Government of Western Australia
Department of Environment Regulation

GUIDELINE

Treatment and management of soil and water in acid sulfate soil landscapes

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This guideline may be applicable to decision-making authorities, proponents, consultants and other interested parties involved in the planning, development and use of areas potentially containing acid sulfate soils. The Department of Environment Regulation (DER) should be consulted regarding policy issues not covered in this guideline or where further clarification and explanation is required.

DER would like to acknowledge the guidelines and manuals produced by the following committees and organisations that were used in the development of this guideline:

- Queensland Acid Sulfate Soils Investigation Team
- National Committee for Acid Sulfate Soils (NatCASS)
- Southern Cross University

This guideline forms part of a comprehensive statutory and policy framework for the identification, assessment and management of acid sulfate soils in Western Australia.

The DER Acid Sulfate Soils Guideline Series contains the following guidelines:

- *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015)
- *Treatment and management of soils and water in acid sulfate soil landscapes* (DER 2015)

Other guidelines include:

- *Is my house built on acid sulfate soils?* (DER 2015)

Copies of these guidelines are available from DER's website at

www.der.wa.gov.au/ass.

This document replaces:

- *Treatment and management of soil and water in acid sulfate soil landscapes* (July 2011)

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Contents

Introduction

Acid sulfate soils (ASS) are naturally occurring soils, sediments and peats that contain iron sulfides, predominantly in the form of pyrite materials. These soils are most commonly found in low-lying land bordering the coast, in estuarine and saline wetlands, and in freshwater groundwater-dependent wetlands throughout the state.

In an anoxic state, these materials remain benign, and do not pose a significant risk to human health or the environment. However, the disturbance of ASS, and its exposure to oxygen, has the potential to cause significant environmental and economic impacts including: fish kills and loss of biodiversity in wetlands and waterways; contamination of groundwater resources by acid, arsenic, heavy metals and other contaminants; loss of agricultural productivity; and corrosion of concrete and steel infrastructure by acidic soil and water.

Projects involving the disturbance of ASS must therefore assess the risk associated with disturbance through the consideration of potential impacts. Successful management of ASS depends on the results of a detailed investigation to determine the most appropriate management strategy for a site. Wherever possible, in areas containing ASS, management measures should be governed by the guiding principle of avoidance of disturbance over any other measure.

Activities that have the potential to disturb ASS, either directly, or by affecting the elevation of the watertable, need to be managed appropriately to avoid environmental harm. An acid sulfate soil management plan (ASSMP) should be prepared and implemented, following advice presented in this document, to effectively manage potential impacts of such activities.

If ASS are not managed appropriately, environmental harm may result (as defined by the *Environmental Protection Act 1986).* Areas of disturbed ASS that have above background concentrations of contaminants[1] in soils, sediments and/or waters and present, or have the potential to present a risk to human health, the environment or any environmental value, may also be classified as contaminated sites, under provisions of the *Contaminated Sites Act 2003*[2]. Such impacts should be remediated wherever possible.

In this document, ASS will be used to mean both potential ASS (PASS) and actual ASS (AASS) as described in *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015).

[1] Typical contaminants of concern in areas of disturbed ASS include: acidity in groundwater and/or surface water; arsenic in groundwater and/or surface water; aluminium in groundwater and/or surface water; acidity in soils; and arsenic in soils.

[2] Under the *Contaminated Sites Act 2003*, 'contaminated', in relation to land, water or a site, means having a substance present in or on that land, water or site at above background concentrations that presents, or has the potential to present, a risk of harm to human health, the environment or any environmental value. 'Site' means an area of land and includes – (a) underground water under that land; and (b) surface water on that land. The presence of naturally occurring ASS beneath a site, in an undisturbed state, in itself, does not represent 'contamination'.

Purpose

The purpose of this guideline is to provide technical and procedural advice to avoid environmental harm and to assist in achieving best practice environmental management in areas underlain by ASS.

The guideline has also been designed to assist decision-making and provide greater certainty to the development, construction and agricultural industries, state and local government and the community when planning for activities that may disturb ASS.

This guideline is applicable to Western Australian sites and has been developed on the basis of experience in both Western Australia and in other States. The guideline should be used in conjunction with the document entitled *'Identification and investigation of acid sulfate soils and acidic landscapes'* (DER 2015) and any other relevant guidelines, standards and information sources.

1 Background information

1.1 Potential adverse effects from acid sulfate soil disturbance

ASS materials will need to be managed when they are disturbed or exposed to oxygen. Typically, excavating or otherwise removing soil or sediment, lowering of groundwater levels or filling or surcharging of low-lying land causes disturbance of ASS (Queensland Government, 2002).

The types of development that may cause ASS problems include:

- coastal developments, such as residential estates, canal estates, tourist developments, marinas, golf courses;
- estate and underground infrastructure development (including installation of sewage pipework and pump station infrastructure);
- major infrastructure projects, such as bridges, roads, tunnels, port facilities, flood gates, dams, railways and flood mitigation works;
- major development projects involving construction at depths at and beyond the standing groundwatertable;
- developments involving disturbance to wetlands, mangrove swamps, salt marshes, lakes and waterways;
- dewatering operations (including those of minor scale);
- compacting saturated soils or sediments;
- drainage works;
- groundwater pumping;
- ditching for mosquito control;
- artificially deepening lakes, waterways and wetlands;
- de-sludging or otherwise cleaning open drains;
- removal or mining of sulfidic peat;
- mining and quarrying operations, including the extraction of sand or gravel;

- dredging operations;
- rural drainage which lowers the watertable;
- laterally displacing previously saturated sediments, resulting in groundwater extrusion and aeration of ASS;
- aquaculture developments, such as prawn farms in mangrove communities; and
- disturbance of areas that have been previously irrigated with wastewater or treated wastewater.

