

# A structured approach to co-disposal program development: standardising methodologies for efficient and cost-effective mine waste management

Mark Rizzuto <sup>a,\*</sup>, Ben Wickland <sup>b</sup>, Devin Castendyk <sup>c</sup>

<sup>a</sup> WSP, Peru

<sup>b</sup> WSP, Canada

<sup>c</sup> WSP, USA

## Abstract

*Co-disposal involves the storage of tailings and mine waste rock together in a single facility. Mixing waste rock and tailings, called commingling, is a form of co-disposal that offers potential benefits over conventional mine waste storage methods, including a more efficient use of space at a mine site, increased geotechnical stability relative to tailings alone, improved seepage water quality relative to waste rock alone, water recovery, and others. In recent years, co-disposal technologies have received increased interest within the mining industry, with several mine owners committing to studies to evaluate co-disposal as a mine waste disposal technology for specific sites and for general application. However, a standardised methodology for evaluating and developing co-disposal – from concept through operational implementation – is currently lacking. Eagerness to ‘try it out’ – to implement field trials without setting objectives based on identified use cases – can lead to unmeasurable or inconclusive outcomes.*

*This paper proposes a comprehensive methodology for developing and executing a tailings and waste rock co-disposal technology development program, including sequencing of project stages and gates within the project cycle. The focus is technical, with a multidisciplinary framework including process/dewatering, geotechnical and geochemical disciplines for testing campaigns at different scales correlated to project phase, illustrating the interactions between the testing programs. The proposed methodology provides a structured approach to co-disposal program development, ensuring that mine owners can make informed decisions to achieve efficient, cost-effective outcomes.*

**Keywords:** co-disposal, commingling, tailings, waste rock, mine waste

## 1 Introduction

Mine proponents following industry standards (GTR 2020) typically undertake options studies using multiple criteria analysis to select the best tailings disposal technology and site for new projects and major expansions. Options studies now typically include co-disposal of waste rock and tailings in the list of alternatives. Some of the potential benefits of co-disposal include:

- eliminated or reduced size of tailings ponds during operations and closure per GTR (2020) goals
- increased geotechnically stable tailings disposal facilities
- improved space conservation using voids in waste rock to store tailings
- increased water recovery through tailings dewatering

---

\* Corresponding author. Email address: [mark.rizzuto@wsp.com](mailto:mark.rizzuto@wsp.com)

- improved seepage water quality and reduced seepage volume from waste rock dumps, lowering the long-term cost of water treatment, and/or
- low-cost, low-carbon-footprint cover materials produced for waste rock dumps and tailings facilities.

The outcome of the alternatives assessment is the selection of the best mine waste management alternative for the project, which is then advanced to support project permitting and funding, then construction, operation and, ultimately, closure. For projects selecting known mine waste technologies, engineering is advanced in a typical manner. When co-disposal is selected as the preferred mine waste alternative for a project, the question of what to do next can be challenging given that co-disposal is a relatively new technology, with limited examples of operational implementation.

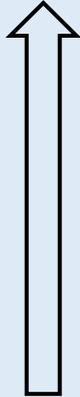
Co-disposal is an umbrella term for the disposal of both waste rock and tailings within a single mine waste storage facility. Table 1 describes several forms of co-disposed materials and the relative degree of mixing required to produce each form. Commingling is one form of co-disposal receiving considerable attention at the time of writing (see GeoStable Tailings Consortium) and requires the highest degree of mixing to produce.

This paper presents a staged program to develop and implement co-disposal as a mine waste management technology. The program includes five phases with decision gates and data requirements to inform each decision, plus criteria to define success or failure:

- Phase 1: co-disposal options identification and screening
- Phase 2: concept development and trade-off analysis
- Phase 3: pre-feasibility design
- Phase 4: feasibility design
- Phase 5: basic/detailed engineering.

The program is intended for use where stakeholders require a structured plan with opportunities to review results along the way so as to allow rationalisation of further investment. It is based on technical requirements in geotechnical, geochemical and process/mechanical disciplines, and includes approximate costs for program development. The authors are subject matter experts in these respective fields and have developed this program through experience in advising several members of the global GeoStable Tailings Consortium (GSTC). See [www.geostabletailings.com](http://www.geostabletailings.com) for more details.

