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Acid Sulfate Soils

Technical Guidance

Waikato Regional Council

7 November 2025

→ **The Power of Commitment**

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The following assumptions were made during the preparation of this document:

- The information contained herein constitutes a high-level overview only and has been provided only for the purpose described in Section 1.1. For further detail or site-specific considerations, it is recommended that the reader engages a suitably qualified and experienced practitioner in Acid Sulfate Soil (ASS) investigations.
- This document has been prepared to reflect the current state of knowledge of the authors relating to ASS in New Zealand and may need to be updated as more info becomes available.
- This document is for general guidance purposes only and does not constitute, nor does it take precedence over, any form of legislation, regulation, policy or rule.
- It is assumed that all documents and information used by GHD in the preparation of this document were complete, comprehensive, accurate and free of error. GHD has not independently verified information beyond its agreed scope of work.

Acknowledgements

In the absence of formal New Zealand-specific guidance on ASS, the development of this document has drawn upon established local assessments and guidance materials from Australia. These sources have been used with consideration for the distinct environmental, regulatory, and land management context of New Zealand. The following documents have been instrumental as reference materials:

Australian National Acid Sulfate Soils Guidance –

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.

Queensland Acid Sulfate Soil Technical Manual –

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, Science and Innovation, Queensland.

Tasmanian Acid Sulfate Soil Management Guidelines –

McDonald, D., & Tasmania Department of Primary Industries, Parks, Water and Environment (2009). Tasmanian Acid Sulfate Soil Management Guidelines. Hobart, Tasmania: Department of Primary Industries, Parks, Water and Environment.

Waikato Region: Acid Sulfate Soils Preliminary Risk Assessment –

GHD., 2024. *Waikato region acid sulfate soils preliminary risk assessment*. Waikato Regional Council Technical Report 2023/2, DM 27390926. Waikato Regional Council.

Western Australia: Identification and investigation of acid sulfate soils and acidic landscapes –

Department of Water and Environmental Regulation (formerly Department of Environment Regulation) (2015). Final version June 2015.

On behalf of Waikato Regional Council, GHD acknowledges the guidance of Dr Jonathan Caldwell (WRC) and the valuable contributions from Dr. Lauren O'Brien (reviewer, Landcare Research Manaaki Whenua) in the development of this guidance document.

Definitions

Table 1 Definitions

Terminology	Definition
Acid Neutralising Capacity (ANC)	A measure of a soils inherent ability to buffer acidity and resist the lowering of the soil pH. Acid buffering in the soil may be provided by dissolution of calcium and/or magnesium carbonates (e.g. shells), cation exchange reactions, and by reaction with organic and clay fractions.
Acid sulfate soil (ASS)	Soils that are rich in sulfides and/or their oxidation products. The oxidation reactions and associated reactions can cause changes to the water (e.g., surrounding groundwater or surface water and any receiving waters) and soil chemistry, such as acidification.
Actual Acid Sulfate Soils (AASS)	Soil that is highly acidic due to the oxidation of soil materials that are rich in iron sulfides, primarily pyrite. This oxidation produces hydrogen ions in excess of the soils capacity to neutralise the acidity, resulting in

Terminology	Definition
	soils of pH 4 or less. These soils are often associated with the presence of jarosite. Also known as “sulfuric soils”.
Actual acidity	The soluble and exchangeable acidity already present in the soil that can be mobilised and discharged, such as following a rainfall event. This acidity may arise as a consequence of the previous oxidation of sulfides. Actual acidity is a component of existing acidity. NOTE: It does not include the less soluble acidity (i.e. retained acidity) held in hydroxy-sulfate minerals such as jarosite.
Anoxic	Materials or areas with very low amounts of oxygen, in reference to conditions where oxidation of a sulfidic material are nearly unable to occur for example, below the water table. This is similar to, and sometimes used synonymously with “anaerobic”, which refers to the absence of oxygen.
Chromium Reducible Sulfur (S_{CRS})	A laboratory test to measure reduced inorganic sulfides (RIS) i.e. the potential acidity (measured as both the acidity (mole H+/t) and the sulfur content (per mass of dry fine earth (<2 mm), as %S) component of the Net Acidity calculations.
CRS Method or Suite	A method of measuring the acid generating potential of an acid sulfate soil. The CRS suite calculates the potential, actual and retained acidity and the ANC, it measures both the acidity and the sulfur content. This provides a set of analytical results and derived calculations that allow calculation of net acidity. It is an alternative to the SPOCAS suite.
Disturbance	Any activity that causes the oxidation of PASS or the mobilization of AASS for example, excavation, the raising or lowering of groundwater or fill emplacement that causes displacement of groundwater or soil.
Existing acidity	The acidity already present in acid sulfate soils, usually because of the oxidation of sulfides, but which can also be from organic material or acidic cations. It can be further subdivided into actual and retained acidity, i.e. Existing Acidity = Actual Acidity + Retained Acidity.
Jarosite	Jarosite is a potassium iron hydroxysulfate mineral that commonly forms in acidic environments as a result of pyrite oxidation. It is a yellow mineral and is often associated with the mottled coloration associated with ASS and AMD.
Liming rate	Fine grained $CaCO_3$ (e.g. agricultural lime) can be mixed into soil as a source of neutralising capacity. The liming rate is a calculation of the quantity of 100% calcium carbonate required to neutralise all existing and potential acidity. The reported liming rates typically include a conservative correction factor e.g. 1.5x.
Limit Of Reporting (LOR)	The detection limit for the specific analysis based on the laboratory determined Method Detection Limit (MDL), usually at 99% confidence.
MBO	Monosulfidic Black Oozes are materials found in soils and sediments that contain monosulfides (predominantly iron monosulfides but also consisting of other compounds including hydrogen sulfide; H_2S). They are typically black gel-like materials, that can be oily, high in organic matter and have a distinct rotten egg gas (H_2S) odour. ASS materials which contain an Acid Volatile Sulfide concentration equal or greater than 0.01%.Often located within low flow, waterlogged anoxic environments (such as drainage channels) and forming black iron monosulfide precipitates through sulfate reduction within iron rich environments. It is significantly harmful to surrounding environment including deoxygenation of water bodies (if mobilised).
Net Acidity	A calculation summing up the capacity of a given soil to generate acidity under favourable conditions. The Acid Base Accounting (ABA) approach is accepted by industry as the main method used to predict net acidity resulting from the oxidation of sulfidic material and is determined via: Net Acidity= (Potential Sulfidic Acidity) + (Actual Acidity) + (Retained Acidity) – (Acid Neutralising Capacity) ANC can only be included in net acidity if corroborated with incubation testing.
Peroxide Oxidisable Sulfur (S_{POS})	Sulfur oxidised by peroxide digestion and calculated as %S (per mass of dry fine earth (<2 mm). As this method employs a strong chemical oxidant (30% w/w hydrogen peroxide; H_2O_2), it provides a measure of the maximum amount of potentially oxidisable sulfur in the soil sample and hence can be used to estimate the potential sulfidic acidity. The peroxide digestion method can overestimate the potential sulfidic acidity in soils where appreciable organic sulfur is present and is oxidised by peroxide (e.g. soil layers rich in organic matter).
pH_{KCl}	Potassium chloride suspension pH. The pH in a 1:40 (Weight/Volume) suspension of soil in a solution of 1 mol potassium chloride. Soils with a pH_{KCl} between 5.5 and 6.5 and no sulfides are deemed to pose a lower risk and therefore do not have Titratable Actual Acidity (TAA) measured. Soils with a pH_{KCl} in this range that do contain sulfides should have TAA measured.
pH_{FOX}	Peroxide oxidised suspension pH. The pH in a suspension of soil after initial digestion by 30% hydrogen peroxide. Following oxidation, pH_{FOX} is measured.

Terminology	Definition
pH_F	A field suspension pH, the pH in a suspension of deionised water, compared to the pH_{FOX}. Typically, a pH_{FOX} value at least one unit below field pH_F may indicate a PASS.
Pore water	Pore water is the water that occupies the small spaces, or pores, within soil, sediment, or rock. It's the water found between soil particles, within the voids of rock formations, or in the spaces of any other porous material. It can also be analogous to groundwater.
Potential acid sulfate soils (PASS)	Soil containing iron sulfides or sulfidic material that has not been exposed to oxygen and become oxidised. The field pH of these soils in their undisturbed state is pH 4 or more and may be neutral to slightly alkaline. These materials will become acidic if given the opportunity to oxidise.
Potential sulfidic acidity	A measure of the unoxidised sulfides in a material that have the potential to produce acid if oxidised. Potential sulfidic acidity is measured through chemically oxidising any sulfides present followed by titrating the acidity generated. For unoxidised soil material (with negligible acid-buffering/acid-neutralising components) the Titratable Sulfidic Acidity is often comparable to the potential sulfidic acidity predicted from sulfur measurements (e.g. S_{POS}).
Reduced inorganic sulfur (RIS)	Reduced inorganic sulfur (RIS) in acid sulfate soils refers to the source of the acidity, for example typically iron sulfide minerals, like pyrite (FeS_2), that form under waterlogged, low-oxygen conditions when sulfate from seawater or groundwater reacts with iron and organic matter.
Retained acidity	The less available fraction of the existing acidity (not measured by the Titratable Actual Acidity) that may be released slowly into the environment by hydrolysis of relatively insoluble sulfate salts (such as jarosite, natrojarosite, and other iron and aluminium hydroxy-sulfate minerals).
Sulfide	Minerals containing the sulfide ion (S^{2-}), in the instance of ASS most commonly found in the form of pyrite (FeS_2). Can be oxidised when removed from an anoxic environment and produce acidity depending on the mineral species.
Sulfidic soils	See potential acid sulfate soils
Sulfate	Minerals containing a sulfate ion (SO_4^{2-}), in the instance of ASS commonly in the form of jarosite. They can be formed from the oxidation of sulfides and can mobilise acidity into pore water under wet reducing conditions.
Sulfuric soils	See actual acid sulfate soils
Suspension Peroxide Oxidation Combined Acidity and Sulfur analytical method (SPOCAS)	The suspension peroxide oxidation combined acidity and sulfur (SPOCAS) method is a peroxide based method of measuring the acid generating potential of an acid sulfate soil. The SPOCAS analytical suite measures both the acidity and the sulfur content and provides a set of analytical results and derived calculations that allow calculation of net acidity. It is an alternative to the Chromium Reducible Sulfur test. The SPOCAS method involves the measurement of pH, titratable acidity, sulfur, and cations on two soil sub-samples. One soil sub-sample is oxidised with hydrogen peroxide and the other is not. The differences between the values of the analytes from the two sub-samples are then calculated. It is not recommended to use this method on samples with high organic matter content as it can overestimate the acidity.
Titratable Actual Acidity (TAA)	Acidity titration with standardised sodium hydroxide to pH 6.5 on 1:40, suspension in 1 mol potassium chloride. TAA is a measure of the soluble and exchangeable acidity already present in the soil, often as a consequence of the previous oxidation of sulfides.

1. Introduction

Following completion of an assessment of the probability of Acid Sulfate Soil (ASS) occurrence in the Waikato region (GHD, 2024), Waikato Regional Council (WRC) commissioned GHD Limited (GHD) to prepare this guidance document. The intent of this guidance document is to provide technical advice to help improve the assessment of ASS and guide the regulatory response. In particular, the aim is to standardize ASS assessment and management to reduce the risks presented by ASS to the environment and infrastructure.

This document will support the reader in the following ways:

- Introduce and define ASS
- Identify the circumstances whereby ASS may present a risk
- Identify how to conduct an investigation and test soil
- Present methods that can be adopted to manage or reduce risks arising from the disturbance of ASS.

This document has been deliberately compiled as a concise summary. As such it does not go into detail on some matters, such as where ASS are to be found in New Zealand or the complex considerations for site specific ASS risk assessment. If further supporting information is required, the reader is directed to the Australian guidance references listed above.

1.1 Purpose of this document

The purpose of this guidance document is to provide an introduction to ASS and assist in identifying the ASS risk for sites located within the Waikato Region of New Zealand. This guidance document also summarizes Waikato Regional Council's technical expectations for the implementation of site investigations, including reporting and management of ASS during site disturbance activities.

This guidance document has been prepared specifically for the above purpose. While the principles presented herein may apply more broadly than for the stated purpose, specific consideration has not been given to other purposes. For example, the applicability of procedural processes to other regions of New Zealand has not been considered.