When ASS materials are oxidised, sulfuric acid is formed, resulting in the release of metals, nutrients and acidity into the soil and groundwater system. The release of contaminants such as acid, nutrients, iron, aluminium, arsenic and other heavy metals may adversely affect the natural and built environment and human health. For example, the release of acid and metal contaminants can:

- have significant adverse effects on the ecology of wetlands and shallow freshwater and brackish aquifer systems by degrading water quality, habitat and dependent ecosystems. Acidified waters may result in the killing or disease of fish and other aquatic organisms;
- corrode concrete and steel infrastructure, such as culverts, pipes and bridges, reducing their functional lifespan;
- have adverse health impacts. Physical contact with ground and surface waters containing toxic concentrations of acid and metal contaminants can cause skin irritation and dermatitis, while dust from disturbed ASS may also cause eye irritation (Queensland Government, 2002); and
- result in loss or deterioration in quality of water sources for stock irrigation and human use.

1.2 ASS management principles

With reference to the *Queensland Acid Sulfate Soil Technical Manual* 2014 – Soil Management Guideline v4.0 , the following eight management principles should be applied:

1. The disturbance of ASS should be avoided wherever possible.
2. Where disturbance of ASS is unavoidable, preferred management strategies are:
    - minimisation of disturbance
    - neutralisation
    - hydraulic separation of sulfides, either on its own or in conjunction with dredging
    - strategic reburial (reinterment)[3] below the watertable or other water body.

    Other management measures may be considered but must not pose unacceptably high risks.
3. Works should aim to achieve best practice environmental management, when it has been shown that the potential impacts of works involving ASS are manageable to make

[3] Within the preferred management strategies avoidance and minimisation of disturbance are the most preferred. The other strategies are not ranked in any order as many site-specific factors need to be considered in determining the most appropriate strategy for a particular project.

sure that short and long term environmental impacts are minimised.

4. The material being disturbed (including the *in situ* ASS and surface water and groundwater systems) and any potentially contaminated waters associated with ASS disturbance, must be considered in developing a management plan for ASS and/or in complying with environmental duty.
5. Receiving waters, be they marine, estuarine, brackish or fresh waters, may not be used as a means of diluting and/or neutralising ASS or associated contaminated waters.
6. Management of disturbed ASS and/or groundwater must occur if the relevant ASS *action criteria* listed in Table 1 of these guidelines are reached or exceeded.
7. Stockpiling of untreated ASS above the permanent watertable with (or without) containment is not an acceptable long-term management strategy. For example, soils that are to be stockpiled, disposed of, used as fill, placed as temporary or permanent cover on land or in waterways, sold or exported off the treatment site or used in earth bunds that exceed relevant *action criteria* listed in Table 1 should be treated/managed.
8. The following issues should be considered when formulating ASS environmental management strategies:
   - The sensitivity and environmental values of the receiving environment. This includes conservation, protected or other relevant value or status of the receiving environment (e.g. conservation category wetlands, Marine Parks, etc.).
   - Whether groundwater and/or surface waters are likely to be directly or indirectly affected.
   - The heterogeneity, geochemical and textural properties of soils on site.
   - The management and planning strategies of local government and/or state government.

The action criteria presented in Table 1 are general texture-based criteria developed by Ahern *et al* (1998), for various soil types in Queensland and New South Wales.

Table 1. Texture-based acid sulfate soil action criteria *(after Ahern et al. 1998)*

Type of material		Action criteria if 1 to 1,000 tonnes of material is disturbed		Action criteria if more than 1,000 tonnes of material is disturbed	
		Existing + potential acidity			
Texture range (AS 1726–1993)	Approximate clay content (%)	Equivalent sulfur (%S) (oven-dry basis[4])	Equivalent acidity (mol H^+/tonne) (oven-dry basis)	Equivalent sulfur (%S) (oven-dry basis)	Equivalent acidity (mol H^+/tonne) (oven-dry basis)
Coarse texture *Sands to loamy sands and peats*	≤5	0.03	18	0.03	18
Medium texture *Sandy loams to light clays*	5–40	0.06	36	0.03	18
Fine texture *Medium to heavy clays and silty clays*	≥40	0.1	62	0.03	18

Bassendean sands – It should be noted that Bassendean sands contain single crystal and framboidal aggregates of sub-micron-sized pyrites. They generally have less than one per cent clay and therefore, extremely poor acid-buffering capacity.

Soil column studies undertaken by DER demonstrated that a sulfur content less than 0.03%S in Bassendean sands can produce a soil field pH peroxide test (pH_{Fox}) of <3.

In the absence of a revised trigger value for Bassendean sands, where a chromium reducible sulfur (Scr) value is less than 0.03%S and field pH_{Fox}<3, the soil should be treated by neutralisation with alkaline materials as if it had an inorganic sulfur content of 0.03%S.

Additionally, a detection limit of 0.005%S is recommended for all sandy soils.