**Table 1 Forms of co-disposal (adapted from Wickland et al. 2006)**

Co-disposal method	Degree of mixing
<p><b>Homogeneous mixtures (commingling):</b> Waste rock and tailings are blended to form a homogeneous mass; sub-categories include:</p> <ul style="list-style-type: none"> <li>• tailings-dominated mixtures</li> <li>• waste rock-dominated mixtures</li> </ul>	
<p><b>Pumped co-disposal:</b> Coarse and fine materials are pumped to impoundments for disposal</p>	
<p><b>Layered commingling:</b> Alternating layers of waste rock and tailings</p> <p>Tailings placed in cells made of waste rock</p> <p>Waste rock added to a tailings facility</p> <p>Tailings added to a waste rock pile</p>	
<p>Waste rock and tailings disposed in the same topographic depression</p>	

## 2 Phase 1: options identification and screening

### 2.1 Phase goals and objectives

Phase 1 is a critical step needed in initiating a co-disposal program, but it is often overlooked. The primary goals of Phase 1 are to:

- Define corporate co-disposal objectives for the entire program.
- Identify co-disposal options for tailings and waste rock that are potentially viable while screening out those that are fatally flawed.

Options that fail basic criteria should be eliminated from consideration, such as:

- not being aligned with waste rock and tailings production schedules (mass balance)
- requiring significant rehandling of waste
- not being operationally compatible with the site
- being unlikely to receive an environmental permit.

The objective of Phase 1 is to establish the overall program drivers, objectives and constraints, and define a short list of technically viable options that align with the program's objectives and constraints. Phase 1 consists of an initial data review of existing information followed by an identification workshop (workshop 1) in which program stakeholders will identify the options that are to be screened. After the options are established, a screening exercise will be performed. Once this is complete, stakeholders will reconvene in a second workshop (workshop 2) to review and discuss the results of the screening.

### 2.2 Data review

The first task in this phase involves a thorough review of existing data and background information. It is important during this step to establish the program drivers and objectives as these will be critical in determining which technologies and use cases are most appropriate. Likewise, project constraints are established including battery limits for the project, available areas for waste disposal, permitting requirements and others.

Available characterisation and test data (both geotechnical and geochemical) for tailings and waste rock are reviewed to establish design criteria for each type of material. Data typically include material properties, material types and production rates (i.e. material quantities) over time, derived from the mine plan(s). Lastly, a review of previous co-disposal studies is performed and summarised to provide an important context for this phase of work.

### 2.3 Objectives and options workshop 1

The first workshop with stakeholders focuses on confirming program objectives with stakeholders and identifying and describing potential co-disposal options. The options are captured in a matrix and will vary based on (but not limited to) the following parameters:

- tailings dewatering technologies available
- potential locations for co-disposed landforms
- forms of co-disposal and options available (Table 1).
- transport methodology
- placement methodology.

In this initial workshop, screening criteria are established that will be used to determine which options are potentially viable and those that do not meet the program objectives. The workshop should be attended by individuals from the owner's team who understand the project sensitivities (cost, mine plan, environmental) and subject matter experts from relevant areas (mine waste management/geotechnical, geochemical, process, environmental, permitting) who conducted the data review (Section 2.2).

## 2.4 Options screening

Once the options have been outlined, a detailed description of each option is developed. The options are evaluated against the overall study objectives and screening criteria to determine viability. The screening criteria may include, but are not limited to, the following:

- quantity of tailings storage and potential for elimination or schedule offset of a new tailings facility
- order of magnitude cost
- potential for enhanced water recovery – qualitative evaluation
- physical stability in earthquake – qualitative evaluation
- environmental impact – qualitative evaluation (co-disposed materials may generate acid rock drainage and/or metal-rich leachate in runoff water quality and/or seepage which must be captured and treated to an acceptable quality prior to discharge. Capex and Opex for water treatment are factored into the cost)
- competing uses for tailings and waste rock materials
- fatal flaws.

