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Completion of the North End Box Cut waste landform rehabilitation: implementation challenges and learnings

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Abstract

The North End Box Cut (NEBC) waste dump at Rio Tinto's Tom Price iron ore operation is a historic waste dump containing an estimated 2.6 Mt of potentially acid forming (PAF) shale material. The waste dump is positioned on the edge of the site's current operational footprint. Construction of the NEBC waste dump began in the 1990s, prior to the current standards for PAF material management and landform design. An overview of the planning and design work to apply best practice standards to this legacy waste dump was presented at the Mine Closure 2019 conference. Following 25 months of project implementation, the rehabilitation earthworks for this landform were completed in February 2022. The project required material movement of 3 million cubic metres, enough to fill the Melbourne Cricket Ground (MCG) twice. It spanned an area of 72 hectares (~36 MCG fields) and utilised 550 kg of seed. The NEBC waste dump is regarded as one of the most technically challenging rehabilitation projects ever undertaken within the Rio Tinto Iron Ore product group. The project navigated the COVID-19 pandemic, along with contractual changes and challenges that provide key learnings on rehabilitation planning and the onboarding of rehabilitation teams and contractors. The learnings from the NEBC rehabilitation project have subsequently been incorporated into an optimised 'tip-to-close' design at a second PAF waste dump at Tom Price, Marra Mamba South (MMS), aimed to significantly reduce closure liability and enable progressive rehabilitation. Earthworks at MMS are currently in progress and due for completion in 2022. This paper reviews the implementation challenges that have arisen throughout both projects and highlights the closure liability reduction opportunities that can present when rehabilitation activities are integrated into the mine plan.

Keywords: *legacy, rehabilitation, earthworks, closure liability, operations, potentially acid forming*

1 Introduction

The Rio Tinto Tom Price mine site is located in the Pilbara region of Western Australia (WA) (Figure 1). The operation was the first iron ore mine in the Pilbara and operations commenced in 1966. The mine is an open cut operation with multiple pits, utilising conventional drill-blast, load-and-haul mining methods. Ore is processed onsite before being transported via rail to either the Dampier or Cape Lambert ports for shipping. The Tom Price mine is owned and operated by Hamersley Iron Pty Limited, which is wholly owned by Rio Tinto Limited and hereafter referred to as Rio Tinto.

The Pilbara region of WA has an arid-tropical climate and can be characterised by two distinct seasons: hot wet summers and cooler dry winters. The average daily maximum temperatures range from 38°C in summer to 23°C in winter. Precipitation results from summer cyclonic activity, with the months of August to November having the lowest average rainfall, and December to March the highest average rainfall. The average annual rainfall (399 mm/year) in the region is highly variable, with mean pan evaporation rates (3,200–3,600 mm/year) in the region greatly exceeding rainfall.

In accordance with the closure objectives for Tom Price, final landforms must be stable and consider ecological and hydrological factors. Vegetation on rehabilitated land must be self-sustaining and compatible with the proposed post-mining land use (PMLU). The PMLU at Tom Price is for the area to be rehabilitated to create a safe, stable and non-polluting landscape, vegetated with native species of local provenance, that maintains environmental and cultural heritage values.