- The *action criteria* refer to existing plus potential acidity for given volumes of ASS. The highest result(s) should always be used to assess if the relevant *action criteria* level has been met or exceeded; using the mean or mean plus one standard deviation of a range of results is not appropriate.
- When calculating the total amount of material which will be disturbed, the calculations must include the ASS material exposed by groundwater drawdown from dewatering and/or drainage works (i.e. the mass of ASS materials contained within the groundwater cone of depression needs to be included within calculations).

[4] Oven-dry basis means dried in a fan-forced oven at 80 – 85°C for 48 hours.

2 Soil management options

Successful management of ASS depends on the results of an adequate investigation to determine the most appropriate management strategy for a site.

Development must be undertaken in a manner that will not create soil, groundwater or surface water contamination problems. This can be done by either minimising the disturbance of pyritic soils (for example by reducing the amount of dewatering, drainage and excavation) and/or treating the soils and groundwater to ensure that any acid generated is effectively neutralised.

2.1 Avoidance strategies

Wherever possible, the best and cheapest strategy to manage ASS is avoidance of its disturbance as ASS remains inert while in anaerobic and/or anoxic conditions. Avoidance of ASS disturbance is usually the most preferred option, being both environmentally responsible and economical in comparison to other ASS management options and requiring no ongoing management measures.

2.1.1 Planning to avoid ASS

In situations where there is a high probability of ASS occurrence, state and local government planning strategies should, as far as practicable, give preference to land uses that avoid or minimise disturbance of ASS.

Where possible, a development should be planned such that non-intrusive activities, for example areas of public open space (POS), are situated in the areas of high sulfide concentration, where the risk of generating acidity is highest, to ensure that sulfides are not disturbed by development.

In areas adjacent to the coastline or estuaries where the watertable is less than about three metres deep, it is unlikely that canal or marina type developments would be able to be constructed without causing significant and difficult to reverse environmental damage, because of the complex bio-geochemical and hydrogeological processes that occur in these areas. In these locations, ‘dry lot’ developments would be more appropriate.

2.1.2 Shallow disturbances

Should soil investigations determine a consistent spatial distribution and depth of ASS throughout a development site, development works may be redesigned to disturb only shallow surface soils situated above the watertable and the identified ASS layer. Using this approach, no ASS would be disturbed; no soils would require treatment and no management plan would be necessary.

2.1.3 Cover *in situ* soils with clean fill

If groundwater levels are not affected by earthworks, undisturbed *in situ* PASS can be covered with a significant volume of fill[5]. A minimum depth of fill cannot be specified for residential or commercial/industrial development. A suitable depth of fill should rather be determined on a site-specific basis, dependent on the severity and extent of ASS, as identified in the investigation. Once a site has been covered by fill, any associated

[5] Fill should be sourced from a certified source, or analysed appropriately (by a NATA-accredited/registered laboratory) to determine that the material is free from contamination.

infrastructure may be placed within the fill, thereby not disturbing any *in situ* ASS by excavation or dewatering.

2.1.4 Maintain *in situ* soils in a saturated state

If development is to occur in an area underlain by ASS, it may be possible to maintain *in situ* soils beneath the watertable to prevent oxidation of sulfides, before the commencement of earthworks. Soils may be flooded or remain buried in water to maintain a saturated state.

2.2 Minimisation of disturbance

Where disturbance of ASS by development is unavoidable, development should be undertaken in a manner that mitigates potential adverse impacts on the built and natural environment using the most appropriate management techniques. Potential impacts of disturbance must be treated and managed to:

- neutralise existing and potential acidity and prevent the generation of acid and metal contaminants;
- avoid releasing surface and/or groundwater flows containing elevated concentrations of acid and heavy metals into the environment;
- prevent potential short and long term environmental harm; and
- make use of technologies that minimise soil disturbance.

2.3 Using technologies to minimise soil disturbance

Completing an ASS investigation to assess the nature and spatial distribution of potential and existing acidity is essential prior to ASS disturbance. Once the site has been adequately characterised, alternative strategies can be considered, such as the technologies listed below, to minimise the disturbance of ASS.

2.3.1 Trenchless technologies

The term ‘trenchless technologies’ encompasses a number of directional drilling or pushing techniques for installing or repairing underground cables or pipelines without the need for open trenching and dewatering, and follows much of the same principles as ‘keyhole surgery’.

Trenchless technologies have been used on large engineering projects in Australia for a number of years and, as operational costs are decreasing, it is anticipated that these techniques will become more widely adopted. More information and guidelines on trenchless technologies can be obtained from the Australian Society for Trenchless Technologies (ASTT) at http://www.astt.com.au/.

For projects involving the installation of services, micro tunnelling is an option that limits excavation and dewatering requirements. For example, micro-tunnellers are designed to install pipe services with an internal diameter less than that permissible for man-entry, using laser guidance systems to maintain the line of installation. The use of micro tunneling and other trenchless technologies for underground works and/or service installation may significantly reduce environmental impacts associated with the development.

The higher cost of using this technology can be offset in areas that would need high levels of ASS management and/or where deep excavation would be otherwise required. The use of trenchless technologies will also drastically reduce the investigation costs as the soil disturbances are much smaller.

2.3.2 Deep soil mixing

Deep soil mixing has been used in Scandinavian countries for many years for construction on peaty soils, and the technology is now being adopted in many other parts of the world.