## 2.5 Review screening analysis workshop 2

A second workshop is held to report back on the screening results and discuss the viability of each option. Workshop attendees review results of the screening exercise and adjust criteria and weightings until agreement has been reached on a short list that will be moved on to the next phase of the program.

The goal is not to arrive at a single viable option that will be carried forward. Rather, it is anticipated that multiple options will be identified for further evaluation and development.

## 2.6 Data, information and permit requirements

The data for this step will be taken from existing studies and literature, with no new testing to be completed at this stage of the program. At the time of writing this paper, more than 125 research papers had been published on the topic of co-disposal, including several PhD and master theses. However, the technology has seen limited application in the industry, with fewer than 40 sites out of the estimated 24,000 tailings storage facilities worldwide (< 0.2%) publishing a co-disposal approach. The GSTC can also serve as a benchmark or reference point.

At this stage of the program, decisions are guided by the available data, which may involve uncertainties or data gaps that need to be acknowledged. Sources of uncertainty are identified and targeted for evaluation in the next phases

## 2.7 Execution cost

It is estimated that the cost to execute Phase 1 of the program will be in the order of USD 50,000 and USD 100,000 (all costs in this document are in 2024 US dollars).

## 2.8 Outcomes and decision milestones

Gate 1 for Phase 1 requires an owner decision as to which options will be carried forward for further evaluation and development.

## 3 Phase 2: concept development and trade-off analysis

### 3.1 Phase goals and objectives

The screening exercise from Phase 1 will narrow down the list of options available for co-disposal. Phase 2 involves the concept development and design of the co-disposal options identified in Phase 1 followed by a trade-off analysis to compare the options.

The goal is to compare each of the alternatives identified in the screening study and narrow the list down to one or more preferred options. The options must be developed to a level suitable to determine if there are any options that have a suitable business case that fits with the project objectives and to allow a decision on what options will be advanced (if any).

This phase of the program includes two components: a conceptual design for co-disposal options selected in Phase 1 of the program, and laboratory testing to characterise the geotechnical and geochemical properties of tailings and waste rock constituents at a basic level.

### 3.2 Scope and tasks

During this phase a conceptual level design is produced for each of the co-disposal options. Key documents and drawings for each option should include:

- a plan and section layout
- a mass balance for tailings and waste rock over mine life, and at the time of co-disposal implementation
- a process flow diagram and materials handling plan, including tailings dewatering method, material transportation method, co-disposal mixing (if required), and placement
- design analyses for geotechnical stability
- preliminary equipment selections and specifications
- site climate and expected water balance, with a preliminary assessment of seepage and runoff volumes
- preliminary assessment of the chemistry of seepage and runoff using assumed material properties.

Phase 2 is the first phase of the program where new laboratory investigations will be conducted. Basic laboratory testing will be undertaken to better understand the materials that will be available for co-disposal and their behaviour. The following is a list of recommended testing to be carried out during this phase (for which approximately 1 tonne of tailings and 1 tonne of waste rock are required):

- geochemical testing (test waste rock alone and tailings alone, assuming co-disposed mixture designs have not been finalised):
  - acid base accounting (ABA)
  - net acid generation pH and leachate chemistry
  - whole-rock elemental analysis by acid digestion
  - semi-quantitative mineralogy by Rietveld XRD
  - shake-flask test or synthetic leach precipitation procedure

- standard humidity cell test (HCT) and/or large diameter kinetic test (LDKT)
- geotechnical testing:
  - index tests, density and gradation
  - mixture trials (if indicated in screening)
  - strength by direct shear, triaxial testing at 25 mm maximum particle size
  - hydraulic conductivity
- process/tailings dewatering testing:
  - physical characterisation
  - sedimentation testing (static, dynamic)
  - flocculant screening
  - rheology
  - slump test
  - filtration testing.

It is not recommended that field trials or pilot testing be undertaken at this phase of the program. This would be premature at this phase since multiple co-disposal options are still being evaluated. Field trials can be lengthy and expensive and are better suited for later in the program, after laboratory results are evaluated.

