATION

The investigation of the project site featured integration of geotechnical, environmental and groundwater aspects to achieve savings in terms of time and cost. Prior to commencing the field work program a desktop review was undertaken to collate pre-existing data on sub-surface conditions and contamination. This identified data gaps and was used to plan the investigation.

The integration of the disciplines during the investigation program was achieved by:

- Geotechnical boreholes were used to collect samples for both geotechnical testing and contamination testing.
- The use of staff trained in geotechnical logging, environmental logging and the appropriate collection of contamination samples.
- Extensive use of cone penetration tests, especially piezocone tests, to better delineate soil stratigraphy, layer permeability and potential flow paths.
- The boreholes were also used for the installation of environmental grade monitoring wells, so that water samples could be collected for contamination testing.
- Groundwater wells were also used to conduct in-situ permeability tests in both aquifers
- New and existing wells (over 150 in total) were gauged on the same day to provide a reliable snapshot of groundwater levels in both aquifers, which could then be used to prepare groundwater contours that for the first time accurately represented the groundwater regime of the site.

It was undesirable for the investigations to create hydraulic connections between the two aquifers, so all boreholes and CPTs were grouted upon completion to seal the aquitard.

Groundwater modelling was undertaken using MODFLOW (with Vistas), MODFLOW-SURFACT and PEST for preliminary parameter estimation. The modelling consisted of calibration of the model to existing conditions followed by modelling the effects of site filling, dredging, salinity and capping the site. Contaminant transport modelling was then undertaken using CONSIM to assess the potential off-site impacts of the proposed development.

4 CONTAMINATION

The investigations identified widespread general contamination and areas of more specific contamination, each with particular characteristics and potential to impact the environment. The main contamination issues are described below.

4.1 Tar Waste Ponds

An area known as Ponds 5 and 7 was found to 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 containing high concentrations of polycyclic aromatic hydrocarbons (PAH) and total petroleum hydrocarbons (TPH). Groundwater impact was also recorded in wells immediately surrounding Ponds 5 and 7. The groundwater impact was primarily within the Fill Aquifer, with some elevated concentrations also recorded in the underlying Estuarine Aquifer. Key findings included:

- Groundwater modelling indicated that the 'squeezing' effect of T4 Project loading would lead to temporarily increased flow of contaminants towards off-site receptors;
- Contaminant transport modelling indicated that contaminant flow rates would increase during dredging and preloading of the site, up to twice for naphthalene, compared to the no development case;
- There would be potential for long term off-site migration of contaminants with or without the T4 Project, however the risks are higher during dredging and preloading stages; and
- Following development over the area of Ponds 5 and 7 (by the proposed coal stockyard), it would not be practical to implement mitigation measures, should off-site impacts become evident.

4.2 Asbestos / Lead Area

The site history review found that an area containing asbestos burial pits also contained lead dust (from steelworks) co-disposed with the asbestos in polyethylene bags.

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

- The asbestos/lead area 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 would be 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 could not 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.

4.3 Free Phase Hydrocarbon Area

Free-phase hydrocarbon impact, comprising Light Non-aqueous Phase Liquid (LNAPL), was encountered in the Fill Aquifer at two monitoring well locations in the southern part of the site. The apparent thickness of floating product was found to be up to 2 m. Fingerprint analysis of the free product found that the sample was degraded mineral lubricating oil with trace amounts of diesel. The analysis concluded that the oil was not a recent release and may have been used in diesel engines.

The degree of impact generally diminished with distance from the wells suggesting that the extent of free product was relatively localised. Groundwater samples collected from the Estuarine Aquifer wells recorded minor hydrocarbon impact in the vicinity of free-phase impact.

4.4 Fines Disposal Facility

A 45 ha portion of the site known as the Fines Disposal Facility (FDF) was used to receive dredged fine sediments during various stages of construction of the existing coal terminal. The dredged fines contain PAHs and heavy metals. A leachate collection system generally maintains the groundwater level below the contaminated sediments. Preload and site development, however, will induce significant settlements which are likely to impact on the leachate collection system. This combined with the capping of the site is expected to result in a rise water table level with the result that the lower 1.5 to 2.0 m of dredge spoil will end up below the water table in the long term.

4.5 Manganese Dioxide Waste Area

This 25 ha former waste site contains electrolytic manganese dioxide waste and localised hydrocarbon contamination (TRH and PAH). The groundwater study identified that the main risk associated with the manganese waste site would be vertical infiltration of saline water during dredging due to the presence of a thinner and more permeable clay aquitard below fill materials compared to elsewhere on the T4 site. This presents a risk of migration of contamination into the Estuarine Aquifer, and increased groundwater effects on nearby surface water bodies, in particular increased salinity levels in nearby surface water ponds during dredging.

5 REMEDIATION

5.1 Review and Ranking 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 regulatory guidelines and policies were also considered when determining preferred options for remediation and management.

Alternative and emerging remediation technologies were also 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 nano-scale zero-valent iron (nZVI). Due to the site conditions preference was given to in-situ technologies that do not require excavation or removal of the contaminated soil and/or water to remediate the area. 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.

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 or not 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 environmentally sustainable development 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 attributes were each scored from 0 to 5 based on a combination of quantitative and qualitative inputs, with zero being ineffective, unavailable or very costly and 5 being the best credible outcome. The total score was calculated as:

$$\Sigma S_i . W_i \quad (1)$$

where S_i is the score for attribute i, and W_i is the weighting for attribute i. The result was an overall score out of 5.