Deep soil mixing is carried out with a large diameter (one to three metres) hollow-flight auger which also has special mixing 'paddles' (Figure 1). As holes are drilled into the soft substrate, cement or lime and a variety of binding agents (such as shredded tyres) are mixed with the soil slurry to form solid supportive columns in the soil when the cement sets.

Figure 1 Deep soil mixing in peaty soils.

More information about utilising deep soil mixing techniques can be found in the European Standard EN14679:2005 Execution of Special Geotechnical Works – Deep Mixing document.

2.3.3 Jet-grouting

Jet-grouting is a soil amendment technique that works in a similar way to deep soil mixing, except that a liquid chemical binding agent is injected under high pressure into the soft soil rather than being mechanically mixed (Figure 2).

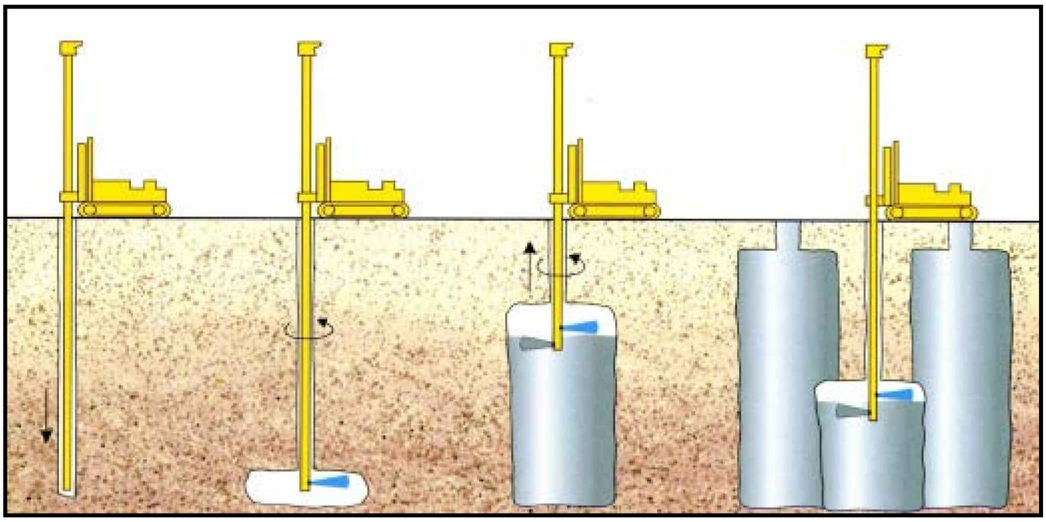

Figure 2 Schematic view of using jet-grouting to stabilise soft soils

2.3.4 Piling and diaphragm walls

'Top down' methods of construction, where underground vertical walls are constructed prior to excavation and construction of basement floors, can significantly reduce the volume and extent of soil and groundwater ASS disturbance. Where dewatering is required, the use of piling or diaphragm wall techniques to construct underground walls can act to eliminate (or limit) the effect of drawdown where dewatering is limited to inside the walls.

2.4 Managing ASS disturbance

Wherever possible, the disturbance of ASS should be avoided. If ASS are to be disturbed, comprehensive management measures will need to be implemented based on the level of risk associated with the disturbance. Factors that may influence the level of risk include the nature, magnitude and duration of the proposed ASS disturbance, the soil characteristics and the sensitivity of the surrounding environment.

Soil management measures are recommended where the volume of ASS to be disturbed is greater than $100m^3$. For disturbances of ASS (greater than $100m^3$) the management should include:

- staging of disturbance such that the potential effects on any area disturbed at any one time are limited and managed;
- staging of earthworks program to minimise the amount of time that ASS are exposed to the atmosphere (i.e. minimise the time that excavations are left open); and
- neutralisation of ASS materials in accordance with 2.5 Soil neutralisation.

2.4.1 Hydrogen sulfide

Disturbance of some ASS landscapes may release hydrogen sulfide gas. This gas has a characteristic offensive 'rotten egg' odour. However, at high concentrations and/or after prolonged exposure, hydrogen sulfide inhibits the sense of smell. The olfactory nerve loses sensitivity and the potentially hazardous gas is no longer detectable by smell.

Hydrogen sulfide is heavier than air and so tends to settle in depressions and may reach toxic levels within excavations and in confined spaces. Therefore, it is strongly recommended that on-site gas monitoring and occupational health and safety measures are implemented to deal with this contingency during the disturbance of ASS materials, particularly when ASS disturbance is planned to be carried out in urban environments.

More information on hydrogen sulfide can be found in the Government of Western Australia's Department of Health document *Environmental Health Guide, Hydrogen Sulphide and Public Health* (Department of Health, 2009). Guidance on the management of hydrogen sulfide in the work place can be obtained from WorkSafe (a division of the Department of Commerce, the Western Australian State Government agency responsible for the administration of the *Occupational Safety and Health Act 1984*).

2.5 Soil neutralisation

Where the disturbance of ASS is unavoidable, the most common technique used in managing the disturbance is neutralisation of the soils with alkaline materials.

2.5.1 Calculating the quantity of neutralising agent for treatment of ASS

It is important to provide adequate neutralising material to reduce the potential for environmental harm or damage. Sufficient neutralising material should be applied to counteract the theoretical acid production potential of the soil. The theoretical acid production potential of the soil is determined based on the existing plus the potential acidity of the soil, multiplied by a 'safety factor' of 1.5.