Kinetic geochemical tests (LDKT and HCT) can take much longer to complete ( $\geq 40$  weeks) relative to geotechnical and process testing programs. As such, it is recommended to begin these long-duration tests on waste rock-only and tailings-only materials early in Phase 2 so that geochemical results can be incorporated into an environmental assessment and inform mixture design decisions. The LDKT is a non-standard procedure that considers a larger mass of sample (25 kg) with a heterogeneous grain size distribution (e.g.  $\leq 25$  mm waste rock mixed with tailings) relative to a standard HCT (i.e. 1 kg mass with  $\leq 6.3$  mm waste rock mixed with tailings). Therefore, the LDKT may be more representative of the behaviour of co-disposed materials.

Upon receipt of laboratory test results, initial predictive hydrological, hydrogeological and geochemical models can be generated to estimate future runoff and seepage volumes, and future runoff and seepage chemistry, likely to be generated during future field trials. Such models can be used to permit field trials and inform field trial design (e.g. select flow measurement instrumentation, drainage channel design, etc.). Models can then be calibrated and validated in the future as observed water balance and chemistry become available.

### 3.3 Data, information and permit requirements

Information collected during Phase 1 is used for concept development along, with new information obtained as part of the basic laboratory testing program for Phase 2. The laboratory results are used for the initial concept development. In the subsequent stages of the program (field tests), the complexity and scale of testing increases in order to validate the results from laboratory testing phases, and designs are adjusted as required based on test results.

### 3.4 Execution cost

It is estimated that engineering for this phase of the program will cost in the order of USD 100,000 to USD 300,000 and laboratory testing will cost in the range of USD 50,000 to USD 150,000.

### 3.5 Outcomes and decision milestones

Conceptual descriptions and designs will be produced for each co-disposal option in Phase 2. The designs will be supported by basic laboratory data. As part of the conceptual design, each option will have a cost estimate, typically using American Association of Cost Engineering International (AAACEI) Class 5 standard (or similar). A trade-off study is performed, comparing the costs and benefits of co-disposal designs against the costs and benefits of base-case tailings and waste rock management options.

Gate 2 for this phase requires a decision on which option(s) to carry forward to the pre-feasibility stage or whether the project should be stopped, based on the results obtained.

## 4 Phase 3: pre-feasibility design

### 4.1 Phase goals and objectives

The pre-feasibility design phase develops the selected co-disposal option(s) from Phase 2 to a more detailed level. Designs should be developed such that they permit the selection of a single option that provides the best value to the operation and meets the project objectives.

### 4.2 Scope and tasks

This phase involves developing a pre-feasibility level design for each co-disposal option. Preliminary design criteria are established based on the laboratory testing results from Phase 2. Using these criteria, preliminary layout configurations, capacity estimates and material handling assessments are developed for each option.

In addition to the engineering development, this phase will also include a more extensive testing campaign than was performed in previous phases. The testing program will include advanced laboratory testing, a pilot plant as well as field-scale trials.

The following is a list of recommended testing to be carried out as part of the advanced testing program:

- mixture trials (to determine mixture designs that can be successfully transported/placed)
- geotechnical testing (on transportable/placeable co-disposed mixtures):
  - critical state line
  - large triaxial – (1 m diameter) (180 mm maximum particle size)
  - liquefaction – centrifuge test with dynamic loading (25 mm maximum particle size)
- geochemical testing (on co-disposed mixtures):
  - LDKT on co-disposal mixtures (25 mm maximum waste rock particle size)
  - confirmation static testing (ABA plus mineralogy).

Phase 3 marks the first phase in the program that will involve testing outside of the laboratory on a larger scale. It is recommended to wait until Phase 3 to carry out this larger-scale testing because at this phase there will be fewer co-disposal options being considered, resulting in a more streamlined and cost-effective field program.

