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Evaluation of Dredge Pond and Groundwater Management Options

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Holcim Salt Ash Sand Operations
8 Oakvale Drive, Salt Ash, New South Wales

Holcim (Australia) Pty Ltd
09 January 2025

AU122186B R03

Quality Management

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This report was prepared in accordance with the scope of services set out in the contract between Geosyntec Consultants Pty Ltd (ABN 23 154 745 525) and the client.

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Executive Summary

Holcim (Australia) Pty Ltd (Holcim) owns and operates the Salt Ash Sand Operations (the 'site' or the 'quarry'), a long-standing quarry located at 8 Oakvale Drive, Salt Ash, New South Wales (Lot 4 DP 774726) that imports, extracts, processes and transports sand products for use in the production of industrial and construction materials, such as glass, asphalt and concrete.

Holcim is proposing to meet part of the increased forecast demand in natural sand in the Hunter and Greater Sydney regions by maximising the extraction of remaining sand resource from the quarry through a State significant development (SSD) application.

The objective of this report is to provide Holcim with advice regarding environmental management measures to reduce the potential for unacceptable environmental outcomes resulting from the generation of acid and release of salinity and dissolved metals during extraction of the sand resource.

The proposed operations will create a dredge pond (DP) by vacuuming (dredging) the sand resource below the water table. A slurry containing a mixture of sand and water will be pumped from the dredge via a floated pipeline to a processing plant where the desired sand fraction will be separated from fine and coarse fractions. Sand is proposed to be extracted within the entire project site to a maximum depth of 30 m below the water table.

The targeted subsurface sand units contain seams of clays and reduced sediment, which possess relatively high acid generating capacity when exposed to air during sand processing and storage of separated fractions. In addition to the low pH, process water in contact with oxidised sand material is anticipated to contain elevated concentrations of sulfate, iron, aluminium, and divalent heavy metals.

Various potential environmental controls were evaluated to address the three potential sources of acidity: (i) sand processing, (ii) chemical process in DP; and (iii) processes in downgradient aquifer. The environmental control measures could be applied during facility operations and after closure to limit the potential for off-site migration of impacted groundwater and prevent unacceptable impacts to downgradient receptors:

- Management of sulfidic fines during sand processing
  - Prevention of cumulative acidification of the DP.
  - Stabilisation of fines and prevention of secondary releases of CoPCs in the DP.
- In-pond treatment
  - Direct management of low pH and COCs in the downgradient section of the DP to prevent migration of CoPCs to the downgradient aquifer.
- Protection of downgradient aquifer:
  - Treatment of residual COCs in water migrating from the DP to the downgradient aquifer.

Based on detailed evaluation of the options presented in this report, the following environmental management measures have been identified to mitigate water quality impacts from the sand dredge operations.

Option	Description	Advantages	Disadvantages	Comments
1. Fines Management				
Process optimisation	Direct return of fines to the dredge pond,	• Minimises exposure to atmosphere and acid generation.	• Potential effect of ASS in very short processing time	Included in proposed

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Option	Description	Advantages	Disadvantages	Comments
	with a short handling time at the surface	• Limits above ground space required to store separated fines	unknown, will require additional testing • Fast rates of fine slurry transport not amenable to discrete monitoring of water quality	production process train
Lime addition	Dosing of lime to neutralize ASS capacity in fines	• Neutralises pH decrease from exposure during production. • Adds additional capacity to neutralize processes in the dredge pond	• Fast rates of fine slurry transport not amenable to direct in-stream lime dosing • Direct dosing to the dredge pond in the fine deposition location may be required.	Applied if needed, based on evaluation of pH in returned fines slurry
2. In-pond Treatment				
Barge application		• Good lateral distribution • Modified dredge could be used for application	• Low to moderate throughput • Requires loading dock • Lime needs to be replenished on boat	Modified barge would be preferable, but requires further evaluation
3. Management of Aquifer Impacts Downgradient of the Dredge Pond				
Hydraulic containment and treatment of groundwater downgradient of the dredge pond	Extraction wells targeting specific zones of groundwater impact	• Reliable, well-established technology • Can be optimised to selectively target discrete zones of groundwater impact	• Does not treat the source of groundwater impact • May become financially unviable if required capture zone/volume is large	Contingency response during operational-phase groundwater monitoring
Reactive fill material on the northern wall of the dredge pond	Deposition of a layer of alkaline permeable fill on the northern wall of pond	• Relatively simple installation method. • Can be replenished easily once capacity is exhausted.	• Requires imported fill with specific characteristics of permeability and capacity. • Requires establishment of a final stable dredge pond wall • Difficult to control reactive zone thickness and stability • Potentially cost prohibitive, subject to refinement of design and unit cost estimates	Installation possible at end of Stage 7 when final dredge pond and stable walls are established*
Periodic in-pond application of lime suspension	Creation of a layer of undissolved lime on dredge pond wall	• On-demand application as dredge pond grows • Deposited lime particles treat COCs and prevent acid generation from the dredge pond	• Frequent applications may be required if dredge pond walls are unstable.	Applicable as an interim measure during Stages 1 through 7

Implementation of the environmental management measures would be initiated based on trigger values from a monitoring program designed to assess environmental conditions relevant to the media targeted by each option.

Based on the review of environmental management options, it is likely that one or a combination of management options will be capable of treating the potential water quality impacts associated with oxidation of acid sulfate soils during dredge operations. The selection, verification, design and optimisation of treatment methods will require a targeted feasibility evaluation to quantify performance relative to the water quality objectives.

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It is also recommended that additional geochemical assessment is designed to address the effectiveness of proposed management option(s), with consideration of the rate of change expected in soil and groundwater chemistry. This approach will inform ongoing monitoring programs. A geochemical program should be completed which aims to quantify:

1. Efficiency of hydraulic separation
2. Characteristics of fines waste stream.
3. Efficacy of ameliorants (i.e., lime/caustic or crushed concrete).
4. Efficacy of containment.

To address these aims:

- Trials of hydraulic separation of site materials to confirm segregation of sulfidic fines and characteristics of washed sand fraction. Trials can be completed at bench scale or field scale as available. Trials can provide information for hyrdocyclone design and assess if liming of sulfidic fines returned to the dredge pond will be required.
- Column tests should be completed to assess the effective neutralising value of any proposed ameliorant needs to be documented. If crushed concrete is to be used to manage pH, its effectiveness must be quantified.
- If cement stabilisation is to be considered, a monolith of stabilised fines should be leach tested to assess the leachability of the resultant solid.

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ACRONYMS AND ABBREVIATIONS

AMD	Acid mine drainage
ADWG	Australian Drinking Water Guidelines
ANZG	Australian and New Zealand Governments and Australian state and territory governments
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ASC NEPM	National Environment Protection Council (NEPC), 1999. National Environment Protection (Assessment of Site Contamination) Measure
ASS	acid sulfate soil
COC	constituent(s) of concern
CSM	conceptual site model
DGV	default guideline values
DO	dissolved oxygen
EC	electrical conductivity
Eh	measure of the oxidation or reduction state of a solution, relative to the standard hydrogen electrode
EPA	Environment Protection Authority (NSW, ACT)
GDE	groundwater dependent ecosystem
Geosyntec	Geosyntec Consultants Pty Limited
GIL	groundwater investigation levels
K	hydraulic conductivity
kg	kilogram
km	kilometre
L	litre
m	metre
m/day	metres per day
mbgs	metres below ground surface
µg/L	micrograms per litre
mg/L	milligrams per litre
µS/cm	microsiemens per centimetre; a measure of fluid electrical conductivity
NATA	National Association of Testing Authorities
NEPC	National Environment Protection Council
NHMRC	National Health and Medical Research Council
NRMMC	Natural Resource Management Ministerial Council
ORP	oxidation-reduction potential (see also: Eh)
pH	measure of acidity or alkalinity of a solution, expressed as -log[H^+]
PRB	Permeable reactive barrier
TDS	total dissolved solids
ZVI	Zero valent iron

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1 Introduction

Holcim (Australia) Pty Ltd (Holcim) owns and operates the Salt Ash Sand Operations (the 'site' or the 'quarry'), a long-standing quarry located at 8 Oakvale Drive, Salt Ash, New South Wales (Lot 4 DP 774726) that imports, extracts, processes and transports sand products for use in the production of industrial and construction materials, such as glass and concrete.

A State Significant Development Application (SSD-9099356) has been submitted by Holcim seeking approval to extract and process a minimum of 10 million tonnes of sand from the quarry at a rate of 550,000 tonnes per annum (tpa), in addition to the processing of 200,000 tpa of sand imported from other local extractive operations. Extraction of sand is proposed to be undertaken by a combination of front-end loader, excavator and dredge plant, with extraction from below the water table by excavator and dredge. Extraction is proposed to a maximum depth of approximately 30 m below the water table.

This report has been prepared by Geosyntec Consultants Pty Ltd (Geosyntec) to provide Holcim with an updated evaluation of environmental management measures for the proposed extension to quarrying operations at the site. The evaluation pertains to management of environmental impacts resulting from the proposed dredging of sand resource below the water table, sand material separation, management of fine and coarse rejects and processes occurring in the resulting dredge pond (DP) and in the aquifer downgradient of the quarrying operations. An initial management options review was presented in Geosyntec (2022) *Preliminary Evaluation of Sand Dredge Pond and Groundwater Treatment Options* dated 30 November 2022 (ref. AU122186 R01 v1). This report presents an updated review of potential management options for the Salt Ash Project based on a refined conceptual site model (CSM).

In response to referral agency submissions on the SSD application and Environmental Impact Statement (EIS), Geosyntec was commissioned by Holcim to complete a detailed characterisation of the presence, nature and extent of acid sulfate soils within the project footprint to provide a basis for hazard identification and development of management measures. Results of the investigation have been presented in the *Final Draft Acid Sulfate Soils Characterisation Investigation* dated 29 November 2024 referenced AU122186B R02, which should be referred to for detailed information relating to acid sulfate soils conditions at the site. A summary of the assessment results is presented in Section 2 of this report, and the refined CSM is presented in Section 3.

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1.1 Objective

The objective of this report is to provide Holcim with updated advice regarding environmental management measures to reduce the potential for unacceptable environmental outcomes arising from disturbance of acid sulfate soils and the generation of acid and release of salinity and dissolved metals during extraction of the sand resource, based on the refined acid sulfate soils CSM.

1.2 Project Description

Holcim is seeking approval to extract and process a minimum of 10 million tonnes of sand from the quarry. Extraction of sand is proposed to be undertaken by a combination of front-end loader, excavator, and dredge plant, with extraction from below the groundwater table by excavator and dredge. Seven phases of extraction are proposed, with a maximum depth of -28 mAHD, approximately 33 m below the current site surface, and approximately 32 m below the average water table.

The proposed development involves the extraction and processing of up to 550,000 tonnes per annum (tpa) of sand using both dry extraction and dredging techniques. Feed sand for the process plant will include up to 200,000 tpa of sand from offsite sources: their Tanilba Bay and Anna Bay operations, as well as other local extractive operations for processing at the site, resulting in a total of up to 750,000 tonnes of sand products processed and dispatched from the site per year (the 'project'). The project will operate for up to 30 years.

The proposed disturbance footprint at Salt Ash Sand Operations covers an area of approximately 35.5 ha and encompasses all areas to be disturbed by sand extraction (dry extraction and dredging), internal access roadways (including slope batters) and processing operations, and all areas of vegetation clearing.

1.2.1 Overview of Resource Extraction, Handling and Dredge Pond Development

The following description of the proposed resource extraction and handling process as part of the development has been paraphrased from the EIS:

- The sand will be extracted by front-end loader to a nominated depth, followed by an excavator above and below the water table within its reach. The excavated sand will then be transferred by front-end loader and/or dump trucks to the existing processing plant.
- As groundwater is encountered, a pond would be created immediately south of the processing area and will be made large enough to float a dredge.
- The project involves progressive extraction of sand over seven operational stages. The dredge would commence immediately south of the processing area of the quarry and will then progressively extract sand in a southerly direction away from the processing plant in a staged process.
- The dredge will move backwards and forwards across the dredge pond, vacuuming (dredging) the underwater sand resource. A slurry containing a mixture of sand and water will be pumped from the dredge via a floated pipeline to a processing plant. The dredge will manoeuvre around the pond and will be secured to the pond banks by wires.
- Once the dredge pond is formed, as the dredge extracts the underwater sand resource, surface sand would slump into the dredge pond at the natural angle of repose and be captured by the dredge. It is envisaged that this process would reduce the need for manual handling of material, however if required sand adjacent to the pond edges may also be placed into the dredge pond by excavator or front-end loader to then be captured by the dredge.
- Sand may be extracted within the entire project site via a combination of dry extraction and dredging operations to a maximum depth of 32 m below the water table.
- During the initial stage of the project, until dredging operations are established, sand extracted by front-end loader or excavator will be transported to the in-feed plant for processing as per existing operations.
- A processing plant and stockpile area will be established for the dredging operations in the processing area within the northern portion of the site. Depending on the desired particle sizing, the sand will be pumped through a hydrocyclone and stockpiled for directly loading into trucks for dispatch off site, or further processed and dispatched as per existing operations.

Details of a proposed process for the extraction of sand using a 300 tpa processing plant is presented in Table 1.1, as reported by Holcim staff.

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Table 1.1: Project Summary

Project Component	Summary of the Project
Extraction method	• Sand will be extracted via dry methods (excavator/loader) to 1-3 m below groundwater level until the dredge can be established. Then, a dredge ladder will likely be set at 12 - 15 m below groundwater level. • The dredge is not selective; it will extract a mix of layers from above the cutting head.
Total Tonnage	Approximately 10,000,000 tonnes of sand will be extracted.
Anticipated extraction ratio of Slurry	30% solids, 70% water.
Process Plant	• 1,000 tonnes per hour slurry processing to generate 300 tonnes per hour of dry sand. • Hydrocyclone separation of <75µm from ≥75µm particles
"Saleable" product	Sand with particle size ≥75µm
Waste Stream	• <75 µm particles and water to be managed, ideally by return to the extraction void. Separate settlement ponds are not currently proposed. • Secondary separation of the <75 µm fraction could be considered, if beneficial.

1.3 Acid Sulfate Soils Definition

Australian Government Department of Agriculture and Water Resources (2018a) *National Acid Sulfate Soils Guidance, Identification and Laboratory Methods Manual* defines Acid Sulfate Soils as materials that are *distinguished from other soil or sediment materials by having properties and behaviour that have either:*

5. *been affected considerably by the oxidation of Reduced Inorganic Sulfur (RIS), or*
6. *the capacity to be affected considerably by the oxidation of their RIS constituents.*

The factor common to all ASS materials is that RIS components have either had, or may have, a major influence on the properties or behaviour of these soil materials.

The Acid Sulfate Soils Manual (ASSMAC, 1998) states that:

Acid Sulfate Soils is the common name given to naturally occurring soil and sediment containing iron sulfides. When these naturally occurring sulfides are disturbed and exposed to air, oxidation occurs and sulfuric acid is ultimately produced. For every tonne of sulfidic material that completely oxidises, 1.6 tonnes of sulfuric acid are produced.

When disturbed and exposed to an oxidating environment both acid generating and acid neutralising processes can occur. Acid generating processes include:

- Oxidation of sulfide minerals by O_2 and Fe^{3+}.
- Release of organic acids from organic material in clays.

Acid neutralising processes include:

- Dissolution of carbonate minerals (weak, shell-type carbonate materials present in localized and discrete layers).
- Dissolution of aluminosilicate minerals (e.g., clays), generation of dissolved Al^{3+}.
- Dissolution of Fe^{3+} iron minerals (oxyhydroxides).
- Oxidation of Fe^{2+}.

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Best practice management of ASS is dependent on both the correct identification of ASS materials, and the accurate quantification of the hazards these materials pose to aquatic and terrestrial environments.

1.4 Relevant Guidelines

The advice provided in this report has considered the information available in the following guidelines and legislation:

Technical guidance for acid sulfate soil assessment and management:

- Sullivan, LA, Clay, C, Ward, NJ, Baker, AKM, and Shand, P 2018, *National Acid sulfate soils guidance: a synthesis*, Department of Agriculture and Water Resources, Canberra, ACT. CC BY 4.0.
- Sullivan, L, Ward, N, Toppler, N and Lancaster, G 2018, *National Acid Sulfate Soils Guidance: National acid sulfate soils identification and laboratory methods manual,* Department of Agriculture and Water Resources, Canberra, ACT. CC BY 4.0.
- Shand, P, Appleyard, S, Simpson, SL, Degens, B, Mosley, LM 2018, *National Acid Sulfate Soils Guidance: Guidance for the dewatering of acid sulfate soils in shallow groundwater environments,* Department of Agriculture and Water Resources, Canberra, ACT. CC BY 4.0.
- Simpson, SL, Mosley, L, Batley, GE and Shand, P 2018, *National Acid sulfate soils guidance: Guidelines for the dredging of acid sulfate soil sediments and associated dredge spoil management,* Department of Agriculture and Water Resources, Canberra, ACT. CC BY 4.0.

The national guidelines supersede the previously published New South Wales (NSW) guidance documents; however these older guidance documents have been referred to in order to provide context to the approach taken in historical assessments of the site.

The following NSW ASS guidance documents were referred to:

- NSW Acid Sulfate Soil Assessment and Planning Guidelines (1998)
- Acid sulfate soil remediation guidelines for coastal floodplains in NSW (2007)

Other statutory guidelines of relevance made or approved by the NSW EPA under Section 105 of the *Contaminated Land Management Act 1997* at the time of this report included:

- National Environment Protection (Assessment of Site Contamination) Measure 1999 (April 2013) (ASC NEPM).
- ANZG (2018) Australian and New Zealand Guidelines for Fresh and Marine Water Quality.
- NHMRC/NRMMC (2011) Australian Drinking Water Guidelines. National Health and Medical Research Council and National Resource Management Ministerial Council of Australia and New Zealand.
- NSW DEC (2007) Guidelines for Assessment and Management of Groundwater Contamination.
- NSW EPA (2020a) Contaminated Land Guidelines: Consultants Reporting on Contaminated Land.

