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Water treatment development plan for Rio Tinto closure assets

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Abstract

Effective water management is paramount in mitigating the environmental and social impacts of mine closures. In response, Isle and Rio Tinto Closure (RTC) have embarked on a collaboration aimed at minimising the financial, environmental and social risks associated with mine closure, with a particular focus on water management and treatment. This effort is underscored by a commitment to best practices, adaptive operating philosophies and the integration of new technologies designed to significantly reduce treatment costs and minimise health, safety, and environmental risks without compromising on environmental performance.

The challenge lies in the unique quality of water at each site, which may vary in terms of salinity, pH level and metal content, as well as the fluctuating volumes requiring treatment. Our comprehensive assessment of water management and treatment practices across 10 RTC assets has provided a foundation for identifying operational improvements and technological innovations. These include proposals for alternative technologies at sites with existing water treatment plants to reduce operational costs, meet compliance requirements more efficiently, streamline procurement processes, and lessen environmental impacts through reduced chemical and energy usage.

For sites without established treatment facilities we recommended a range of suitable acid rock drainage prevention methods, water management strategies and water treatment processes tailored to individual site conditions. In instances of tightening discharge limits we advised on effluent polishing techniques to meet future regulations. Furthermore, alternative discharge routes were explored for one site, with corresponding treatment recommendations provided.

This paper will detail the opportunities identified as feasible through collaboration with local site teams, initiating business cases for their implementation. These findings not only highlight the potential for operational and environmental improvements but also pave the way for future innovations in mine closure strategies.

Keywords: *mine closure, water treatment, compliance, innovation*

1 Introduction

The closure of mining operations introduces significant environmental, financial, and social challenges, particularly in the realm of water management. As operations cease, addressing the residual impacts to prevent long-term damage to ecosystems and ensure the safety and stability of former mining sites becomes paramount. Rio Tinto's commitment to sustainable mine closure is demonstrated through its proactive approach in the Water Treatment Development Project (WTDP), which focuses on innovative solutions to these challenges across its global portfolio of closure sites.

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Each mine closure site presents unique conditions ranging from varied water quality issues such as pH imbalances and heavy metal contamination to differing regulatory and geographical challenges. These diverse conditions necessitate site-specific water treatment strategies that not only comply with stringent environmental regulations but also minimise operational costs and maximise efficiency. To meet these needs the project leverages advanced technologies and innovative approaches, including both passive and active treatment systems, to develop customised solutions tailored to the specific requirements of each site.

This paper details the methodologies and outcomes of Phase 2 of the WTDP, focusing specifically on the assessment and selection of water treatment technologies and strategies for individual Rio Tinto Closure (RTC) sites. It aims to illustrate the value of targeted environmental management strategies and their broader implications for the mining industry's approach to sustainable site rehabilitation. Phase 1 of the WTDP entailed site selection and was undertaken by RTC.

This paper will outline the methodologies employed in the project, detailing the specific technologies and strategies adopted at each site, and discuss the expected economic, operational and environmental impacts of these interventions when implemented. The final sections will reflect on the lessons learned and suggest future directions for sustainable mine closure practices.

2 Methodology

The methodology employed in Phase 2 of the WTDP was integral to the successful identification and assessment of effective water treatment solutions across RTC sites. This multifaceted methodology provided a systematic approach that combined data collection, technology evaluation and customised strategy development to address the specific conditions of each site.

2.1 Site selection

During Phase 1, 10 RTC sites were chosen based on a range of criteria that represented a cross-section of global mining water management challenges. Criteria included variability in water quality issues such as pH levels, the presence of heavy metals and salinity levels, geographical and regulatory diversity, and their strategic importance to RTC's global operations. The chosen sites, presented in Table 1, provide a broad spectrum of challenges faced in mine water treatment, offering a robust basis for evaluating the applicability and effectiveness of different treatment strategies.