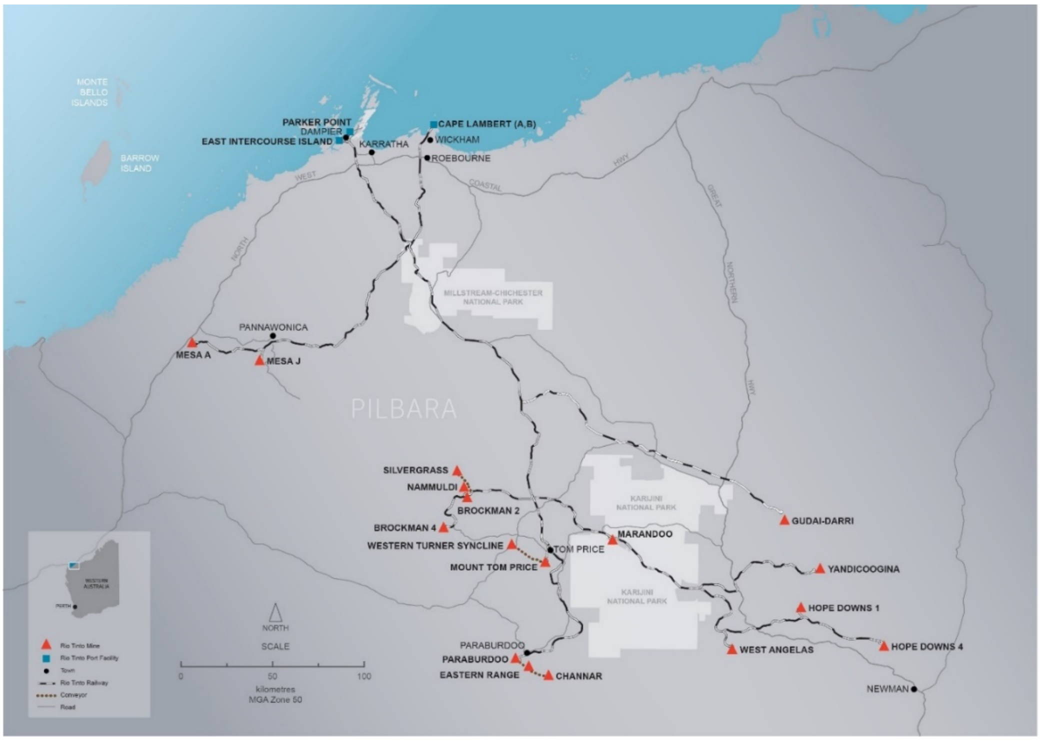

Figure 1 Rio Tinto Iron Ore operations in Western Australia

Rehabilitation of the NEBC waste dump has been a long-term focus for Rio Tinto, with planning for rehabilitation commencing in 2015, four years prior to physical implementation. The NEBC waste dump is a historic waste landform at the Tom Price mine. It is 72 hectares in size, with a maximum height of approximately 65 m (Figure 2). Construction of the NEBC waste dump began in 1994 and it was used for disposal of unoxidised Mount McRae shale material from nearby pits. This waste rock is commonly referred to as black shale and is conservatively assigned as potentially acid forming (PAF), with average total sulfur concentrations ranging from 0.2 to 1.6% (Worthington et al. 2019). The presence of reactive black shale waste represents a rehabilitation and closure risk due to its potential to generate acid and metalliferous drainage (AMD), which may be triggered by the presence of sulfides, in particular pyrite (FeS_2), within the waste material. In its final operational stages, the NEBC dump was used for the disposal of inert, non-reactive waste, which was deposited above the stored PAF material (Worthington et al. 2019).

Rehabilitation of a waste dump with limited information on the location of the black shale results in a high risk of exposure during earthworks. To develop an acceptable rehabilitation design that meets current PAF management strategies, Rio Tinto undertook a comprehensive review of the location and behaviour of PAF material, which included:

- Two drilling programs to determine the depth of clean fill material present above black shale waste to ensure adequate cover depth.
- Detailed analysis of net acid generation potential, internal temperatures and intrinsic oxidation rates.
- Detailed review of aerial photography and mapping to GIS software.
- Walk-over inspection.

To manage and monitor AMD risk, a store and release cover trial was installed in the early 2000s at the NEBC waste dump. The purpose of this trial was to control the amount of water that infiltrated through the dump

(Shurniak et al. 2012). The trial was monitored over a 14-year period and consisted of two 2 m lifts on the highest bench of the dump (now 832 RL). Each 2 m lift was paddock dumped with non-acid forming waste material and levelled. The trial was also complemented by additional store and release cover trials at the MMS waste dump. Preliminary monitoring results of the cover indicate low net percolation rates (i.e. between 5 and 15% of the rainfall), as suggested in O'Kane & Ayres (2012), and following additional modelling work, a reduced cover depth of 3 m was considered adequate to manage PAF risks.

Groundwater quality surrounding the NEBC dump has been monitored since 2001. There are currently four bores that are sampled every six months for water chemistry. No evidence of AMD has been detected within these bores. The pH is typically circum-neutral, and the groundwater is generally fresh (median TDS 580 mg/L). Sulphate concentrations were generally low (median 35 mg/L) and some alkalinity is present (median 370 mg/L) (Worthington et al. 2019).