In addition, the most recent Australian guidance on Acid Sulfate Soils management has been referred to as the most up to date best practice management methods:

- Dear SE, Williams KM, McElnea AE, Ahern CR, Dobos SK, Moore NG, and O'Brien LE 2024, *Queensland Acid Sulfate Soil Technical Manual, Soil Management Guidelines, Version 5.1*, Department of Resources and Department of Environment and Science, Queensland.

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- WA DER (2015) Identification and investigation of acid sulfate soils and acidic landscapes, WA Department of Environment Regulation.

1.5 Previous Technical Studies

The following technical studies were prepared in support of the EIS and were provided to Geosyntec for review in the preparation of this advice:

- Geoterra Pty Ltd (30 November 2022) Holcim Salt Ash Sand Operations, Hydrogeochemical and Acid Sulfate Assessment, Salt Ash, NSW (Referenced: HOL1 – R2B) – Appendix C of the EIS
- Hydrominex Geoscience Consulting (29 November 2022) Groundwater Impact Assessment, Holcim Salt Ash Sand Operations (Referenced: 202010, Version 10) – Appendix E of the EIS
- Southeast Engineering and Environmental (29 November 2022) Surface Water Impact Assessment, Holcim Salt Ash Sand Operations (Referenced: 523 Revision B Final Draft) – Appendix G of the EIS.

As noted in Section 1 Geosyntec completed a detailed acid sulfate soil assessment:

- Geosyntec Consultants (29 November 2024) Final Draft Acid Sulfate Soils Characterisation Investigation (Referenced AU122186B R02 Revision 01).

1.6 Department of Planning and Environment Comments

Department of Planning and Environment (DPE) issued a response to the Holcim State Significant Development Application *Subject: Holcim Salt Ash Sand Operations (SSD-9099356) Environmental Impact Statement (EIS)* dated 18 April 2023. The response noted "*examples of recorded groundwater quality impact caused by deep dredging operations at the Hanson Tweed Sand Project (HTSP) located at Cudgen NSW, the Tomago RZM operations at Tomago, and a former short term dredge operation at Boral's Stockton Sand Quarry"*

A copy of *Report on Data review & assessment of hydrogeological and hydrogeochemical impacts of heavy mineral mining on the Tomago Sandbeds, Newcastle, NSW* prepared by Coffey Partners International Pty Ltd dated 08 February 1996 was provided by Holcim, which provides details on the effects of heavy mineral sands extraction on groundwater quality in an area known as the Tomago Special Mining Area by Rutile & Zircon Mines (Newcastle) Limited (RZM), which commenced in 1972, with extraction completed at various depths including "deep mining to the base of the Tomago aquifer" from 1990.

A detailed discussion on recorded iron concentrations prior to and following mining operations is provided. Iron concentrations in groundwater prior to mining works were reported to be in the range of 1 to 11 mg/L, with an average of 5 mg/L, with concentrations of up to 200 mg/L reported following deep mining works. The two key mechanisms of iron mobilization identified: Oxidation of pyritic sediments, generating Iron (III) precipitates, and biological reduction of Iron (III) precipitates by iron reducing bacteria during oxidation of organic matter.

The report notes that "*the areal extent of the increased iron concentrations and associated sulphate concentrations in the groundwater was largely confined within the Tomago Special Mining Area. There is no definitive evidence for increased iron concentrations beyond this boundary*" – iron mobilised through biological reactions is also readily converted back to iron precipitates in the presence of oxygen – i.e. locally elevated iron concentrations in the immediate disturbance footprint are unlikely to migrate far beyond the disturbance footprint.

Mining operations are described with the report, summarised below:

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- Mining is completed on a continually advancing pond (around 100 m long and 50 m wide), in three benches, to 6 m depth, 6 to 12 m and 12 to 18 m (typical). Dredging is completed at a rat of 800 tonnes per hour using a bucket wheel dredge.
- Water and sand slurry is pumped from the dredge cutting head to a trommel screen and series of “spirals” to separate the heavy minerals from the remaining sand.
- Waste sand is then reported to be sprayed to the tailings pile, located at the back of the pond, to a height of approximately 4 m above the dredge pond.
- Water generated by the dredging operations is discharged to the dredge pond from the processing plant.
- Early operations (pre-1986) fine material (slimes, <75 µm) were not returned to the dredge pond, and instead were pumped to settlement ponds following processing through a thickener. This practice was discontinued in 1986, after which slimes were discharged to the dredge pond.

As such, operations and waste sand handling did not include measures to minimise the risk of pyrite oxidation as required by best practice acid sulfate soils management:

- Reduction of atmospheric exposure.
- Segregation of pyritic material (identified as grey sands at depth in the aquifer).
- Lime amendment to neutralise ASS.
- Subaqueous discharge of waste sand to reduce contact with atmospheric oxygen.

Details of the acid sulfate soils management at the Hanson Tweed Sand Project (HTSP) are presented in Appendix K *Acid Sulfate Soils Assessment* (prepared by Gilbert and Sutherland dated January 2021) of *EIS Hanson Tweed Sand Plant Expansion Phase 5 to Phase 11* prepared by Zone Planning Group Pty Ltd dated 30 March 2021, which is available on the NSW Government Major Projects website.

With respect to water quality impacts Geosyntec reviewed the Surface Water Assessment and Groundwater Assessment presented as Appendix B and C, respectively of the EIS. Surface Water Assessment prepared by Gilbert and Sutherland dated March 2021 presents the results of long-term surface water quality monitoring including pH, and metals, typically associated with the disturbance of acid sulfate soils, particularly iron and aluminium, which are generally reported within the sites target range. Reported pH within the dredge lake ranges from 6.36 to 9.85, with a median value of 8.34, with iron and aluminium ranging from 0.002 to 0.560 mg/L (median 0.05 mg/L) and 0.005 – 1.98 mg/L (median 0.014 mg/L), respectively.

Groundwater quality monitoring is presented in Groundwater Assessment prepared by Gilbert and Sutherland dated March 2021. The report states that iron concentrations in groundwater exceed the site performance criteria at “a small number of locations”, however review of time series plots presented in the report indicates that iron concentrations exceed the sites performance criterion at almost all groundwater monitoring locations, with some locations reporting iron concentrations up to 98.3 mg/L in comparison to a performance criterion of 0.3 mg/L. Sporadic exceedances of pH (3.33) and aluminium (0.92 mg/L) indicates that disturbance of acid sulfate soils may be locally impacting groundwater quality.

Acid sulfate soils management in current operations reported in the EIS include hydraulic separation of fine particles from the sand fraction using a hydrocyclone, followed by sub aqueous deposition of the fine fraction (noted to include sulfidic fines) in the dredge lake. The fines discharge point of the fines return is located at least three metres below the water surface and is located to ensure that the fine particles settle at least eight metres below the water surface. Sampling and analysis are completed on the recovered sand fraction to determine if lime treatment is required. It is reported that to date no lime treatment has been required due to the acid neutralising capacity of the sites sand resource.

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The management options presented in this report have been determined to minimise the risk of water quality impact arising from the proposed project and provide suitable options to address impacts if identified. The proposed management options go beyond and improve upon the management approach utilised at the HTSP site and the absence of acid sulfate soils management completed during the RZM operation. The measures provide both proactive and responsive measures to be implemented as required by the project's acid sulfate soils management plan and environmental monitoring programme.

Information relating to short term dredge operation at Boral's Stockton Sand Quarry referenced by DPE has not been identified by Geosyntec.

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2 Environmental Setting

2.1 Site Identification

The site location is presented in Figure 1, with the site layout plan showing the sampling locations is presented in Figure 2, Appendix A.

Table 2.1: Site identification

Title	Details
Street Address:	8 Oakvale Drive, Salt Ash, NSW 2318
Property Description:	Lot 4 in DP774726
Current Site Ownership:	Holcim (Australia) Pty Ltd
Geographical Coordinates (Centroid): MGA 56 2020	Easting 398500 Northing 6370159
Property Size:	47 hectares
Local Government Area:	Port Stephens Council
Zoning	RU2: Rural Landscape Zoning Port Stephens Local Environmental Plan 2013 (12/05/2013)
Proposed disturbance extent and maximum extraction footprint.	It is noted that the total development disturbance area will cover 35.4 ha. The maximum extraction footprint is approximately 29 ha, as presented on Figure 2 in Appendix B.

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2.2 Surrounding Land Use

Land uses immediately adjoining the Site are described as follows:

Table 2.2: Immediate Site Surrounds

Title	Details
North:	Agricultural used (livestock).
East:	Macka's sand quarry.
South:	Stable forested dunes. Further south is Stockton Bay Beach and Stockton Bight.
West:	Macka's sand quarry.

2.3 Geological and Hydrogeological Setting

The geology, hydrogeology and hydrology are summarised in this section. This information has been sourced from the reports listed in Section 1.5 and readily available public sources.

Table 2.3: Subsurface Conditions (sourced from Hydrominex, 2022)

Item	Details
Regional Geology	The site is underlain by Quaternary (Pleistocene and Recent) age sands, silts and clays known as the Stockton Sandbeds.

Item	Details
	The Stockton Sandbeds consists of extensive barrier sand ridges extending from the Hunter River estuary in the west to Port Stephens in the northeast inland from the present coastline. The Stockton Sandbeds comprises fine to medium grained, well sorted, quartzose beach sand with discontinuous indurated sand. The Sandbeds are highly porous and permeable and store a significant quantity of water.
Acid Sulfate Soils	The Site is mapped as L4: Low probability >3 m below the ground surface on the Acid Sulfate Soils Risk Mapping available on the eSpade V2.2 viewer data source State Government of NSW and NSW Department of Climate Change, Energy, the Environment and Water 1998. The site is mapped as Class 4 under the Port Stephens Local Environment Plan 2013. Class 4 lands require that for *Works more than 2 metres below the natural ground surface* and/or *Works by which the water table is likely to be lowered more than 2 metres below the natural ground surface* development consent must not be granted unless an acid sulfate soils management plan has been prepared for the proposed works in accordance with the Acid Sulfate Soils Manual and has been provided to the consent authority or a preliminary assessment of the proposed works indicates that an acid sulfate soil management plan is not required for the works. All stratigraphic units below the water table have a high risk of containing sulfides and therefore are likely to be ASS. Surface soils (D1) are iron rich and are acidic although they have a low risk of being acid sulfate soils.
Site-specific Geological Conditions	Previous subsurface investigations at the Site have defined three key stratigraphic units: • D1 amber sand unit 3-12m thick above the water table • D2 clay layer (organic podsol) with underlying white sand 5-15m thick which lies below the water table. • D3 coarse white sand with a shell layer, below water table unit.
Soil pH	pH ranges from 5.7-8.7 (average pH 6.85) pH generally increases with depth
Regional Hydrogeology	Hydrominex (2022) described the hydrostratigraphic units as: • Stockton Sandbeds - The dune sands of the outer barrier at the site are well sorted, rounded to sub-rounded, medium-fine to fine grained quartz sands which are generally free from shell, organics, sulfides and other deleterious materials. • Coarser sands are present to the south towards Stockton on the coast and are finer towards Anna Bay in the northeast. • Basal unit is in essence a mix of sands and muds underlain described as Estuarine marine sands and muds. These units are generally recharged by rainwater as all outcrop at the surface.
Site-specific Hydrogeology	Based on the stratigraphy described by Hydrominex (2022) and the results of the current investigation, the hydrostratigraphic units present at the site are described as follows: • D1: unconfined aquifer, vertically defined by the clay layer at the top of unit D2 that acts as a leaky aquitard between D1 and D2, recharged by direct rainfall infiltration. • D2: semi-confined aquifer, separated from unit D1 by the organic podsol clay layer at the top of the unit. Discrete clay lenses may cause local perched/confined aquifer conditions. • D3: variable hydraulic properties due to presence of sands and muds.
Direction of Groundwater Flow:	Groundwater flows generally towards the north-northwest across the site, sympathetic with topography. The coastal dune complex is reported to comprise a groundwater flow divide, with groundwater to the south of the dune ridge flowing south towards the Stockton Bight.
Hydraulic Conductivity and Porosities:	Effective porosity was estimated at approximately 25%, typical of a sand aquifer. Hydraulic conductivity was reported by Hydrominex (2022) to range between 1.5 and 13.3 m/day based on single well pumping tests (with an anomalously higher value of

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Item	Details
	82.6 m/d reported at BH6), higher values correspond to coarse sands in the south of the site
Depth to Groundwater:	Hydrominex (2022) noted that depths to groundwater ranged from 1.37 m to 16.64 m below ground level (mbgl). For comparison, depth to groundwater from Geosyntec's March 2024 monitoring ranged from 1.93 to 11.74 mbgl, with the greatest water levels at BH2D and BH3D, which are at a much higher elevation. The water table is generally understood to be less than 5 mbgl for most of the site.
Beneficial Uses of Aquifer:	Downgradient the aquifer supports various beneficial uses, including: • Stock and domestic users north of the site and north of Tilligerry Creek • Possible agricultural users • Drought relief water supply wells owned by HWC, present in the dune area south of the site (two wells are located west of the stie), a minimum of 680 m or more from the site
Future Realistic Uses of Aquifer:	• Drought relief water supply – potable water resource to the west of the site • Ongoing stock and domestic users north of the site and north of Tilligerry Creek • Ongoing potential agricultural use
Potential Groundwater/Surface Water Receptors:	High priority GDEs are listed to include the following: • SEPP14 Coastal wetlands. • Wetland vegetation. • Swamp-Heath woodland Sensitive nearby groundwater receptors include the following: • The well field area owned by HWC in the Stockton drinking water catchment reserve. • The nearby Worimi National Park and State Conservation Areas • Wells that could potentially be affected by changes in water level
Recharge Sources, Discharge Points, Other Hydraulic Boundaries:	The aquifers are recharged via direct infiltration of rainfall recharge. Groundwater flowing towards the north from the coastal dune complex is regionally inferred to discharge to Tilligerry Creek. Water supply bores to the north of the site would also comprise local groundwater discharge points.

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2.4 Summary of Findings of Soil and Groundwater Assessments

A summary of soil and groundwater investigations completed for the project to date (Geoterra, 2022; Hydrominex, 2022) is provided in Table 2.4, focusing on the details of primary relevance to this report.

Table 2.4: Summary of Previous Reports

Scope	Details relevant to this report
Soils investigation (Geoterra, 2022)	• Three phases of investigation were completed in June 2020, August 2021 and February 2022. - Phase 1 – June 2020. Bores were drilled and logged. Samples were collected for "slab incubation tests". - Phase 2 - August 2021. Composite samples were generated from June 2020 samples - additional characterisation and elutriate testing with local groundwater was performed. - Phase 3 – February 2022. Drilling of 6 holes to a maximum depth of 30 mbgl. Sampling with additional soil characterisation.

	• Typically, soil and sediment samples were assessed for readily available metal content (weak acid digest) and acid generation potential.
	• All soil units assessed contained metals and varying levels of sulfide.
	• Processed soils/sediments and settlement pond water
	  - Sediments within on-site settling ponds are predominantly composed of Al, Mn and trace elements As, Ba, Cr, Pb, Ni and Zn. pH or sulfide content was not reported.
	  - Process pond water is acidic to neutral (pH 5.48 – 7.53), with low salinity (TDS 177-188 mg/L). Metal content of water is dominated by Al, Fe, Mn and Zn.
	• Indicated that the proposed dredging / excavation beneath the water table, without appropriate management, is anticipated to lead to generation of acid with the potential to affect groundwater quality.
	• It is anticipated that the amount of alkaline buffering capacity in the sediments and groundwater, without appropriate management, will not be sufficient to neutralise the amount of acid / metallic leachate that could be generated through pyrite oxidation.

Groundwater quality investigation (Hydrominex, 2022)	Hydrochemistry of the aquifers reflects the soil/sediment descriptions:
	• Shallow sand units are fresh water, major ions dominated by HCO_3, Ca, Na and Cl
	• Basal sand unit D3 hydrochemistry was similar but not the same; major ions in D3 are dominated by Na and Cl with little bicarbonate present.
	• pH of groundwater in all aquifer units is naturally acidic indicating that acid inputs regularly exceed natural aquifer buffering capacity.
	• Groundwater is generally fresh with maximum TDS of around 500 mg/L.
	• Nutrient levels are low, generally nitrate is below 0.1 mg/L, and reactive phosphorus levels are also low (max 0.09 mg/L)
	• Trace element contents are also low except for iron (max 4.74 mg/L)
	• Although elemental content of water is low, exceedances of the nominated guideline values were reported:
	  - EC, pH, Al, As, Cr, Cu, Ni and Zn
	  - Fe levels at the site are some of the highest regionally.
	• Comparison with other local sites demonstrates the effect of evaporation on surface water chemistry with EC increasing to over 1000 µS/cm.
	• Other trace metals in groundwater also display seasonally variable concentrations.