For this phase a pilot plant will be constructed to simulate and test different aspects of the co-disposal process at a limited scale. In general, each process will operate independently to characterise the feasibility, performance and limitations of each individual process that will make up the parts of the co-disposal system. Processes to be evaluated as part of the pilot plant will include the tailings dewatering equipment, mixing system and conveyance/transportation system. The following is a list of recommended parameters to investigate as part of the pilot plant:

- determine feasibility (and the cost) of producing desired dewatered tailings
- dewatering rate
- solids contents for each type of tailings (output)
- methodology and equipment needed for mixing of tailings and waste rock (if applicable)
- methodology and equipment needed for transporting and placing the materials.

Co-disposal pilot plant testing and transportability testing have been presented in Machin (2024) and Wisdom et al. (2018).

Field-scale trials will also be conducted during this phase to observe the behaviour of co-disposal materials at limited scale under site conditions. The field trials should include but are not limited to the following:

- stacking
- trial pads (e.g. 5 m high × 25 m long × 25 m wide) built upon a lysimeter, or columns (e.g. 6 m high × 1.5 m diameter), with the option to irrigate to generate seepage under arid conditions. Trial pads and/or columns are fully instrumented to record the water balance over time, record in situ profiles of porewater pressures, oxygen, soil suction and soil moisture, and to generate seepage and runoff samples for water chemistry analysis. Co-disposal trial pads have been presented in Bareither et al. (2022) and Castendyk et al. (2022), and column tests have been presented in Leon & Espinoza (2024), Machin (2024), and Wickland et al. (2003)
- segregation and placement
- erodibility
- trafficability
- geochemical rain barrels i.e. irrigated and non-irrigated 200-litre barrels containing co-disposed materials, waste rock-only material and tailings-only material. Barrels are a simple, low-cost geochemical trial option used for scaling purposes and to explore a wider variety of co-disposal options than trial pads alone. Barrels can be irrigated to accelerate geochemical reactions and/or not irrigated to reflect site meteorological conditions. An example of rain barrel tests with co-disposal materials was presented in Leon & Espinoza (2024).

Several of the field trial tests (trial pads, columns, rain barrels) are intended for long-term monitoring. As such, a site layout review should be performed as part of the planning stage for the field trials to identify locations suitable for long-term field trials. The selected test site should remain undisturbed by operations or rising water levels in a tailings storage facility for a minimum of five years as the geochemical/environmental value of field trial results increases with time.

A pilot plant may be used to generate materials for the field-scale trials that will be carried out as part of this phase. However, this may not be practical given the size of the pilot plant equipment. As an alternative, simulated tailings and waste rock materials may also be used for the field trials.

### 4.3 Data, information and permit requirements

Phase 3 will build on the data gathered in the previous phases, supplemented by advanced laboratory testing, pilot testing and field trials.

Permits for pilot testing and field trials may be required so it is important to account for permitting of the trials during the planning stages for Phase 3. This ensures that permit approvals do not cause delays in execution. This is also an excellent time to engage stakeholders to view trials onsite. Results from the field trial can potentially be used in environmental permit applications to demonstrate the technology.

## 4.4 Execution cost

It is estimated that engineering for this phase of program will cost in the order of USD 200,000 to USD 500,000.

The cost for laboratory, pilot testing and field trials can vary significantly based on scope and scale but could be in the range of USD 500,000 to USD 10 million.

## 4.5 Outcomes and decision milestones

At the end of Phase 3, a pre-feasibility level design will be produced for each option, along with an AAACEI Class 4 (or similar) cost estimate for each. The testing program should determine which option(s) can be successfully operated. Results from the field trial may be applicable to environmental permit applications and provide opportunities for informing regulators/stakeholders of potential future mine waste changes.

Gate 3 for this phase requires a decision on which option to carry forward to the feasibility level, or a decision to stop the program.

# 5 Phase 4: feasibility design

## 5.1 Phase goals and objectives

Phase 4 involves the feasibility design of the preferred co-disposal option. The design will inform permitting and support the execution of an industrial-scale trial, validating the operability of the proposed solution.