A knowledge base, including data from ongoing monitoring programs, was developed for this landform over a number of years, and further detailed design information is contained in Worthington et al. (2019).

In 2021, Rio Tinto undertook rehabilitation planning for a second waste dump at Tom Price, Marra Mamba South (MMS) waste dump, to reduce closure liability. Earthworks for this project are currently in progress.

Figure 2 Aerial image of the NEBC waste dump at Tom Price operation. Top image is pre-rehabilitation and the bottom image is following completion of rehabilitation earthworks in January 2022

2 The NEBC waste dump rehabilitation design

Initial design work was completed at the NEBC waste dump, with a 5 m cover thickness requirement. Following the completion of net percolation and salt uptake modelling, this cover was able to be reduced to a 3 m depth on flat surfaces and a 2.5 m depth on sloped surfaces (Worthington et al. 2019). The reduction in encapsulation material volumes was significant, with the initial requirement of 2.49 Mm^3 decreased by 33% to 1.68 Mm^3.

The parameters for the waste landform were developed using the Rio Tinto erodibility-based batter selector design tool. To achieve a safe and stable landform and meet closure requirements, the design parameters are a maximum of 20° slopes, maximum 20 m high lifts and minimum 10 m wide berms with an 11° back slope. Specifically, water erosion prediction project runoff and erosion modelling for specified batter profile heights, using a 200-year climate sequence specific to Tom Price, was carried out using waste data generated from previous sampling and testing of Pilbara waste types (Worthington et al. 2019). The design required a reshaping of the batters and placement of a layer of inert fill over all slopes and berms. A rock armour (to reduce surface water erosion) of 0.5 m depth was applied to all sloped surfaces and a final 100 mm of topsoil was applied to all final surfaces.

The total material movement required to implement the NEBC rehabilitation design is outlined in Table 1. The final design meets the requirements of internal Rio Tinto guidance for both the management of PAF black shale material and for landform design. A conceptual cross-section is illustrated in Figure 3. The decision to shape the dump prior to application of the encapsulation layer was based on an assessment of volumes to encapsulate with and without initial shaping. The volumetric savings of encapsulation material were significant.

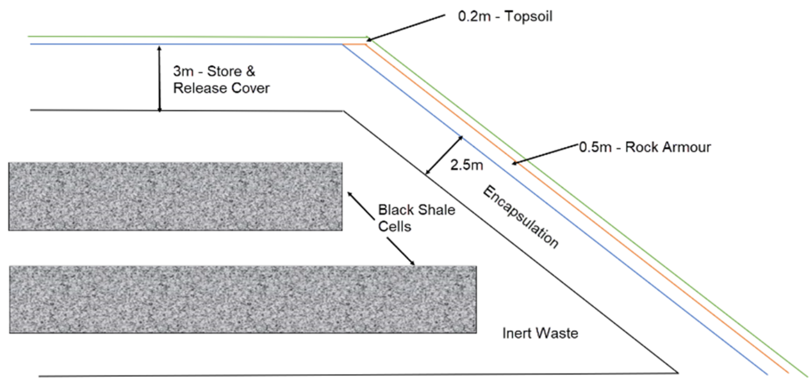

Figure 3 NEBC design conceptual cross-section illustrating depth of soil, rock and encapsulation utilised

Table 1 Material movements required for the implementation of the NEBC waste dump rehabilitation design

Rehabilitation stage	Volume (m^3)
Surface re-profile (cut)	1,140,000
Encapsulation	1,684,000
Rock armour	211,000
Bunding	150,000
Topsoil	75,000
Total	**3,260,000**

2.1 Rehabilitation haulage integration

The NEBC rehabilitation design required over 2 Mm^3 of material to be hauled into place. Initial cost estimates assumed the use of contractor fleet to haul material to the project site up to a 5 km distance. Significant savings were realised by collaborating with operational and mine planning teams to secure the Rio Tinto fleet to perform the haulage and incorporate the work into the operational mine plan.