Groundwater quality investigation (Kleinfelder, 2024)	Summary of monthly groundwater monitoring and sampling that occurred between September 2020 and January 2024. Samples were collected at least 1 m below the top of the water column. A summary of the most recent sampling results shows the following ranges (Note: Geosyntec refers to BH1 - BH7 as BH1D - BH7D and MW1 - MW3, MW5 - MW7 as BH1S - BH3S, BH5S - BH7S): • pH: 5.08 (BH3S) to 6.57 (BH1S) • EC (µS/cm): 63 (BH3D) to 584 (BH6D) • Total alkalinity (mg/L as $CaCO_3$): 4 (BH3D) to 252 (BH6D) • Sulfate (mg/L as SO_4): <10 (BH6D, BH1S, BH5S, BH7S) to 29 (BH6S) • Chloride (mg/L): 12 (BH3D) to 65 (BH7D) • Calcium (mg/L): <1 (BH2D - BH5D) to 66 (BH6D) • Magnesium (mg/L): <1 (BH2D) to 17 (BH6D) • Potassium (mg/L): 1 (BH2D & BH3) to 4 (BH6D) • Sodium (mg/L): <1 (BH2D) to 17 (BH6D)
Review of adequacy of current environmental characterisation reports, Holcim Salt Ash Sand Operations (Geosyntec, 2022)	Reviewed the existing hydrogeological and acid sulfate soil (ASS) assessment data and prepared advice regarding data gaps in the current ASS characterisation and concept-level strategies for management of ASS and potential groundwater quality impacts. The key issue noted is the lack of site characterisation data, such as the following: • Baseline redox conditions at the site • Geochemical characterisation of the source material (soil) and waste material (dredge spoil) • Acid-base accounting (ABA) of all aquifer units • Spatial distribution of the sulfur throughout the proposed excavation area Additional data gaps included the following: • Lack of a sampling, analysis, and quality plan (SAQP)

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- Mine plan inclusive of mine method, run of mine stockpile size, product placement and expected timing of carting, or graphic of pipe work for dredge material.
- Expected timing of backfill operations

Based on these data gaps, the following recommendations were proposed:

- Develop a 3D representation of the geology at the proposed mine location.
- A simple source-pathway-receptor model should be developed which succinctly presents the potential linkages to the onsite and offsite receptors in context of the current regulatory framework.
- The following additional site characterisation is recommended:
  - Improve the knowledge of the stratigraphy beneath the site to quantify the volume of fines and product sand.
  - Information on the particle size distribution of the proposed product sand and waste should be provided with current best estimates of volumes of fines likely to be produced.
  - Additional information to quantify the spatial distribution of sulfide using the following methodology:
    - Additional drilling and collection of representative samples of each lithology present across the site.
    - Analysis of a representative number of samples for near total elemental content via four acid digest method followed by inductively coupled plasma mass spectrometry (ICP-MS).
    - Current pH, and pH following oxidation, with determination of the electrical conductivity of the resultant solution.
- Additional geochemical assessment should be designed to address the effectiveness of proposed management option(s), with consideration of the rate of change expected in soil and groundwater chemistry. This approach will inform ongoing monitoring programs. A geochemical program should be completed which aims to quantify:
  - Rate of sulfide oxidation
  - Efficacy of ameliorants (i.e., lime/caustic or crushed concrete)
  - Efficacy of containment

Final Draft Acid Sulfate Soils Characterisation Investigation (Referenced AU122186B R02, Geosyntec 2024)	Detailed characterisation of acid sulfate soils conditions within the site, targeting the extend of the proposed disturbance. Drilling of 24 boreholes within the proposed extraction footprint for soil sample collection, installation of five temporary groundwater monitoring wells in the proposed extraction footprint, and installation of 13 groundwater wells in five clusters up and down gradient of the proposed extraction footprint. Collection of soil samples at 0.25 m intervals, acid sulfate soils field screening and soil and groundwater sample analysis including chromium reducible sulfur analysis, metals and total elemental content and leaching assessment. A summary of the assessment results is presented below: • The soils at the site are characterised as predominantly quartz rich silica sand soils, which were classified into three distinct units based on changes in soil texture, composition and colour: D1, D2 and D3, with an organic clay horizon interpreted as a paleosol between units D1 and D2 (referred to herein as unit D1/D2). In terms of hydrostratigraphy, D1 represents the upper unconfined aquifer, and D2 and D3 are fully saturated, semi-confined aquifers. • Groundwater levels in D1 (representing the water table) were measured between 0.5 and 6.6 m below ground level. Groundwater flow in all units is towards the northwest, consistent with the crest of the dune complex to the south of the site representing a recharge zone and groundwater flow divide, with groundwater to the north of the divide flowing generally northward towards Tilligerry Creek. • The sulfur content of many of the soil samples is sufficient to classify the soils as acid sulfate soils (ASS). ASS is present in all soil units, with the highest sulfide content found in unit D1/D2. ASS is present as potential ASS (PASS) and actual ASS (AASS). AASS, where encountered, is constrained to the soils above the water table or within the zone of water table fluctuation (primarily D1 and the upper portion of D1/D2). PASS, where encountered, occur within fully saturated soils. The spatial distribution of PASS across the site indicates that saturated soils in the centre of the proposed void in unit D3 have a lower net acidity than the soils towards the pit walls. • Various chemical constituents present in the soils are capable of being leached through contact with water, a process that is enhanced under acidic conditions that could be created through oxidation of ASS. • Kinetic column leach testing evaluates time-dependent oxidation of soils containing sulfide and allows for an assessment of leached trace elements generated through the oxidation process and the resultant quality of the water in contact with the oxidised soil. The methodology consists of allowing a volume of water to gravity drain through a column of soil at set time intervals (hence, no mechanical agitation), and measuring the leached concentrations of various constituents over time in response to ASS oxidation. The results

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confirmed that leaching of oxidised ASS (primarily the first flush) produces lower pH and higher dissolved constituent concentrations, which diminished once the sulfide minerals were fully oxidised (units D1 and D2). The higher sulfide content in unit D1/D2 correlated with sustained release of higher leached constituent concentrations, whereas the natural alkalinity present in unit D3 improved the ability of the soils in this unit to buffer acidity produced by oxidised ASS and inhibit the leaching of chemical constituents.

- Kinetic testing demonstrated that ANC identified in Unit D3 is available and acts to buffer acid generated by oxidation of this unit and maintain a neutral pH.
- Kinetic column leachate analysis identified aluminium, arsenic, cadmium, chromium, cobalt, copper, iron, manganese, molybdenum, nickel, vanadium, and zinc as COI, with elevated sulfate and iron concentrations as indicators of ASS oxidation.
- The current groundwater at the site is neutral to acidic (pH values between 5 and 7 are typical), with predominantly low alkalinity (< 100 mg/L). The low alkalinity concentrations indicate that the groundwater system is in quasi-equilibrium with ASS in the aquifer and has limited capacity to buffer additional acid inputs to the site. Although low redox conditions are maintained within the aquifer, sulfate to chloride ratios in groundwater indicate that groundwater has already been affected by the oxidation of ASS. Consequently, careful management of sulfidic soils will be necessary to minimise ASS oxidation and acid generation to the extent practicable, and lime amendment would be necessary to buffer incidental acid generation (and hence limit mobilisation of leachable constituents) to compensate for the limited natural buffering capacity in groundwater, as recommended in the National Acid Sulfate Soils Guidance (2018).
- The principal risk associated with oxidation of ASS and leaching of chemical constituents into groundwater would be the migration of those constituents with the flow of groundwater beyond the site boundary towards downgradient sensitive receptors associated with the local groundwater resource, including water supply bores and groundwater dependent terrestrial and aquatic ecosystems. To mitigate this risk in accordance with the National Acid Sulfate Soils Guidance (2018), an ASS management plan is recommended to specify standard management measures for disturbed soils to reduce the potential for ASS oxidation and to buffer incidental acid generated. A groundwater monitoring and management plan is also recommended to assess the efficacy of the soil management measures with respect to maintaining baseline groundwater quality to the extent practicable, and to specify contingency actions to respond to adverse groundwater quality trends in a timely manner if they occur.

2.5 Detailed Acid Sulfate Soil Characterisation (Geosyntec 2024)

Detailed assessment of the potential for the soils to be classified as ASS was completed using the CRS method of assessment in accordance with relevant guidance (National and Queensland guidance documents as referenced in section 1.4)

The approach adopted assesses the balance of acid to neutralising components this is known as acid base accounting.

The acid component is a sum of the potential (Chromium reducible sulfur, Scr), actual (Titratable Actual Acidity, TAA) and retained acid (Net Acid Soluble Sulfur, S_{NAS}). Net acidity does not include the base component (Acid Neutralisation Capacity, ANC) until assessment of its availability are completed. Corroboration of ANC was limited to Unit D3.

The results of the ASS assessment demonstrated that acid sulfate soils with net acidity in excess of the adopted action criteria were identified in all units encountered at the site:

Measurable sulfide sulfur levels were reported in all units, with sulfide sulfur concentrations exceeding the 0.03% S action level to varying degrees in all units. Not in all samples, but the presence of sulfide sulfur is ubiquitous across the site; there are areas of higher acid generation potential (Scr concentrations) than others.

Statistical analysis of the data demonstrates that unit D1/D2 had the highest average sulfide sulfur content of approximately 0.3 % w/w S as well as the largest range, with the majority of the samples from this unit returning Scr values more than 10 times the action criterion (0.03 %S).

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For D1, D2 and D3 the average Scr levels are lower than for D1/D2, but the median Scr is still above the action criterion for D2 and D3. The median Scr for D1 is 0.01 % S, below the action criterion.

Unit D1/D2 also contained the highest levels of TAA, with D1 also reporting appreciable concentrations. TAA corresponds to approximately one third of the net acidity in D1, whereas in D1/D2, D2 and D3, the majority of the net acidity measured is present as potential acidity from sulfide sulfur. This is attributed to the fluctuations in the water table, which occurs primarily in unit D1, exposing PASS to atmospheric oxygen and converting PASS to AASS.

Retained, slowly released acidity was also reported in the soils, mostly in D1.

Consequently, the soils at the site were assessed as being both potential acid sulfate soil (PASS), and actual acid sulfate soils (AASS).

AASS exist in soils generally above or within the zone of groundwater fluctuation where the ingress of atmospheric oxygen in the unsaturated zone, and oxygen enriched rainfall infiltration, has resulted in sulfide minerals oxidation. This corresponds to D1 and the contact with D1/D2. PASS occurs in fully saturated soils.

The extent of the presence of PASS and AASS within the proposed void was modelled in Leapfrog to provide a visual assessment of the spatial distribution both vertically and horizontally within the proposed void.

The figures present the areas where the net acidity exceeds the 0.03%S criterion. The figures clearly demonstrate that the highest net acidity values are concentrated around the D1/D2 contact, which is lithologically characterised by the presence of an organic clay layer. Exceedances of the action criterion exist in all other units, however the central soils in units D2 and D3 generally present the lowest ASS risk.

Modelled volumes of net acidity in excess of the Action Criterion (0.03% S) are presented in Table 2.5.

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Table 2.5: Estimate of Unit Volumes with Net Acidity in Excess of the Action Criterion

Unit	Net Acidity (%S) W/O ANC		Total
	<0.03 % S w/w	>0.03 % S w/w	m^3
D1	1,357,800	112,100	1,469,900
D1/D2	45,400	345,000	390,400
D2	786,000	1,458,300	2,244,300
D3	1,251,800	1,002,200	2,254,000

2.5.1 Mineralogy and elemental content

Mineralogical and elemental analyses identified quartz as the dominant mineral in all samples (66-95% % w/w), and silica as the major element. Minor contributions (<6% w/w) from other determinants were noted. These were attributed to mineral phases such as silicates, clays (kaolinite), feldspars (potassium feldspar, and sodium plagioclase) mica, sulfates (gypsum) and sulfides (pyrite).

Where silica accounted for a comparatively smaller percentage of the bulk elemental content in unit D1/D2 (66 % w/w), relative proportions of other elements, including sulfur were higher in this unit.

The ASS results indicate that the soils contain acid source from the oxidation of sulfides. However, it is likely there are multiple sources of acid within the soils, not just sulfide oxidation. The presence of organic carbon can lead to the release of organic acids into groundwater. pH_{KCl} below 6.5 indicates the presence of exchangeable acidity in the soils, which may not be solely attributable to the oxidation of sulfides.

Most soils contained low ANC (note that ANC was only measured on soils with a pH_{KCl} above 6.5), which correlates well with total inorganic carbon analysis results and the mineralogical analysis where carbonates were not found in any soil tested. The samples with relatively higher ANC also reported higher total inorganic carbon content.

Sulfides in the soils exist as single crystal pyrite grains typically measuring between 5-20 µm in diameter. These pyrite grains are free and not bound to any other mineral phase. From their size, pyrite will be present in the <75 µm fraction of the material.

The mineralogical analysis demonstrates that quartz is the major mineral present, typically 80-95% of the soil. PSD results indicate that the grain size of this quartz is smaller than what is considered to be sand.

Given that there is potentially a silicate source of acid neutralising potential in the soils, the small particle size of the quartz grains in the soil could be due to their dissolution in groundwater at the site. The grain size would decrease as they gradually dissolve to buffer the pH of surrounding groundwater.

2.5.2 Leachability

Although the soils are currently exposed to acidic to neutral conditions (pH around 5 to 7), they still contain appreciable potential to alter water quality if soils are not adequately managed. Aluminium, arsenic, barium, beryllium, chromium, cobalt, copper, iron, manganese, molybdenum, nickel, lead, strontium, and zinc were found to be present in the soil matrix through aqua regia digest. When exposed to a range of pH, it was determined that of these metals (aluminium, chromium, copper, iron, nickel, lead and zinc) were also leachable at high pH (alkaline conditions). This amphoteric behaviour demonstrates the importance of maintaining circumneutral pH conditions to minimise mobilisation of metals from soils to groundwater.

Kinetic column leachate analysis identified aluminium, arsenic, cadmium, chromium, cobalt, copper, iron, manganese, molybdenum, nickel, vanadium, and zinc as contaminants of interest (COI), with elevated sulfate and iron concentrations as indicators of ASS oxidation. Contaminants of Potential Concern (CoPC), defined as COI of which the concentrations generated by the soil exceed background and or health-based or ecological water quality criteria.

Identified CoPC are aluminium, arsenic, cadmium, chromium, cobalt, copper, iron, manganese, molybdenum, nickel, vanadium, zinc, and sulfate. Based on the analysis, concentrations of the identified CoPC in groundwater are likely to increase if oxidation of acid sulfate soils occurs within the extraction void, or in soils adjacent to the extraction void through the disturbance caused by the dredge processes or increased oxygen mixing within the extraction pond without suitable acid sulfate soils management.

2.6 Hydrogeological Characterisation (Geosyntec 2024)

The conceptual hydrogeological model of the aquifers beneath the site is described as they relate to the potential risk of acid and trace element mobilisation from oxidised ASS. Three hydrostratigraphic units were identified that correspond to the geologically defined units D1, D2 and D3.

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The water table in unit D1 was encountered between 0.5 and 6.6 m below ground level. Hydraulic head values were progressively lower in co-located wells in units D1, D2 and D3, indicating a downward hydraulic gradient that is characteristic of groundwater recharge zones. The Kleinfelder and Geosyntec pressure transducer data from the three aquifer units indicates that water levels are relatively responsive to rainfall events, as would be expected in a permeable sand aquifer.

Groundwater flow in the intermediate aquifer (D2) and the deep aquifer (D3) is towards the northwest. There were insufficient wells screened in unit D1 to characterise flow direction, but it is reasonable to assume that it mimics the flow in the underlying D2 and D3 units.

The major ion chemistry generally identified two distinct water types present at the site: an Na-Cl signature in the shallow aquifer (D1), and a Ca-HCO_3 signature (in D2 and D3).

Comparison of all groundwater results shows that alkalinity levels are typically below 100 mg/L (median values are 72, 26, and 9 mg/L for units D1, D2, and D3, respectively), where present alkalinity exists as bicarbonate alkalinity. Consequently, buffering capacity in groundwater is limited, particularly in units D2 and D3.

From the analysis of sulfate, chloride and alkalinity ratios in groundwater, there is evidence that groundwater has already been affected by the oxidation of sulfides across the site (11 bores in both shallow, intermediate and deep aquifer units displayed increases in sulfate indicating acid input).

Units D1, D2, and D3 represent the shallow, intermediate, and deep aquifer units, respectively. Units D1 and D2 are partially separated by unit D1/D2, which acts as a leaky aquitard. Units D2 and D3 are not physically separated by a lower permeability geological unit and are therefore more accurately described as shallower and deeper portions of a contiguous aquifer, albeit with slightly different hydraulic properties due to differences in soil texture. Topography at the site broadly slopes downward towards the north, and the water table and potentiometric surfaces generally follow topography. During drilling works, saturated conditions were encountered between 0.5 and 6.6 mbgl. Therefore, the water table is understood to generally be within 5 m of the ground surface, and in the areas of the site where dry extraction of sand in accordance with the sites current approval have been completed, the water table was generally closer to 1 mbgl.

The results of the recent pressure transducer collection show that hydraulic head generally follows rainfall patterns, illustrating higher rates of rainfall from April to July, then showing lower rates of rainfall from July to October (i.e. end of the data collection). The trend seen in the shallow and intermediate wells is also followed in the deep wells, with BH126D having more of a dampened response compared to BH128D.

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2.7 Lithostratigraphic Model (Geosyntec 2024)

A three-dimensional model of the subsurface has been prepared using Seequent Leapfrog Geo Version 2023.2.1. The model presents the following geological units, consistent with the hydrostratigraphical units:

- Unit D1: fine to medium amber to grey sand.
- Unit D1/D2: low to medium plasticity dark grey clay and low to medium plasticity, dark grey sandy clay with shell fragments, and fine to medium dark grey clayey sand.
- Unit D2: fine to medium grey sand and medium grained, grey to dark grey sand with trace of fine gravel.
- Unit D3: fine grained, dark grey, silty sand with trace gravel and fine to medium grained, grey sand.

The model confirmed the persistence of the four units across the proposed extraction footprint, with generally horizontal/gently sloped interfaces between the layers, consistent with previous

investigations, with the exception of the clay layer (Unit D1/D2) which was not identified as persistent in all locations in previous investigations.

A selected indicative lithostratigraphic cross section is presented as Figure 2.1.