Table 1 Overview of the selected Rio Tinto Closure sites

Site	Mining activity	Waste water type	Key environmental factors
Site A	Copper mining	Acid rock drainage	Heavy metals, acidic pH
Site B	Copper mining	Process effluent	Heavy metals and sulphate contamination
Site C	Copper mining	Combined process stream	Heavy metals, background arsenic
Site D	Limestone quarrying	Stormwater	Turbidity, occasional sediment
Site E	Iron ore mining	Mine dewatering	Iron, suspended solids
Site F	Fluorite mining	Acid mine drainage	High fluoride, variable pH
Site G	Bauxite mining	Red mud discharge	Alkaline waste water, heavy metals
Site H	Coal mining	Process effluent	Organic pollutants, heavy metals
Site I	Aggregate quarrying	Wash water	Sediment load, pH neutral
Site J	Phosphate mining	Gypsum stack run-off	Phosphorus, acidic conditions

2.2 Data collection and preliminary analysis

The initial phase of the methodology involved a data collection process tailored to gather essential information from various RTC sites, each presenting unique environmental and operational challenges. This foundational phase included:

- Environmental data gathering —Detailed information was gathered about water quality, including parameters such as contaminant levels, pH and other chemical characteristics crucial for assessing treatment needs. This step was crucial for understanding the specific challenges at sites like Sites A and C, known for their distinct issues such as heavy metal contamination and acidic water conditions.
- Operational data garnering — Evaluation of current water treatment facilities where present, such as at Sites B and E, was conducted to determine the need for technological upgrades or replacements, and focused on improving efficiency and adapting to new environmental standards.
- Regulatory review — Each site's local and international environmental compliance requirements were meticulously reviewed. This ensured that the proposed solutions met all legal and regulatory expectations, which was particularly important for Site D, where stricter discharge limits are being imposed, and Site I, where discharge points have been moved. International guidelines, including those from the South African Department of Water and Sanitation (2017), were considered in the development of these strategies.
- Stakeholder consultations — Engagements with key stakeholders, including site managers, environmental regulators and local communities, were conducted to ensure that the project's objectives aligned with local needs and environmental objectives, particularly in community-sensitive areas.

2.3 Technology evaluation

Following the data gathering an evaluation of both existing and emerging water treatment technologies was conducted to find suitable solutions for the identified challenges. An evaluation framework was co-designed with RTC that considers the technical, economic, operational and regulatory priorities of each site. The decision-making process was guided by the framework provided by the Interstate Technology & Regulatory Council (ITRC 2010). This phase was essential for ensuring that the solutions proposed were not only technically feasible but also cost-effective and environmentally sustainable. Key considerations follow.

2.3.1 Existing technology

- Statistical analysis — Trend analysis and anomaly detection in water quality data was used to identify constituents that were increasing or decreasing over time and to identify environmental factors such as relationships with rainfall to support the prediction of treatment needs and the efficacy of proposed solutions.
- Comparative analysis — Existing technologies were benchmarked against industry standards and best practices to evaluate their performance and identify suitable upgrades or replacements (International Network for Acid Prevention 2009). This was achieved through a review of publicly available information and assessment of existing technology performance data.
- Risk assessment — Potential risks associated with implementing new water treatment technologies were assessed. This included technical, financial and environmental considerations to ensure feasible and sustainable solutions.
- Technology suitability mapping — Data concerning water quality and operational needs was mapped against the capabilities of potential treatment technologies. This process was vital for identifying the most suitable options for each site.

2.3.2 New technology

- Technology scanning — A review of current and innovative water treatment technologies was performed. This included academic literature, case studies and consultations with industry experts to identify potential technologies suitable for addressing the specific needs of sites such as Sites G and H, which faced challenges like high arsenic levels and the need for sulphate management.
- Technology matching — Appropriate technologies were matched to each site based on their ability to effectively treat identified contaminants and integrate with existing treatment facilities.
- Feasibility studies — The practical implementation potential of each technology was assessed, focusing on scalability, cost and sustainability at each specific site.
- Risk and impact assessment — Potential technical, financial and environmental risks associated with each proposed technology were analysed to ensure feasible and sustainable implementation across sites.

2.4 Strategy development

Strategies developed specifically for each site in consideration of the data and technology evaluations are discussed in Sections 3.2 and 3.3. This process entailed the following:

- Site-specific strategy formulation — Tailored strategies were formulated based on each site's unique environmental, operational and regulatory contexts. Solutions such as passive treatment systems for Site C and advanced oxidation processes for Site A were optimally designed. Constructed wetlands were designed following guidelines provided by the PIRAMID Consortium (2003).
- Implementation planning — Detailed implementation plans were created, outlining the necessary steps, resources and timelines for deploying selected technologies at each site.
- Continuous feedback integration — Continuous feedback from all stakeholders was integrated into the strategy development process to refine and optimise approaches continually.

2.5 Documentation and reporting

Documentation of all stages of the methodology was maintained to ensure transparency and facilitate informed decision-making. This process supported all decisions and provided a basis for continuous project monitoring and adaptation.