## 5.2 Scope and tasks

The feasibility design will include a comprehensive evaluation of the selected co-disposal options, integrating data from previous phases and pilot testing. Stability, seepage and water balance analyses will be conducted, and the design will be evaluated by failure mode and effects analysis and hazard identification studies to inform the next stage of design.

An industrial-scale trial will also be conducted during this phase of the program. The purpose of the industrial-scale trial is to validate the design assumptions, technical feasibility and operational processes at a large-scale (1/10–1/4 full tailings production) under real-world conditions. The industrial trial will include all components of the full-scale system operating in a single continuous process from production to deposition. The trial allows for testing of equipment and methods for handling and depositing the co-disposed materials, ensuring they can be effectively scaled up for full production. Likewise, the industrial trial aims to identify and resolve any unforeseen challenges that may arise from interactions between the tailings and waste rock streams.

Monitoring systems installed during the trial will capture data over time, providing insights into the long-term geotechnical and geochemical behaviour of the materials. Results from the trial will provide feedback for refining the final design, cost estimates and risk management strategies, ensuring the co-disposal system is able to operate continuously and consistently at full-scale.

## 5.3 Data, information and permit requirements

This phase will leverage the data collected in the previous phases, including the results of advanced laboratory testing, pilot plant and field trials.

The feasibility design will inform the submittal of environmental permitting and stakeholder engagement for the full-scale system. This will typically be in the form of an Environmental Impact Assessment or similar type of assessment.

## 5.4 Execution cost

It is estimated that engineering for this phase of program will cost in the order of USD 500,000 to USD 2 million.

The cost for an industrial-scale trial will vary greatly depending on the size of the system and is likely to cost in the multi-million USD range.

## 5.5 Outcomes and decision milestones

The key outcome of Phase 4 is the feasibility level design of the system, supported by the results of the industrial-scale trials. In addition, an AAACEI Class 3 (or similar) cost estimate will be generated to inform the business case.

Gate 4 for this phase includes a go/no go decision on whether to proceed with detailed design and implementation.

# 6 Phase 5: basic/detailed engineering

## 6.1 Phase goals and objectives

The final phase focuses on the detailed design of the selected co-disposal strategy, ensuring the project is ready for construction. The project scope and execution methodology will be fully optimised in this phase.

## 6.2 Scope and tasks

In this phase the design will progress to a detailed engineering level to support the procurement of all equipment and materials needed for the system and the subsequent construction stage. This includes finalising the design criteria and system configuration based on the results and findings from the industrial-scale trial. Once completed, detailed site and design descriptions, construction drawings, technical specifications, and operation, maintenance and surveillance (OMS) manuals will be finalised.

During the development of the detailed engineering design, the industrial-scale trial will continue to be monitored. Relevant findings from the trial will be reviewed and incorporated into the design as necessary, ensuring that the engineering reflects the operational data and performance metrics. Any significant updates will also be included in the OMS manual.

## 6.3 Execution cost

It is estimated that engineering for this phase of program will cost in the order of USD 3 million to USD 10 million.

Monitoring of the industrial trial will continue through this phase of the program. Monitoring is expected to cost approximately 25–50% of the initial set-up costs for the industrial trial.

## 6.4 Outcomes and decision milestones

The outcome of Phase 5 of the program is a detailed engineering design. This phase will advance the project to the point that is ready to proceed with procurement and construction. AAACEI Class 2/Class 1 (or similar) cost estimates will be generated for final budgeting and as a baseline for monitoring project costs during execution.

# 7 Lessons learned for best practice

Table 2 summarises the phased evaluation process presented herein.