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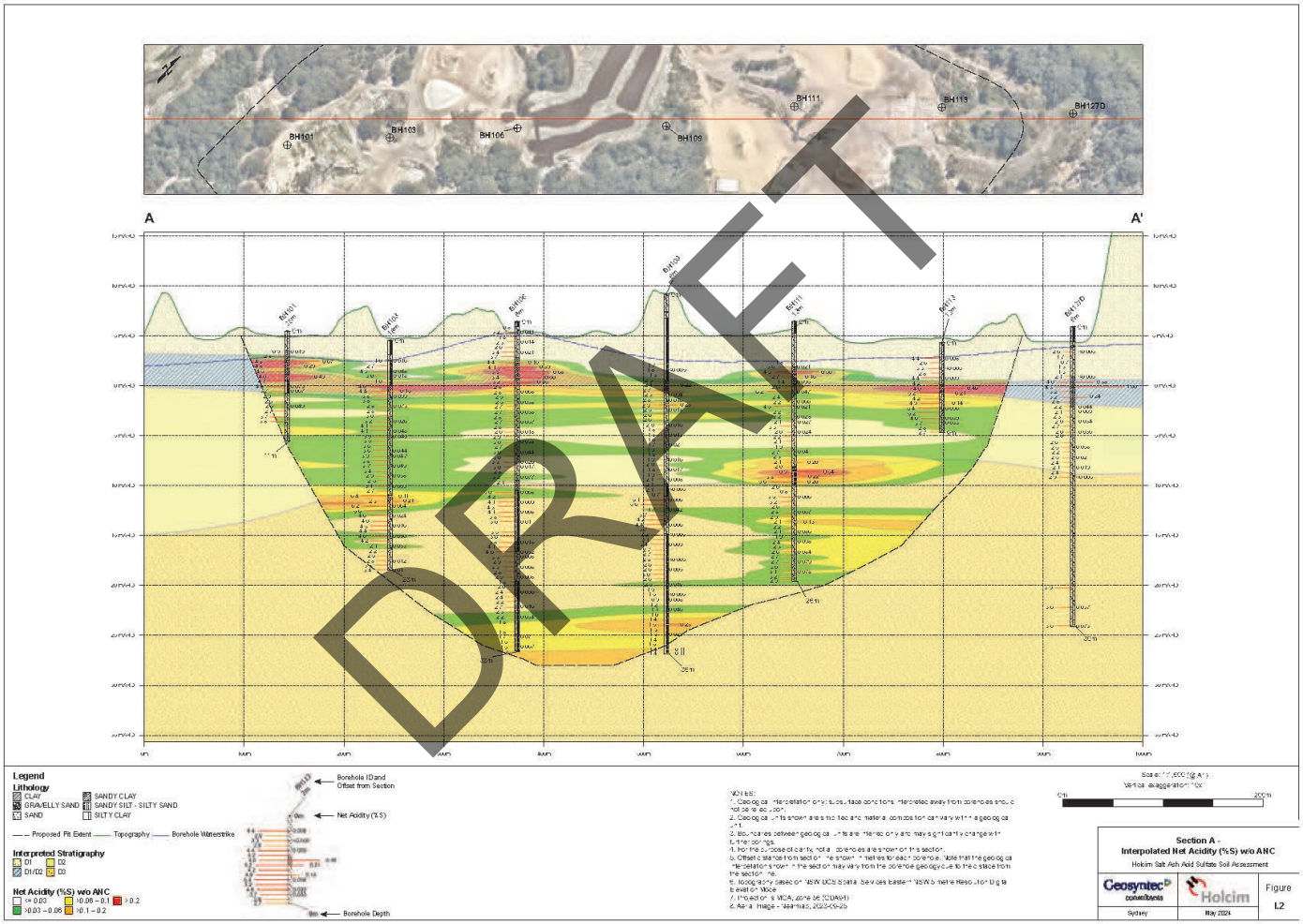

Figure 2.1: Indicative lithostratigraphic cross section

3 Conceptual Site Model of Dredge Pond Geochemical Processes

3.1 Sources

From the data collected in this investigation all units contain ASS with the potential to release acidity and dissolved metals and metalloids if they are disturbed. There are multiple sources of acidity in the soils:

- Mineral acidity – sulfides
- Exchangeable acidity – metal hydroxide hydrolysis and clay surface ion exchange
- Organic acidity

Both potential acidity in the form of sulfides, actual acidity and retained acidity in the form of exchangeable metals formed from the historical oxidation of sulfides have been reported. The naturally acidic baseline groundwater pH demonstrates that the in-situ soils have limited ability to neutralise current levels of acid input, and the results of the ASS investigation demonstrate the soils have the potential to release acid into the environment upon further oxidation.

The acidity in groundwater at present may be due to the presence of iron in solution. These iron levels may be due to offsite or historical sulfide oxidation; the latter also generates acidity directly. Buffering of groundwater by silicates (the quartz sand grains) may be occurring, thus measurement of total alkalinity did not show any appreciable change as carbonate buffering is not the primary mechanism.

3.1.1 Release Mechanisms

There are multiple mechanisms which could cause the release of metals and metalloids to groundwater, including:

- Oxidation
- Ion exchange
- Hydrolysis
- Mineral dissolution – of silicates, sulfates, oxides and hydroxides

In the context of a dredge pond, there are operational activities with the potential to enhance these release mechanisms resulting in generation of acid and salinity (through mobilisation of trace elements from solid to dissolved phase).

The primary activities with the potential to impact groundwater include the handling of dredged materials above water, the return of the waste stream to the pond, and the enhanced introduction of oxygen to the pond water that can interact with ASS in the immediately surrounding formation.

Dredge and materials handling processes with the potential to oxidise ASS include:

1. Material handling and management of fine fraction from sand separation
    a. Direct discharge of fine slurry
    b. Discharge of water only following solids separation (settling ponds etc)
2. Return of drainage water from wet sand piles
3. In pond processes
    a. Atmospheric oxygen mixing (particularly near pond surface)/temperature stratification/diffusion

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   b. Contact of dissolved oxygen (DO) with pit bottom, walls and suspended fines from dredge/sloughing and returned fines.

4. Dredge processes
   a. Mechanical mixing by dredge cutting head
   b. Sloughing of pond walls
   c. Direct slurry discharge
5. Migration of oxygenated pond water and contact with downgradient aquifer

3.2 Pathways

The primary transport mechanism for acidity, salinity and/or mobilised trace elements in the dredge pond water is transport into the surrounding aquifer and migration with groundwater flow. From review of the available site data, groundwater in aquifers beneath the site generally flows to the north-northwest. This is consistent with historical regional groundwater studies, which indicate that a groundwater mound exists beneath the Stockton Sand Dunes, with a north-south flow divide present along the crest of dunes. Accordingly, the pathway of primary interest is associated with the flow of groundwater towards the northwest of the site.

3.3 Receptors

The groundwater resource in the vicinity of the site is part of the Stockton Groundwater Source that is managed under the *Water Sharing Plan for the Tomago Tomaree Stockton Groundwater Sources 2003*. The groundwater resource has limited development for private water supply and has an inactive borefield in place to support Hunter Water Corporation's (HWC's) emergency municipal water supply for extreme drought conditions and supports local groundwater dependent ecosystems.

Sensitive groundwater receptors near the site include:

- The drinking water supply borefield owned by HWC (located to the south of the site, on the opposite side of the groundwater flow divide). It is understood that this borefield is not currently instrumented with pumps and has never been used for water supply extraction, but HWC does reserve the right to activate the borefield for water supply security if needed. It is understood that this borefield, as with HWC's other borefields in the region, would only be activated for emergency water supply in extreme drought conditions, and does not otherwise contribute to the standard HWC water supply scheme. In addition to their network of emergency water supply borefields, HWC is considering other emergency water supply security strategies including development of a desalination plant.
- Terrestrial GDE's of the Worimi National Park and State Conservation Area.
- Private water supply bores accessing groundwater down hydraulic gradient from the site (primarily for irrigation and livestock watering).
- The aquatic ecosystem of Tilligerry Creek, which is a gaining creek and a receptor for regional groundwater discharge originating from both north and south of the creek. .

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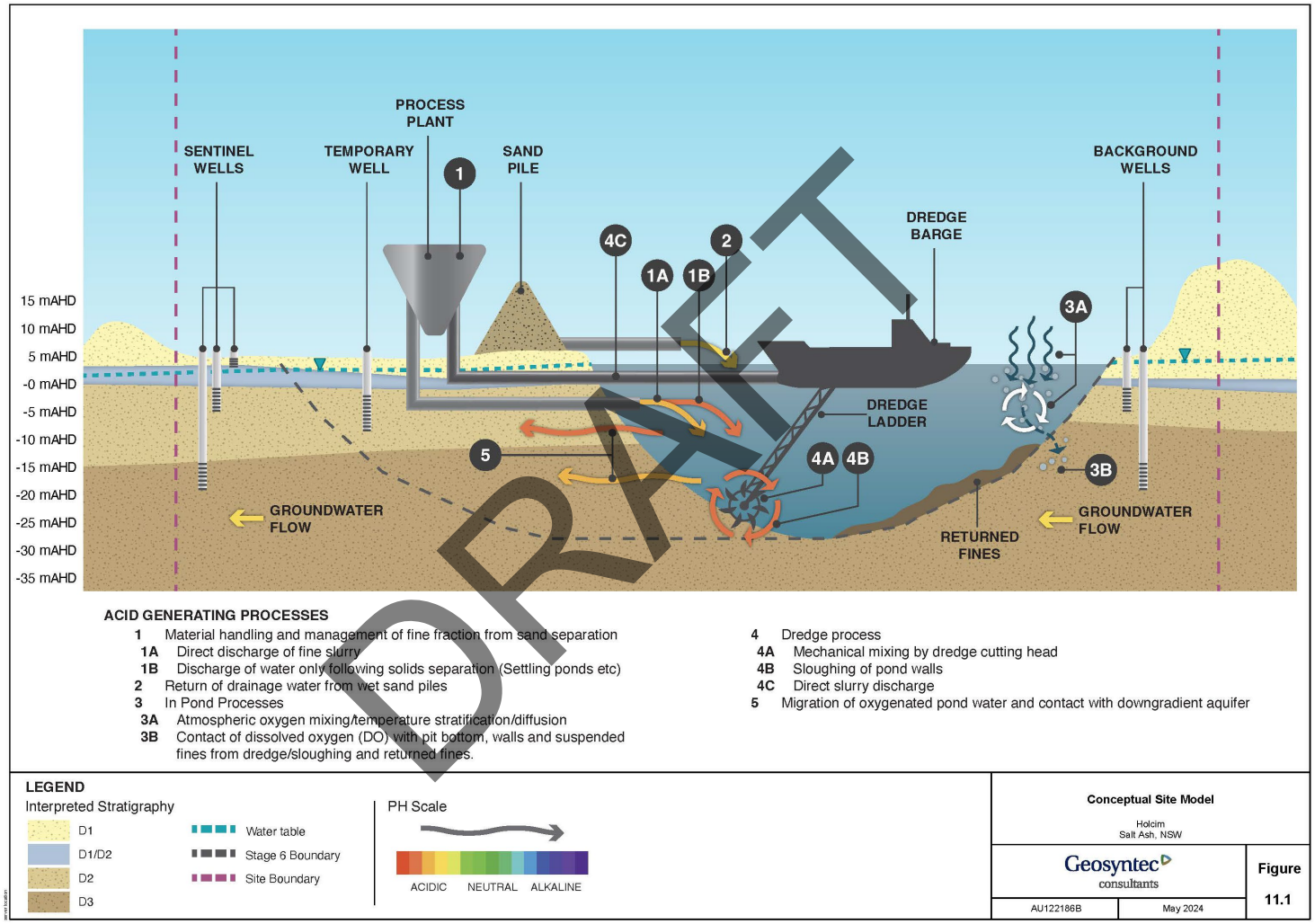

Figure 3.1: Conceptual Site Model

4 Potential Environmental Management Measures

Based on the CSM described in Section 3, various environmental management measures were evaluated to address potential sources of water quality impacts, including: (i) sand processing, (ii) chemical processes in the dredge pond; and (iii) processes in the downgradient aquifer. The proposed management measures are summarised as follows:

- Hydraulic separation of sulfidic fines and neutralisation of returned fines and process water:
  - Separation of sulfidic fines from sand product
  - Prevention of cumulative acidification of the dredge pond
  - Stabilisation of fines and prevention of secondary releases of CoPCs in the dredge pond
- In-pond treatment:
  - Direct management of low pH and CoPCs in the downgradient section of the dredge pond to prevent migration of CoPCs to the downgradient aquifer
- Capture and/or treatment of residual CoPCs in water migrating from the dredge pond to downgradient aquifer:
  - A groundwater interception scheme to prevent offsite migration of groundwater impacted by ASS oxidation
  - Creation of a reactive zone emplaced on the downgradient (northern) dredge pond wall

The management measures associated with the sand processing operations are based on best practice guidance in the national acid sulfate soil guidelines and the most recent state-based guidelines and are widely applicable to activities that involve disturbance of ASS. Management measures to address in-pond water quality, and for management of groundwater quality downgradient from the dredge pond, are contingencies in the event that some degree of ASS oxidation occurs either during interment of the fines waste stream in the dredge pond or as a result of oxidation processes in the formation immediately surrounding the dredge pond. Whilst these are considered contingency options, given the scale of the proposed dredging operations and the volume of ASS that will be disturbed, it is not unreasonable to assume that one or more contingencies will need to be implemented during the course of the operations.

The evaluated management measures all have benefits and limitations, and the optimal environmental outcome will likely require a combination of management measures to limit the potential for off-site migration of impacted groundwater and prevent unacceptable impacts to downgradient receptors. The following sections present conceptual environmental control measures that were evaluated for water quality management during facility operations and after closure.

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5 Management of Sulfidic Fines during Sand Processing

Environmental management options that can be incorporated into the sand extraction and separation process flow include the physical separation of sulfidic fines and process water from the target sand product using hydrocyclone techniques, and management of the reject fines and process water to minimise the potential for sulfide oxidation and buffer incidental acid generation to maintain baseline water geochemical conditions. These techniques are described in detail in the following sections.

5.1 Hydraulic Separation of Sulfidic Fines

Hydraulic separation using a hydrocyclone, as proposed by Holcim, is identified in the Queensland Acid Sulfate Soil Technical Manual (Dear et al, 2024) as an established method for managing the sulfidic fines component of acid sulfate soils, where combined with neutralisation of the fine fraction and sand product, as required, and/or strategic reburial of fine fractions.

The technique generally consists of directing the extracted slurry from the sand dredge (the “feed”) within a closed pipework system to one or more hydrocyclones, depending on the grading requirements of the sand product. The centrifugal forces within the hydrocyclone direct larger particles to the outside wall of the hydrocyclone and are discharged from a spigot at the bottom of the hydrocyclone (the “target flow”), while finer particles move towards the centre of the hydrocyclone and discharge through the top of the hydrocyclone (the “reject flow”). Given the strong association of sulfide minerals with the fine fractions, as identified during the detailed ASS characterisation program, an optimised hydrocyclone operation should effectively separate the sulfidic fines from the sand product. The separated reject flow will then require management to minimise exposure to atmospheric oxygen (to minimise acid generation and mobilisation of trace elements) and to buffer incidental acid via lime amendment as necessary to maintain the baseline groundwater geochemical conditions at the site.

The following operational and environmental considerations must be taken into account during hydraulic separation operations to optimise the environmental performance of the technique:

- Hydraulic separation is best suited to deposits with low organic matter and less than 10-20% clay and silt. Deposits with >20% of clay and silt are not well suited to hydraulic separation techniques as the materials do not easily separate.
- Hydraulic separation is not a perfect separation method and requires both continual management of the process and verification testing of the target flow product. A hydrocyclone process flow that is not optimised through continual management can result in coarse particles being entrained in the reject flow, and entrainment of fine-grained sulfidic particles with the target-flow product.
- The reject flow consisting of sulfidic fines or ‘slimes’ generated by the separation process requires specialised management. The separation process will result in concentration of sulfidic fines within the waste stream with a high acid generating potential, and care must be taken to:
  - minimise the duration of exposure of the waste stream to atmospheric oxygen – preferably maintaining this waste stream within a closed-loop system from the point of dredge extraction to subaqueous internment back into the dredge pond.
  - neutralise incidental acidity generated during the process, prior to subaqueous discharge into the dredge pond, to maintain baseline water quality to the extent practicable and minimise the potential for mobilisation of trace elements. The limited baseline alkalinity in

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groundwater beneath the site indicates that the system will have a very limited capacity to neutralise additional acidity generated through oxidation of sulfide minerals.

- Rigorous site management with respect to the separated product is necessary as even a continually optimised hydraulic separation process will not separate 100% of the sulfidic fines from the target flow. Hydrocycloned sand may still contain acid generating sulfidic fines, especially if they occur as mineral coatings on sand grains. The separated product and any associated drainage from sand stockpiles must be continually monitored for acid generating potential. Environmental management measures for the sand stockpiles may include guard layers (a neutralising agent spread on the soil surface prior to sand placement to buffer incidental acid generation), drainage water containment and pH control, in-line dosing of the product stream and neutralising procedures to reduce long term risk.
- Incidental exposure of sulfides to oxygen can occur during the process including extraction, delivery of the sediments to the separation process stream, during each step of the separation procedure itself, and following the separation procedure. Environmental performance will be enhanced if the process occurs within a closed loop system within the shortest possible timeframe between slurry extraction and the return of the reject flow via subaqueous discharge to the dredge pond.
- Hydrocycloning generally uses a closed water circuit, which may become progressively enriched with non-settling fines. These fines may impede the separation process and increase the exposure of sulfidic fines to oxygen. Eventually this dirty water will need separate treatment or replacement. Such process waters may become acidic, and if so, will require neutralisation.
- It can be difficult to accurately predict the volume of sulfidic fines from any proposed large hydraulic separation project if the in-situ materials are heterogeneous. The fines volume will increase due to a 'bulking by water' effect as fines are separated from the coarser (ideally largely sulfide-free) fraction. These fines are poorly draining and will take significant time (i.e. years) for large volumes in their final location to dewater and compress. The uncompacted wet volume of fines must be considered (not the final compacted volume) when calculating the void volume required for the reinternment of the sulfidic fines.
- If strategic reburial by returning the fines to the dredge pond is adopted for the sulfidic fines, the returned fines must be managed to minimise further exposure to oxygen through turbulent flows or spraying which increases the dissolved oxygen within the suspension water and dredge pond. This is likely to have been a primary factor contributing to the water quality impacts reported in conjunction with the RZM mineral sands operations, which referral agencies have repeatedly referenced as the "bad example" of environmental management of sand mining operations.
- Dissolved oxygen can sometimes be high enough to cause significant oxidation of the reburied submerged sulfidic fines. Risks may increase when the oxygen transport mechanism is not limited to diffusion. Moving water can transport oxygen much faster than diffusion, and if the sediments are also resuspended, oxidation reactions may occur more rapidly due to the significant increase in surface area available for the reactions. Both oxygen concentration and oxygen transport mechanisms should be considered. In non-flowing water bodies vertical mixing in the water body may provide sufficient oxygen transport.
- Verification testing is required to confirm that the non-fines fraction contains net acidity below the Action Criteria presented in the National Acid Sulfate Soils Guidelines (Sullivan et al 2018) and confirm that sulfidic fines have been appropriately managed.