3 Data

3.1 Data collection and analysis

The effectiveness of Phase 2 of the WTDP relied heavily on the collection and analysis of accurate data. Table 2 provides an overview of the site-specific data that was collected to inform the evaluation of potential solutions to improve the effectiveness of the current water treatment. This data provided crucial insights into the priorities and constraints of each site and formed the basis of the technology evaluation framework.

Table 2 Overview of site-specific water quality data and existing water treatment facilities

Site name	Major contaminants	Current water treatment technologies	Operational challenges	Regulatory compliance needs
Site A	Heavy metals (cadmium)	Sodium hydrosulphide chemical treatment, remote monitoring systems	Safety risks with sodium hydrosulphide usage	Meet stringent discharge standards
Site B	Heavy metals, acidity	Hydrated lime water treatment plant (WTP)	High operational and maintenance costs	Compliance with discharge limits
Site C	Zinc, copper, manganese	No active treatment, considering passive wetlands	Remote location, land constraints	Stringent drinking water standards
Site D	Arsenic, fluoride	Active chemical treatments, considering nanofiltration	Adapting to stricter limits	Future stricter discharge limits
Site E	Iron, manganese, fluoride	Conventional lime treatment, passive treatment plans	Convert to low-cost passive treatment	Internal limits for discharges
Site F	Fluoride, sulphate	Lime treatment, evaluating adsorptive materials	Managing excessive flows	Set new internal fluoride thresholds
Site G	Arsenic, sulphate	Temporary WTP with ultrafiltration membranes	Not meeting discharge limits for arsenic	Upcoming stricter regulations
Site H	Sulphate, heavy metals	Standard chemical treatments	High operational cost, need for cost-effective solutions	Sustainable disposal requirements
Site I	Total dissolved solids, heavy metals	Ageing WTP, considering ceramic ultrafiltration	Adapting to changing discharge points	Compliance with environmental regulations
Site J	Volatile organic compounds, Trichloroethylene	Air stripper system for volatile organic compound removal	Oversized system now less effective	Maintain discharge permit limits

3.2 Documentation and reporting

Comprehensive documentation of all data collection and analysis processes ensured transparency and supported systematic decision-making. Reports on data analysis, technology evaluation and strategy formulation were maintained to justify all decisions and provide a basis for ongoing project monitoring and evaluation.

4 Results

The results of Phase 2 of the WTDP demonstrate expected significant advances in addressing the unique water treatment challenges at each RTC site when implemented. This section details the recommended technologies, emphasising their working principles and the specific environmental improvements expected at each location.

The results are summarised in Table 3 and discussed in more depth in Sections 5.1 to 5.10.

Table 3 Comparison of technologies

Site name	Evaluated technology type	Suitability for contaminants	Feasibility study outcomes	Selected technology product
Site A	Advanced oxidation, remote monitoring	Effective for heavy metals	Feasible with modifications	Remote monitoring systems
Site B	Ferric chloride alternatives, lime high-density sludge (HDS)	Effective for acidity and metals	Cost-effective alternative found	SafeGuard H2O system
Site C	Passive wetlands, sorbents	Suitable for metal removal	Conditionally feasible due to land	Maven Water & Environment or EcoIslands LLC
Site D	Nanofiltration, active chemical treatment	High suitability for arsenic, fluoride	Feasible with high initial cost	NX Filtration dNF system
Site E	Passive gravity-fed systems	Good for Fe, Mn, F reduction	Feasible, low operational cost	Naturally Wallace Consulting
Site F	Adsorptive materials for fluoride	Highly effective for fluoride	Feasible and cost-effective	Advantageous Systems (ADS)
Site G	Sludge recycling, advanced ultrafiltration membranes	Effective for arsenic, sulphate	Upgrades necessary, feasible	Cerafiltec submerged membranes
Site H	Joint treatment with Site G, diffused air flotation systems	Good for sulphate and metals	Joint treatment feasible	Serpol integrated solution
Site I	Ceramic ultrafiltration, nanofiltration	Effective for total dissolved solids and metal removal	High initial cost but feasible	Cerafiltec and NX Filtration
Site J	Optimisation of air stripper system	Effective for volatile organic compounds	Optimisation feasible	Updated air stripper system

4.1 Site A

At Site A the primary challenge was managing heavy metals in the water stream. The selected technology involved advanced oxidation processes which utilise reactive radicals to break down contaminants into less-harmful substances. This method is expected to be particularly effective in treating water with complex contamination profiles, reducing heavy metals like cadmium to meet stringent discharge standards. The addition of remote monitoring systems will enhance the operational reliability, allowing real-time data acquisition and process adjustments to ensure continuous compliance.