The safety factor is used for the following reasons:

- In most situations the neutralising agent is not fully mixed with the soil regardless of the mixing method used.
- The distribution of sulfides within soil profiles can be highly variable, so there is a risk that investigations may underestimate the theoretical acid production potential of the soil.
- Neutralising agents such as fine aglime (calcium carbonate) have a low solubility and hence a low reactivity and coatings of gypsum, and/or iron and aluminium compounds can form on the grains of neutralising agents during neutralisation, reducing the neutralising efficiency.

In 'high risk' situations larger safety factors may be needed.

The actual amount of neutralising material needed is calculated using the 'net acidity' of the soil as determined during ASS investigations for the project. Note that ASS investigations for this purpose should be undertaken in accordance with *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015).

Net acidity should be determined from the suspension peroxide oxidation combined acidity and sulfur (SPOCAS) or chromium reducible sulfur (CRS) methods[6], as detailed in *Acid Sulfate Soils Laboratory Methods Guidelines* (Ahern *et al*., 2004). Soil samples should be analysed to a detection limit of 0.005%S such that net acidity can be calculated, according to an acid-base account (ABA), expressed by the following equation:

- **Net acidity = potential acidity + existing acidity – acid neutralising capacity (ANC)**[7]

For linear disturbances, and for non-linear disturbances less than 1,000m^3, the highest net acidity detected at the site should be used to calculate the amount of neutralising material needed.

When the volume of soil to be disturbed is more than 1,000m^3, the mean net acidity plus the standard deviation may be used to calculate the amount of neutralising material needed, provided a sufficient number of laboratory analyses have been performed to satisfactorily characterise the soil profile and ASS at the site. Detrimental environmental impacts may occur if incorrect liming rates are used.

Calcium carbonate ($CaCO_3$), in the form of finely crushed limestone or 'aglime', is the most commonly used neutralising agent for the treatment of ASS, and is used in the calculations provided below.

Once the net acidity has been determined, the amount of lime needed for soil treatment can be calculated using the following equation:

[6] For highly leached and poorly buffered **Bassendean Sands** in Western Australia, net acidity should be determined to a detection limit of 0.005%S. For further information refer to *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015).

[7] Due to the particular characteristics of the sandy soil and groundwater regime in Western Australia, DER does not recognise the validity of ANC values without confirmatory kinetic testing or modified laboratory methods to determine particle size distribution to provide a more accurate estimate of the actual amount of neutralising capacity that would be available under real field conditions. For further information refer to *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015).

- **Lime needed (kg $CaCO_3$/tonne soil) = net acidity (kg H_2SO_4/tonne of soil) x 1.02[8] x safety factor[9] x 100/ENV[10]**

As net acidity is most commonly reported in units of percentage sulfur (S%), the equation is rewritten below using S% units:

- **Lime needed (kg $CaCO_3$/tonne soil) = net acidity (S% x 30.59) x 1.02[8] x safety factor[9] x 100/ENV[10]**

The bulk density (BD) of the soil needs to be taken into account when calculating the amount of lime needed to treat a given volume of soil. The liming rate calculation for volumes of soil in cubic metres is shown below.

- **Lime needed (kg $CaCO_3/m^3$ soil) = bulk density soil (tonne/m^3) x net acidity (S% x 30.59) x 1.02[8] x safety factor[9] x 100/ENV[10]**

To access the DER web-based 'Lime rate calculation tool to calculate the amount of lime needed to treat ASS, go to http://www.der.wa.gov.au/your-environment/acid-sulfate-soils/67-lime-rate-calculations-for-neutralising-acid-sulfate-soils.

2.5.2 Selecting neutralising materials

There are many types and sources of neutralising agents. These vary greatly in their ability to change soil pH and the speed at which this happens. This is referred to as their effective neutralising value (ENV).

Calcium carbonate ($CaCO_3$), in the form of finely crushed limestone or 'aglime', is the most commonly used neutralising agent for the treatment of ASS, however, other neutralising agents may also be used. These include magnesite, dolomite, hydrated lime/slaked lime[11], burnt or quicklime, sodium carbonate, sodium bicarbonate, soda ash, etc. Any chemically-amended liming products should be used with caution due to their high alkalinity which has the potential to impact on the receiving environment.

Note on the use of sodium-based compounds in ASS landscapes

Should sodium-based compounds be considered as a neutralising material, precautions should be taken to ensure that the salinity and sodicity of soils are not increased as a result of free sodium ions being introduced into the landscape. Sodium has a dispersive effect in soils and in water and its use should be carefully managed.

The use of sodium-based compounds also increases the salinity of any discharge waters and may contribute to adverse downstream impacts in sensitive waterways.

The use of soda ash (Na_2CO_3) is particularly risky as it has a pH >11 and is highly soluble (one kilogram is soluble in 3.5 litres of water). Its use is not recommended as it releases heat on combination with water and is known to cause sodicity effects on soils. Products such as sodium hydroxide (NaOH) may have little residual alkalinity and buffering capacity over time.

If sodium-based compounds are used, sodium should be added to any water quality

[8] The factor 1.02 is used to stoichiometrically convert units of sulfuric acid (H_2SO_4) to units of calcium carbonate ($CaCO_3$).
[9] A minimum safety factor of 1.5 should be used.

[10] The actual rate of application of neutralising materials required must be corrected for the effective neutralising value (ENV) of the neutralising materials.