In the authors' experience, prior trials of co-disposed materials have yielded several lessons which can be beneficial to consider when designing future studies:

- Co-disposal trials are expensive; greater value will result from trials that focus on a specific use case(s) at a specific mine site versus general testing for the sake of scientific exploration.
- Ensure that the site selected field trials will remain undisturbed for at least five years as observed long-term water quality data can provide a valuable contribution to environmental permit applications. Study sites also provide a valuable educational tool/demonstration for regulators and other stakeholders unfamiliar with this technology.
- Projects should be approached from multiple disciplines (e.g. process engineering, geotechnical, geochemical, etc.) to ensure the greatest likelihood of success.
- Ensure sufficient work has been completed at the conclusion of each phase to determine potential 'fatal flaws' across multiple disciplines, such as whether or not a given design can be operated (e.g. synchronisation of tailings and waste rock sources, transportation and placement).
- At the conclusion of each phase of a trial, a trade-off study should be performed comparing the costs and benefits of base-case mine waste management and co-disposed waste management. The trade-off should factor into the decision to advance a trial to the next phase and to advance the business case for co-disposal.
- Due to wide variability between mine sites with respect to particle size distributions in different mine wastes, climate and water balance, waste mineralogy and geochemistry, etc., it is recommended to conduct pre-feasibility study and feasibility study field trials at the specific mine site where co-disposal will potentially be implemented. It is possible to generate surrogate materials and, to a lesser extent, represent different site climates at a field-scale. But, ultimately, variability between the trial site and the mine site will introduce uncertainty in the decision-making process.
- Two common drivers for co-disposal investigations are (1) increasing the geotechnical stability of tailings disposal facilities, and (2) improving water quality in seepage from mine wastes. The optimal co-disposal facility should have the geotechnical stability of waste rock and the hydraulic conductivity and oxygen supply of tailings. To date, this 'kill two birds with one stone' optimal mixture design has not been identified or implemented. Most mixture designs have prioritised geotechnical stability using waste rock dominated blends which do not fully occlude pore volumes with tailings and, therefore, allow greater airflow and water flow relative to tailings alone. Such mixture designs may not limit geochemical reactivity.
- From an environmental perspective, regulators and stakeholders require co-disposal facilities to do one of the following – (1) produce acceptable water quality for discharge without treatment, (2) produce similar water quality as currently permitted facilities, allowing use of the same water management plan and treatment plant, or (3) capture and treat seepage and runoff from new facilities using a new water management plan and upgraded treatment plant. Due to reductions in infiltration rates caused by co-disposal it is expected that runoff volumes will increase. As such, environmental permits involving new co-disposal facilities will likely require a field trial and/or numerical models that predict future seepage and runoff water quality and quantity, plus an estimate of future water management and treatment costs associated with co-disposal.
- Kinetic geochemical laboratory tests and field trials take a considerably longer time (i.e. months to years) to produce sufficient data (e.g. to develop source terms used in predictive geochemical models) compared to geotechnical or process engineering tests. Therefore, geochemical tests should be started as soon as possible to allow data to be received in time to inform key decisions and environmental permit applications.

- The performance of various mixture designs proposed for use in co-disposal may not be finalised until field trials on material transportation and placement have been completed. This is because materials that appear to be suitable in the laboratory may liquefy and/or segregate during transport and placement. Multiple transportation and placement options should be explored, i.e. more than just conveyor belts.
- Some degree of segregation upon final placement is likely. Field trials should define the degree of segregation that is acceptable to meet project objectives, and the degree of segregation that is unacceptable.

**Table 2 Phased program to evaluate co-disposal options**

Phase	Name	Major activities	Outcomes	Starting options	End options
1	Options identification and screening	Screening fatal flaws; stakeholder workshops	Approved objectives; list of options	> 12	< 6
2	Concept development and trade-off	Data review, laboratory testing on tailings-only and waste rock-only samples	Conceptual description of options	< 6	< 3
3	Pre-feasibility design	Pre-pilot plant; generate tailings; mixture trials; field trials	Granular knowledge of options	< 3	1
4	Feasibility design	1/10 to 1/4 full production; permit applications	Detailed understanding of a specific option at industry scale	1	1
5	Basic/detailed engineering	Specification for full implementation	Implementation	1	1

## 8 Conclusion

This paper presents a structured five-phase program for developing and implementing co-disposal of waste rock and tailings as a mine waste management technology (Table 1). The program provides a systematic approach to advance the design from initial concept through to detailed engineering, with defined decision gates and outcomes at each stage. This is intended to be a generic methodology that is robust enough to be used for different sites and different types of mine waste, and which enables the user to determine which co-disposal form is most appropriate for their site (Table 2).