5.2 Neutralisation of Returned Fines and Process Water

The ambient groundwater flow rate (approximately 23 m/yr) at the site is relatively low. As a result, it is estimated that for the Stage 4 facility the residence time in the dredge pond would be

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approximately 20 years. For the Stage 7 facility the residence time in the dredge pond is estimated at approximately 40 years. Due to those long residence times, sand dredging and related sand material processing, including return of separated fines and process water, are expected to cumulatively lower the pH of the pond water if neutralisation of returned water and fines is not performed.

Based on the proposed handling of dredged sand slurry and returned materials, Geosyntec has performed an initial evaluation of production processes that are expected to influence acid generation in the returned fines and process water and hence effect water quality in the dredge pond.

5.2.1 Guiding Principles for Dredged Fines Management

To minimise the potential for oxidation of sulfides present in the fines, management options need to consider the following:

- Sulfides release acidity upon oxidation in an aqueous environment.
- Oxidation does not require contact with air, it can occur under water, albeit more slowly.
- The process of oxidation alters the chemistry of the sulfides from an insoluble mineral to a soluble sulfate mineral.
- The release of acidity may cause the other minerals in the fines to dissolve.
- Minerals dissolving results in the release of bound metals and metalloids into solution.
- These releases may result in lowering of the pH of water in contact with the fines and an increase in salinity.
- This salinity may contain elements at concentrations which pose a risk to receptors (human, terrestrial, and aquatic).
- Management options for the fines should strive to minimise:
  - The disturbance area
  - Changes in pH
  - Contact with oxidants (oxygen, nitrate, etc)
  - Pore space within the fines
  - Transport of dissolved solutes from the fines to the surrounding environment

The national ASS guidance recommends several management measures, noting that the adoption of any of these options must not pose an unacceptable risk to the environment. Guidance from Simpson et al (2018) *Guidelines for the dredging of acid sulfate soil sediments and associated dredge spoil management* is summarised below.

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Overarching management principle

Work should be performed in accordance with best practice environmental management to ensure that the potential short- and long-term environmental impacts are minimised.

1. The material being disturbed (including the in-situ ASS) and any potentially contaminated waters associated with ASS disturbance, must be considered when developing a management plan for ASS and/or in complying with the general environmental duty.

2. Receiving marine, estuarine, brackish or fresh waters are not to be used as a primary means of diluting and/or neutralising ASS or associated contaminated waters.

3. Management of disturbed ASS is to occur if the ASS action criteria is reached or exceeded.

4. Stockpiling of untreated ASS above the permanent groundwater table with (or without) containment is not an acceptable long-term management strategy. For example, soils that are to be stockpiled, disposed of, used as fill, placed as temporary or permanent cover on land or in waterways, sold or exported off the treatment site or used in earth bunds, that exceed the ASS action criteria listed in Table 1 should be treated/managed.

5. The following issues should be considered when formulating ASS environmental management strategies:

- the sensitivity and environmental values of the receiving environment. This includes the conservation, protected or other relevant status of the receiving environment (for example Fish Habitat Area, Marine Park, Coastal Management District and protected wildlife)
- whether groundwaters and/or surface waters are likely to be directly or indirectly affected
- the heterogeneity, geochemical and textural properties of soils on-site
- the management and planning strategies of local government and/or state government, including regional or catchment management plans/strategies and state and regional coastal management plans.

Note: excised from Simpson et al., 2018.

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5.2.2 Production Fines Handling

It is our understanding that settling ponds are not proposed to separate fines. In the proposed dredge operation for extraction of the sand resource below the water table, the fines will be separated via hydrocyclone (closed method, not open to the atmosphere), and the separated fines (identified by Holcim to be the <75µm fraction) will be directly returned to the dredge pond as a water slurry for subaqueous discharge.

Analysis of samples recovered in the detailed acid sulfate soils characterisation identified that around 90% of the soils analysed had detectable inorganic sulfide concentrations, likely in the form of pyrite. Limited analysis using scanning electron microscopy identified that these crystals are likely to be between 5 -20 µm in size and are therefore likely to be separated with the <75µm fine fraction retained by the hydrocyclone, proposed to be returned to the dredge pond .

5.2.2.1 Minimizing exposure to atmosphere of dredged sand slurry during separation and fines return

Based on information provided by Holcim, the process train including sand dredging, transport of sand slurry to the separators, and return of the reject flow and process water is anticipated to take approximately 2 to 3 minutes. Although acid generation kinetics for the fines slurry under such conditions have not been evaluated, it is anticipated that the decrease in pH may be relatively small

given the expected limited exposure to atmosphere. In addition, the sand and separated fines will be contained in a water suspension which would further limit the initiation of and rate of oxidation reactions. Finally, the returned fine slurry will be pumped at a depth of at least 5 m below the DP surface to limit contact with the surface water layer containing the highest concentration of dissolved oxygen (DO).

Previous ASS testing performed by GeoTerra (2022) indicated that after 2.5 hrs of exposure (i.e., the shortest time interval tested), the effect on pH was relatively minor. However, this was static testing on a bulk sand material exposed to the atmosphere, and therefore was more representative of how the aquifer would respond to exposure to atmospheric oxygen rather than how the fines would behave. A review of literature indicates that the sulfide related acidification process in mine tailings is relatively slow (i.e., a scale of 10s or 100s of days), similar to the results of long-term testing performed by GeoTerra, but again this is based on static tests and of materials typically containing flocculant and other construction chemicals designed to improve particle binding and settling. The effects of these chemicals on reactivity of the sulfides such as passivation is not considered in the static testing.

To refine the understanding of potential acid generation during the extraction-separation-fines return process, analysis of a simulated waste stream would be required to confirm if/how much acidity is generated in the separated fines slurry within the timeframe for this process indicated by Holcim (i.e., 2-3 minutes). These results would inform the need for additional ASS management measures such as liming of the fines, as described below.

5.2.2.2 Additional ASS Management Measures for Fines

ASS characterisation at the site has shown that the subsurface sand deposits exhibit variable acid generating capacity, which is highest in discrete units containing sulfide solids and organic carbon. It is expected that the dredging process will extract sand materials from various depths that would generally have a moderate to high capacity for acid generation. Even though the sand and fines handling process time will minimise the acid generation, as described above, it is likely that fine material neutralisation using liming before return to the dredge pond will be required.

A detailed fines-related ASS management plan, including the use of liming, will be required once results of testing simulating the extraction-separation-and fine return process is completed. A cost-benefit analysis should also be performed to determine if lime dosing directly into the returned fines stream may lengthen the fines exposure to atmosphere and decrease the pH by itself. In such cases, direct in-pond application of lime in the location of fine deposition may be preferred (refer to Section 6).

A range of calculated liming rates (Aglime) based on Net Acidity (excluding Acid Neutralising Capacity (ANC)) using the 25th, 50th, 75th, 90th, 95th and 100th percentile Net Acidity is presented in Table 5.1. The calculated liming rates presented are based on whole sand samples, not specifically the fine fraction. The lime required to manage the waste stream once the sand fraction of interest is removed and the sulfidic fines are concentrated will likely be higher than the values presented; however, as it will be a smaller volume, the total lime required may be similar. Thus, the table below is considered relevant to indicate the total tonnage of lime required for management purposes based on currently available analytical data but should be refined based on testing to simulate the extraction-separation-fine return process.

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Table 5.1: Calculated Liming Rates for Each Unit

Unit	Percentile	Net Acidity (without ANC) %S w/w	Net Acidity (without ANC) mol H+/tonne	kg CaCO3/ tonne	Liming rate (Aglime) kg/tonne
D1	25	0.009	5.6	0.3	0.4
D1/D2	25	0.094	58.3	2.9	4.6
D2	25	0.026	16.2	0.8	1.3
D3[1]	25	0.019	10.0	0.5	0.8
D1	50	0.016	9.4	0.5	0.7
D1/D2	50	0.245	152.8	7.6	12.1
D2	50	0.036	22.5	1.1	1.8
D3[1]	50	0.029	18.1	0.9	1.4
D1	75	0.024	15.0	0.7	1.2
D1/D2	75	0.498	310.3	15.5	24.5
D2	75	0.056	34.9	1.7	2.8
D3[1]	75	0.052	32.4	1.6	2.6
D1	90	0.043	26.8	1.6	2.1
D1/D2	90	0.700	436.61	21.9	34.5
D2	90	0.083	51.9	2.6	4.1
D3[1]	90	0.082	51.1	2.6	4.0
D1	95	0.160	98.5	4.9	7.8
D1/D2	95	1.00	623.7	31.2	49.3
D2	95	0.124	77.6	3.9	6.1
D3[1]	95	0.123	76.7	3.8	6.1
D1	100	0.730	455.3	22.8	36.0
D1/D2	100	1.20	748.4	37.5	59.1
D2	100	0.420	262.0	13.1	20.7
D3[1]	100	0.330	336.8	10.3	16.3

Note 1: Net acidity in D3 includes ANC, as this unit contains corroborated buffering capacity.

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An alternative to lime amendment of the returned fines slurry would be cement stabilisation of the fines, in the form of a thickened paste. Paste technology has been increasingly applied over the past 20 years for management of sulfidic tailings in the metals mining industry, as amendment of the thickened paste with Portland cement (a common paste amendment) has been shown to be

very effective in reducing metals mobility, and acid generation in the tailings can be markedly reduced by mixing with alkaline materials (Verburg, 2001; Mudd, 2011). Management of the fines as a cement stabilised paste would have the additional benefit of encapsulating the sulfidic fines in a cement matrix, which would significantly reduce the surface area available for exposure to oxygen, especially where the paste is disposed underwater (at the base of the pond). The applicability of paste technology would require bench-scale laboratory testing to assess optimal cement amendment to mitigate acid generation and metals leaching, including appropriate cement chemistry to ensure the long-term stability of the emplaced cement-stabilised paste. In application, this technology would require a cement batching plant as part of the fines management process, the footprint of which may preclude access to the sand resource beneath the batching plant. The effect of the cement-fines paste on dredge extraction efficiency should also be considered.

5.2.2.3 Early Fines Management

Management of fine fraction produced early in the project, prior to development of a sufficient pond void volume to accommodate the discharge of returned fines greater than 5 m below the permanent water table will require an alternative management approach. Dependent on the extraction method adopted, noting that dry extraction methods are proposed until such time as a dredge can be established, the early fines are likely to be derived predominantly from unit D1/D2, with a lesser contribution from units D1 and D2.

Alternative methods for managing the early reject flow material include:

- Subaqueous storage of fines in temporary settling ponds, the volume of which would need to be calculated based on the expected fine fraction (reject flow) derived from the total dredge volume required to create adequate void capacity in the main dredge pond to accommodate direct subaqueous discharge of the reject flow. If the current onsite pond doesn't have sufficient capacity, then construction of additional temporary ponds would be required. Additionally, this material may require lime amendment if it is stored at shallower depths within temporary storage ponds than the target discharge depth (>5m) in the dredge pond, as it may have greater exposure to diffusion of atmospheric oxygen.
- Cement stabilisation of the fines and storage in geofabic sediment dewatering bag (geobags, Solmax Geotubes or similar), with the stabilised fines returned to the dredge pond once sufficient capacity is available. This option would require a storage area for the geobags to be established, again based on the calculated volume of fines generated before sufficient pond void volume is available to directly return the reject flow to the pond via subaqueous discharge. While material stored on the ground surface is more susceptible to atmospheric oxygen exposure, cement stabilisation of this material would provide buffering capacity to manage the potential generation of acidic leachate and would reduce the permeability of the material to ingress of oxygen. The storage location would require similar environmental controls to the surface storage of product sand, such as establishment of a guard layer on the ground surface, and collection and pH adjustment of drainage water as necessary.

5.2.3 Management of Processed Sand Fraction

As previously noted, hydraulic separation is unlikely to successfully remove 100% of the fine fraction. Typically, up to 10% entrained fines with the washed sand can be expected, dependant on a range of factors such as efficiency of separation, material composition and consistency, and management decisions/design of the Hydrocyclone (Dear et al 2024). As a result, the washed sand fraction requires verification and assessment, and management.

5.2.3.1 Guard layers

A guard layer of neutralising agent should be established on the site surface prior to the placement of separated washed sand. The guard layer can be constructed of compacted crushed limestone or

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washed sand mixed with a neutralising agent. As a rule of thumb, 5 kg fine aglime/m^2/ vertical metre of washed sand should be used a guard layer.

The intention of the guard layer is to intercept and mitigate potential migration of generated acidity vertically and should not be utilised as leachate treatment. A leachate collection and conveyancing system should be implemented to manage leachate generated by the washed sand piles. Leachate should be routinely tested for pH and other contaminants of concern, and if necessary, treated by neutralisation prior to discharge, typically to the dredge pond.

As an alternative to a guard layer a low permeability layer combined with a leachate collection and conveyancing system can be implemented.

5.2.3.2 Verification Testing

Verification testing of the processed washed sand is required to demonstrate the efficacy of the hydraulic separation and sufficient removal of sulfidic fines. A verification testing plan should be developed which determines required testing frequencies and performance criteria.

Dear et al. (2024) suggest the following performance criteria:

To account for the fact that there may be some residual level in the washed sand, the performance criteria are:

- *No sample shall exceed 25 mol H+ /t (0.04 %S).*
- *If any single sample exceeds 18 mol H+ /t (0.03%), then the average of any 6 consecutive samples (including the exceeding sample) shall have an average not exceeding 18 mol H+/t (0.03 %S).*

Where processed washed sand does not meet the performance criteria the material will require neutralisation or reprocessing (provided Actual or Retained Acidity can be neutralised).

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6 In-Pond Treatment

This management option consists of dredge pond water in the downgradient section of the pond being periodically surface amended to treat the process resulting in acid generation and release of trace elements before the water enters the downgradient aquifer.

6.1 Applicable Amendments

Previous application of direct remedial approach at AMD sites included addition of various powdered solids or liquid amendments to induce chemical or biological processes needed to address the COCs, including:

- Fine-grained adsorbents or pH buffers (e.g., powdered lime, micro- zero valent iron (ZVI), red mud), which are expected to adsorb metals and increase the pH, as particles settle and dissolve through the water column.
- Soluble chemicals (e.g., soluble carbon sources, caustic solutions, sulfide or iron salts) to induce reduction of sulfate, precipitation of mineral solids containing metals, followed by settling in the water column. The remediation processes would rely on natural mixing, driven diffusion, density, temperature and mixing due to DP circulation.

Based on our experience, listed below are several different amendment materials that could be applied directly to the dredge pond, along with their expected efficacy in treating the site COCs (**Table 6.1**).

Table 6.1: Preliminary list of in-pond treatment materials applicable to site COCs

COCs	Lime/ Alkali material	Soluble Carbon Source	Sulfide Salts	Iron Salts	Zero-Valent Iron	Red Mud
pH (acidity)	Y	--	--	--	--	--
Sulfate	P	Y	--	--	--	--
Iron	Y	P	Y	--	--	Y
Aluminium	Y	P	P	--	--	Y
Metals and metalloids	Y	Y	Y	Y	Y	Y

COCs – constituents of concern
Y = treatable; P = potentially treatable; -- = not applicable

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The listed remediation methods rely on physicochemical and biological processes that result in immobilisation and/or degradation of the CoPCs, including adsorption, reduction and chemical precipitation. This section provides a detailed analysis of two treatment options that provide treatment of most site CoPCs, as they relate to the anticipated conditions at the site: (i) use of liming; and (ii) addition of a carbon substrate.

6.1.1 Lime/Alkali Addition

Chemicals such as hydrated lime ($Ca(OH)_2$), limestone ($CaCO_3$), pebble quick lime, soda ash briquettes, caustic soda, ammonia, magnesium hydroxide, and fly ash are widely used for acid neutralisation and treatment of various metals in AMD (Saha and Sinha, 2018; Rottling et al.,

2006). Liming is the most common method of in-pit treatment of mine pit lakes and is mainly applied for pH neutralisation and dissolved metal treatment in acidic lakes (Gammons et al, 2009). Lime treatment involves modifying the pH, typically of water impacted by AMD resulting in generation of insoluble metal precipitates. By controlling the pH of the water, metals sensitive to pH conditions, including aluminium, iron and divalent heavy metals such as zinc and copper which were shown to leach from site soils in low pH conditions are readily precipitated as oxides or hydroxides. Caustic treatment typically via sodium or potassium hydroxide addition utilises a similar removal mechanisms as liming (McCullough, 2008), or in cases where lime solubility is low (Croall et al., 2017). However, caustic treatment can result in significantly larger quantities of precipitates that may not settle readily and may actually hinder the treatment process and therefore may not be preferable for this application.