[11] Hydrated lime/slaked lime (liquid lime) is the preferred material to be used for neutralisation of water.

monitoring suite and precautions taken with regard to any precipitates/sludge in settlement/retention ponds. This sediment should be analysed and appropriately remediated or disposed of.

The important factors to be considered in selecting neutralising agents are:

- neutralising value (NV) and effective neutralising value (ENV);
- ability to deliver ongoing buffering capacity;
- solubility;
- pH, chemical constituents, moisture content and other impurities/contaminants;
- purity of lime, fineness rating or particle size;
- method of application; and
- occupational safety and health issues.

From an environmental perspective, the most critical factors in managing outcomes are the pH of the neutralising agent, effective neutralising value (ENV) and solubility.

In some circumstances, DER may approve the use of alkaline waste materials as neutralising agents.

However, DER will require assessment of these materials to be carried out to ensure that the concentration of metals (and/or other contaminants) in the neutralised soil will not pose a risk to the environment or human health.

For further information consult DER's policy and guidelines on waste-derived materials http://www.der.wa.gov.au/your-environment/waste/waste-derived-materials.

2.5.3 Calculating effective neutralising value (ENV) of a neutralising material

The effective neutralising value (ENV) of a neutralising material is the ability of a unit mass of neutralising material to change soil pH. The higher the ENV, the more effective the neutralising material will be at increasing pH.

ENV takes into account:

- neutralising value (NV)—i.e. the amount of calcium or magnesium as oxides or carbonates, expressed as a percentage;
- particle size distribution (percentage by weight)—i.e. the fineness of the neutralising material. The finer the product, the greater the surface area for the neutralising chemical reactions to occur; and
- solubility of the neutralising material.

The NV and the solubility of the neutralising material are determined by laboratory analysis. The particle size distribution is determined by mechanical sieving.

The fineness of the neutralising agent will influence the effectiveness and reactivity of the agent. As particle size increases, the amount of soil that portion of neutralising material is able to neutralise decreases. For example, lime particles in the size range 0.30–0.85 millimetres have around 60 per cent effective neutralising value, while lime particles over 0.85 millimetres but below one millimetre have only 10 per cent effective neutralising value. Particle sizes greater than two millimetres are considered ineffective at neutralising acidity.

Generally, DER recommends fine aglime (crushed limestone which passes through a < one millimetre sieve) as a neutralising agent for acidic or potentially acidic soils because:

- it has a relatively high neutralising value (NV) of 85 per cent to 95 per cent;
- it has a pH in the range pH 8.5 to 9.0, making it safe from an occupational health and safety perspective and reducing the risk of environmental harm from excess alkalinity (i.e. pH 'overshoot'); and
- it has a low solubility in water so it can provide acid buffering capacity over a sustained period of time.

The use of quicklime (burnt lime) and/or slaked lime is generally not recommended because it is highly caustic and presents occupational health and safety challenges. Although most amended liming products have a higher NV (ranging between 150 to 179 per cent) compared to aglime, they are highly alkaline (pH 12.5–13.5) and represent an environmental risk if inappropriately applied to soils. In addition, amended lime products are more soluble in water and generate considerable heat, both of which could impact the receiving environment.

Due to their high dissolution rate, the residual effect of amended lime products may have little residual alkalinity so their ability to neutralise acidity over time may be limited.

Table 2 provides an example, adapted from *New South Wales Acid Sulfate Soil Management Advisory Committee Manual* (Stone *et al.*, 1998), which can assist to clarify the method of calculating ENV values. In this example the crushed limestone product is calculated as having an ENV of 59 per cent. Therefore, 1.7 parts (100/59) of the product is equivalent to one part of pure fine $CaCO_3$, so a correction factor of 1.7 needs to be used for this product. Note that ENV values may need to be further corrected for solubility when the more soluble type of lime products are used (e.g. slaked lime).

Table 2. Calculating ENV values

Materials	Particle size	Proportion (%)	Utilisation factor	ENV
Example: crushed limestone NV 75%	1.00–2.00mm	0	0.01	0.00
	0.85–1.00mm	15	0.10	1.0
	0.300–0.850mm	20	0.60	9.0
	<0.300mm	65	1.00	49.0
	Total	100		59.0%
ENV = % Proportion/100 x Utilisation Factor x NV				

2.5.4 Lime application

Successful treatment of disturbed ASS is based on the effective incorporation of the neutralising material into the soil. It should be noted that over the longer term, iron, aluminium and low solubility gypsum compounds are likely to coat the neutralising agents, reducing their effectiveness. Application methods include, but are not limited to:

- mechanical application and mixing in small windrows using conventional earth working equipment;

- broadscale mechanical application using rotary hoeing and tillage—this method is useful in treating agricultural land and treatment of stockpiled materials for future landscaping use;
- application of a lime slurry to the surface of a soil and further blending;
- injection of an aglime or hydrated lime slurry into an up-hydraulic gradient trench, perpendicular to the direction of groundwater flow;
- injection of an aglime or hydrated lime slurry into dredging pipelines particularly during dredging operations—this method is suitable for sand and silty materials but is not suitable for heavy clay soil; and
- using 'lime buffer' on exposed ASS and covering with clean fill or sandbagging the face and incorporating lime under and in the sandbags—this method is suitable for infrastructure earthworks or rehabilitation of undisturbed ASS landscapes.