By following this methodology, mining companies can systematically evaluate co-disposal options while managing technical, financial and operational risks. The approach ensures that critical technical aspects are addressed at appropriate stages, avoiding premature investment in large-scale testing while maintaining sufficient rigour in evaluation.

As co-disposal technologies continue to evolve, this framework provides a road map for mining companies to evaluate and implement these solutions effectively. The methodology presented in this paper is theoretical and requires validation through case studies or real-world applications. Future work should focus on documenting case studies of successful implementations using this methodology and refining the technical criteria based on operational experience.

## References

- Bareither, CA, Scalia, J & Aparicio, M 2022, 'Case studies in commingling part 2: water balance observation from field-scale commingled and waste rock test piles in a sub-tropical highland climate', in M Edraki, D Jones & KR Jain (eds.), *Proceedings of the 12th International Conference on Acid Rock Drainage*, Sustainable Minerals Institute, The University of Queensland, Brisbane, pp. 388–397, <https://smi.uq.edu.au/conferences/international-conference-acid-rock-drainage-2022>
- Castendyk, D, Aparicio, M, Verburg, R & Thompson, JA 2022, 'Potential benefits of comingling waste rock and tailings as indicated from a multi-year field trial', in M Edraki, D Jones & KR Jain (eds.), *Proceedings of the 12th International Conference on Acid Rock Drainage*, Sustainable Minerals Institute, The University of Queensland, Brisbane, pp. 398–410, <https://smi.uq.edu.au/conferences/international-conference-acid-rock-drainage-2022>
- International Council on Mining and Metals, United Nations Environment Programme, & Principles for Responsible Investment 2020, *Global Industry Standard on Tailings Management*, <https://globaltailingsreview.org>
- Leon, C & Espinoza, C 2024, 'Antamina's codisposal project - a holistic Vision', presented at *9no Congreso de Relaves Peru (9th Peru Tailings Congress)*, DEEV,.
- Machin, D 2024, 'Antamina's codisposal project - testing program requirements', presented at *9no Congreso de Relaves Peru (9th Peru Tailings Congress)*, DEEV, Lima.
- Wickland, B & Longo, S 2017, 'Mine waste case examples of stacked tailings and co-disposal', *Proceedings of the 21st International Conference on Tailings and Mine Waste*, The University of Alberta, Edmonton.
- Wickland, B, Wilson, GW & Johnson, G 2003, 'A meso-scale column test for co-mixed tailings and waste rock', *Application of Sustainability of Technologies: Proceedings of the 6th International Conference on Acid Rock Drainage*, Australian Institute of Mining and Metallurgy, Melbourne, pp. 1171–1173.
- Wickland, B, Wilson, GW, Wijewickreme, D, & Klein, B 2006, 'Design and evaluation of mixtures of mine waste rock and tailings', *Canadian Geotechnical Journal*, vol. 43, no. 9, pp. 928–945, <https://doi.org/10.1139/T06-058>
- Wilson, GW, Wickland, B, Miskolczi, I, Andrina, J & Salzsauler, K 2022, 'Commingling waste rock and tailings to produce geochemical and physical stability in mine waste deposits', in M Edraki, D Jones & KR Jain (eds.), *Proceedings of the 12th International Conference on Acid Rock Drainage*, Sustainable Minerals Institute, The University of Queensland, Brisbane, pp. 38–54, <https://smi.uq.edu.au/conferences/international-conference-acid-rock-drainage-2022>
- Wisdom, T, Jacobs, M & Chaponnel, J 2018, 'GeoWasteTM – continuous comingled tailings for large-scale mines', in RJ Jewell & AB Fourie (eds), *Paste 2018: Proceedings of the 21st International Seminar on Paste and Thickened Tailings*, Australian Centre for Geomechanics, Perth, pp. 465–472, [https://doi.org/10.36487/ACG\\_rep/1805\\_38\\_Wisdom](https://doi.org/10.36487/ACG_rep/1805_38_Wisdom)