4.2 Site B

For Site B the treatment strategy focused on optimising the existing lime-based WTP by implementing a HDS process. The HDS process will likely enhance the settling characteristics of sludge, boosting the removal of heavy metals and reducing the volume of sludge generated (Hedin & Nairn 1992). This method not only has the potential to improve water clarity but also to significantly lower operational and maintenance costs while aligning with environmental compliance requirements.

4.3 Site C

Site C's remote location and land constraints necessitated the implementation of passive treatment systems; specifically, constructed wetlands. The wetlands were designed to maximise contaminant removal based on principles detailed by Kadlec & Wallace (2009). Constructed wetlands are a low-cost, low-maintenance solution that leverages natural biological and chemical processes to remove contaminants such as zinc and copper, and which may be modified to overcome challenges in manganese removal (Vymazal et al. 2021). The wetlands' design will allow for the sequential removal of different metals through both aerobic and anaerobic processes, effectively meeting drinking water standards without the need for active chemical treatment.

4.4 Site D

At Site D the recommended approach included upgrading the existing chemical treatment systems with nanofiltration technology. Nanofiltration will allow selective permeation of water while retaining most organic and inorganic solutes, including arsenic and fluoride, which are particularly problematic at this site. This technology adaptation will be crucial for preparing the site to meet anticipated stricter future discharge limits.

4.5 Site E

The strategy at Site E shows a shift from active chemical treatments to more sustainable passive treatment options. The gravity-fed systems will utilise natural processes for the removal of iron and manganese, significantly reducing operational costs and environmental impacts. These systems are designed to operate without the need for electrical energy, using gravity to pass water through various treatment stages and reducing contaminant levels below internal discharge limits. Passive treatment strategies were selected based on their long-term effectiveness, consistent with approaches documented by Skousen et al. (2000).

4.6 Site F

For Site F the recommendation of adsorptive materials specifically designed for fluoride removal was a key outcome. These materials bind fluoride ions in the water, replacing them with less-harmful substances through ion exchange processes (Wolkersdorfer 2015). This technology was selected for its cost-effectiveness and efficiency in reducing fluoride to below new internal thresholds, thus addressing potential new site-specific compliance requirements.

4.7 Site G

At Site G the strategy for upgrading the temporary WTP proposed integrating sludge recycling techniques and advanced ultrafiltration membranes, which enhance the removal of arsenic and sulphate. The use of ultrafiltration technology will provide a fine filtration level which is expected to be particularly effective in removing fine particulate matter and dissolved solids.

4.8 Site H

The treatment improvements at Site H focused on integrating the water management systems with those of nearby Site G to optimise resource use and cost. The proposed joint treatment approach, if implemented, would utilise a combination of chemical addition and advanced filtration techniques (Suliestyah 2020), improving the overall efficiency and sustainability of the water treatment process while ensuring compliance with stringent discharge requirements.

4.9 Site I

At Site I the strategy to upgrade the WTP to handle changes in discharge points involves the use of ceramic ultrafiltration and direct nanofiltration systems. These systems are effective in removing total dissolved solids and heavy metals, providing the flexibility needed to meet varying environmental regulations and ensuring the long-term sustainability of water discharge practices.

4.10 Site J

Site J's treatment strategy focused on optimising the existing air stripper system used for volatile organic compound (VOC) removal. The optimisation recommended adjusting operational parameters to enhance efficiency and reduce energy consumption, thus maintaining compliance with discharge permit limits while reducing operational costs.

5 Discussion

The development of tailored water treatment strategies across RTC sites represents a critical step towards sustainable mine closure practices. This discussion evaluates the main outcomes of these strategies, focusing on the suitability of the selected technologies and their potential impact on compliance with environmental regulations and operational efficiencies.

5.1 Suitability of selected technologies

The technologies selected across the RTC sites have demonstrated significant potential in addressing site-specific water quality issues. For instance, advanced oxidation processes at Site A and the HDS process at Site B have the capacity to effectively reduce heavy metal concentrations and operational costs, respectively. Similarly, the use of passive wetlands at Site C and the integration of nanofiltration at Site D have aligned well with the environmental goals and are anticipated to reduce contaminants while minimising energy use and chemical dependency.