1.2 Acid Sulfate Soils

Defining Acid Sulfate Soils

Acid sulfate soils are naturally occurring sediments and soils which contain, or have been affected by, reduced inorganic sulfur (RIS). The Australian National Acid Sulfate Soil Guidelines (Sullivan et al, 2018) distinguish ASS from other soil or sediment materials as having the following properties or behaviours:

1. Having been affected considerably by the oxidation of RIS, or
2. The capacity to be affected considerably by the oxidation of their RIS constituents.

RIS components can have significant influence on the geochemical and mechanical properties and behaviours of materials and/ or soils. These RIS components are often in the form of iron sulfides, with the main form of sulfide present being pyrite (FeS_2). While most ASS material is associated with former coastal marine sediments, there are numerous possible explanations for the presence of these iron sulfides.

Despite the similarities in the risk presented, multiple origins of the RIS components sometimes leads to differences in opinion on which soils or sediments should be defined as ASS. For example, whether inland RIS-containing soils are included, whether volcanogenic sources of sulfur are included, or whether anthropogenic contamination or acidic drainage associated sediment sources are included. However, these differences predominantly impact the prediction of where ASS may be present, rather than whether it may present a risk.

Therefore, for the purpose of this document, all RIS-containing and/ or RIS-affected materials are included. It is noted that regional maps (including the maps generated by GHD (2024) for WRC) which indicate the probability of

ASS being present are unlikely to reflect all these possible sources, and due consideration should be given to these limitations.

Table 23 summarises the common classifications used to describe ASS.

Table 23 Common classifications of ASS materials

Term	Definition
NASS	Non acid sulfate soil
AASS	Actual Acid Sulfate Soil (ASS materials that have already been oxidised and are strongly acidic) Already acidic with a pH <4 Often contain jarosite Also known as sulfuric soils
PASS	Potential Acid Sulfate Soil (ASS materials that would become strongly acidic if allowed to oxidise completely) Neutral pH (or near neutral pH) with a potential to oxidise Not harmful to the surrounding environment if left undisturbed Also known as sulfidic soils

Formation and occurrence

The sulfides present in ASS form and persist in anoxic (oxygen-limited) conditions. Some sulfides are formed by naturally occurring, sulfate-reducing bacteria. The bacteria reduce sulfate to form sulfide. The sulfate can be derived from any source; however it commonly originates from seawater, which has an abundance of sulfate. Sulfides can also be present in soil and rock from other sources, such as in volcanogenic soils or because of anthropogenic environmental contamination.

The typical genesis of ASS occurs when sulfate-reducing bacteria degrade organic matter through anoxic respiration involving sulfate, which produces hydrogen sulfide (H_2S) as a waste. Once the H_2S waste is available within the environment, it reacts with positively charged metals, with the most commonly available metal being iron, to produce pyrite and bicarbonate. The soluble bicarbonate is often flushed out via tidal movement or groundwater outflow, while the insoluble pyrite and other metal sulfides typically accumulate and persist within the sediments.

The typical environment where this formation occurs is anoxic, aquatic environments. These environments are also, typically, relatively warm, low energy (calm) marine environments rich in organic matter (Macdonald, et al., 2002). As a result, ASS are usually found in coastal environments such as wave-protected mangroves, saltmarshes, outer barrier tidal lakes, backswamps, other wetlands, and sites of land reclamation. These soils are commonly, but not exclusively, coastal and of Holocene age (up to ~10,000 years ago). ASS can also be found inland or at higher elevations due to favourable environments of formation, tectonic uplift, receding sea level or human activity. Similarly, while it is unusual for ASS to have persisted longer than 10,000 years to the present day, it can occur in older sediments or soils of sedimentary origin.

Common impacts of ASS disturbance

Acid sulfate soils are stable when in an anoxic environment. However, when exposed to oxygen the sulfides become unstable and oxidise, producing sulfuric acid and resulting in the mobilisation of metal ions (Equation 1)[1]. As acidity builds up, ferrous iron can facilitate the generation of additional acid. These processes can happen rapidly, sometimes within a matter of days or hours in extreme cases, such as may be encountered with monosulfidic materials (often referred to as monosulfidic black ooze (MBO).

$$FeS_2 + \frac{15}{4}O_2 + \frac{7}{2}H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$$

Equation 1

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[1] This is a simplification of the more detailed processes, equations, and kinetics. It is not intended as a full explanation but to assist the reader in a general understanding of the process.

$$pyrite + oxygen + water \rightarrow iron\ hydroxide + sulfuric\ acid.$$

The risks associated with the oxidation and subsequent acidification of ASS can generally be summarized into five (5) groups, including:

1. Environmental degradation
2. Loss of economic value
3. Damage to infrastructure
4. Loss of social, amenity or cultural value
5. Human health risk

Environmental degradation

Acid generation from the oxidation of ASS materials can result in degradation of soil, surface and groundwater quality. In extremely low pH conditions acidity can lead to increased solubility of metals in water (Wilson, 1995) and have deleterious effects on flora and fauna (Sammut et al, 1993).

Metals normally bound to soil minerals and particulates (particularly aluminium, iron, arsenic, manganese, zinc and copper) within conditions typically less then pH 4 generally dissolve within groundwater and surface water. Once exposed to atmospheric conditions (oxygen) and/ or increases in pH these metals may undergo precipitation and or oxidisation and lead to further harm including deoxygenation in water bodies, staining banks and infrastructure, and a reduction in biodiversity due to smothering of aquatic vegetation and fish kills). These changes in geochemical conditions can also lead to physical degradation of the soil structure.

Likewise, nutrient dynamics can also be affected by acidic conditions which can lead to increased mobility (or leaching) of nutrients (such as nitrogen, phosphorous and potassium). Fixation of phosphorous due to the increased presence of iron and aluminium oxides can also contribute to a decline in soil fertility and soil condition.

The affected surface water and groundwater may impact surrounding environments located some distance away from the original site via (including but not limited to) the transportation of precipitate and/ or secondary reactions.

Undisturbed ASS typically oxidise slowly over time due to gradual environmental changes (e.g. a seasonally fluctuating groundwater table). The effects of gradual oxidation are commonly within an environment’s ability to buffer and tolerate the changes, resulting in only minor degradation. However, this does not preclude the possibility of natural rapid oxidation, such as through erosion and downcutting of waterways or rapid tectonic uplift.

Loss of economic value

The presence of ASS can adversely impact on land value through actual and perceived cost implications for management, landowner legal obligations and reduced agricultural productivity. This effect on land value can be more pronounced where the impacts of ASS become so severe as to noticeably influence environmental degradation, damage infrastructure, cause loss of amenity, or where there is a risk to human health.

Besides the impacts on the terrestrial environment, acid runoff has also been implicated in the decline or failure of agriculture, fishery and aquaculture industries.

However, where the risks of accelerated oxidation of ASS are avoided or appropriately managed, impacts on economic value can be minimised and, in many cases, become negligible.

Damage to infrastructure

The geochemical changes which result from the oxidation of ASS, such as acidification and production of sulfate, can directly lead to the degradation of infrastructure exposed to these conditions. For example, the generation of highly corrosive sulfuric acid can degrade concrete structures, shortening their lifespan.

Concrete exposed to acidic conditions can experience various forms of deterioration, including loss of cement paste and aggregate, rust staining, cracking, and spalling. This is particularly concerning for concrete infrastructure in contact with groundwater that has been designed with long life expectancies, such as structural foundations, bridge abutments, stormwater pipes and pavements.

In addition to the direct corrosive effect, the exposure of concrete to acidic conditions can lead to the formation of secondary minerals, like gypsum, which in turn lead to cracking, spalling and loss of strength.

Metal infrastructure, such as products made from iron and aluminium, is also vulnerable to direct corrosion under strong acidic conditions, compromising their integrity and potentially affecting reinforced pipes and other utilities in direct contact with strong acid (Fitzpatrick et al, 1998).

Degradation of infrastructure tends to occur through chronic exposure to acidified conditions but can be rapid under extremely acidic conditions. For example, prolonged dry periods can lead to the accumulation of sulfuric acid in soil, which is released into the surrounding environment following “first flush” rainfall.

Although these risks can be reduced through carefully selecting construction materials resilient to aggressive conditions, it is worth noting that many materials standards, such as NZS3101:2006 (Standards New Zealand, 2006), do not consider the processes associated with ASS, and particular care should be taken when considering materials for use in acidic or potentially acidic environments.

Loss of social, amenity or cultural value

The environmental degradation that may result from the oxidation of ASS can reduce the social value and have significant cultural impacts, particularly for tangata whenua. These losses can occur in a number of ways, such as reduced natural character, reduced aesthetics, reduced function or through the impact on cultural value systems, such as Te Ao Māori (the deeply interconnected and holistic Māori worldview).

In Te Ao Māori, the land is not a resource but a living ancestor — Papatūānuku. Harm to the land is a direct harm to whakapapa and the spiritual responsibilities of kaitiakitanga (guardianship/stewardship). These impacts can manifest as the loss of access to taonga (treasure) such as mahinga kai (traditional food gathering places and practices), degradation of wāhi tapu (sacred sites), and disruption of tikanga (cultural practices) and mātauranga Māori (customs and traditional knowledge). Such losses diminish the mana (authority/integrity) of tangata whenua and sever the relational ties that underpin identity, wellbeing, and intergenerational connection.

Similarly, the degradation of natural character and reduced land function can affect broader social values, including the loss of recreational spaces, emergence of noxious odours, and closure of culturally significant gathering areas.

Human health risks

The potential impacts from ASS (and subsequent acidification) may extend to human health in certain circumstances such as exposure to acidic soils and waters contaminated with elevated metals such as arsenic through ingestion, inhalation and dermal contact.

While any rapid oxidation of ASS has the potential to cause these effects, ASS are relatively inert when undisturbed and generally natural processes of oxidation are slow enough to not result in significant accumulation of adverse impacts.

Examples of impacts and associated activities

Figure 1 provides some examples of how ASS and subsequent metalliferous mobilisation can impact the environment.

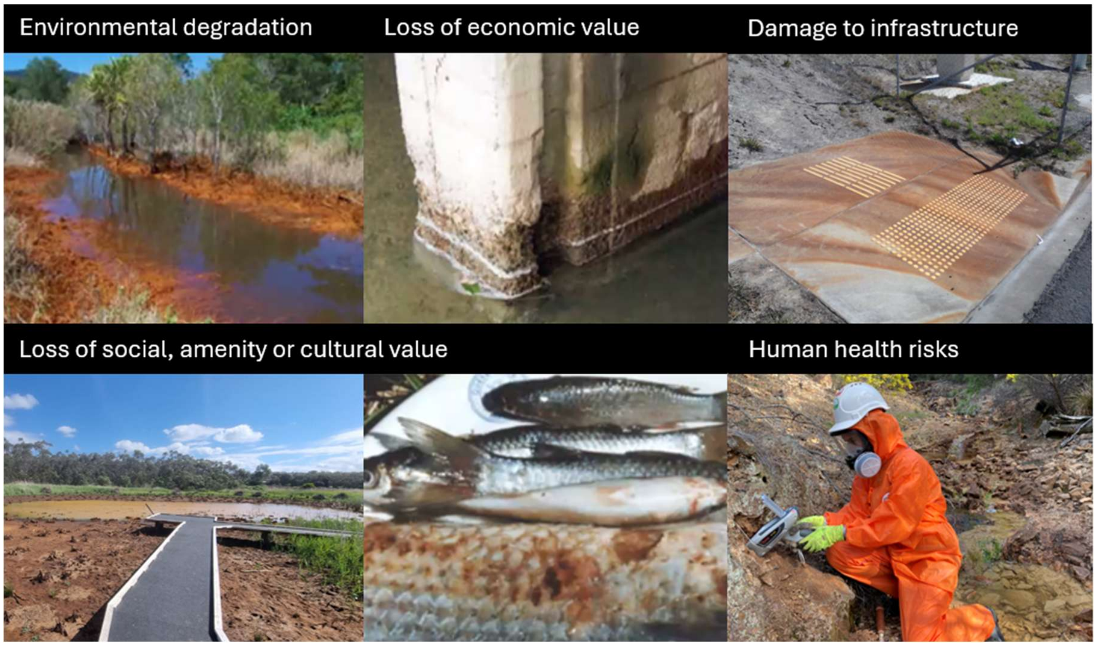

Figure 1 *Examples of the direct and indirect impacts from ASS.*

Common activities or disturbance that can expose AASS and PASS include:

1. Land development and infrastructure (installation of services, roads and railways)
2. Drainage and flood mitigation works including changing flow paths
3. Any activity that alters drainage patterns and disturbs soils e.g., agricultural practices.
4. Dredging and/ or land reclamation using dredged sediment
5. Dewatering or lowering of the groundwater table to expose ASS materials that aerates previously saturated soils
6. Surcharging or displacement of naturally occurring soils
7. Reuse of AASS and PASS (Naylor et al, 1998) without appropriate management.