Based on the ranking system described, the preferred remediation options for each of the identified contamination issues were selected, as summarised in Table 1. In each case the three options with the highest score were identified so that alternatives were not ruled out for the detailed design stage.

Table 1. Summary of Selected Remediation Options

Contamination Issue	Preferred Remediation Option	Second Ranked Option	Third Ranked Option
Pond 5/7 tar waste	Barrier Wall	Permeable Reactive Barrier	Cap and Monitor
Lead Dust / Asbestos	Permeable Reactive Barrier	Barrier Wall	Interception Drain and Monitor
Free Phase LNAPL	Multi Phase Extraction	Pump and Treat	Barrier Wall
Fines Disposal Facility	Permeable Reactive Barrier	Cap and Monitor	Interception Drain and Monitor
Manganese Dioxide area (EMD) - Dredging Phase	Liner (GCL) prior to dredging	Barrier Wall	Interception Drain and Monitor

5.2 *Tar Waste Ponds*

The soil-bentonite barrier wall enclosing the Pond 5/7 tar waste would be approximately 1 km long and 10 m deep, keyed into the clay aquitard. The design of the wall will take into account the hydraulic conditions of the contained volume under initial loading (especially preload), which would be a one-off event during construction. Key design issues for the barrier wall were:

- Pre-trenching through the existing slag cell walls and other cemented layers in the fill for slurry trench construction;
- Mix Design of the bentonite slurry, including compatibility with site groundwater and soil conditions;
- Mix design of the soil-bentonite backfill, including compatibility with site groundwater and soil conditions;
- Global and local stability of the slurry trench;
- Density and viscosity of the slurry and backfill materials, such that trench stability is maintained, while permitting the backfill to displace the slurry; and
- Provision of vertical drainage (e.g. wick drains or sand drains) internal to the enclosed barrier wall to control pore pressures generated during preloading.

5.3 *Asbestos / Lead Area and Fines Disposal Facility*

The ‘precautionary principle’ was applied to the potential risk resulting from the asbestos/lead dust area. 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.

The PRB at the fines disposal facility would also be designed to maintain northerly groundwater flows while ‘treating’ leachate potentially generated by dredged sediments coming into contact with the groundwater. The target contaminants are metals (mainly aluminium) and PAH.

The two PRBs will be a ‘funnel and gate’ type 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 Operational Environmental Management Plan for the terminal will incorporate regular monitoring and maintenance of the reactive media.

The PRBs will be installed along the northern boundary of the site and keyed into the clay aquitard at a depth of about 4 m to 5 m.

Key design considerations and aspects of the design and life cycle of the PRBs included the panel and gate widths, reactive media and treatment process, hydrogeology, contaminant distribution, geochemistry; reaction kinetics and residence time; and installation methods. The ratio of panel width to gate width was selected as 6:1 following groundwater modelling of flows and residence times through the gates.

It is also proposed to extend the wall as a continuous low-permeability barrier to the west, adjacent to a surface water body now as Deep Pond to protect the wetlands to the west and north from the saline water during dredging.

5.4 *Free Phase Hydrocarbon Area*

The preferred remediation option for the free-phase LNAPL contamination is multi-phase extraction (MPE). MPE is an in-situ remediation technology for simultaneous extraction of vapour phase, dissolved phase and separate phase (e.g. LNAPL) contaminants from the vadose zone, capillary fringe, and saturated zone soils and groundwater. It will likely be followed by monitored natural attenuation (MNA) for residual dissolved phase hydrocarbon contamination.

5.5 *Manganese Dioxide Waste Area*

The preferred remediation option to manage risks associated with dredging activities within the manganese dioxide waste site is to install a low-permeability geo-synthetic clay liner (GCL) over the site prior to dredging.

An overall plan showing the location and extent of the preferred remediation options is presented in Figure 3.

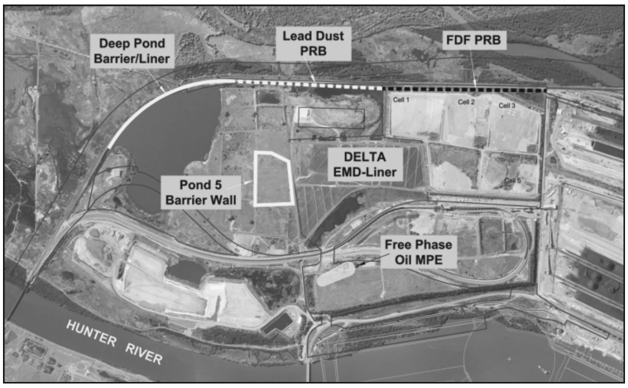

Figure 3. Remediation Plan.

6 CONCLUSIONS

The Terminal 4 Project is planned to be constructed at a site that presents complex geotechnical and environmental conditions. The investigation required close integration of geotechnical, contamination and groundwater assessments. The project will beneficially re-use a highly degraded site by implementing several remediation measures on a large scale, making the project unique to Australia and unusual worldwide. The method of selecting the preferred remediation options is described, and the key design considerations discussed. The Terminal 4 Project is expected to improve the long-term environmental condition of a site previously contaminated by industrial waste, while protecting the surrounding sensitive environment.

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