***Note**: soils often need to be mixed a minimum of two times and may need to be mixed several more times to ensure sufficient mixing.*

2.5.5 Treatment pad

For treatment of large volumes of material by mechanical application of neutralisation materials, treatment should be carried out on a treatment pad. The treatment pad should consist of a minimum 300-millimetre thickness of compacted crushed limestone, or other appropriate neutralisation material. The treatment pad should be bunded with a minimum 150-millimetre high perimeter of compacted, crushed limestone to contain potential leachate runoff within the treatment pad area and prevent surface water runoff from entering the treatment pad area. The level of compaction used should produce an appropriately low permeability to prevent infiltration of leachate.

In addition, the following management strategies may need to be implemented to manage risk:

- installation of leachate collection and treatment systems; and
- construction of erosion and sediment control structures.

The following issues should also be considered in the treatment pad design.

Earthworks strategy

An earthworks strategy should be formulated to ensure that sufficient space is available to accommodate the volume of soil requiring treatment. Expected rates of throughput in cubic metres, mixing times and validation testing times, along with the capacity of the treatment pads to accept the materials, need to be identified in the strategy.

The earthworks strategy should also ensure that adequate time is available to obtain the results of validation testing before the treated soils need to be reused.

Climate, seasonal conditions and soil texture may affect treatment rates and hence the size of treatment pads needed.

Spatial tracking

The accurate spatial tracking of large volumes of ASS during the neutralisation process (e.g. survey with a hand-held global positioning system (GPS), differential GPS, designated lot numbers or conventional survey, depending on the level of accuracy needed) is essential to ensure that soil treatment can be properly validated.

Some sites may have difficulty developing an appropriate tracking program, due to spatial constraints. In such situations, alternative management and treatment facilities should be used.

Decommissioning

Once soil treatment has finished the treatment area must be appropriately decommissioned. Decommissioning should include remediation and validation of the ground surface where the treatment pad and associated infrastructure was placed.

Please note that a management plan for an on-site ASS treatment facility is valid only for the duration of the project for which approval was provided. ASS materials from other sites should not be accepted for treatment without considering potential licensing requirements under the *Environmental Protection Act 1986*

2.5.6 Validation of soil treatment

The effectiveness of soil neutralisation activities needs to be validated to confirm that an appropriate amount of neutralising material has been thoroughly mixed with the soil.

Validation sampling should be undertaken using field testing (pH_F and pH_{FOX}) at a sampling intensity reflective of DER's *Landfill Waste Classification and Waste Definitions 1996 (As amended)* (Department of Environment and Conservation, 2009).

The accuracy of the field testing program should be 'calibrated' by sending 25 per cent of samples to a laboratory for confirmatory analysis.

Appropriate laboratory analytical methods for validation purposes include: the SPOCAS suite; pH_{KCl} and pH_{OX} undertaken in a laboratory on an un-ground sample; the CRS with the inclusion of a measurement of total potential acidity (TPA) from the SPOCAS suite.

Additional laboratory analyses are needed to confirm validation if there is poor correlation between laboratory results and field test results.

The following performance criteria should be met to confirm effective neutralisation of soils:

- the neutralising capacity of the treated soil must exceed the existing plus potential acidity of the soil, (e.g. pH_{fox} must be >5);
- the neutralising material has been thoroughly mixed with the soil;
- soil pH must be in the range 6.0 to 8.5; and
- excess neutralising agent must remain within the soil until all acid generation reactions are complete and the soil has no further capacity to generate acidity[12].

Additionally, in order to account for all sources of acidity for poorly buffered sands (e.g. soils of the Bassendean sand formation), measurements of TPA should be less than the limits of reporting.

If soils fail validation, additional neutralisation is needed until results comply with performance criteria.

[12] Choice of appropriate neutralising agent is important to achieve this long-term performance criterion (see 2.5.2 Selecting neutralising materials)

Quality assurance/quality control (QA/QC)

Any sampling program should include measures to ensure the quality and reproducibility of all sampling methods used at the site. Adequate QA/QC is needed to ensure that the samples collected are of the highest quality and integrity, and that analysis is completed with the highest accuracy. Where results are produced with inadequate QA/QC procedures, they cannot be accepted as being accurate or representative of the site conditions.

QA/QC measures are needed regardless of the number of samples taken.

When undertaking validation sampling, standard QA/QC procedures should be followed as outlined below.

Field QA/QC

The minimum field QA/QC procedures that should be performed are:

- collection of field duplicates as quality control samples;
- use of standardised field sampling forms (including Chains of Custody) and methods; and
- documenting calibration and use of field instruments.

Field duplicate samples (also known as blind replicates) are used to identify the variation in analyte concentration between samples collected from the same sampling point and also the repeatability of the laboratory's analysis. Field duplicates should be collected at the rate of one field duplicate for every 20 investigative samples. The field duplicate sample and investigative sample from the same sample location should be submitted to the laboratory as two individual samples without any indication to the laboratory that they have been duplicated.

Laboratory QA/QC

Analysis of samples should be completed by laboratories which hold National Association of Testing Authorities (NATA) accreditation for the particular parameters and methodologies needed. Information on QA/QC methods should be obtained from the designated laboratory before sampling to ensure that they meet acceptable standards.

The laboratory report should be a NATA endorsed report and include the results of the analysis, sample numbers, laboratory numbers, a statement about the condition of the samples when they were received (e.g. on ice, cold, ambient, etc.), date and time of receipt, dates and times of extraction and analysis of samples, quality control results and a report on sampling and extraction holding times.