1.3 NZ Context

Acid sulfate soils have only recently been identified in New Zealand at a limited number of locations. In at least one instance, the infrastructure damage has been subject to civil litigation, and details regarding the practical and financial consequences are unavailable in the public domain. There are several examples in the Waikato region where ASS has been investigated by WRC due to unacceptable environmental risks. Overall, there is limited research on the occurrence of ASS within New Zealand and limited industry guidance with no specific (or mandatory) regulations to date. Waikato Regional Council has been proactive and wishes to improve on the identification and management of ASS in the region.

To help understand the ASS risk present in the region, Waikato Regional Council prepared the Waikato Region - Acid Sulfate Soils Preliminary Risk Assessment (GHD, 2024). This risk assessment provides a report and associated map presenting the findings of a preliminary spatial assessment of the probability of occurrence of ASS within the Waikato region. Other regulatory authorities such as Auckland Council (Roberts & McConchie, 2017) and Whangarei District Council (Whangarei District Council GISMaps) have undertaken similar assessments, but these assessments have not been published in full, and further revisions of these assessments are being considered. Following publication of the Waikato assessment and map, Waikato Regional Council commissioned this guidance document to be prepared to help achieve improved management of the ASS risks by raising the level of awareness and understanding of the issue.

In lieu of specific domestic regulations and/or guidance documents, international guidance can be used to inform ASS risk assessments in New Zealand. For example, the Australian National Acid Sulfate Soils Guidance and the similarly designed state-based guidance documents provide robust reference material. Australia also provides numerous standards applicable to design in ASS environments, which may under specific circumstances be helpful when considering domestic projects. However, it should be noted that these foreign guidance documents and standards were not designed for use in New Zealand, and as such care should be applied when considering whether they are appropriate to apply in the New Zealand context. Furthermore, guidance documents do not have legal status, unless incorporated by reference into New Zealand regulations.

As the foreign guidance and standards have not been prepared for a New Zealand context, any risk assessments conducted in New Zealand should carefully consider how the risks of ASS may differ within a local context. There are many factors which may impact the significance of ASS in one location compared with others. For example, the Waikato region experiences large volumes of regular and consistent rainfall, which could influence the production, retention and release of acidity, thereby changing the risk profile. Another factor to consider is that, due to being a geologically active and diverse country, ASS may be encountered in localities and at altitudes not generally expected elsewhere. Similarly, differences in geology, hydrogeology and hydrogeochemical conditions may contribute to variations or nuances in the spatial distribution and persistence of ASS in the region. Despite these differences, insights from experiences with ASS, both domestic and foreign, can provide valuable guidance on the potential significance of the ASS in the Waikato region, if used carefully by appropriately qualified and experienced practitioners.

1.4 Regulatory Requirements

This section is presented only as a high-level guide for the reader and is not intended to be a complete guide. It is recommended that the reader seek up-to-date and independent planning or legal advice on the regulatory requirements that apply to the activities being considered.

This section outlines the regulatory requirements for assessing and managing ASS within the Waikato Region at the time of writing. The regulatory requirements discussed are only those specific to Waikato Regional Council. However, as ASS can also affect land, District Plan rules (set by territorial authorities) may also apply but are not discussed here.

The Resource Management Act 1991 (RMA) is the overarching environmental legislation in New Zealand. Section 15 of the RMA says that no person may discharge any contaminants into water, or into water via land (including as a result of natural processes), unless expressly allowed by a national environmental standard or other regulations, a rule in a regional plan as well as a rule in a proposed regional plan for the same region (if there is one), or a resource consent.

Waikato Regional Council considers discharges from ASS to be regulated by Section 15 of the RMA because, through the activity of a person, ASS may discharge contaminants. These contaminants may include acid or the mobilisation of hazardous substances, such as heavy metals via the activities of a person. Contaminants may then change the physical, chemical and biological condition of the land and water into which it is discharged.

Consequently, ASS can be regulated under the Waikato Regional Plan (WRP) rules for managing the discharges of contaminants. Most often the regulation of ASS will be where they are identified as creating contaminant risk, where it is associated with:

- a land disturbance activity under rules in Section 5.1 of the WRP, which regulate soil disturbance for whatever purpose including general earthworks or other specific activities such as land development, quarrying and mining. The rules for soil disturbance in Section 5.1 incorporate consideration of the discharge of contaminants into water associated with that disturbance; and/or
- discharges to land under rules in Section 5.2 of the WRP where the discharge includes acid-producing material (e.g. potentially in overburden)

In addition, Section 3.5 – Discharges (Water) may be relevant in some cases. The specific rules in these sections may apply pending the nature of the activity being considered. Where a discharge of contaminants is otherwise identified and is not regulated by any specific rule, it is considered a discretionary activity (requiring resource consent).

When considering the above rules and that New Zealand-specific guidelines do not exist, Section 5.2 of the Waikato Regional Plan incorporates the Australian & New Zealand Guidelines for Fresh & Marine Water Quality (formerly Australia/New Zealand Environment and Conservation Council - ANZECC) and United States

Environmental Protection Agency guidelines to aid in determining whether contamination is likely to present a “significant risk”, a term used throughout Section 5.2.

Where a resource consent is required under the rules mentioned above, the objectives and policies in the National Policy Statement for Freshwater Management, the Waikato Regional Policy Statement, the Waikato Regional Plan and the District Plans, can apply to the issue of ASS.

Waikato Regional Council considers assessment of the risk of acid leaching potential from ASS for resource consent purposes is generally likely to be required for land disturbance activities, where:

1. that disturbance is proposed to occur in an area identified in the Waikato Region – Acid Sulfate Soils Preliminary Risk Assessment map as having a ‘medium’ or ‘high’ probability of occurrence of ASS; and
2. the disturbance will be:
    a. greater than 250 m^3, and
    b. deeper than 1 m, and / or
    c. associated with a drainage activity, and / or
    d. If there are any other factors associated with the proposed activity that might increase the risk of disturbance of ASS.

- However, as noted above, we recommend obtaining independent planning or legal advice on the specific regulatory requirements that apply to the activities being considered.
- To ensure that applications for consent are considered complete, Waikato Regional Council asks that applicants describe how they propose to confirm the presence of ASS and manage the soil to avoid, minimise and / or manage the formation of acid leaching effects. While Waikato Regional Council appreciates that ‘one size does not fit all’, the following sections of this guidance document provide a high-level overview of the considerations expected to be addressed by the applicant.

2. Does it apply to my site?

Before commencing any project that may disturb soils or sediments, or indirectly affect soils or sediments through groundwater drainage, it is important to consider the risk of encountering ASS. This section is designed to outline the necessary steps recommended to determine the risk and resulting actions for the assessment of ASS risk in a project. Figure 2 outlines these steps as a decision tree, adapted from McDonald and TDPIPWE (TDPIPWE, 2009) to consider the unique environmental context of New Zealand.

The following process tree details the steps for considering the environmental risk of ASS on a project within the Waikato Region. However, ASS may still be a consideration to your project from the perspective of materials selection and durability for ensuring sufficient protection of infrastructure.

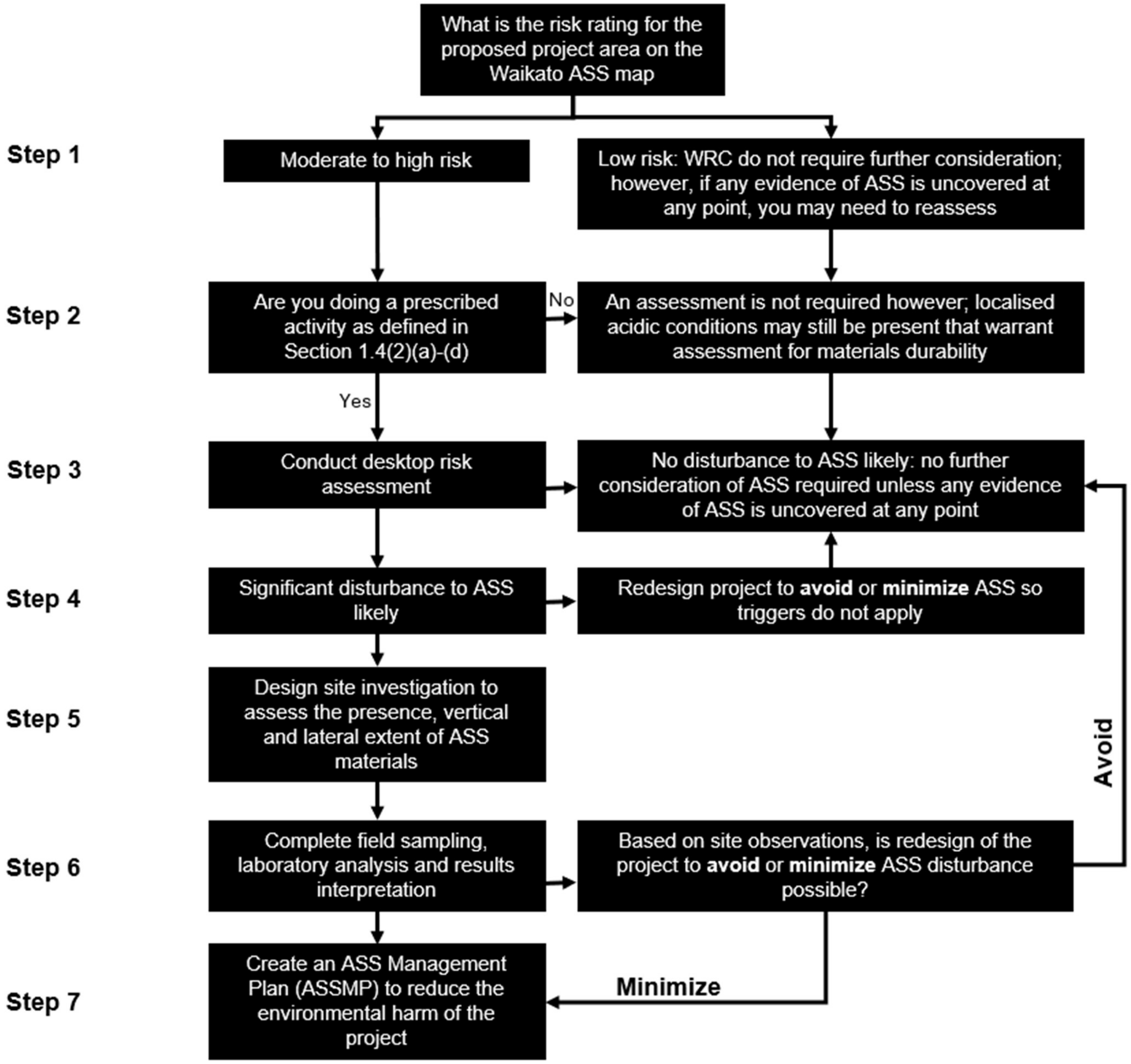

Figure 2 *Decision Tree*

3. Guiding principles

When a project is proposed to be undertaken on a site likely to be impacted by ASS, a staged approach should be taken to risk management. The following hierarchy of management options is recommended to reduce the costs of assessment, remedial actions and the possibility of residual ASS impacts. The hierarchy of management options is presented below:

1. Avoidance
2. Minimisation
3. Management and treatment

3.1 Avoidance

The most effective and environmentally safe strategy is always to avoid disturbing ASS. This approach minimizes risk, as PASS remain stable when confined to anaerobic (oxygen-free) conditions. Moreover, avoiding disturbance is typically the most cost-effective option since the potential harm to public health, ecosystems, infrastructure, and the associated remediation or regulatory expenses often outweigh any perceived benefits.

Disturbance encompasses more than physical excavation of soil. It is intended to include any activity that impacts groundwater levels, as changes in groundwater can increase the risks associated with ASS, such as:

- Raising groundwater: This may interact with existing AASS, mobilizing stored acidity into groundwater and surface water.
- Lowering groundwater: This may expose PASS above the water table, increasing oxygen exposure and potentially triggering acid generation.
- Displacing acidic groundwater: This could introduce acidic water into adjacent water bodies.