Liming can be performed directly by placing the lime into the impacted water body, or indirectly through introduction into treated/recycled off-take water (Arnold, 1991). However, lime chips have been shown to offer little alkalinity to the affected water, as it rapidly becomes armoured with calcite, iron and aluminium (McCullough, 2008). The passivation of the added material may require frequent replenishment of the media, if lime treatment is used. Based on our experience, lime slurry or dry lime mixed directly into water should be used in direct lime applications for effective use of the material.

Limestone ($CaCO_3$) addition is a physicochemical treatment method that can be potentially applied for removal of sulfate from mine pit lake waters. The treatment process involves binding of sulfate ions to calcium ions on the surface of the limestone matrix (Silva et al., 2012). There are several case studies involving the use of limestone to treat mine-impacted water.

Remediation of mine waters containing 1,200-2,000 mg/L of sulfate using limestone addition has been shown to be ineffective. Silva et al. researched limestone as an alternate sorbent for sulfate treatment of said waters (Silva et al., 2012). Their experiments were conducted on three different mine waters with initial pH ranging from 6.5 to 7.9 resulting in a post-treatment pH range of 8.1 to 8.2. The preliminary batch experiments were performed in stirred tanks, with the objective of defining the required mass of powdered limestone for effective sulfate removal. Their findings indicated that using 25 grams per litre (g/L) of powdered limestone (particle size <0.045 mm) decreased sulfate concentrations from 1,100 mg/L to 597 mg/L within 300 minutes at a pH of 7.9. However, additional dosages were not tested to evaluate the effect of dosage on removal efficiency.

There are some inherent challenges associated with adding limestone as a solid substrate. This method requires a dependable and consistent source of limestone, which may not be easily available and/or economically viable for this application. While limestone could be added as a bed into the dredge pond, the effects of limestone addition are short lived, requiring routine dosing; therefore, this method often fails to deliver long-term results if used alone (Lu, 2004). For this application, hydrated lime (Aglime) has been selected as the pH neutralising amendment, which is also the most likely amendment for use during sand processing operations.

6.1.2 Biological Treatment

Biological treatment of site CoPCs would be achieved by stimulation of anaerobic microorganisms to reduce sulfate and causing an ensuing removal of dissolved heavy metals via precipitation as metal sulfides. This technology utilises either naturally occurring microorganisms or laboratory enriched cultures that are capable of sulfate reduction, particularly in anoxic conditions, and the successful treatment depends on providing and controlling such conditions within the pond.

Several types of carbon substrates have been tested and applied at sites with similar CoPCs, mainly at AMD impoundments, including: (i) simple soluble carbon sources (e.g., various alcohols, organic acids, lactate); and (ii) complex solid carbon sources such as wood chips, mulch and compost. The latter types of materials have been previously evaluated for use in ex-situ

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bioreactors treating pumped water from impacted reservoirs. Such a full-scale ex-situ bioreactor would be difficult to implement at the site due to the potentially large volumes of water requiring treatment and the space constraints at the site as the project develops. Therefore, only simple carbon sources were considered for this evaluation. Moreover, the potential application of a carbon source at the site would likely involve a combined use with liming materials. Use of simple carbon sources would facilitate direct application of a combined approach. **Appendix A** provides a review of different soluble carbon sources including advantages and limitations of their field application.

6.1.3 Summary of Applicable In-Pond Treatment Solutions

A treatment technology using a combination of physicochemical methods of pH buffering (e.g., liming) and a biological method using a simple carbon source is relevant to the potential in-pond treatment of all CoPCs at the site. Liming alone could be used in this application which would address most CoPCs, except for sulfate. At present, the potential concentrations of sulfate in the dredge pond and the need for treatment of sulfate is unknown. Therefore, the hydrated lime is recommended as treatment material. If sulfate treatment is needed, addition of locally available liquid carbon or limestone along with lime is feasible within the selected implementation methodology and can be considered.

6.2 Recommended In-Pond Application Method

A comprehensive literature search and review of lime application and distribution systems identified several that have been commercially implemented for liming AMD lakes (**Appendix B**). Four general liming application systems were reviewed: (i) shore-based plants with pipe or spray distribution systems, (ii) mobile shore-based systems, (iii) boats/barges, and (iv) dry liming application (e.g., aerial). Application of spray guns to deliver lime slurry has been used on a smaller scale and has been initially evaluated for a potential application at the site in **Appendix B**. However, due to the required infrastructure and high capital cost (confidential evaluation), this option was eliminated from consideration.

Based on discussions with the Holcim team, the dredge used for sand extraction could be modified for use to perform in-pond liming. In this approach, the sand extraction would be stopped temporarily to complete the liming event using the modified dredge, after which extraction would resume. Similar applications of barges and boat-based liming systems have used self-propelled vessels that had the capability of mixing and distributing lime without relying on shore-based infrastructure (**Appendix B**). The infrastructure on the barge/boat typically includes a dry lime storage tank, a lime slurry mixing system, and supporting accessories including pumps for conveying water and lime slurry. Some of these systems also use the water displaced by the barge for water intake and the engine propeller to enhance lime mixing after it is applied to the lake. A modified dredge capable of surface applying dry lime to the dredge pond by surface mixing would be the most efficient implementation.

6.2.1 In-Pond Treatment System Components

Based on the selected in-pond lime distribution method and site conditions, the proposed in-pond lime delivery system would be comprised of the following components (**Figure 6.1**):

- A lake curtain or bund[1] that would physically separate the downgradient section of the dredge pond targeted for in-pond treatment, while allowing for water exchange at the bottom.
- A lime storage silo to hold dry lime material and a loading dock.

[1] Bund could be constructed from cement stabilised fines, however this would present engineering challenges in its construction.

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- A modified dredge capable of applying and mixing dry lime in the surface of the dredge pond.

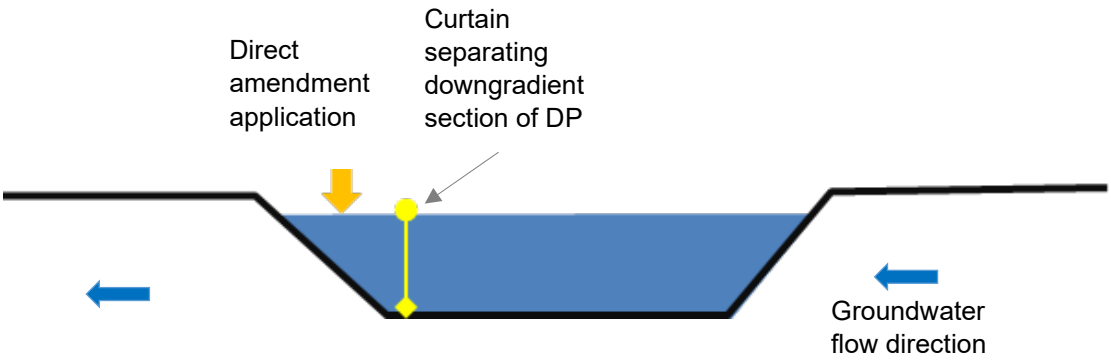

Figure 6.1. Conceptual design of in-pond treatment in downgradient section of the dredge pond isolated by a lake barrie*r.*

6.2.2 Conceptual Design Basis

Based on site conditions, anticipated dimensions of the DP and previous Geosyntec experience in direct application of lime, the design basis parameters assumed for developing the conceptual scope are presented in Table 6.1.

Table 6.1 DP Liming Design Basis Parameters (Stage 7 dredge pond dimensions)

Parameter	Value	Notes
Targeted Volume	392,000 m^3	10% of the estimated dredge pond volume at Stage 7
Ambient Residence Time in Treatment Zone	4 yrs	Based on a groundwater flow rate of 23 m/year
Dredge Pond Water pH	4.0 std units	Assumed for purpose of initial estimate
Dredge Pond Target Treatment pH	6.5 std units	Assumed for purpose of initial estimate
Target Lime Concentration	600 mg/L	Based on lime buffer demand and typical hardness (Ca=20 mg/L, Mg=10 mg/L)
Lime amount	235 tonnes	

The principal simplifying assumption in the in-pond lime dosing calculations used to develop the conceptual design is that the initial concentration of lime in the targeted dredge pond section would reach its target value within the time of application which is much shorter than the treated pond residence time. For this application it is anticipated that the in-pond dosing may take approximately 5-20 days of continuous dosing, depending on the capacity of the modified dredge and the treated volume at different stages of development. Given the relatively long residence time in the dredge pond, which is estimated at approximately 20 years for Stage 4 and approximately 40 years for Stage 7, that assumption is reasonable. Subsequently, the rate of migration of amended dredge pond water to the downgradient aquifer will be relatively slow allowing for periodical re-applications to maintain the desired chemistry in water migrating from the dredge pond.

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The use of a lake curtain would be beneficial to limit mixing between the amended dredge pond section and the rest of the pond. If a lake curtain could not be installed effectively, the in-pond operation could still proceed. However, the frequency of re-amendments would likely increase. For example, assuming the isolated dredge pond section contains 10% of the total dredge pond volume, the residence time in the targeted section for a Stage 7 dredge pond would be approximately 4 years (**Table 6.1**). Therefore, in the presence of a lake curtain, it is estimated that reapplications would be required approximately every 2 years. In the absence of lake curtain, application every year or more often may be required. The frequency of reapplications will also be controlled by the size of the dredge pond at each stage of dredge pond development. Most importantly, the need for in-pond lime application would be determined in the field throughout dredging process stages, based on dredge pond chemistry monitoring.

6.3 Path Forward for Optimising In-Pond Amendment Option

Geosyntec has identified the following future steps required to define the procedures for an in-pond treatment approach at the site:

- *Developing representative scenarios of dredge pond water composition*. The geochemical composition in the dredge pond will be dependent on the measures taken to neutralise and stabilise process water and fines returned to the dredge pond. This will control the amendment dosing.
- *Design of modified dredge*. Detailed design of dredge modification and mode of operation for powder lime delivery. The optimal application rate would be developed to estimate application times.
- *Complete bench testing for design parameter collection and confirmation of remedial performance*. The proposed bench testing is described in **Appendix C**.

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7 Measures to Protect Downgradient Aquifer

Whilst it is expected that the management measures discussed in Sections 5 and 6 are appropriate and consistent with best management practices for maintaining the baseline water quality in the dredge pond to the extent practicable, it is possible that a combination of in-pond chemical processes and reactions within the aquifer immediately adjacent to the dredge pond could result in some degree of mobilisation of acidity and metals in groundwater in the aquifer downgradient from the dredge pond. Given that this was a point of sensitivity raised by the regulatory agencies involved in assessing the SSD application, potential contingency options are discussed in this section to address the scenario where groundwater impacts are identified through routine monitoring migrating from the dredge pond towards the property boundary.

Two contingency measures were evaluated:

- Hydraulic containment via groundwater extraction downgradient of the dredge pond
- Creation of a reactive zone on the downgradient edge of the dredge pond

7.1 Hydraulic Containment

If routine groundwater monitoring during the operational phase of the project identifies potential groundwater quality impacts from ASS oxidation, a hydraulic containment strategy consisting of one or more groundwater extraction wells could be implemented to capture the groundwater for treatment and discharge to the dredge pond. The design of such a system, including the number and configuration of wells, in-well pumps and associated pipework, would depend on the lateral and vertical extent of affected groundwater and detailed analysis of the capture efficiency of an extraction well network based on the hydraulic properties of the aquifer.

With proper implementation of the sand processing environmental management measures and in-pond treatment if required, groundwater quality impacts downgradient of the dredge pond would most likely be associated with oxidation of PASS immediately adjacent to the dredge pond wall. The magnitude and extent of such impacts could be variable given the lateral and vertical distribution of PASS within the target formations, however the higher net acidity values associated with the D1/D2 horizon would make that horizon a likely source of PASS oxidation in the surrounding formation.

Given that the water chemistry requiring treatment would be similar to the sand processing and in-pond water chemistry, it is possible that treatment of groundwater captured by a hydraulic containment system could be co-managed by a water treatment system designed for process water treatment, subject to verification of capacity and feed water quality.

Hydraulic containment via groundwater “pump-and-treat” systems is a mature, well-understood technology used in a broad range of settings and applications throughout the world. It is conceptually simple, however would require consideration of various factors and potential limitations in the design, installation and operation of such a system:

- Groundwater interception systems are most effective when there is a high-resolution characterisation of where the affected groundwater occurs within the aquifer, such that the extraction well(s) can be designed to efficiently target the vertical and lateral zone requiring management. Water quality impacts that are associated with discrete vertical intervals within an aquifer can appear to be more widespread if measured in long-screened wells, potentially resulting in an overestimate of the groundwater capture and treatment requirements.

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- The design of such a system would require verification through modelling to optimise the number of wells and pumping rates required to capture the zone of interest, without extracting more groundwater than necessary.
- Groundwater extraction can result in lowering of the water table in the immediate vicinity of the extraction wells, which could have the unintended consequence of exposing additional PASS to atmospheric oxygen (similar to a naturally fluctuating water table). Accordingly, any such system should be designed to minimise drawdown to the extent practicable to avoid exacerbating PASS oxidation in the formation.
- In the event that groundwater quality impacts were identified across a broad lateral and vertical zone downgradient of the dredge pond, an interception scheme could require a large number of extraction wells to achieve hydraulic capture, and generate a large volume of water requiring treatment, which would have both cost and infrastructure footprint implications.
- Previous studies of groundwater quality impacts associated with sand mining operations (e.g., RZM) have indicated that elevated CoPCs concentrations in groundwater – notably iron – were identified in close proximity to the disturbance zone but were not identified outside the mining lease. Hence, before progressing to the installation of a hydraulic containment scheme in response to groundwater monitoring results close to the edge of the dredge pond, a more appropriate interim contingency measure would be to install additional monitoring wells downgradient of the affected zone to assess whether and to what extent natural attenuation of CoPCs occurs within the formation. A substantial reduction in groundwater CoPCs along the groundwater flow path may indicate that groundwater interception is not required, and that natural attenuation within the aquifer would suffice to manage the PASS oxidation impacts (potentially in conjunction with in-pond treatment such that pond water with elevated alkalinity flows into the adjacent aquifer to neutralise oxidised PASS).
- Any hydraulic containment scheme should be viewed as a temporary management measure, as interception of affected groundwater would not address the processes resulting in the groundwater quality impacts. Hence, neutralisation of oxidised PASS should be employed to rectify the source of groundwater quality impact, to re-establish a geochemical equilibrium and maintain baseline water quality in the pond and aquifer.

7.2 Treatment Zone on Downgradient Wall of the Dredge Pond

This management option, referred to as a Flow-Through Treatment Zone (FTTZ), represents a potential passive water treatment option to treat acidity and metals/metalloids in pond water before it migrates into the downgradient aquifer.

Based on site conditions and the proposed dredge pond development stages, there are several limitations for constructing a FTTZ to create a “sloped PRB” using granular reactive materials, including:

- An FTTZ can only be installed after dredging operations have been completed and final, stable walls of the dredge pond have been established. If granular reactive media was installed while dredge operations were still active (for example, in early development stages), there would be a high risk of the dredging operations undermining the emplaced media or directly capturing it, resulting in a sacrificial placement that would need to be replaced at the end of extraction.
- It would be difficult to control the consistency and thickness of the FTTZ along the slope of the batter if materials are simply backfilled from the top of the bank. The Stage 7 batter slope also extends approximately 200 m laterally from the bank of the pond, making shore-based emplacement methods challenging. It is possible that FTTZ media could be placed from a barge using a GPS-equipped excavator, with visual verification of thickness using an unmanned underwater drone, but it is unlikely that the dredge barge would be suitable for this task without modification.

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- Separation of mixed FTTZ media during underwater placement is likely.
- Collapsing (slumping) of the emplaced FTTZ layer may occur over time.

For these reasons, an FTTZ created by direct emplacement of granular materials on the northern dredge pond slope was eliminated from initial consideration for application during Stage 1-7 of production. However, this option is possible as a long-term solution after Stage 7 is complete and facility operations have ceased, if required. It may also be possible to consider alternative staging to the dredge pond development to enable a stable slope to be established on the northern (downgradient) side of the DP earlier for granular FTTZ implementation, however it is uncertain whether refinements to the design could make this option financially feasible for the project.

A potential construction alternative for a granular FTTZ is the use of a hybrid approach in combination with the in-pond amendment (Option 2). In this option, in-pond liming would be designed so that lime particles would not dissolve fully as they sink through the water column. That would result in a layer of deposited lime covering the wall and bottom of the downgradient section of the DP targeted by Option 2. The lime layer would then act as a treatment zone for dredge pondwater entering the aquifer. The advantages of this option over the use of a granular material FTTZ include:

- The “deposited” FTTZ can be installed and rejuvenated as the DP enlarges, during each of the in-pond treatment events or additional events, if needed.
- A relatively uniform zone of lime layer can be emplaced.
- Granular FTTZ, which would last longer than a deposited lime layer, could be installed after Stage 7 completion after a final stable dredge pond wall has been established, if required (and a financially viable design could be identified).

In summary, the recommended measures for Option 3 include: (i) targeted hydraulic containment and treatment of groundwater, (ii) creation and reinstallation of interim FTTZ zones of deposited lime during Stages 1 through 7; and (iii) creation of a FTTZ composed of granular material following Stage 7, if required.

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8 Summary of Evaluated Environmental Controls

Three types of environmental control measures were evaluated to address potential effects of ASS processes related to the proposed sand dredge operation. The measures are designed to address the processes expected to occur in: (i) reject fine materials generated from sand separation; (ii) dredge pond water in contact with returned fines and with sand deposits; and (iii) within the aquifer located downgradient of the dredge pond. **Table 7.1** summarizes the environmental controls for each medium.