Stockpile locations for both encapsulation material and rock armour (Figures 4 and 5) were designed within the project area. Material was hauled to these stockpiles by the Rio Tinto fleet prior to, and during, project implementation. Waste being mined from a nearby operational pit was hauled directly to the project stockpile area, resulting in minimal additional costs for site operations. To achieve the required waste balances, a small volume of material was rehandled from an adjacent waste dump. While longer haulage routes are generally not favoured in a mining environment, the ability to integrate rehabilitation and closure activities in a mine plan can result in overall life-of-mine cost savings and liability reduction. Cost savings relative to 30% of the total project cost were achieved through implementation of operational ex-pit haulage. Reduced interaction of contractor and operational fleet also minimised the safety risks associated with the project.

Figure 4 Encapsulation stockpile area located on the NEBC waste dump and additional waste material stockpile

Figure 5 Rock armour stockpile locations on and adjacent to the NEBC waste landform

3 NEBC implementation challenges and learnings

3.1 Procurement and setting contract partners up for success

The NEBC project is one of the largest and most technically challenging rehabilitation projects ever undertaken within the Rio Tinto Iron Ore product group. The project went through a competitive tender process in 2019 and was awarded to two contractors in a joint venture (JV) business structure. One JV partner was a national business, while the other was a Pilbara Aboriginal business (PAB). During this time, Rio Tinto established a rehabilitation earthworks contractor panel with five master service agreements (MSAs). This was implemented to provide efficiency in procurement time frames and to build capacity and capability to meet growing rehabilitation demand. Under the terms of the MSAs, contractors can be engaged on fixed-price or rates-based engagements across multiple years and projects.

Each Rio Tinto rehabilitation project has an agreed project execution plan containing a detailed scope of work, implementation schedule, and a delivery and execution model outlining key roles and responsibilities. Within the Rio Tinto Iron Ore product group, responsibility for the day-to-day supervision and safe implementation of rehabilitation projects is allocated to a site-based contractor management supervisor (CMS), with reporting lines through the site-based operational team. CMS supervisors are supported by a rehabilitation subject matter expert, who is accountable for the project scope, schedule, cost and quality of work performed.

Key learnings:

- As the NEBC project was awarded to a newly established JV, the Rio Tinto Rehabilitation team provided additional coaching and support to build contractor capability and de-risk project outcomes. Dedicated CMS supervision was established to guide, support and coach the contract partner on onboarding, safety, work and behaviour expectations. Daily pre-starts, weekly project progress meetings and monthly partnership meetings were incorporated into the project. The contract partner was also included in mining operations team communications and meetings. This comprehensive and 'hands-on' approach to partnership supports Rio Tinto's strategy to increase Indigenous business development and local procurement spend to improve socio-economic outcomes across the Pilbara and WA.
- A staged development pathway for establishing aspiring contractors is recommended to support rehabilitation capacity and capability uplift. Building experience with smaller and simpler projects involving less material movement provides contractors with the knowledge and experience to adequately manage and deliver rehabilitation projects based on appropriate equipment selection and productivity assumptions. This approach also mitigates the risk of cost and schedule overrun on current and future projects.

3.2 COVID-19, contractual changes and employment

The NEBC project mobilised in January 2020 and was in the early stages of implementation when the COVID-19 pandemic began. In an environment of uncertainty, many projects across the industry were deemed non-essential, demobilised and deferred. Rio Tinto Iron Ore sites moved to an 'all-in/all-out' 2:2 roster, and the availability of flights and accommodation was greatly reduced under social distancing and safety protocols implemented by the business. Despite these challenges, there was clear and consistent business support for the continuation of rehabilitation projects and partnerships with PABs. The continuation of the NEBC project throughout the COVID-19 pandemic is evidence of this unwavering support.

During the project, one of the JV partners ceased at relatively short notice to Rio Tinto and the other JV partner. The resulting loss of personnel with tactical knowledge of the project required active management from Rio Tinto's procurement and contracts teams. The remaining JV partner assumed sole responsibility for completion of the project, avoiding the requirement to undertake additional design work and re-tender the NEBC project midway through implementation.

In the later stages of the NEBC project, the remaining JV partner elected to cease providing rehabilitation and earthworks services in WA. As the NEBC project was the last earthworks project in their portfolio, there was an increased retention risk for skilled contractors with no internal opportunities beyond the NEBC project. In order to manage this risk, Rio Tinto provided redeployment opportunities for contractor personnel, with flexible start dates to enable completion of the project.