A site-specific ASS Management Plan should be prepared to demonstrate the proactive steps taken to avoid disturbance, where practicable. If disturbance is unavoidable, the plan should present a well-reasoned justification based on site-specific considerations.

It is critical to recognize that ASS can exist not only in disturbed or undisturbed natural soils and sediments, but also within fill material. In areas with both a high likelihood of ASS and past land disturbance, historical earthworks may have occurred without proper documentation or assessment. These sites pose additional risks, as reburied ASS material may have already oxidized into AASS without adequate treatment or mitigation.

3.2 Minimisation

When it is not feasible to avoid disturbing ASS, the next best approach is to minimise the extent and impact of any disturbance.

Effective minimisation begins with a comprehensive ASS investigation that accurately maps both the distribution of actual and potential acidity across the site, as well as the local groundwater dynamics and interaction with surface water. This thorough understanding of site conditions should inform a conceptual site model and an assessment of relevant risks. These steps allow for the development of tailored minimisation strategies that are both site-specific and informed by a robust risk assessment process.

Minimisation techniques may include, but are not limited to, adjusting the scope and location of earthworks, choosing methods that reduce soil or groundwater disturbance, and carefully timing interventions to limit exposure to adverse conditions.

By proactively identifying areas of higher risk and planning works accordingly, projects can substantially reduce the environmental, civil and health risks associated with disturbing ASS, while also minimising the need for costly remediation measures down the line.

3.3 Management and treatment

There are several options for management and treatment in areas where avoidance and minimisation measures are deemed insufficient to reduce risks to acceptable levels.

As for mitigation, the development of management and treatment measures for a project should consider the site-specific conditions and be informed by the results of thorough site investigation.

Broadly, management can include strategic reburial, temporary stockpiling and containment and / or soil treatment. Summaries of acceptable management strategies can be found in Section 5.

4. Investigation planning

4.1 Investigation levels

We have identified the different levels of ASS investigation that are relevant for a project based upon the stage of works, scale of the project and the risk of ASS for the area. These are summarised in Table 4.

Table 4 Investigation levels

Investigation level	Suggested use
Desktop assessment	This can be completed at the pre-feasibility stage of a project. The assessment should use existing information including previous reports, council information, satellite imagery, and maps. The desktop assessment should determine the likelihood of ASS based on the elevation, geology, depth / extent and volume of disturbed material and consult the ASS probability layer of Waikato Maps (Biodiversity & Environment) on the Waikato Regional Council's webpage, . On the basis of the desktop assessment a site-specific preliminary conceptual site model should be developed that considers the potential sources, exposure pathways and receptors for contaminants derived from ASS.
Site assessment	If the desktop assessment established that there may be potentially unacceptable risk(s) from ASS within the project area, a site assessment should be designed to gain an in depth understanding of the extent and severity of ASS. This should include a targeted field sampling program, with laboratory analysis and interpretation. This assessment should include an updated conceptual site model.
Management plan and Remediation Action Plan	If ASS discovered in the site assessment cannot be avoided through project redesign, a management plan or remediation action plan (RAP) should be developed that considers the risks of ASS that can be mitigated. The management plan/ RAP should provide detailed instructions that mitigate the risks created by ASS disturbance. The management plan/RAP should also detail the remedial goals, actions, methods, success parameters and contingency measures.
Remedial options assessment and remedial action plan	If there is ASS discovered in the site assessment, which cannot be avoided or mitigated to an acceptable level of risk, a remedial options assessment can be conducted to evaluate and compare different approaches to address the ASS risk onsite. With the aim of selecting the most effective and sustainable method of remediation. This process should also further consider options to avoid or minimise the disturbance in the first instance. This is a useful step when a proposed project is very complex or large in scale and there are several remediation options that could be applied.
Validation reporting	If the project disturbed ASS and a management plan or remedial action plan has been implemented to mitigate the risk(s) of ASS disturbance, a validation assessment and report should be undertaken during and upon finalisation of the project to confirm that the management plan has effectively mitigated the risk. The scope of this assessment is proportionate to the magnitude of the risk(s) remedied or mitigated.

4.2 Desktop Assessment

The desktop assessment is a useful preliminary review of the risk of ASS without the need to complete intrusive works. It will determine the need for further works and help develop a conceptual understanding of the site-specific features.

A desktop assessment should consider the relevant regulatory framework for the site. It should also consider the interaction between the potential ASS and the proposed activities, as not all activities will disturb ASS to the same extent. While a desktop assessment should take advantage of the Waikato ASS map, the limitations of the map need to be acknowledged (including limitations of scale). The practitioner should adopt an evaluation approach that considers multiple lines of evidence, such as soil type, geology, hydrogeology and hydrology, topography and ecological setting.

4.3 Field Investigation

A field investigation program should be tailored to suit the scope and limitations of each project. The design and sampling practices described below are based upon the considerations for a typical investigation.

Design

The field investigation program should be designed to provide sufficient information regarding the ASS site risk(s). A site assessment report should include a detailed map or other representation of the identified ASS occurrence and absence. This may include cross-sectional diagrams or conceptual models. These outputs will require adequate sampling intensity and statistically robust methods. Soil sample intensity is dependent on the nature, depth and size of the disturbance proposed and the sensitivity of the surrounding environment.

The Australian National ASS sampling and identification methods manual provide Table 5 as a typical intensity for test pits or boreholes required based on expected ground disturbance.

Table 5 Typical number of sampling locations based on site disturbance area.

Area of site	Typical number of sampling locations
Up to 1 ha	4 locations
1-2 ha	6 locations
2-3 ha	8 locations
3-4 ha	10 locations

The appropriate number of sampling locations and samples is specific to the project and should be informed by the judgment of an appropriately qualified and experienced practitioner. The rationale for the sampling intensity should be provided in a “Sampling and Analysis Plan” to guide the field work which should be appended to the site assessment report.

Projects that involve extensive excavations in high risk settings may require more intensive sampling programs (e.g. 50 m intervals along a transect for canals, manmade lakes, drainage channels or borrow areas). Sampling intensity and placement should consider the likelihood of ASS, and site-specific factors including elevation and the presence of surface water bodies on the site. There can be instances where reduced sampling intensity may be appropriate, such as areas where the ASS risk is low (e.g. areas with hard rock underlying the soil material).

Each sampling location should have the following information recorded:

- The location of each borehole or test-pit using New Zealand Transverse Mercator 2000 (NZTM2000) or latitude and longitude and its existing surface height (NZVD) should be recorded in the report as coordinates (at a minimum) and preferably also plotted on a map.
- Field descriptions of the soil horizons following the NZ soil logging standards outlined in the New Zealand Geotechnical Society’s guidelines (NZGS, 2005) or the Soil Description Handbook – New Zealand (Milne et al., 1995). The descriptions need to include details such as soil texture, colour, mottling, odour and presence of jarosite, shell and carbonate materials.
- Photographs of the soil profiles or soil cores.
- Depth below the surface of any water table. If groundwater is encountered a sample of groundwater should be collected and analysed.
- Field pH (pH_F) and peroxide pH (pH_{FOX}) in each soil horizon (guided by soil texture and/or colour changes).

Subject to the site geological and hydrogeological conditions, at each sampling location the sampling of the vertical soil profile should be conducted at 0.5 m intervals and should continue to at least 1 m below the depth of the expected ground disturbance or at least 2 m from surface, whichever is the greater.

If distinct soil horizons occur, all discrete samples should be confined to a singular horizon. If there are multiple soil horizons in a 0.5 m interval, all soil horizons should be sampled (ensuring that each sample represents a distinct horizon).

It is important to collect and store an adequate number and volume of samples during the field investigation. The minimum dry weight of samples should be approximately 0.5 kg (at <2 mm particle size) to ensure sufficient volume for lab analysis. Additional sample will be required for samples with particles greater than 2 mm as these are discarded prior to testing. Even if not all samples are analysed initially, collecting additional samples at the onset will reduce the risk of needing to conduct additional field sampling later, saving the project both time and expense.

Soil Sampling

While there are several factors to consider when sampling for ASS, the methodology generally mirrors the standard practice used for sampling contaminated soil, such as those presented in the Ministry for the Environment, Contaminated Land Management Guidelines No.5 Site Investigation and Analysis of Soils (2021). There are a few key sampling practices to consider:

- Sampling methods should avoid cross contamination between specified depths as much as practicable. Decontamination of sampling equipment between sampling intervals is essential.
- Remove all visible shell fragments within a sample. Remaining shell could lead to overestimation of the acid neutralising capacity of the sample, as broken or ground shell caused by sample prep/drilling can create fresh exposure and increase the reactive surface area. Moreover, shells found in ASS are often coated with relatively insoluble substances such as gypsum, silica, or iron compounds. This reduces the effectiveness of the carbonate content for neutralisation in a natural state, which further increases the likelihood of overestimating a sample’s true neutralising capacity.
- Use waterproof labels. Due to the high moisture content commonly found in ASS samples, waterproof labels are essential to avoid misidentification of materials.
- Samples need to be frozen, or else dried by the laboratory immediately on receipt to minimise sulfide oxidation. Place samples in a portable freezer or chilly bin with ice blocks and transfer to a freezer at the end of each field day. Samples must also be fully frozen and kept cold during transport to the laboratory. Keeping samples refrigerated is adequate provided that the refrigerated samples are received by a lab within 24 hours and dried locally. However, due to the limitations of available local testing in New Zealand (discussed in Section 4.3) the practice of freezing all samples is generally preferred.

Field pH_F and pH_{FOX}

Field pH and field peroxide pH determine the pH of the soil in its current state and the pH of the soil once full oxidation of RIS has occurred. Field pH is collected using a soil:water paste method with deionised water. The field peroxide pH is collected using 30% H_2O_2 (hydrogen peroxide) and soil mixture. These tests generate a rapid initial result for the estimated unoxidized versus oxidised acidity, however they should not replace actual laboratory analysis. Samples with high organic content will also react with the hydrogen peroxide and cause a false positive result, which is why completing the laboratory analysis is important to verify the preliminary field test results.

These tests can also be quite time consuming in the field and are hard to achieve during a field program if there are many samples being collected. While in an ideal scenario these tests should be performed during the site sampling, in some cases it has been acceptable to complete them as soon as practicable after the field sampling event.

Indications of a risk of ASS can be determined by looking at the difference in the initial field pH and the field peroxide pH test, a difference of 1 pH unit or more can indicate that ASS is present. Samples with a pH of 4 or less suggest there is a likelihood of ASS and this should be confirmed with additional laboratory testing. Samples with a pH higher than 4 could either have some inherent neutralising ability or a lower acidity. In all cases further testing will quantify the acidity and the potential, actual and retained fractions and give an indicative level of ANC.

MBOs

Monosulfidic black oozes are black gel like materials, often with high moisture content and an oily appearance. They may also have a sulfidic (rotten egg) odour. These monosulfides have the potential to oxidize extremely quickly since they have an amorphous structure and they can represent a severe environmental hazard requiring special testing and treatment.

If monosulfidic black oozes are suspected, they should be collected as a discrete sample and their extent documented as part of the field notes and photography. Australia has a dedicated guidance document for MBOs that is the most appropriate resource for the overview and management of these materials (WQA, 2018). This includes specific laboratory testing known as acid volatile sulfide (AVS).

Water sampling

Similar to soil sampling, most of the sampling techniques for water mirror the standard practices used for contaminated water sampling, such as those described in the Drinking Water Standards for New Zealand (DWSNZ, 2008) and the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG, 2018). The same considerations as those described above should be applied for cross contamination, sample preservation and labelling.

At a minimum the following should be completed:

- Any identified surface water (or GW, if wells exist) on site should have field analysis of pH, electrical conductivity (EC) and dissolved oxygen (DO) measured with a water quality meter.
- Surface water (or GW if available) should be sampled and analysed, information about recommended minimum analysis is included in section 4.4.

ANC corroboration sampling

Using total carbon or back titration alone is not a reliable method for determining the acid neutralising capacity (ANC) of a soil sample. These approaches may fail to provide an accurate reflection of how effectively the material (such as biogenic shells and large shell fragments) can neutralise acidity. These shells, although present, are not effective in neutralisation but are still measured as ANC when the soil is oven-dried, finely ground, and analysed by standard ANC methods. As a result, ANC values should be ignored and not be relied upon when calculating a sample’s net acidity (refer to Section 4.4) or required lime amendment rates unless the ANC testing is supported by additional evidence, such as incubation testing.