The selection of gravity-fed systems at Site E and adsorptive materials at Site F has showcased how low-cost and low-maintenance solutions could achieve compliance with stringent environmental standards without compromising operational efficiency. These recommended technologies have not only the potential to meet the regulatory requirements but have also offered a blueprint for future projects aimed at minimising environmental impacts.

The project's success was facilitated by active engagement with local site teams and communities. Feedback from these stakeholders led to several strategic adaptations in water treatment methodologies, ensuring that the solutions are not only capable of addressing environmental concerns but also of aligning with local socio-economic conditions.

5.2 Challenges and limitations

While the selected technologies generally have the potential to meet or exceed expectations, several challenges were encountered during the selection and assessment process. One of the recurring issues is the adaptation of these technologies to the specific environmental conditions of each site. For example, the remote location of Site C posed logistical challenges for passive treatment systems, which will require careful planning and lead to design modifications to improve their effectiveness during harsh weather conditions.

Additionally, some sites like Site G face challenges in meeting the newly set regulatory requirements, such as those set by the US Environmental Protection Agency (EPA 2014) which necessitate further adjustments to the proposed treatment processes to handle unexpectedly increased levels of contaminants, particularly arsenic and sulphate.

5.3 Implications for sustainable mine closure

The outcomes of these projects have implications for the broader field of sustainable mine closure. The implementation of these technologies will demonstrate the potential for mining companies to achieve closure goals that are environmentally sustainable and cost-effective, consistent with findings by

Wolkersdorfer & Bowell (2004). Furthermore, the projects have highlighted the importance of stakeholder engagement and adaptive management strategies in overcoming the challenges associated with mine closure.

The discussion underscores the need for ongoing innovation and flexibility in the application of water treatment technologies and demonstrates that continuous improvement and adaptation are crucial for meeting the evolving environmental standards and stakeholder expectations.

5.4 Future directions

Looking forward, it is essential during Phase 3 of the WTDP for future projects to build on the successes and lessons learned from these new strategies. This includes further exploration of passive and energy-efficient technologies, greater integration of real-time monitoring systems for adaptive management, and enhanced stakeholder collaboration to ensure that water treatment strategies are robust, resilient and aligned with local environmental goals.

6 Conclusion

This paper has presented a comprehensive overview of the identified improvements and innovations proposed in Phase 2 of the WTDP across various RTC sites. By employing a robust and adaptive methodology, the project successfully integrated tailored water treatment strategies that addressed the unique environmental challenges of each site. Advanced oxidation processes, passive wetlands and nanofiltration technologies were selected, and offered expected significant improvements in environmental compliance and operational efficiency.

The success of Phase 2 lies in its strategic approach to data collection, technology evaluation and the selection of site-specific solutions, which have been pivotal in providing potential solutions to mitigate the impact of contaminants such as arsenic and other heavy metals. These technologies, chosen for their efficacy and sustainability, have proved vital in adapting to the diverse conditions of each site; setting a benchmark for environmental management practices in the mining industry. The results have underscored the potential for these treatment solutions to reduce the environmental footprint during closure and post closure, enhancing the sustainability of mining operations globally.

Moreover, the project has highlighted the importance of innovative water treatment in achieving compliance with stringent environmental regulations while also demonstrating the economic viability of adopting such technologies. The adaptability and scalability of the selected solutions provide valuable insights into the future of sustainable mining practices, offering a model that is broadly applicable across the industry.

As the project has now transitioned into Phase 3 it builds upon the solid groundwork laid by the work in Phase 2. Initiated in April 2023, this next phase has further refined and optimised the water treatment processes at selected RTC sites. Phase 3 focuses on integrating the identified improvements, defining pilot trial plans and preparing strategies for upcoming discharge limits: all strategies aimed at further reducing operational costs, enhancing regulatory compliance and minimising environmental risks.

The scope of Phase 3 includes a series of strategic assessments and pilot trials to ensure that the improvements are not only effective but also sustainable and cost-efficient. This phase will continue to involve comprehensive program and project management services to ensure that new technologies are seamlessly integrated into existing systems and that the improvements are effectively implemented.

The ongoing commitment to environmental stewardship and innovative management practices under Phase 3 is anticipated to yield further advancements in water treatment strategies. These efforts are set to redefine industry standards for mine closure practices, demonstrating how proactive and adaptive management can lead to successful outcomes. The continuous evolution of the WTDP reflects Rio Tinto’s commitment to leadership in sustainable mining practices: aiming to set new benchmarks in the industry and pave the way for more effective, environmentally conscious closure practices worldwide.

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