Key learnings:

- It is recommended that agreed manning and equipment standby and variation rates be established during project tender. Potential variations to project scope, schedule and delivery should also be considered prior to commencement, along with a formalised variation sign-off process. This will support the timely approval of variations and cash flow for smaller contractors.
- Similar to learnings in Section 2.2, procurement of this large-scale rehabilitation project to a newly formed JV may have been better supported as part of a rehabilitation development pathway demonstrating previous project completion. Adapting to dynamic business arrangements will always be challenging. A recommendation is to have regular interfaces with contract partners to understand their forward outlook and aspirations and share near- to medium-term requirements of the client.

3.3 Management of materials and oversize

During load and haulage of inert waste, numerous oversize boulders were encountered in encapsulation waste materials (Figure 6). If utilised within the encapsulation layer, these oversize rocks could jeopardise the ability to manage PAF material in accordance with the design and modelling parameters (Green 2012). Several options, including rock breaking and relocation from the project area, were investigated. The final outcome was to preserve and segregate these boulders for use as rock habitat formations (Figure 6) in locations determined in consultation with mineral waste specialists.

Key learnings:

- Quality control is an important requirement in the haulage of rock armour materials to stockpile locations. Awareness information packages were produced and shared with project and operational teams to provide context and education on acceptable material characteristics. Materials used in bund formation were also specified to be of a competent nature in future scopes of work.
- Consideration of stockpile locations can be optimised by considering the ease of future recovery. As illustrated in Figure 4, the southern stockpile areas were subject to access difficulties and contamination potential.
- Construction of the backslope berms can be completed with greater efficiency utilising an excavator rather than a dozer.

Figure 6 Oversize boulders were placed into rock habitat formations

3.4 PAF cover system monitoring installation

The main NEBC earthworks scope of work did not incorporate the requirement for the small earthworks component associated with the installation of the PAF cover system monitoring. As these items are generally installed towards the final stages of projects, it is recommended to incorporate this requirement and consider smaller equipment that may be required for this task.

3.5 Inadequate maintenance resourcing impact on schedule

The project experienced delays due to poor equipment reliability caused by an inadequate maintenance strategy. This issue was eventually remediated through the onboarding of additional maintenance personnel and, in some instances, a change out of equipment.

Key learnings:

- It is recommended that projects adequately consider planned resources for asset management and maintenance.
- An understanding of selected equipment's hours at the procurement stage can help to highlight where additional maintenance should be factored into the schedule, based on the age and productivity of specified fleet. In the process of building capacity with established and aspiring contractors, consideration should be given to the use of hired equipment, which may require additional maintenance strategies.

3.6 Implementation plans and conformance sign-off

The project was awarded on a fixed-price basis and completed to a high standard, although behind schedule due to multiple factors highlighted in this paper. Upon commencement, the JV contract partner segregated the project into zones A to W, over four different benches. As the design was required to meet reshape, encapsulation and rock armour conformances, this resulted in approximately 300 conformance-to-design sign-off processes.

The project was presented in an as-built surface and a final designed surface. There was limited recommended sequencing provided, which was left to the contract partner to develop. Due to the turnover of key contract partner personnel, there were variations in the implementation and sequencing strategy of the work. As a result, it was challenging to develop a sequence and schedule with adequate detail and time frames for reshaping, encapsulation, rock and topsoil coverage. Schedule conformance proved to be challenging for the duration of the project.

Key learnings:

- In order to effectively manage the conformance sign-off complexity, it is recommended that clear tracking and sign-off processes are developed prior to the project commencing, including client sign-off and a shared understanding of turnaround time frames.
- A key learning from the NEBC waste dump is to consider the development of milestones based on staged implementation sequences (with increased material movement details) at project commencement from which to build milestones.
- An additional consideration is to request further clarification during procurement phases, with input from earthworks specialists to gauge if the plan will meet the schedule based on the manning, equipment and sequence proposed. However, when engaging on a fixed-price basis, the cost of overrun sits with the contract partner, with smaller supporting costs, such as accommodation, covered by the client.