Corroboration can be performed by completing slab or chip tray incubation testing. It is therefore prudent to collect sufficient sample material for ANC corroboration during the field investigation to avoid having to resample later. These samples must be collected as a separate sub-sample to the parent ASS sample as their preparation and storage differ from the primary ASS samples. Samples for incubation need only be collected for material with a field pH of ≥4. Samples need to be a minimum of 200 g for slab incubation testing and 20 g for chip tray testing. Samples must be kept sealed to reduce moisture loss during transport. Samples should be refrigerated but not frozen during transport. Incubation testing can take a minimum of 9 weeks to complete so this should be considered when designing a site investigation plan. For further details on incubation testing see Appendix C: Laboratory incubation within the Australian National Acid Sulfate Soils Guidance report (Sullivan et al., 2018).

4.4 Laboratory analysis

At the time of writing this guidance document the full suite of ASS lab analysis required for a site assessment is not provided locally in New Zealand. However, several laboratories will act as collection points and will prepare the samples before arranging shipment to Australia for the full suite of tests. This should be a consideration when designing field sampling programs and site assessment, as it will impact the timeline and costs associated with the investigation.

The chemical analysis of samples should be conducted by laboratories which hold National Association of Testing Authorities (NATA) accreditation for the parameters and methodologies required. Quality control procedures should include laboratory control standards (LCS) and duplicate analyses (for example 10% of samples duplicated). When undergoing ASS assessment soil samples should be analysed for both chemical and physical properties.

Physical analysis

There are three main considerations for physical properties: testing for moisture content and bulk density and determining gravel fraction (>2 mm). The moisture content must be determined when quantifying the chemical composition of any soil materials and the bulk density of the soil needs to be considered when determining the amount of soil being disturbed, as well as for calculating the amount of lime needed to treat a given volume of soil.

Chemical analysis

The current New Zealand standard for ASS chemical analysis is ISO14388-2 which uses the chromium reducible sulfur (CRS) suite to determine acid base accounting (ABA). ABA should include the chemical methods summarised in Table 6.

Table 6 Chemical methods of ASS assessment.

Chemical method	Presented as	Comments
Potential sulfidic acidity	Chromium reducible sulfur (CRS) Peroxide oxidizable sulfur (S_{POS})	Potential Sulfidic Acidity is calculated from the chromium reducible sulfur and peroxide oxidisable sulfur and assumes both are in the form of pyrite, with the potential to be completely oxidised. This method provides both sulfur and acidity content.
Actual acidity	KCL extractable pH (pH_{KCL}) Titratable actual acidity (TAA)	Actual Acidity consists of the soluble and exchangeable acidity in the soil. Actual Acidity is calculated with the Titratable Actual Acidity (TAA) method and is excluded from analysis when the KCl Extractable pH (pH_{KCl}) is greater than or equal to a pH of 6.5.
Retained acidity	Net acid soluble sulfur (S_{NAS})	Retained Acidity is the acidity retained in poorly soluble iron and aluminium hydroxy sulfate minerals (for example jarosite and schwertmannite). Retained Acidity is included in the analysis when a TAA extract has a pH_{KCl} less than 4.5, or where jarosite has been observed in the soil layer/horizon from which the sample was taken.
Acid neutralising capacity	Total inorganic carbon (C_{IN}) Back titration (ANC_{BT})	The Acid Neutralising Capacity (ANC) is a measure of a soil's inherent ability to buffer acidity and resist the lowering of the soil pH. In the analysis of ASS materials, ANC is only considered to be effective when the TAA extract has a pH_{KCl} of greater than or equal to 6.5. When the TAA extract has a pH_{KCl} less than or equal to 6.5, ANC is excluded from the Net Acidity calculation.

Things to note when selecting analyses:

- The Peroxide Oxidisable Sulfur method is unsuitable for soil materials with high organic matter contents (>0.6% organic carbon) as it can cause false positive identification of ASS. Peroxide Oxidisable Sulfur results need corroboration by Chromium Reducible Sulfur results regardless of the soil organic matter content.
- While the ANC of a soil material can be determined by Total Inorganic Carbon (C_{IN}) and back-titration (ANC_{BT}) methods, these ANC methods cannot be used as part of the net acidity of a sample or liming rate calculations unless the ANC results are corroborated with other data such as incubation testing.
- While acidity is the main hazard from ASS, metal and metalloid mobilisation risk should also be considered, especially if there are sensitive areas downstream of the disturbance area. The oxidation and acidification of ASS materials can lead to substantial changes in metal and metalloid mobility. Sequential metals and metalloid extraction should be completed at a range of pH values to assess metal and metalloid mobility risk. This is commonly done with sequential leaching but other leaching techniques such as, Leaching Environmental Assessment Framework (LEAF) method 1313 (EPA, 2025) and Australian Standard Leaching Procedure (ASLP) (Australian Standards, 2019) can also be useful.

At a minimum water samples (surface and groundwater) should be analysed for the parameters listed in Table 7.

Table 7 Water quality analysis

Analyte	Comment
General water suite: Major ions (Ca, Mg, Na, K, Cl, SO4) pH EC DO Alkalinity, Acidity	The general suite provides a broad understanding of the sites existing water quality, this can be expanded on depending on the specific concerns and risks of the site.

Analyte	Comment
Fluoride Hardness TDS and TSS Nitrogen suite Phosphorus suite	
Total metals/metalloids suite	Consider which metals are likely of concern for the specific site, or include the full suite if unknown. Consider limit of reporting (LOR) and ensure it is appropriate for the applicable water quality criteria.
Dissolved metals/metalloids suite	

Other analysis

- The suspension peroxide oxidation combined acidity and sulfur (SPOCAs) method is an alternative to the chromium reducible suite (CRS) method for classifying ASS materials. The CRS method is recommended in this guidance document as it allows for the speciation of the sulfur into sulfide and sulfate contents and is not affected by higher organic carbon content, which is common in many known ASS environments in the Waikato Region. If adopted, total organic carbon (TOC) can be tested first to determine if it is suitable to use SPOCAS, with Sullivan et al., (2018) recommending avoiding it's use if organic carbon is greater than 0.6%. SPOCAS results are required to be verified with CRS results to avoid an overestimation due to high organic content. If soil is identified as Gley Soils, organic carbon commonly exceeds 0.6% within the first 30-50cm and often deeper, so the CRS method should be adopted.
- Acid metalliferous drainage from mining also provides similar analytical suites designed to calculate the Net Acid Production Potential (NAPP) and Net Acid Generation (NAG) of a material, outlined in AMIRA (2002) and the GARD Guide (INAP, 2018). These tests have been designed specifically for mining waste materials and are customisable depending on the source material and mineralogy. They are not considered suitable for ASS characterisation as they have not been designed for the unique properties of ASS. The most significant factor is the sample handling and preparation that was designed for rock material rather than ASS soils and sediments. The rock preparation method involves oven drying, crushing and pulverising and does not have the strict sample preservation requirements that are necessary for ASS sample testing. The NAPP calculation can be applied to various methods of sulfur speciation and works under the assumption that all acidity is in the form of pyrite. It does not always allow for the differentiation of potential actual and retained acidity and can be conservative depending on the sulfur testing method selected.
- There are no current standards in Australia or New Zealand for kinetic testing for acidity in ASS, other than incubation testing, which does not provide information on reaction times. Reaction times in Australia are generally assumed to be 48 hours however this is an estimate, and it can vary depending on the site. Kinetic testing can be useful when developing management plans/remediation options assessments as it can inform reactivity rates and guide treatment methodologies. Bespoke tests or trials simulating oxidation conditions can be designed to determine an approximate reactivity rate, these should be designed on a site specific, case by case basis and consider site conditions. In lieu of kinetics testing, reactivity timeframes can be inferred through multiple lines of evidence, including consideration of existing site conditions, previous disturbance activities and incubation testing. Reactivity rates can inform site management and remediation decisions.

4.5 Action criteria

While New Zealand does not currently have nationally agreed action criteria for sulfur content in ASS, Australia's national guidance document provides trigger values for the preparation of an ASS management plan. While these action criteria are not mandatory in New Zealand they are a useful tool to provide context to results and assist in the interpretation of laboratory analyses. It is recommended that they be taken into consideration until action criteria for New Zealand are developed.

The action criteria summarised in Table 8 are based on net acidity and consider the texture of the material, which can influence the soil's natural pH buffering capacity. It should also be noted that net acidity can only include a soil's measured ANC when that result is corroborated with other data such as slab or chip tray incubation.

Table 8 Action criteria based on ASS soil net acidity for three broad texture categories.

Type of material		**Action criteria 100-1000 tonnes disturbed**		**Action criteria if more than 1000 tonnes disturbed**	
Texture range*	Approx. clay content (%<0.002 mm)	Sulfur trail S%[1] oxidisable (oven dry basis)**	Acid trail mol H+/tonne (oven dry basis)#	Sulfur trail S%[1] oxidisable (oven dry basis)	Acid trail mol H+/tonne (oven dry basis)
Coarse texture	≤5	0.03	18	0.03	18
Medium texture	5-40	0.06	36	0.03	18
Fine texture	≥40	0.1	62	0.03	18

*as defined in McDonald et al., 1990, **e.g., S_{TOS} or S_{POS}, #e.g., titratable peroxide acidity (TPA) or titratable sulfidic acidity (TSA)
1 (per mass of dry fine earth (<2 mm)

Calculating net acidity

Net Acidity is the calculation of the total possible acidity of ASS materials. It is determined from an Acid Base Accounting (ABA) approach using one of the following equations:

Equation 1: Net acidity where ANC has been corroborated by other data.

$$Net\ Acidity = Potential\ Sulfidic\ Acidity + Actual\ Acidity + Retained\ Acidty - Acid\ Neutralising\ Capacity$$

Equation 2: Net acidity where ANC has not been corroborated by other data.

$$Net\ Acidity = Potential\ Sulfidic\ Acidity + Actual\ Acidity + Retained\ Acidty$$

Equation 3: verification net acidity.

$$Verification\ Net\ Acidity = Potential\ Sulfidic\ Acidity + Actual\ Acidity + Retained\ Acidty - (post\ treatment\ of\ ANC - initial\ ANC)$$

4.6 Post treatment criteria

The following performance criteria for neutralised soil are summarised from the QLD ASS guidelines and should be taken into consideration as a measure of successful soil neutralisation:

- The neutralising capacity of the treated soil must exceed the net acidity; and
- Post-neutralisation, the soil pH (pH_{KCL}) is to be greater than 6.5[2]; and
- The amount and texture of applied neutralising agents should be such that excess remains within the soil until all acid generation reactions are complete and the soil has no further capacity to generate acidity.

pH considerations

Neutral pH targets are typically considered optimal to reduce the solubility of most metals. However, some metals are amphoteric such as aluminium and can mobilise at both acidic and alkaline pH values. To account for this risk, an upper pH limit of 8.5 should also be applied.

The resultant target pH range of 6.5 to 8.5 does not take into consideration natural background pH and native pH sensitive flora and fauna. Background sampling undertaken pre-disturbance is essential to determine existing soil and water parameters. Existing (pre-disturbance) soil and water pH levels are preferred as a remediation target over the general range indicated above.

4.7 Reporting

The following report structure examples provide a guide for reporting on ASS investigations at the varying stages of assessment. The examples below are intended to promote greater consistency in the types of information included in reports, while allowing practitioners the flexibility to determine the appropriate level of detail based on

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[2] The QLD ASS guidelines state the pH should be greater than 6.5 but the Tasmanian ASS guidelines reference McElnea and Ahern (2000) and state a minimum of 5.5. Ultimately this target should be used as a guideline and consideration of the site-specific background pH should take precedence over any generic value.

the investigation's objectives, complexity, and purpose. The aim is not to mandate identical reporting formats or enforce a particular style.

The recommended reporting structures outlined in Table 9 to Table 13 are intentionally aligned with the format used for preliminary site investigation reports under the Contaminated Land Management Guidelines No. 1: Reporting on Contaminated Sites in New Zealand, Appendix A (MfE, 2021). This deliberate alignment is intended to provide authors with a familiar reporting structure and support practitioners who are required to assess ASS as part of a broader contamination assessment, enabling them to integrate ASS findings within existing reporting frameworks.

Desktop assessment

A desktop assessment is the first step in an ASS investigation; it allows for a non-intrusive initial phase of investigation which will determine if a more detailed investigation is required.