Table 7.1 Measures selected for the control options

Option	Description	Advantages	Disadvantages	Comments
1. Fines Management				
Process optimisation	Direct return of fines to the dredge pond, with a short handling time at the surface	• Minimises exposure to atmosphere and acid generation. • Limits above ground space required to store separated fines	• Potential effect of ASS in very short processing time unknown, will require additional testing • Fast rates of fine slurry transport not amenable to discrete monitoring of water quality	Included in proposed production process train
Lime addition	Dosing of lime to neutralize ASS capacity in fines	• Neutralises pH decrease from exposure during production. • Adds additional capacity to neutralize processes in the dredge pond	• Fast rates of fine slurry transport not amenable to direct in-stream lime dosing • Direct dosing to the dredge pond in the fine deposition location may be required.	Applied if needed, based on evaluation of pH in returned fines slurry
2. Direct In-pond Treatment (Liming)				
Barge application		• Good lateral distribution • Modified dredge could be used for application	• Low to moderate throughput • Requires loading dock • Lime needs to be replenished on boat	Modified barge would be preferable, but requires further evaluation
3. Management of Aquifer Impacts Downgradient of the Dredge Pond				
Hydraulic containment and treatment of groundwater downgradient of the dredge pond	Extraction wells targeting specific zones of groundwater impact	• Reliable, well-established technology • Can be optimised to selectively target discrete zones of groundwater impact	• Does not treat the source of groundwater impact • May become financially unviable if required capture zone/volume is large	Contingency response during operational-phase groundwater monitoring
Reactive fill material on the northern wall of the dredge pond	Deposition of a layer of alkaline permeable fill on the northern wall of pond	• Relatively simple installation method. • Can be replenished easily once capacity is exhausted.	• Requires imported fill with specific characteristics of permeability and capacity. • Requires establishment of a final stable dredge pond wall • Difficult to control reactive zone thickness and stability • Potentially cost prohibitive, subject to refinement of design and unit cost estimates	Installation possible at end of Stage 7 when final dredge pond and stable walls are established*

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Option	Description	Advantages	Disadvantages	Comments
Periodic in-pond application of lime suspension	Creation of a layer of undissolved lime on dredge pond wall	• On-demand application as dredge pond grows • Deposited lime particles treat COCs and prevent acid generation from the dredge pond	• Frequent applications may be required if dredge pond walls are unstable.	Applicable as an interim measure during Stages 1 through 7

*Earlier application could be possible if a modified dredging plan is identified that results in earlier establishment of a stable northern dredge pond slope.

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9 Recommendations

9.1 Additional Investigations and Treatment Feasibility Testing

Based on the review of environmental management options, it is likely that one or a combination of management options will be capable of treating the potential water quality impacts associated with oxidation of acid sulfate soils during dredge operations. The selection, design and optimisation of treatment methods will require a targeted feasibility evaluation to quantify performance relative to the water quality objectives. The additional information requirements are specified throughout this document.

It is also recommended that additional geochemical assessment is designed to address the effectiveness of proposed management option(s), with consideration of the rate of change expected in soil and groundwater chemistry. This approach will inform ongoing monitoring programs. A geochemical program should be completed which aims to quantify:

4. Efficiency of hydraulic separation
5. Characteristics of fines waste stream.
6. Efficacy of ameliorants (i.e., lime/caustic or crushed concrete).
7. Efficacy of containment.

To address these aims:

- Trials of hydraulic separation of site materials to confirm segregation of sulfidic fines and characteristics of washed sand fraction. Trials can be completed at bench scale or field scale as available. Trials can provide information for hydrocyclone design and assess if liming of sulfidic fines returned to the dredge pond will be required.
- Column tests should be completed to assess the effective neutralising value of any proposed ameliorant needs to be documented. If crushed concrete is to be used to manage pH, its effectiveness must be quantified.
- If cement stabilisation is to be considered, a monolith of stabilised fines should be leach tested to assess the leachability of the resultant solid.

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9.2 Acid Sulfate Soils Management Plan

An Acid Sulfate Soils Management Plan should be developed that identifies the adopted management options to be implemented through the dredge project. The plan should consider management of the fine fraction, the saleable sand fraction, and the dredge pond.

9.3 Preliminary Monitoring Program

An initial monitoring program was developed to define the scope and schedule of monitoring and water quality triggers for implementation of the proposed measures (Table 9.1). it is anticipated that this would be incorporated into a project-wide monitoring plan to be prepared prior to commencement of works. As indicated in previous site evaluations, background water quality in groundwater monitoring wells located at the site indicate naturally acidic pH values, elevated salinity and concentrations of metals, with some CoPCs exceeding water quality criteria at select well locations. The objectives of the monitoring program below are to refine the baseline characterisation of groundwater quality, and to assess the requirement for, and performance of, the various environmental management measures. It is noted that this monitoring program is

preliminary in nature and may require refinements based on the results of additional feasibility testing recommended in this document.

Table 9.1 Monitoring plan and triggers for implementation of ASS control measures

Option	Monitoring Network	Analyses/ Frequency of sampling	Triggers for implementation
Baseline/upgradient Groundwater Condition Establishment and Downgradient	Groundwater monitoring wells Shallow:BH1S, BH3S, BH5S, BH6S, BH125S, BH126S, BH127S Intermediate: BH7S, BH101, BH106, BH111, BH121, BH122, BH125I, BH126I, BH127I, BH128I, BH129I Deep: BH1D, BH2D, BH3D, BH4D, BH5D, BH6D, BH7D, BH125D, BH126D, BH127D, BH128D, BH129D	• Quarterly sampling for pH, EC, silica, aluminium, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, lead, iron, manganese molybdenum, nickel, selenium, vanadium, , antimony, nickel, zinc, major ions, alkalinity and acidity.	• ANZG (2018) for slightly to moderately disturbed freshwater ecosystems (95% species protection default guideline values) • Drinking water primary and secondary recreational contact the Australian Drinking Water Guidelines (ADWG, 2011 as updated 2023) • ANZECC 2000 Livestock Watering and ANZECC &ARMCANZ 2000 Short-Term Irrigation Water and ANZECC &ARMCANZ 2000 Long-Term Irrigation Water Or • Site specific trigger values based on the above guidelines and baseline monitoring data.
1. Fines Management – Lime addition	Grab sample from fine return pipes	• Daily field measurement for pH	• Lime dosing to fine slurry if pH decreases by 0.5 unit or more compared to average background value
	Grab samples from three depths in dredge pond area of fines disposal	• Weekly field sampling for pH, EC, sulfate and metals	• Additional lime dosing to dredge pond in fine disposal area if pH decreases by 0.5 unit or more compared to average background value
2. In-Pond Treatment – Modified Dredge Application	Grab samples from three depths in DP in the downgradient wall of the dredge pond, at 3 locations spaced 100 m apart	• Weekly field measurement for pH • Additional analyses for sulfate and metals on weekly samples exhibiting pH that is 0.5 higher than maximum background value	• In -pond lime dosing if pH decreases by 0.5 • Addition of organic carbon to lime if sulfate increases by 50 mg/L or more compared to maximum background value
3. Aquifer Protection – in-pond applied lime FTTZ	Porewater samples from three depths in the downgradient wall of dredge pond, at locations spaced 100 m apart	• Weekly field measurement for pH • Additional analyses for sulfate and metals on weekly samples exhibiting pH that is 0.5 higher than maximum background value	• Triggers for in-pond treatment, or • Any metal concentrations 25% higher than maximum background value

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A detailed Sampling, Analytical and Quality Plan should be prepared, including sample collection methods and field and laboratory analytical methods should be prepared once the monitoring scope is finalised.

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11 Limitations

This report has been prepared by Geosyntec Consultants Pty Ltd ("Geosyntec") for use by the Client who commissioned the works in accordance with the project brief only and has been based in part on information obtained from the Client and other parties. The findings of this report are based on the scope of work in our proposal dated 17 August 2022. The report has been prepared specifically for the Client for the purposes of the commission and use by any explicitly nominated third party in the agreement between Geosyntec and the Client. No warranties, express or implied, are offered to any third parties and no liability will be accepted for use or interpretation of this report by any third party (other than where specifically nominated in an agreement with the Client).

This report relates to only this project and all advice, conclusions and recommendations made should be reviewed by a competent person with experience in environmental assessment and management specific to the subject of this report, before being used for any other purpose. This report should not be reproduced without prior approval by the Client or amended in any way without prior written approval by Geosyntec.

Geosyntec relied on information prepared by third parties in developing the advice in this report. The information was provided by the Client, in draft format, and verification of the accuracy and integrity of the information was beyond the scope of this commissioning.

This report does not comment on any regulatory obligations based on the findings. This report relates only to the objectives stated and does not relate to any other work conducted for the Client.

The absence of any identified hazardous or toxic materials on the site should not be interpreted as a guarantee that such materials do not exist on the site.

All conclusions regarding the site are the professional opinions of the Geosyntec personnel involved with the project, subject to the qualifications made above. While normal assessments of data reliability have been made, Geosyntec has not independently verified and assumes no responsibility or liability for errors in any data obtained from regulatory agencies, statements from sources outside of Geosyntec, or developments resulting from situations outside the scope of this project.

Geosyntec is not engaged in environmental assessment and reporting for the purpose of advertising sales promoting, or endorsement of any client interests, including raising investment capital, recommending investment decisions, or other publicity purposes. The Client acknowledges that this report is for its exclusive use.

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Appendix A Summary of Soluble Simple Carbon Sources

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Table A-1: Summary of Soluble Simple Carbon Sources

Carbon Sources	Advantages	Limitations/ Considerations	References
Methanol	• Relatively Inexpensive • Easily utilised by microbial community • Easy to apply with a pump	• Consumed quickly, requires constant dosing • Highly flammable and presents health and safety storage risk • Additional capital cost associated with hazardous area classification • Logistically challenging and limited availability	(Doshi, 2006)
Ethanol	• Relatively Inexpensive • Easily utilized by microbial community • Easy to apply with a pump	• Consumed quickly, requires constant dosing • Highly flammable and presents health and safety storage risk • Additional capital cost associated with hazardous area classification • Logistically challenging and limited availability	(Kumar et al., 2011)
Acetic Acid/ Acetate	• Acetate shows high reactivity for SRB • Easy to apply with a pump	• Expensive • Flammable vapours, presents storage risk • Additional capital cost associated with hazardous area classification • Low odour threshold, provides strong smell • Acetate can inhibit SRB at high concentrations (15 mmol/L) • Poor longevity and will require constant dosing	(Koschorreck et al., 2004) (Kumar et al., 2011) (Oremland et al., 1989)
Lactic Acid/ Lactate	• Lactate shows high utilisation for SRB Easy to apply with a pump	• Poor longevity and will require constant dosing • Expensive	(Kumar et al., 2011) (Oremland et al., 1989) (Oremland et al., 1999)
Molasses/ Sugar Industry Waste	• Easily utilised by microbial community • Can provide carbon, nitrogen, sulphur and phosphorus • Sugar industry byproduct, commonly a waste	• Poor longevity and will require frequent dosing • Logistically challenging and limited availability • Challenging to apply with a pump at lower temperatures	(Kumar et al., 2011) (Opara et al., 2018)

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Appendix B Review of Lime Application and Distribution Systems

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APPLICATION SYSTEMS

The following section summarizes the four primary application techniques for handling dry lime and incorporating lime into pit lakes for treatment of pit lake water.

Shore-based Plant

Shore-based systems use permanent infrastructure to store, mix, and distribute lime allowing for operation of larger applications ranging from a pond (e.g. > 200,000 m^3) to large lakes (e.g. > 1M m^3) [Scholz et al., 2007]. Water is pumped from the pit lake into a mixing tank where dry lime powder is added, through a mechanical conveyor system, to prepare a homogenous slurry. Alternatively, a pre-mixed lime slurry, often supplied by commercial vendors, can also be directly used in place of a lime slurry mixing system. A second pump distributes this slurry to the lake for application. The lime slurry can be applied from shore using nozzles or pumped to a boat or floating platform for application [Serediak et al., 2002].

Depending on site conditions, these systems may present a number of advantages, mainly delivering higher volumes of lime slurry to pit lakes [Totsche et al., 2018]. Such systems are sophisticated enough to minimize manual handling by employing pneumatic transfer systems for powdered lime or slurry. Finally, the water used for the plant can be pumped from deeper depths within the pit lake, allowing the mixing of the slurry throughout the water column by creating a recirculation system. This is an advantage for stratified lakes where the application of lime to the top layer may not treat the entire water column.

Considerations for application of these systems include engineering design of lime handling, mixing and distribution systems, geotechnical evaluation for site preparation, and foundation construction. Access to site for system construction and maintenance will also need to be considered along with access to power and utilities availability.

A shore-based plant provides a potentially flexible option in terms of lime distribution to the pit lake as it can distribute lime slurry in several different ways: spray gun nozzle or sprinkler, pipeline, or boat distribution. The following sections highlight each of the distribution methods used for shore-based systems.

Mobile Shore-based Approach

Mobile, shore-based lime application systems are often used for smaller applications such as ponds or a portion of a larger water body (e.g. < 200,000 m^3), see Figure 1. These systems are often custom built to meet the needs of the application. They typically consist of two containers for lime addition and mixing, two small pumps capable of solids handling and a nozzle for slurry application [Serediak et al., 2002]. Pond water is first pumped into a container where dry lime powder is added to create the lime slurry of a desired concentration. The slurry is then pumped into a second container for better mixing and then applied to the pond via a truck-mounted high-pressure nozzle. Depending on the pump and the spray nozzle specifications, up to a 100-metre (m) spray radius can be achieved [Serediak et al., 2002]. This allows application of the slurry from the shoreline, if necessary. Alternatively, the lime slurry can be applied via a perforated hose pulled across the water surface by a small boat. This system is simple, inexpensive and can be easily transported and applied at multiple sites. Health and safety considerations involving the handling and distribution of lime include proper use of personal protective equipment (PPE), high-pressure nozzle awareness, and controls in place to safely handle, spray and mix lime. This system is challenging to scale up to treat larger bodies of water effectively.

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Figure D1: A mobile shore-based plant [Scholz et al., 2007].

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Barge/Boat Application

Barges and boat-based liming systems use self-propelled vessels that have the capability of mixing and distributing lime without relying on shore-based infrastructure (Figure 2). The infrastructure on the barge/boat typically includes a dry lime storage tank, a lime slurry mixing system, and supporting appurtenances including pumps for conveying water and lime slurry. Some of these systems also use the water displaced by the barge for water intake and the engine propeller to enhance lime mixing after it is applied to the lake [Serediak et al., 2002]. The lime slurry can be applied using booms or spray guns located on each side of the boat/barge to achieve a wider lateral distribution over a larger area. Commercial liming barges have been successfully used in Europe but are often expensive as they are custom built for a specific location and have to be transported, stored, and maintained [Totsche et al., 2018]. Alternatively, wooden barges can be engineered and built using locally sourced material. These wooden barges are similar in operation to the mobile shore base system but are built on a platform with a boat engine to be driven across the pit-lake. Wooden barges are thus less expensive.

Figure D2: Self-reliant barge/boat application system [Scholz et al., 2007].

Scholz et al. [2007] describes the barge application of lime at Lake Bernstein, an acidic pit lake in central Germany resulting from lignite mining. This lake was limed using a commercial barge system where lime slurry was delivered underwater to minimize the potential for airborne lime particles. The lime slurry was carried by pipeline from a shore-based plant to submerged water guns on each side of the barge and sprayed downwards into the water. Predictably, smaller lime particle size resulted in better dissolution.

In comparison to shore-based plants, boat/barge systems have less lime throughput, may require frequent replenishment of lime, particularly for large applications, and would require a dock for replenishment operations. However, boat/barge systems have an advantage over shore-based plants for pit lakes where the terrain does not allow permanent installation of a shore-based plant. Additional considerations include the downtime required to load the lime on the barge between each trip and handling dry lime on the barge/boat during dusting and ventilation events.

For pit lakes with larger surface area, a motorized barge or boat can be used to distribute lime slurry produced by a shore-based plant (Figure 3). This can be achieved by using flexible hoses that connect the plant to a delivery system on the boat such as a nozzle array or jet nozzles. This distribution system is mostly used for pit lakes that have a large surface area where lateral mixing is difficult to achieve with a stationary distribution system, such as a pipeline. However, as in the case with spray nozzles or sprinklers, the effectiveness of the application can be limited if coarse lime particles are used which settle rapidly. Better lime dissolution can be achieved with finer lime particles, but vertical mixing needs to be considered to avoid partial lake treatment, particularly in a stratified system. This distribution system may thus be appropriate for pit lakes with larger surface area and relatively shallow or unstratified water columns.

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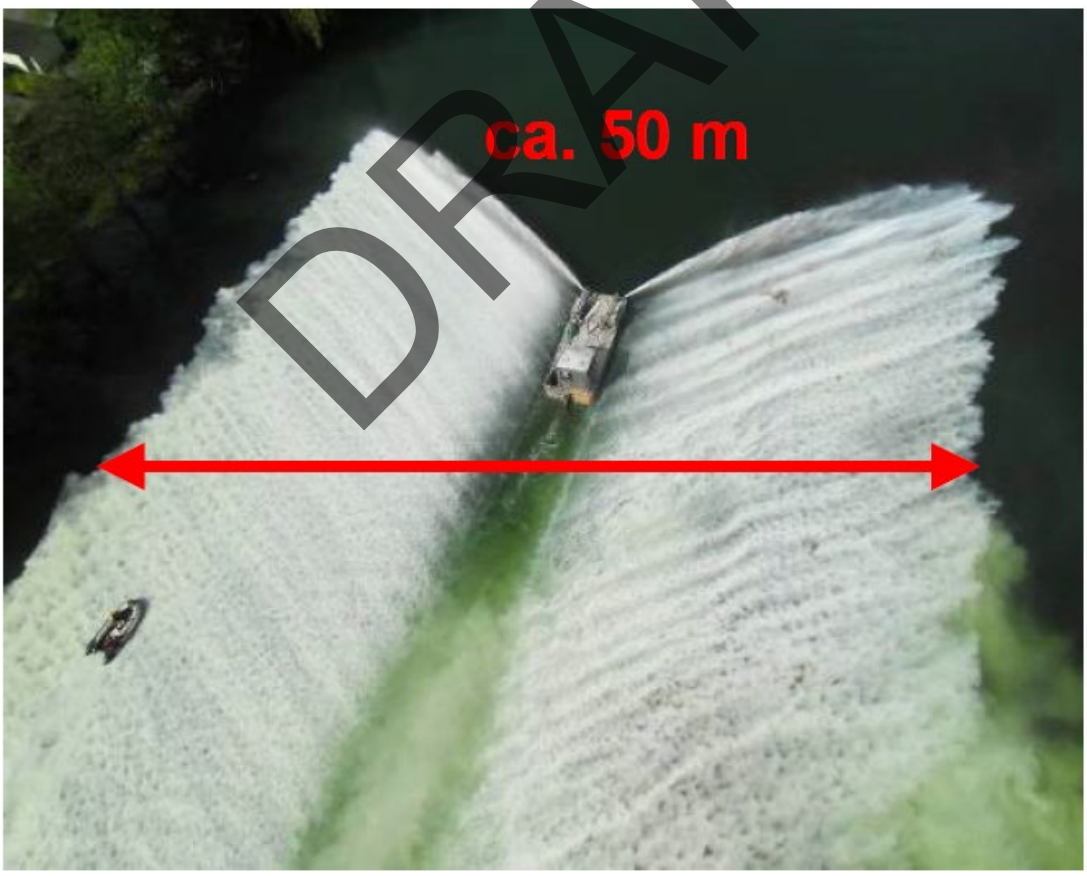

Figure D3: Boat Distribution [Scholz et al., 2007].