4 NEBC completion

After 25 months of implementation, the NEBC project was completed at the end of January 2022 (Figure 7). Ripping and seeding were completed with a mechanical seeder attached to a dozer. There was 550 kg of seed (8 kg per hectare) applied across the project. The seed mix included flamed spinifex seed for increased flow through the seeder. The project has been fortunate to receive good summer rainfall and slightly unseasonable rain in May 2022. Early vegetation establishment is looking promising, with a good mix of native species, including spinifex (Figure 8).

Record keeping of rehabilitation projects is an industry-wide area for improvement. Detailed close-out reports that capture project successes, challenges and lessons learned are a rich source of information for future projects and provide historical context when looking back to understand how rehabilitation is performing. In line with the requirements of the Rio Tinto Iron Ore Rehabilitation Management Plan and to maximise the opportunity to capture learnings from the project, a detailed close-out report was collated at the conclusion of the project. This information will also complement the future rehabilitation monitoring of the project.

Figure 7 Overview of the NEBC waste dump earthwork completion, January 2022

Figure 8 Early vegetation establishment at the NEBC waste dump in May 2022

5 Planning for rehabilitation of MMS waste dump

5.1 Overview of the MMS waste dump

The MMS waste dump is another historic PAF waste dump at the Tom Price operation. The waste dump began construction in the 1990s and is composed of waste materials from a number of historic and current pits. The waste dump is estimated to contain 18.6 Mt of black shale (including black shale with low total sulfur concentrations, as well as black shale with elevated total sulfur, posing a spontaneous combustion risk) and has also been utilised to store approximately 888 kt of potentially fibrous mineral waste material. An assessment of the locations of the black shale material has been undertaken utilising historic aerial imagery and mining records.

Similar to the NEBC waste dump, there is a network of monitoring bores and a store and release cover trial in place at the MMS waste dump. To date, there is no evidence of influence of acid and/or metalliferous drainage in the monitoring bores. Monitoring of the store and release cover trial suggests net percolations of between 9% and 11% of rainfall.

The footprint of the waste dump proposed for rehabilitation is 68 ha. There are planned future mine pits in proximity to the northern and western boundaries of the waste dump that have constrained the area available for current progressive rehabilitation. Potential future zones of instability stand-off requirements have also been considered in the development of the rehabilitation boundary.

The waste dump was identified for potential rehabilitation in 2019 and an assessment of rehabilitation options was prepared. These options included:

- Reclamation of waste dump into a nearby pit.
- Undertake a similar approach to NEBC and haul and stockpile required encapsulation for use after re-profiling and reshaping the existing waste dump.
- Integration of ex-pit mine waste movement opportunities into the design, allowing tipping of the required encapsulation waste in place, as a 'tip-to-close' option.

Given the similar material types to be utilised for encapsulation and the acceptance of the reduced encapsulation depth for the NEBC landform, a 3 m encapsulation has been adopted (Figure 9).

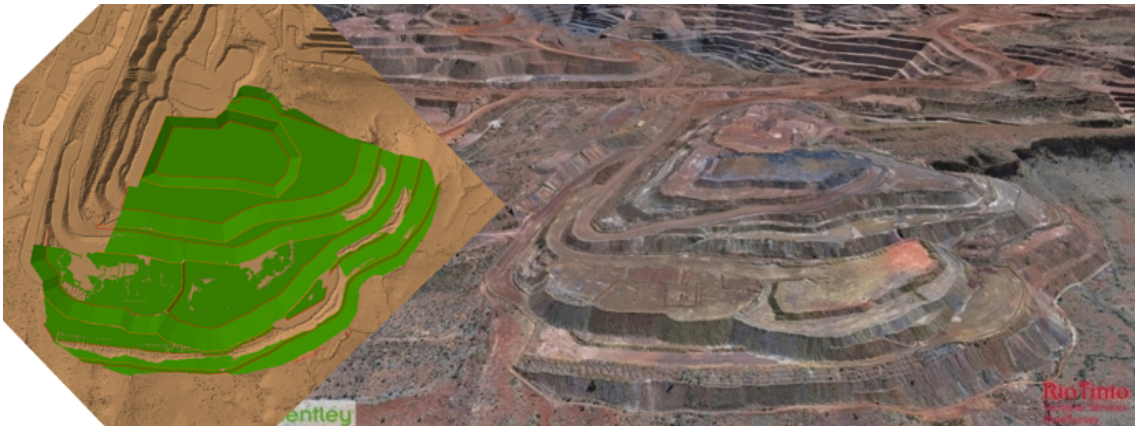

Figure 9 Overview of the MMS waste dump (right) and proposed rehabilitation design (left)