Table 9 Desktop Assessment

Section	Content	Required	Required if relied on
Introduction	Investigation purpose and objectives	X	
	Site identification (site name, location, boundaries/extent, a map reference and geographic coordinates)	X	
	Proposed site use	X	
	Detailed description and figures presenting the scope and extent of the proposed activity being considered.	X	
Site description	Environmental setting, which should include, but not be limited to geology, hydrogeology and hydrology, topography and ecological setting.	X	
	Site layout	X	
	Current site uses	X	
	Surrounding land uses	X	
	Site inspection (if conducted)		X
Regulatory context	Establish the applicable legislation, regulations, policies and / or rules.	X	
Historical site use	Summary of site history gained from:	X	
	Review of existing investigation reports		X
	Review of council information		X
	Review of aerial photographs		X
	Interviews		X
	Review of other historical information		X
Summary of previous ASS assessments	Summary of sampling plan including: numbers, extent and classification		X
	Summary of lab analysis		X
	Key findings and potential gaps in previous assessment.		X
Discussion	Preliminary Conceptual Site Model Discuss the findings of the assessment and the probability of significant ASS disturbance based on the site-specific activities.	X	
Conclusion and recommendations	Include direct reference to the decision tree and using the criteria justify why further ASS assessment is or is not required	X	
	Provide comment on the expected regulatory status of the proposed activity	X	

	Recommend additional investigations such as site assessment if required.	X	

Site assessment

A site assessment may be required if the desktop assessment and decision tree determines there is a risk of ASS in the area of disturbance for the project. It will involve a more intrusive approach but will allow for a better understanding of the extent of ASS and inform management decisions.

Table 10 Site Assessment

Section	Content	Required	Required if relied on
Introduction	Investigation purpose and objectives	X	
	Site identification (site name, location, boundaries/extent, a map reference and geographic coordinates)	X	
	Proposed site use	X	
Site description	Environmental setting, which should include, but not be limited to geology, hydrogeology and hydrology, topography and ecological setting.	X	
	Site layout	X	
	Current site uses	X	
	Surrounding land uses	X	
	Site inspection	X	
Historical site use	Summary of site history gained from:	X	
	Review of existing investigation reports		X
	Review of council information		X
	Review of aerial photographs		X
	Interviews		X
	Review of other historical information		X
Regulatory Context	Establish the applicable legislation, regulations, policies and / or rules.	X	
Methodology	Field program including Sampling and Analysis Plan	X	
	Justification of sample program design and basis for guidelines values	X	
	Field sample locations (a map reference and geographic coordinates) and depth	X	
	Laboratory analysis	X	
	Tests completed	X	
	Laboratory information	X	
	QAQC	X	
Analytical Results and interpretation	Summary of works undertaken with rationale for any departure from, or addition to, sampling and analysis plan	X	
	Field observations (e.g., staining, odour, soil characteristics, water if observed)	X	
	Evaluation of analytical laboratory results and field results with comparison to background concentration levels (if relevant) and contaminant standards and/or environmental guideline values	X	
	Results of field and laboratory sample quality assurance and/or quality control	X	
Risk Assessment	Conceptual site model, consider sources, pathways and receptors	X	
	Understand the vertical and lateral extent of the source and how the proposed activity is likely to impact on the source.	X	
	Determine the likelihood that the source of ASS presents a risk to the receptors should disturbance occur.	X	

Section	Content	Required	Required if relied on
Regulatory Status	Provide comment on the expected regulatory status of the proposed activity	X	
Conclusions and Recommendations	Depending on the scale of the works and the complexity of the ASS extent recommend either remedial options assessment or a management plan as the next step in the assessment.	X	

Management plan

Once the ASS extent and risk is adequately understood a detailed management plan needs to be designed. Table 11 provides an example of the contents that should be included in a management plan. The management plan or remedial action plan should be a blueprint that contractors can follow during earth moving activities to ensure that the risks of ASS are adequately addressed. Details on the preferred management techniques are summarised in Section 5.

Table 11 Management plan

Section	Content	Required	Required if relied on
Introduction	Project background and context	X	
	Management plan purpose and objectives	X	
	Description of the site	X	
Regulatory Context	Establish the applicable legislation, regulations, policies and / or rules.	X	
Site responsibilities and document control	Define who implements the project controls onsite	X	
Summary of proposed works	Include modification extent and volume, consider using design drawings and site plans.	X	
Summary of expected ASS conditions	Provide a summary of the ASS results, characteristics and expected occurrence onsite. This should draw heavily on the conceptual site model and include if there are any known visual cues that aid in the identification of ASS include descriptions or images.	X	
Site control procedures	If using avoidance or minimisation strategies, have clear instructions on exclusion areas with figures if applicable.		X
	If using treatment or reburial strategies include treatment rates, treatment stockpile design parameters, treatment method, outline record keeping procedure for waste movement onsite.		X
Unexpected ASS discovery protocol	Covers action plan for if unexpected discovery is encountered during site works, this can be incorporated into a broader unexpected finds protocol for the site if applicable.	X	
Monitoring and management	Include any ongoing monitoring required during the site works or after completion, detail frequency, analytical suite, monitoring targets and actions to be taken based on results.		
Soil sampling and validation	The collection of validation sampling occurs prior to reporting and is usually done at various stages throughout the site management and treatment. The method and frequency should be outlined in the management plan.	X	

Remedial options assessment

In situations when a project and/or site conditions are complex, a remedial options assessment can allow for the identification and evaluation of a range of options to determine which is the most appropriate course of action. Considerations include uncertainties, cost, timeframes and environmental impacts.

In some cases, avoidance or minimisation through a change of site location can end up being a more cost-effective option than fully remediating the disturbed ASS material. For smaller less complex projects where only a few options are available a full options assessment may not be required. Table 12 provides an example of the contents that should be included in a remedial options assessment.

Table 12 Remedial options assessment

Section	Content	Required	Required if relied on
Introduction	Summarise the extent and severity of the ASS risk across the site	X	
	Provide background on the initial site plans including proposed disturbance	X	
	Define remediation objectives	X	
Remediation options	Outline the main remediation options available for the site	X	
Evaluate feasibility	Consider using a comparison matrix to compare the different remediation options, include key factors for your project such as, timeframes, cost, environmental impacts, ease of consenting, technical and logistical complexity and health and safety.	X	
Conclusion and recommendation	Summarise the findings and recommend the most suitable option based on the weighted factors.	X	

Validation reporting

Validation reporting occurs at the completion of the project. It documents the remediation or management process and provides evidence that the remediation or management goals have been achieved. Table 13 provides an example of the contents that should be included in validation reporting.

Table 13 Validation reporting

Section	Content	Required	Required if relied on
Introduction	Description of the site, report purpose, regulatory context	X	
Site description	Site layout	X	
	Summary of previous investigations	X	
Scope and purpose of remediation	Summary of ASS extent and disturbance	X	
	Remediation strategy and objectives	X	
Remediation method	Details of remediation activities, treatment rates and plan, material movement / reburial or disposal documentation, identify any deviations from the management plan.	X	
Unexpected ASS discovery protocol and documentation	If any unexpected ASS discovery occurred, document location extent, management and validation that occurred.	X	
Validation methodology	Details of the validation methodology including sampling rate and analysis	X	
Results	Comparison of validation results to remediation objectives	X	
Conclusions	Provide conclusions and comment on the regulatory compliance of the works.	X	
Recommendations	Recommend any additional works if required		X

5. Management

There are numerous options to consider when approaching the management of ASS. This guidance document summarises the most common options for consideration, with prioritisation given to less intrusive methods. This section also highlights options that are not considered suitable for ASS management. For a more detailed review of management options refer to the Queensland Acid Sulfate Soil Technical Manual[3] from Australia.

5.1 Avoidance

The discussion below expands on the information presented in Section 3.1.

The preferred management approach for ASS is avoidance of disturbance, which has the lowest environmental and financial risk. Avoidance is generally:

- Lower-cost than long-term treatment, monitoring, and remediation,
- Environmentally protective, preventing leachate release and ecosystem degradation,
- Aligned with regulatory expectations.

Avoidance does not necessarily imply a site is unsuitable for a project. Rather, avoidance can be strategic, focusing on specific activities or areas which have been identified as higher risk. For example, at sites where ASS requires extensive management or soil treatment, such as through the application of agricultural lime, avoidance is considered best practice. This is because although technically manageable, the high cost and complexity of treating such soils, the risk of unforeseen outcomes, disposal requirements and associated emissions, often render active management unsustainable.

Other circumstances where avoidance should be considered include:

- Where there are environments, or receiving environments, which may be prone to algal blooms, such as due to cyanobacteria. This is because ASS-related drainage may contribute micronutrients, for example iron, that can stimulate harmful algal blooms. Algal blooms are known to occur in the Waikato Region and are of particular concern for Waikato Regional Council.
- Sites that are hydrologically connected to groundwater-dependent ecosystems, such as may occur at wetlands. Changes to the hydrogeological environment can lead to offsite changes in groundwater profiles, cause the oxidation of offsite ASS and lead to subsequent ASS related discharges. Assessing these offsite effects can be costly and challenging.
- Sites where the disturbance of ASS may impact on sensitive ecosystems, such as wetlands. Prioritization should be given to avoidance near habitats of high ecological or cultural value, where pH-sensitive species may occur. In addition to the risks of acidification, the use of neutralising agents in these areas can inadvertently alter ecosystem chemistry, threatening biodiversity through shifts in water hardness and pH.

Alternative options for higher-risk areas where disturbance should be avoided can include:

- Capping with fill material, to raise the ground level, any ground disturbance can then occur in the fill instead of the ASS material. Filling, however, brings its own risks.
- Repurposing high-risk zones for low-impact uses (e.g. open space, parking). Nevertheless, any already acidified soils on site may still require active remediation as part of development works.

5.2 Minimisation

When ASS cannot be avoided, minimisation of the disturbance is the next preferred management strategy. For minimisation to be effective, an ASS investigation should be completed to inform the spatial extent of the actual and potential acidity and the site groundwater characteristics.

Strategies for minimisation may include:

Redesign earthworks – Where sites can be spatially delineated by sulfide content, through a thorough sampling program, the redesign of earthworks can be an effective minimisation strategy. Areas with lower or negligible sulfide content can be focused on in preference to areas with higher sulfide content.

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[3] 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, Science and Innovation, Queensland.

Soil texture – Soil texture can inform decision making. Areas with coarser sandy material could be suitable for floatation dredging and hydraulic separation, and coarse soils are also easier to blend with lime amendments. Prioritising areas for excavation based on soil texture could help minimise the disturbance of sulfidic material that is difficult to treat.

Limit excavation depth – In some situations, ASS is located in deeper horizons, with surface materials either classed as non-reactive or consisting of ASS material that is above the water table and has already oxidised (AASS). In these scenarios, limiting the excavation depth can ensure that ASS is not disturbed.

Site drainage – When drainage systems are required as part of a project, decisions regarding the placement, depth and width of trenching should take account of the presence of ASS.

Minimise groundwater fluctuations – Site works can affect the groundwater levels, raising it through fill emplacement or capillary rise, or lowering it through dewatering, construction of canals, drains and groundwater extraction bores. Areas where there is known ASS should avoid activities that disturb groundwater levels. Lowering groundwater can oxidise PASS and raising groundwater can remobilise acidity from AASS.

5.3 Strategic reburial

Strategic reburial is a remediation option available for PASS material that has been excavated. It involves reburying PASS material in an anoxic (preferably anaerobic) environment. The absence of oxygen inhibits the sulfide oxidation process preventing acid generation.

Appropriate scenarios for strategic reburial include:

- Reburial underneath low-flow or no-flow surface water (e.g., lakes, canals, artificial wetlands)
- Reburial below groundwater and compacted soil (ensuring the seasonally lowest water table elevation is not exceeded)

The Figure 3 and Figure 4, sourced from the QLD ASS technical manual (Dear et al., 2024) present examples of how strategic reburial can be designed.