Dry Liming

Dry liming involves the direct application of dry hydrated lime to a pit lake or waste rock pile. Several case-studies assessing application of dry hydrated lime determined it to be ineffective.

Scholz et al. [2007] describes the ineffectiveness of dry liming of Lake Senftenberg, an acidic pit lake in central Germany resulting from lignite mining. The lake was limed using hopper barges without any mixing system. This caused the lime particles to settle to the bottom too rapidly without dissolving, which then were passivated, likely due to the formation of gypsum in waters containing elevated sulfate concentrations.

Aubé [2009] found that the surface application of hydrated lime powder to the surface of the water was ineffective due to settling. The lime powder particles settled rapidly with limited dissolution. This method has been found not to be very effective (~15% of lime used to increase pH, potential for ferric hydroxide coating and subsequent passivation) making it likely to not to meet treatment objectives.

Delgado et al. [2016], treated an acid generating pit lake by dry liming a stream that discharged into the pit lake. The pH of the stream was raised to 12.3 by adding dry lime directly to the surface of the stream from a storage silo. The high pH water discharging from the stream was able to neutralize the pH of the pit lake. This lime application method is limited to pit lakes with a single, large-flow point source influent into the lake that has enough turbulence to dissolve the lime prior to flowing into the pit lake and distribute it in the water column thereafter.

Aerial Application

Aerial lime application consists of dispersing dry lime from an airplane or helicopter on the target area to be treated [Scholz et al., 2007; Figure 4]. Few examples of aerial lime applications were found in the literature since it requires specialized equipment (aircraft capable of dropping dry lime) and specially trained crew. In BC, firefighting crews use helicopters to apply water and fire retardant to hilly areas and could potentially apply the same technique to lime application. Additionally, this technology has mostly been used to lime whole watershed catchments rather than direct application to a water body and is limited to the application of dry lime rather than a slurry [Schipek, 2011]. Application of dry lime can be advantageous for liming large extents of water bodies such as whole watersheds, offering longer term buffering capacity but likely has limited effectiveness due to the potential for inefficient lime dissolution when applied as a powder [Aubé, 2009]. It must be noted that quicklime was applied in this study and likely was a major factor contributing to the low dissolution and low utilization of the lime. Nonetheless, this method offers the advantage of being able to apply lime in areas that have no road access or have hazardous conditions that prevent human presence.

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Figure D4: Aerial application [The Essential Chemical Industry, 2021]

LIME SLURRY DISTRIBUTION METHODS

The following section summarizes the two main distribution techniques are the primary methods for delivering lime slurry to pit lakes for treatment of pit lake water.

Spray Gun Nozzle or Sprinkler

Spray gun nozzles or sprinklers are high pressure nozzles that spray lime slurry in an arc pattern over a set distance (Figure 5). Depending on site conditions, they can be installed on shore or on a floating platform with lime slurry supplied from a shore-based plant. Spray guns and sprinklers offer good surficial lime distribution, especially for smaller pit lakes (e.g., 200,000-500,000 m^3) where a few spray guns could adequately cover the surface area. However, once applied, these systems provide little control over contact of the settling CaO (quicklime) particles in the water column [Aubé, 2009]. In stratified systems, surface application with spray nozzles may not treat the entire water column, only treating the surface water layer if insufficient natural or artificial lake mixing is present. In addition, if the quicklime particles are coarse, they can quickly settle to the bottom of the pit lake with limited dissolution, reducing the effectiveness of the lime particles. Therefore, such systems require optimization of the lime slurry preparation process onshore by either using fine hydrated lime powder, using low concentration slurry to reduce the lime particle settling rate, or augment application with a mixing approach to achieve adequate contact time [Scholz et al., 2007]. Spray gun nozzles and sprinklers may be better suited for pit lakes that require good lateral distribution such as shallow and small surface area pit lakes and would likely need to rely on natural mixing or induced mixing to distribute lime to deeper waters for stratified lakes.

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Figure D5: a) A permanent shore-based plant; b) spray nozzle sprinkler system [Scholz et al., 2007].

Scholz et al. describes the effectiveness of lime application using a sprinkler for treatment of both Lake Geierswalde and Lake Hain, acidic pit lakes in central Germany resulting from lignite mining [Scholz et al., 2007]. Lake Geierswalde contained deposits of lime from previous dry liming treatment attempts, which were collected through suction dredging after re-suspension using effluent from the water treatment plant. Distribution of the lime slurry was achieved using a pipeline and ten shore mounted large sprinklers. In contrast, Lake Hain was limed using an onshore plant and a floating sprinkler system. Lime was stored in silos and the slurry was created using lake water before being pumped to a sprinkler on a

floating platform. Both studies demonstrated that lake mixing driven by wind and density convection was sufficient to re-distribute the lime throughout the pit lake, enhancing lime dissolution.

Pipeline Distribution

Pipelines can also be used to distribute lime slurry for the application to pit lakes which can facilitate additional lime dissolution through turbulent flow prior to application [Scholz et al., 2007; Figure 6]. This additional dissolution provides better lime treatment efficiency but is dependent on slurry concentration. Two types of pipelines are commonly used to distribute lime in pit lakes: underwater pipelines and floating pipelines. Underwater pipelines are weighted so that the outlet of the pipeline sinks to a specific target depth in the water. On the other hand, floating pipelines stay on the surface and discharge directly to the surface of the pit lake. Both systems use turbulent flow through a nozzle at the outlet, similar to spray guns, to maximize the dissolution of the lime particles in the slurry but do not have the capacity to distribute lime throughout the lake. The rate of dissolution is dependent on the lime particle size distribution and slurry concentration. Mixing throughout the lake is usually accomplished using convective currents from natural lake mixing or from shore-based plant water circulation. For stratified lakes, the spring and fall turnover can provide the natural lake mixing but limits the timeframes during which the lime can be applied. Alternatively, shore-based plants can pump water from the hypolimnion (i.e., bottom layer of lake) of a stratified lake and use a floating pipeline to discharge lime slurry in the epilimnion (i.e., surface layer of lake), creating an artificial mixing that can distribute lime throughout the water column. Lateral distribution is more difficult to achieve using a pipeline distribution system, but it has been found that not all of the lake volume needs to be mixed to achieve treatment [Scholz et al., 2007]. Where site conditions allow, internal convection currents can be sufficient to achieve lateral mixing. Pipelines are thus a more effective lime distribution method for pit lakes that are deeper and present stratification but do not have large surface areas that require large lateral distribution.

Duck Pond Mine, located in central Newfoundland (NL), uses a lime distribution system to apply lime to their tailings pond (~1.5 kilometer [km] long) and adjust pH at two small acidic pits [Teck email correspondence, 2021]. First, a thick slurry is produced in a tank, then reclaimed water is mixed with the slurry in the tank and the mixture is gravity fed at 3,000 litres per minute (L/min) to the tailings pond, where the reclaimed water makes up 25% of the volumetric feed. The lime distribution system is installed on a floating platform in the tailings pond which uses a 30 cm diameter insulated high density polyethylene (HDPE) pipe for recirculating water continuously year-round. Due to their use of separated cells in the tailings pond, the lime addition and water quality in each cell is closely controlled.

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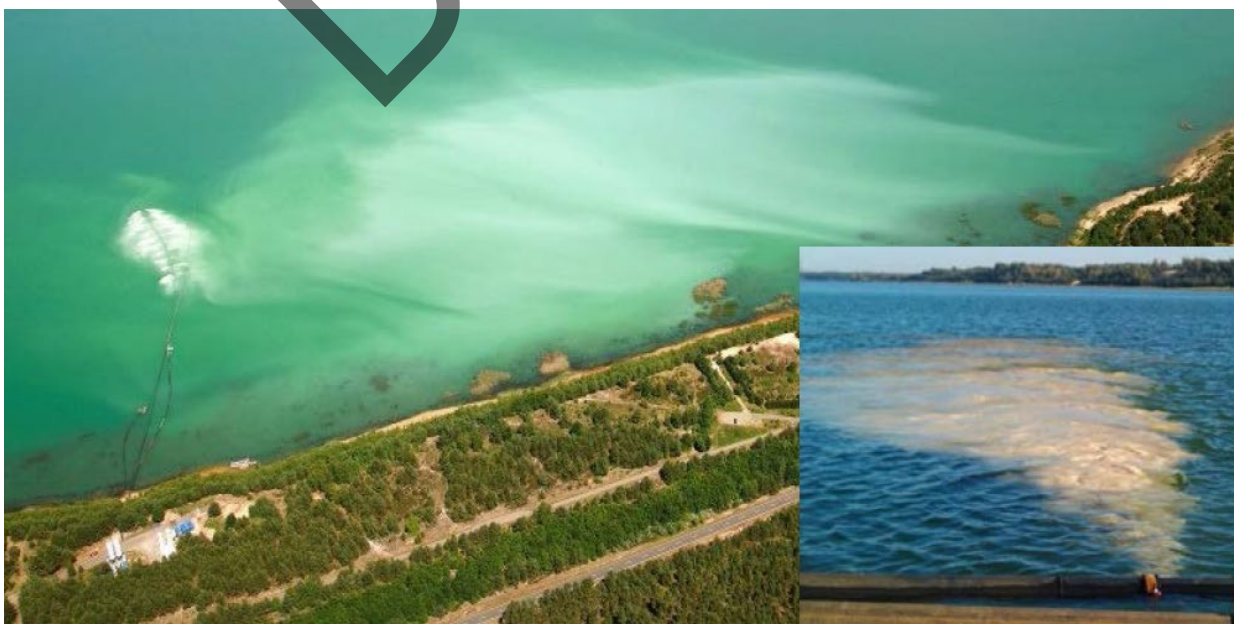

Figure D6: Lime pipeline distribution method (Scholz et al., 2007).

Jensen et al., 2014 developed an in-situ treatment system for Nero Lake, a shallow, acid contaminated lake from legacy mining activities in northern Saskatchewan. Between 10-20% of the lake volume was circulated and dosed with lime using a shore-based plant to achieve treatment. The lime slurry was prepared using lake water. The slurry was then diluted with additional lake water in a mixing tank before being pumped to the lake via a pipeline. The natural turnover of the lake resulted in the distribution of the slurry throughout the water column. The system was first pilot tested using limnocorrals to determine the mass of lime amendment required to treat the whole lake. During the piloting phase it was hypothesized that direct addition of lime to the lake may result in unreacted lime deposition at the bottom without dissolution. However, it was later determined that adequate lime dissolution was achieved through direct slurry injection into the lake and that a dilute slurry mixing tank was not necessary to improve lime dissolution.

Berkeley pit lake is another example of a lake impacted by acid mine drainage that was partially treated with addition of dense lime sludge [Gammons and Icopini, 2020]. The sludge was produced as a by-product of a copper recovery plant on shore. The water was pumped from the hypolimnion, mixed with the lime sludge, and discharged without further mixing into the surface of the pit lake by a pipeline. Despite constituting only 8% of the total influx of water to the lake, the lime slurry was sufficient to raise the pH from 2.5 to 4 between 2003 and 2020. However, it is suspected that the efficiency of the lime was lower than expected due to the high concentrations of iron (Fe) and aluminium (Al) that potentially reacted with the lime to form a metal hydroxide shell on the lime particles, thereby lowering dissolution efficiency and reactivity [McCullough, 2008].

Öhlander et al. [2007] studied the liming of an acidic, metal laden stratified lake in Sweden approximately 527,000 m^3 in volume with a surface area of 49,191 m^2. A lime slurry was pumped from a truck and injected into the lake via a pipeline. The pipeline was heavy and sank partway through the lake. A total of 200 tons of lime was injected in three weeks using this method. Liming did not disturb the stratification of the lake, but the lime dosing was still successful in increasing the pH of the pit lake from approximately 2-4 to approximately 8-11. A review summary is provided below.

Lime In-Pond Application Technologies Summary

Lime Application System	Advantages	Limitations/ Considerations
Shore-based plant application	• Higher throughput than other system • Multiple options for slurry application (pipeline, jets, sprays) for both lateral and vertical distribution • Can be automated with fewer dedicated operators, used many times	• Requires road access and power • Requires a permanent or semi-permanent installation • Largest footprint of all systems • Not easily transferable to other sites
Mobile shore-based plant application	• Simple construction • Lower cost than permanent shore plant • Reusable for subsequent liming events at other locations	• Low throughput • Requires road access • Limited to surface application (spray) • Limited liming area (dependent on pump power)
Barge/Boat application	• Multiple option for slurry application (booms, jets, sprays) • Good lateral distribution	• Low to moderate throughput • Requires boat launch ramp, dock, • Lime needs to be replenished on boat • Difficult to operate in shallow areas

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Lime Application System	Advantages	Limitations/ Considerations
Aerial application	• Capable of liming in remote locations with no road access/ limited access • Option for liming full watershed, offering longer term buffering capacity	• Expensive and requires an aircraft • Limited to dry lime application • Potential for limited efficiency due to low lime dissolution in pit lake • H&S issues related to exposure to aerosolized lime dust
Spray gun nozzles/sprinklers in air distribution	• Useful for achieving wider surficial distribution of amendment, treating larger surface areas • Can be used in a portable setup or installed on shore depending on water footprint	• May not promote vertical mixing unless used in conjunction with natural turnover or artificial mixing methods • Generally low to moderate throughput because of typical spray gun nozzle capacity
Pipeline with underwater jet nozzle distribution	• Can be used to deliver amendment at the surface or at depth • Can be used to achieve mixing within the water column • Can achieve high throughput	• Requires a high volumetric flow of lake water to be circulated through pumps, which can lead to high power needs and higher costs
Dry liming distribution	• - Lower cost than integrated slurry distribution techniques. • - Potential solution for low required doses of lime with a single high-flow point source	• -Ineffective at distributing the lime within the pit lake. Dry hydrated lime tends to aggregate and settle without slurry make-up prior to application

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Appendix C Recommendations for Treatability Studies for In-Pond Treatment

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Based on previous experience, a laboratory treatability test for in-pond limning application should be comprised of two separate phases:

- Phase 1: Titration Batch Study
- Phase 2: Column Testing

Water used in the test would be both de-ionised water sourced in a laboratory and water collected from a groundwater well located on the Site. The groundwater would be exposed to aerated Sand II material to create acidic conditions at the anticipated pH level and other COC concentrations. These conditions would be cross checked with the leachate concentrations measured in the open draining column tests.

Phase 1 comprises of titration tests using lime ($Ca[OH]_2$) product from a local supplier. The objective of this phase is to determine the relationship between pH and dosing of fully dissolved lime, under constant mixing conditions. During a typical titration test, 200 millilitres (mL) of water is amended with varying amounts of lime to increase the starting pH by 0.5 standard unit until neutral conditions (i.e., pH of 7) are achieved. After a 24-hour equilibration time, the final pH is measured again.

Phase 2 would consist of column testing. Geosyntec recommend two parallel phases of column testing, which will assess the rate of oxidation of the placed fines in both treated and untreated state, and a second phase of testing to assess treatment if the water column is in contact with the fines (in both treated and untreated state). The aim of the tests is to assess the range of conditions the materials could experience in the DP, and their effect on reactivity to assist in understanding potential water quality evolution and effectiveness of treatment options.

- Open draining column leach test – this test involves packing a short, wide aperture column with the treated material and saturating it with water. The column is subjected to heat and light under controlled conditions and then leached with a known volume of water, with analysis of the leachate generated. The timing of the leach events is commensurate with the expected reactivity of the materials. Sulfide oxidation rates are calculated from the rate of export of sulfate from the system. Columns would be generated for a range of sulfur contents/material types and for amended/treated materials. Typically, column tests provide oxidation rates which are faster than those observed in the field.
- A settling column test using the selected lime source. The objective of this phase is to determine the pH evolution in the DP water column under surface lime dosing using a concentrated lime suspension which simulates field in-pond application, without mechanical mixing used in titration tests. Previous columns used in such test measured 120 centimetre (cm) in length and 7.6 cm in diameter for a total usable volume of 5 litre (L). Each column had three ports located on the side of the columns at 33 cm, 66 cm and 1 m from the top for sample collection. Several columns would be setup to verifying pH value and distribution depth, using dosing developed in Phase 1 and dosing that is 25% and 50% higher. Based on previous experience, surface dosing and static mixing has resulted in a less pH buffering, compared to that observed in titration tests.

Results obtained in the column tests would be used as basis of optimizing system design and cost estimate.

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