5.2 Implementation of a 'tip-to-close' rehabilitation design

The 'tip-to-close' design option was selected as it provided the ability to meet closure requirements at significantly lower cost. The reduction in closure liability that will be realised on completion of this waste dump project will be significant. It has been estimated that the cost saving between a reshape and encapsulate approach versus a tip-to-close scenario is approximately 60%.

The parameters for the waste landform were developed utilising the Rio Tinto erodibility-based batter selector design tool. To achieve a safe and stable landform and meet closure requirements, the design parameters for the occurring waste types are a maximum of 20° slopes, maximum 20 m high lifts and minimum 10 m wide berms with an 11° back slope. Aligned with the NEBC design, a layer of rock armour (to reduce surface water erosion) of 0.5 m depth will be applied to all sloped surfaces and a final layer of 200 mm of topsoil applied to all final surfaces.

As illustrated in Figure 10, the tip-to-close design provides confidence that a sufficient encapsulation cover depth will be achieved over all known and potential PAF materials. The ability to integrate haul requirements into the mining process means the encapsulation waste is direct tipped and not being double handled. Waste movement commenced in 2020 utilising ex-pit waste haulage of a nearby pit development. The tip to close presented a short-haul opportunity for mine operations, resulting in a win-win scenario. The total material movement required to implement the MMS rehabilitation design is outlined in Table 2.

Waste movement of the encapsulation material continued during 2021 and the tip to close was completed in early 2022. The optimised tip-to-close design reduces reshaping requirements, enabling completion to be completed with a dozer fleet. Spatial conformance to the tip-to-close design was actively monitored during this time to avoid unnecessary material movements during the reshaping of the waste dump. Cost savings are realised by eliminating the requirement for load-and-haul fleet to remove significant volumes of waste.

Topsoil haulage has been completed by the mining operations team and has been placed in an identified stockpile area within the project boundary. Haulage of rock armour is currently in progress. The project was awarded to an established MSA contract partner and rehabilitation works commenced in February 2022. This project is progressing well and is due for completion in approximately September 2022 (Figure 11).

Figure 10 Areas of possible black shale deposition within the MMS waste dump (red shading) at Tom Price operations, based on a review of historic aerial imagery and mine records

Table 2 Material movements required for the implementation of the MMS waste dump rehabilitation design

Rehabilitation stage	Volume (m^3)
Surface re-profile (cut)	664,100
Encapsulation (by Rio Tinto fleet)	2,900,000
Rock armour	172,000
Bunding	45,636
Topsoil	134,705
Total	**3,916,441**

Figure 11 MMS waste dump rehabilitation in progress, May 2022

6 Conclusion

The successful rehabilitation of the complex NEBC waste dump at Tom Price is a result of considerable knowledge gathering, planning and resilience during the implementation phase. It is an example of managing a technically challenging legacy waste landform to meet increasing closure expectations over time. The resulting landform has been completed to a high quality and is showing promising early vegetation establishment and stability.

The MMS waste dump rehabilitation provided an opportunity for Rio Tinto Iron Ore to take on learnings gained from the NEBC waste dump rehabilitation project and further integrate closure into the operational mine plan. This will deliver efficient, cost-effective and improved rehabilitation outcomes. It is also evidence that a rehabilitation project can deliver a win-win scenario for both operations and rehabilitation teams.

Acknowledgement

The Eastern Guruma traditional owners of the land on which the Tom Price mine is located are acknowledged, with recognition of their continuing connection to land, waters and culture. We pay our respects to their Elders past, present and emerging.

The projects discussed in this paper, in particular the NEBC waste landform rehabilitation, would not have been possible without significant effort from many who have been involved in its planning and execution over the years. Special mention goes to Kjestine McNamara, Amelia Johnstone, Ed Charsley, Trudy Worthington, Chantal Latham, Ros Green, Lisa Terrusi, Steven Lee and Belinda Yaqub.

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