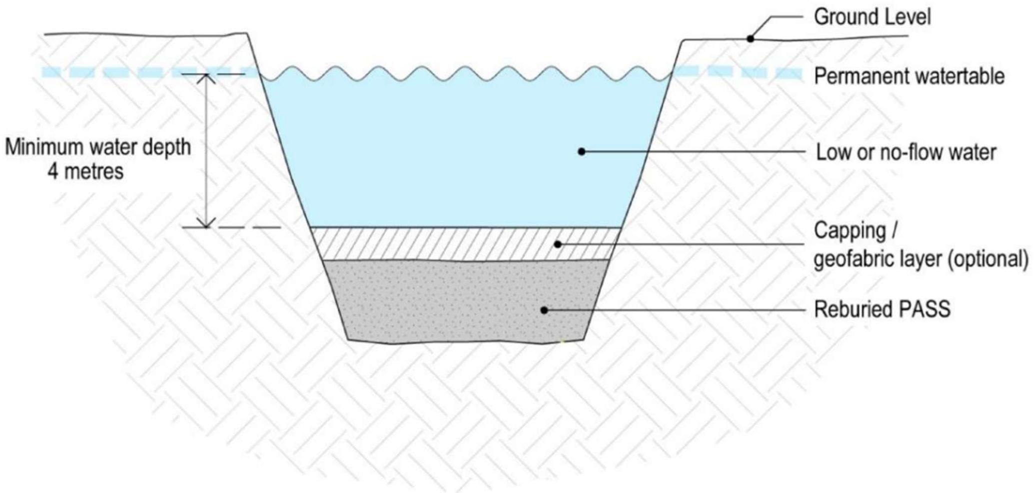

Figure 3 Example of strategic reburial under surface water

Source: Dear et al., 2024

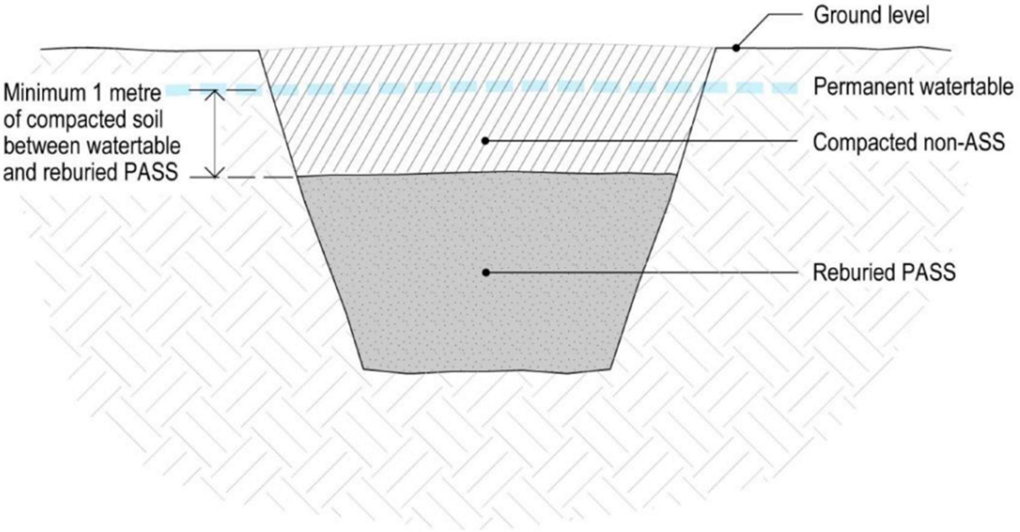

Figure 4 Example of strategic reburial below groundwater and compacted soil

Source: Dear et al., 2024

There are several risk factors to consider when implementing strategic reburial as part of a management plan:

- The physical properties of the material such as highly dispersive soils and fines that can be easily resuspended and pose a greater risk. When particles are resuspended, the risk of oxidation and acid production increases. This can be caused by dissolved oxygen higher up in the water column or from moving water which can transport oxygen to the suspended solids.
- The reactivity rate of the material and planned storage time prior to reburial. Some PASS materials, such as very fine-grained sulfides or monosulfides, are highly reactive, oxidising in a matter of hours.
- Oxygen ingress during the reburial can be a risk. It can occur through physical disturbance of the soil, drainage during stockpiling opening pore spaces, and flowing groundwater delivering oxygenated waters. There is an increased risk of these factors with sloping ground, uncompacted porous soils and permeable paleochannels. Sufficient compaction or saturation needs to be achieved to ensure an anoxic environment.

This technique is only successful if the soils have undergone minimal oxidation and the selected reburial location creates conditions that permanently prevent further oxidation. The reburial void should be available prior to excavation of the PASS and adequate volume inclusive of a safety factor should be available in the void. A clear method for earthworks needs to be planned, to ensure exposure timelines are adhered to. When considering this approach it is ideal, but not always practicable, to assess the suitability of the material by completing analysis of the potential reaction kinetics, such as via incubation testing (Creeper et al., 2012).

Reburial needs to be documented, such as in a closure/validation report, and should include volumes and extents of disturbed material, treatments used (if applicable), reburial design information and validation results. Treated sample results should be compared to remediation target levels for the validation reporting.

5.4 Temporary Stockpiling and Containment

Stockpiling is often necessary as an intermediary step prior to treatment, disposal, containment or reburial. There are several factors to consider when designing a stockpile / treatment pad. It is also essential to consider the properties of the ASS to be stockpiled, such as the sulfide content and the reaction kinetics (if known), and any other mitigating factor. These considerations may influence what stockpile management strategies are most suitable to the site-specific conditions.

The minimum features of a stockpile design should allow for the collection and isolation of the ASS leachate from the surrounding environment. Ideally stockpiling should occur onsite as it minimises the handling costs and the potential for environmental harm offsite.

The QLD ASS technical manual provides recommendations for design parameters including:

Basal layer

A basal layer involves a minimum of 300 mm compacted, non-ASS, clayey material that provides a low-permeability layer or an impervious physical barrier such as a bunded concrete slab. Other options could be considered appropriate provided they are proven to prevent the movement of leachate through the base of the pile.

The shape of the basal layer should prevent the leachate from pooling in the stockpile pad and direct runoff into collection drains. Neutralising material such as lime can be mixed into the basal layer to provide additional buffering capacity provided it doesn't interfere with the low permeability features of the material.

Guard layers

This refers to a layer of neutralising material placed on top of the base layer prior to ASS placement. This layer should consider the net acidity of the ASS material. The QLD ASS Management guidelines recommend a minimum of 5 kg/m^2 of fine for material with less than 1%S (per mass of dry fine earth (<2 mm), and a minimum of 10 kg/m^2 for material with a net acidity greater than 1%S. This guard layer is effective for ASS material layers placed at a thickness of 300 mm or less. This layer does not negate the need for blended treatment of the ASS waste, which should be done during stockpiling.

Containment

The stockpile should use bunding, diversion drains, leachate collection drains and sumps or detention basins to allow for the containment of leachate. The stockpile and other containment features should be hydrogeologically isolated, and any materials used for containment should have low permeability properties and not contain ASS or other sources of contaminants.

Stockpile placement

Stockpiles should ideally be located onsite on level ground, away from surface water and overland flow pathways. They should also avoid disturbing in-situ ASS during the construction phase. The optimal size for soil amelioration / treatment stockpiles is 500 m^3 as it is harder to complete accurate validation sampling for larger stockpiles. Figure 5, taken from Dear et al., 2024 provides a cross section for stockpile design.

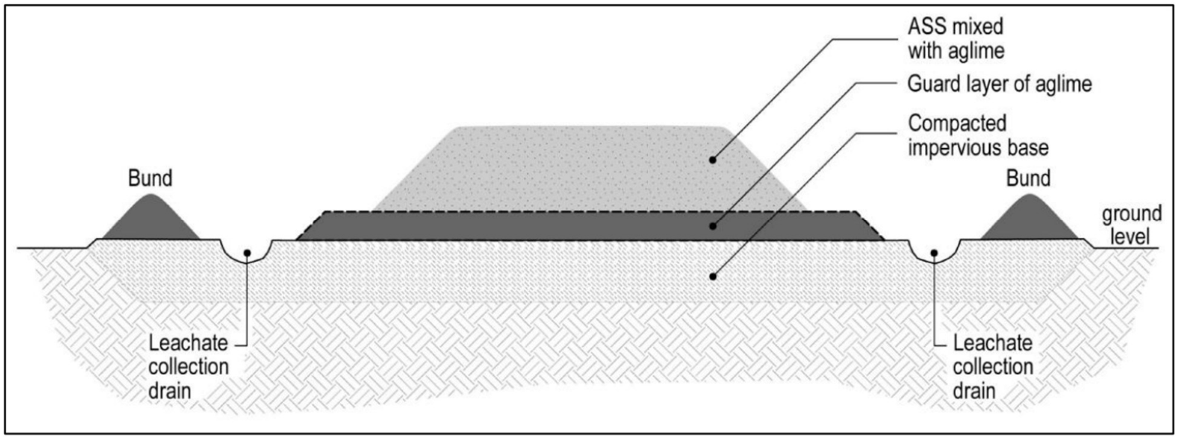

Figure 5 Example of a suitable stockpile design for ASS treatment

Source: Dear et al., 2024

Water Treatment

Water collected in dredge ponds and sumps may require pH adjustment and iron and aluminium removal prior to reuse. Water can be used for dust suppression and rewetting of stockpiles. Typically, agricultural lime (aglime) is recommended for treatment, although more alkaline neutralising agents such as hydrated lime $Ca(OH)_2$ can be used in contained water treatment plants. Water should also be tested for ammonia and metals such as iron, manganese, aluminium, copper, zinc and arsenic, which are commonly elevated in ASS-associated runoff and groundwater.

Stockpile Cover

As the stockpile treatment pad is intended to be used temporarily during earthworks, there is no permanent cover included in the design, as this would prevent treatment and deposition of the material. In some cases, depending on the scale and timeframe of the stockpile treatment program, a temporary cover may be needed to reduce the effects of rainfall and subsequent runoff and prevent the dispersal of dust during treatment. Typically, waterproof plastic liners can be implemented during periods where the stockpile is inactive such as overnight or on weekends, if this is logistically practical.

5.5 Soil treatment

Neutralisation is a core remediation strategy involving the mechanical incorporation of suitable alkaline reagents into ASS. The selected neutralising material must be applied at a rate sufficient to fully address:

- Actual Acidity and/or Retained Acidity present within the soil matrix, if not strategically re-buried[4]
- Potential Acidity that may arise through the complete oxidation of iron sulfide minerals over time.

These are cumulatively referred to as the Net Acidity of the soil. To ensure effective treatment and account for uncertainties in field application, an appropriate safety margin should be incorporated into the calculated neutralising dose.

The most commonly utilised neutralising agent is calcium carbonate ($CaCO_3$), typically supplied in the form of agricultural lime (aglime) due to its cost-effectiveness, reactivity, and availability.

A liming rate can be calculated using the following formula:

$$S\% \times 30.59 \times 1.02 \times 1.5 = kg\ CaCO_3/tonne\ of\ soil$$

Where:
30.59 converts S% (per mass of dry fine earth (<2 mm) to H_2SO_4
1.02 converts H_2SO_4 to $CaCO_3$
And 1.5 is the applied safety factor

ASS should be treated in layers of no more than 300 mm thick during stockpiling, to allow for adequate mixing of the neutralisation product and the ASS material. Mixing can occur in several different ways, with some common examples including soil mixing machinery, excavator, bulldozer or a towed disc plough. Each layer should be validated prior to the commencement of treatment for the next layer.

Treatment with lime amendments can neutralise acid and subsequent increased metal mobilisation caused by acidity but does not address the risks of contamination by other compounds that are not pH dependent. For example, the decay of organic matter in the soil and sediments can lead to increased concentrations of ammonia in the groundwater.

5.6 Alternative strategies

The following are examples of potential alternative management/remediation strategies that may be suitable depending on the project-specific conditions.

Offsite disposal – While the first preference should always be appropriate reuse onsite, offsite disposal is currently a commonly utilised method in New Zealand, offsite disposal is considered acceptable provided that the receiving site is a suitably licensed and operated fill site. The WasteMINZ (2023) Technical Guidelines should be consulted to inform disposal decisions. However, it is expected that it will mostly not be appropriate to dispose to either controlled fills (class 4), since these do not have any form of engineered containment, or to clean fills (class 5), since these require inert material. Other alternatives include Class 1, 2, and 3 landfills. This method must ensure the recipient is fully aware that the material contains ASS. Material characterisation testing should be

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[4] While it can be difficult to differentiate naturally acidic soils from those which have acidified due to disturbance, care should be taken not to neutralise naturally acidic environments. Ecosystems may have adapted to acidic conditions and comprise of predominantly acidophilic flora and fauna. Neutralisation of this acidity may adversely affect ecosystem health.

provided to the disposal facility, so that a comparison between the material characteristics and the facilities resource consent conditions and waste acceptance criteria can be made. Documentation must be recorded and kept outlining the original source of the material, tonnages and extent. This option does not negate the need to treat any disturbed areas exposed or affected during site works.

Offsite treatment – Though normally not a preferred method, on sites where space is a constraint (e.g. small excavations in a high-density urban area or where there is no space for a treatment pad), the preferred management strategy is offsite treatment at an appropriately consented / licensed and managed site or facility. Transportation of PASS material offsite prior to treatment carries the risk of oxidation in transit, in situ treatment should be considered prior to transport if possible. At no time should PASS be strategically re-buried offsite at an unlicensed facility or private property.

Hydraulic separation – Hydraulic separation can include hydro-sluicing or hydro-cloning and involves separating sediments or soil through settling into two or more fractions where grain size and particle density determine the fractions. This can be a suitable solution when sulfides are present in the fine-textured material and this component makes up less than 10-20% of the total material. Preliminary investigations need to confirm that the sulfides are associated with a specific fraction for this to be appropriate. High clay content or highly organic peaty materials will not separate easily and are not suitable for this technique. The separated sulfides still need to be managed but can represent a smaller volume than if the material was left whole. This technique is often limited to scenarios where the material is already in slurry form, such as suction dredging or hydraulic mining.

Dredging – While not a management strategy, dredging has the potential to disturb ASS and has unique factors to consider when designing a management or remediation plan. The unique considerations for dredging and ASS management are best covered in the Australian Guidelines for the dredging of ASS sediments and associated dredge spoil management (Simpson et al, 2018). Aside from the key principles of avoidance and minimisation, Simpson (2018) provides the following considerations to minimise risk during dredging projects:

- Minimise the release of sediments and dispersal of turbid plumes into the water column as much as practicable (specialised dredging equipment), particularly where sediment-sensitive benthic communities exist. For example, use of dredges equipped with sediment management devices, as these are found to minimise sediment generation and dispersion, and use of silt curtains where they are operable and likely to be effective in controlling turbidity release and dispersion
- Consider the time of year of dredging and disposal to avoid critical life-cycle phases within the ecosystem, for example coral spawning, and animal migration, breeding, nesting or birthing periods
- Use suitable equipment and monitoring procedures during dredging activities.
- Use real time data collection of turbidity and other water quality parameters to monitor environmental impacts during the dredging.

Dredging of drainage channels is common in the Waikato region. Minimisation and avoidance of ASS during dredging could involve;

- avoiding the creation of drainage lines in known ASS areas,
- if PASS is constrained to a specific depth, reducing the depth and size of the drainage lines

The Treatment and management of dredge spoil material from drainage lines can be developed using the methods described in section 5.5, or for more detailed information the Australian Dredging Guidelines (Simpson et al., 2018).

5.7 Unacceptable strategies

The following management strategies have been deemed to have high environmental risk and are unacceptable for management in Australia. Currently, they should not be considered suitable as management strategies in New Zealand, unless a risk assessment has been undertaken that shows in sufficient detail that the method is appropriate for the specific project being considered. Other strategies not listed in this guidance document should be carefully considered on a site-specific case by case basis.

Above ground capping - Above-ground capping places untreated ASS beneath an impermeable cover to block water ingress and oxygen exposure. It differs from using treated, compacted ASS as fill over natural soils comprising of undisturbed PASS to raise surface levels. Above-ground capping is considered a high-risk method, as the untreated ASS remains fully reactive beneath the cap. Any cap compromise from cracks, root penetration or erosion will result in oxidation and water ingress and subsequent conversion of PASS to AASS. Once acidification has occurred, the treatment of the material and the surrounding impacted environment and infrastructure is far more costly.

Hastened oxidation - Accelerating oxidation of ASS without adequate neutralisation is a high-risk, unsupported practice. Natural oxidation of sulfidic soils may span decades making this difficult to achieve. Techniques to accelerate this process exist but depend on material permeability, sulfide content, temperature, moisture and microbial activity. This approach can incur lengthy delays, particularly in marine clays or material with high sulfidic content, and produces large volumes of acidic, metal-rich leachate. Unless fully contained and treated, the soil and leachate pose an unacceptable risk to the environment. Effective collection, treatment and monitoring systems are critical but complex, costly and reliant on robust site supervision and technology. System failure during storm or flood events risks major environmental harm.

Seawater and groundwater neutralisation - Seawater or groundwater neutralisation of ASS, or of drainage from these soils, is not considered acceptable as a primary management option. Although seawater is naturally alkaline, with a high buffering capacity, and can neutralise up to two moles of acidity per cubic metre (through its dissolved bicarbonate and carbonate buffering capacity) (Dickson & Goyet, 1994), the long-term impacts of acidity neutralisation on coastal, estuarine and groundwater chemistry are unknown and may stress or irreversibly alter aquatic ecosystems. Groundwater alkalinity is varied but the same risks apply. The main risks from neutralising ASS acidity with water from the natural receiving environment include:

- The exhaustion of the natural carbonate-bicarbonate buffer in the seawater which can impact shell formation in invertebrates such as crustaceans and molluscs.
- Oxidation by-products such as iron hydroxides can increase turbidity, degrade sediment and water quality at the sediment interface, lower the dissolved oxygen concentration and increases the risk of algal blooms. All of these factors can impact the health of flora and fauna in the receiving environment.

Offshore disposal of ASS - Offshore disposal of ASS may carry high risk to the receiving environment. Consequently, any proposed offshore disposal of dredged materials or dumping of waste would require appropriate approvals, for example, submission of an application and attainment of consent from the EPA, in compliance with the Exclusive Economic Zone and Continental Shelf (Environmental Effects - Discharge and Dumping) Regulations 2015. Risk can include acidification and or heavy metal or other toxicant contamination of the marine environment.

Unconfined groundwater dewatering – Dewatering creates an oxidising cone of depression where sulfidic soils generate acid and metal-rich leachate. Containing and treating this leachate is extremely difficult, and predictive models rarely capture long-term flow paths accurately. Rainfall can mobilise pollutants along paleochannels, causing immediate or delayed environmental harm. Once oxidised, these soils are very difficult to nearly impossible to remediate, leading to ongoing treatment and disposal costs that outweigh any initial savings. Moreover, soil shrinkage can damage surface and subsurface infrastructure.

Permeable Reactive Barriers – are a subsurface treatment zone for passive treatment of groundwater, typically using limestone. They allow groundwater to flow through the reactive material. It is not considered appropriate as a management solution as they have a finite lifespan and require monitoring for the duration of the treatment. They may be a suitable temporary treatment option in conjunction with a broader management plan. Though consideration should be given to the effects of iron and manganese oxyhydroxides causing armouring of the limestone and reducing the overall efficacy of the treatment method.

6. References

AMIRA. (2002). Project P387A Prediction & Kinetic Control of Acid Mine Drainage - ARD Test Handbook. Melbourne: AMIRA International Limited.

ANZG (2018), Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

Australian Standards. 2019. AS4439.3:2019. Wastes, sediments and contaminated soils, Part 3: Preparation of leachates - Bottle leaching procedure.

Creeper, N., Fitzpatrick, R. & Shand, P. (2012), 'A simplified incubation method using chip-trays as incubation vessels to identify sulphidic materials in acid sulphate soils', Soil Use and Management, vol. 28, pp. 401–408.

Dear, S.E., Williams, K.M., McElnea, A.E., Ahern, C.R., Dobos, S.K., Moore, N.G., and O'Brien, L.E. (2024), Queensland Acid Sulfate Soil Technical Manual, Soil Management Guidelines, Version 5.1, Department of Resources and Department of Environment, Science and Innovation, Queensland.

Dickson, A.G. & Goyet, C. (Eds.) (1994). Guide to Best Practices for Ocean CO_2 Measurements: A report of the CO_2 Quality Control Charting Activity of the Marine Working Group, SCOR and IAPSO. North Pacific Marine Science Organization, pp 21–23

DWSNZ, (2008). Drinking Water Standards for New Zealand 2005 (revised 2008). Wellington: Ministry of Health.

EPA. (2025). SW-846 Test Method 1313: Liquid-Solid Partitioning as a Function of Extract pH Using a Parallel Batch Extraction Procedure. United States Environmental Protection Agency. [online] Available at: https://www.epa.gov/hw-sw846/sw-846-test-method-1313-liquid-solid-partitioning-function-extract-ph-using-parallel-batch Accessed: 30.10.2025.

Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 (NZ).

Exclusive Economic Zone and Continental Shelf (Environmental Effects—Discharge and Dumping) Regulations 2015 (NZ).

Fitzpatrick, R. W., Powell, B., & Leonard, M. (1998). Acid Sulfate Soils: Environmental Issues, Assessment and Management. CSIRO Land and Water, Australia. Medawela, R. M., Chen, Z., & Indraratna, B. (2019). Corrosive effects of acid sulfate soils on infrastructure materials: A review. Construction and Building Materials, 213, 159-173.

GHD (2024). Waikato region acid sulfate soils preliminary risk assessment (GHD Ltd). Waikato Regional Council Technical Report 2023/2, DM 27390926. Waikato Regional Council.

INAP. (2018). Global Acid Rock Drainage Guide (GARD Guide). (The International Network for Acid Prevention.) Retrieved from http://www.inap.com.au/GARDGuide.htm

McDonald, D., & Tasmania Department of Primary Industries, Parks, Water and Environment (2009). Tasmanian Acid Sulfate Soil Management Guidelines. Hobart, Tasmania: Department of Primary Industries, Parks, Water and Environment.

McElnea, A.E., Ahern, C.R. (2000a) Effectiveness of Lime and Cement Kiln Dust as Acid Sulfate Soil Ameliorants – Leaching Column Experiments. In 'Acid Sulfate Soils: Environmental Issues, Assessment and Management, Technical Papers'. (Eds CR Ahern, KM Hey, KM Watling, VJ Eldershaw) pp. 30/1–30/12 (Queensland Department of Natural Resources: Brisbane)

Milne, J.D.G., Clayden, B., Singleton, P.L., Wilson, A.D. (1995). Soil Description Handbook New Zealand. Manaaki Whenua Press, Lincoln, NZ. *(it is noted that an updated version is due for publication by Landcare Manaaki Whenua in 2025)*

MfE, Ministry for the Environment (MfE) (2021) Appendix A: Reporting on Contaminated Sites in Contaminated Land Management Guidelines No. 1: Reporting on Contaminated Sites in New Zealand, Ministry for the Environment, Wellington. [online] Available at: https://environment.govt.nz/assets/acts-and-regulations/orders-in-council/Auckland-flood-resilience-works/contaminated-land-management-guidelines-no-1. Accessed: 30.10.2025.

MfE, Ministry for the Environment, (2021). Contaminated land management guidelines No. 5: Site investigation and analysis of soils. [online] Available at: https://environment.govt.nz/publications/contaminated-land-management-guidelines-no-5-site-investigation-and-analysis-of-soils/ Accessed: 30.10.2025.

Naylor, S.D., Chapman, G.A., Atkinson, G., Murphy, C.L., Tulau, M.J., Flewin, T.C., Milford, H.B. & Morand, D.T. (1998). Guidelines for the Use of Acid Sulfate Soil Risk Maps, 2nd edn, Department of Land and Water Conservation, Sydney, New South Wales.

NGZS (2005). Field Description of Soil and Rock; Guidelines for the field classification and description of soil and rock for engineering purposes. New Zealand Geotechnical Society Inc.

Roberts, R. C., and J. McConchie (2017). “Preliminary Assessment of the Acid Sulphate Soils Hazard in the Auckland Region.” In Proc. 20th NZGS Geotechnical Symposium, edited by G. J. Alexander and C. Y. Chin. Napier, New Zealand: The New Zealand Geotechnical Society. https://fl-nzgs-media.s3.amazonaws.com/uploads/2017/11/NZGS_Symposium_20_Roberts3.pdf

Sammut, J., White, I., & Melville, M. D. (1993). Acidification of an estuarine tributary in eastern Australia due to drainage of acid sulfate soils. Marine and Freshwater Research, 44(5), 629-639.

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.

Standards New Zealand. (2006). NZS 3101.1&2:2006 Concrete structures standard.

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.

WasteMINZ. (2023). Technical Guidelines for Disposal to Land Revision 3.1. Waste Management Institute New Zealand.

Whangarei District Council. (n.d.) https://gismaps.wdc.govt.nz/GISMapsViewer/?map=201ccfa7455b44f58ba00236755c8158

Wilson, B. P. (1995). Environmental impacts of acid sulfate soils. In: Proceedings of the National Conference on Acid Sulfate Soils. Canberra, Australia.

WQA. (2018). National Acid Sulfate Soil Guidance – Overview and management of monosulfidic black ooze (MBO) accumulations in waterways and wetlands.