Data review

Following receipt of field and/or laboratory data, a detailed review of the data should be completed to determine their accuracy and validity, before being used to make any decisions. Analytical data should be reviewed against field data and field observations to identify any spurious results inconsistent with field findings. Where inconsistencies are identified, re-sampling or re-analysis may be needed.

2.6 Strategic reburial under water

Strategic reburial is another option that may be considered for managing ASS. This option requires a neutral void, consisting of an area of non-ASS material, to hold the excavated ASS. The void should be deep, beneath a water body, and the ASS should remain wholly under water to prevent oxidation of sulfide by excluding oxygen from the reburied soils, thereby limiting acid generation.

This technique should only be employed when soils to be reburied have not been exposed to oxygen and the reburial environment must be one that is permanently anaerobic. Heavy clays have been demonstrated to have a slow rate of oxidation once exposed to air and may be most suited to this practice. Conversely, sands may not be suitable and require neutralisation prior to re-burial. A field trial to assess the oxidation rate of a particular ASS and potential need for the addition of a neutralising material is recommended prior to reburial.

The reburial location must be available when needed and timelines for earthworks need to be calculated and met to ensure the appropriate conditions are achieved. The reburial location will need to be managed into perpetuity.

2.7 Hydraulic separation techniques

Other options that may be considered in terms of management of ASS are hydraulic separation techniques commonly used in dredging operations and extractive industries. Hydraulic separation refers to the segregation of sediment or soil components through the use of water mechanics using natural or accelerated differential settling into two or more fractions based on differences in grain size or grain density. The common hydraulic separation techniques used include hydro-sluicing and hydro-cycloning. Separation of sediment containing more than 20 per cent clay and silt and high organic matter content is usually not feasible. Hydraulic separation techniques can produce significant amounts of acidity that require management to minimise long term risk.

Hydro-sluicing is a term used whereby fine silty materials including sulfidic fines are hydraulically separated from the coarser materials. Sluicing is a form of settling-based separation operated on a continuous process stream using a series of settling lagoons/ponds. The aim is to settle out the coarser and heavier particles of the slurry from the dredging operation at a location, while retaining the fine particles (including sulfides) in suspension until the end of the sluicing channel, where the fine particles are then treated and settled in a stilling basin before off-site discharge. As long as the fines are kept wet and in an anoxic environment they are relatively stable. It should be noted that drying of the sulfidic fines would present a high environmental risk. Stilling basins should be sufficiently deep to retain the fines under water.

Hydro-cycloning is used in mining and extractive industries, particularly in mineral sand mining. Cyclones are centrifugal clarifiers used primarily to separate particles based on their density and particle size. It is an effective mineral separation method for uniform or constant feed. The slurry from mined minerals is fed into the hydro-cyclone under pressure and the solid particles of different weights in the feed are separated by centrifugal drag and gravity. Hydro-cycloning may not be effective in removing fine-grained pyrite in clayey or cemented soils.

For further information refer to the *Queensland Acid Sulfate Soil Technical Manual—Soil Management Guidelines* available at https://publications.qld.gov.au/dataset/acid-sulfate-soil-management-guidelines/resource/6d880993-4b80-45e3-9110-5c24fa7a7e75 on enhancing sulfidic fines recovery.

2.7.1 Management considerations

Where hydraulic separation activities are proposed, the key to management lies in careful site investigation to determine the spatial distribution of sulfides (including monosulfides). This investigation must include an assessment of potential conflict between protecting the environmental values and dredge spoil disposal techniques. Areas with high sulfide values are best avoided otherwise additional management measures are needed.

Best management techniques should be used to mitigate the impacts from dredging operations and the disposal of dredged spoil. A dredging or extractive industry proposal should include details concerning all phases of the project including sediment removal, staging, dewatering, water treatment, sediment transport, sediment treatment, re-use or disposal. Of particular concern are the contaminant load of the dredged material and the dewatering of the spoil.

When choosing dredge spoil disposal options, a comparative assessment of environmental and human health risks for each disposal option must be carried out. Containment methods for the spoil need to have enough capacity and be sufficiently robust to fully contain the spoil under worst case scenario conditions.

A dredging or excavation project must be monitored during implementation to assess re-suspension and transport of contaminants, immediately after implementation to assess residuals and after implementation to measure long term recovery of biota and to test for recontamination.

2.8 Stockpiling

The risks of stockpiling large volumes of untreated ASS may be very high even over the short term. Stockpiling of untreated ASS should **only** be undertaken as a **short-term** activity. (**Note:** all stockpiled ASS requires treatment)

It is acknowledged that short-term stockpiling may be needed:

- due to weather conditions that may prevent treatment;
- due to delays obtaining laboratory results; or
- where land areas needed for soil neutralising treatment may not be available as quickly as anticipated leading to the creation of small stockpiles before changes can be made to earthworks programs.

Significant quantities of acid can build up, especially in porous sandy stockpiles, if left in an oxidising condition for even short periods of time. Large stockpiles are difficult to neutralise, primarily due to the earthmoving needed.

Stockpiles should be created, where possible, up-gradient of development sites, such that all leachate and run-off water will be directed towards already-disturbed ASS areas.

2.8.1 Management considerations

Stockpiling untreated ASS should be minimised by preparing a detailed earthworks strategy that documents the timing of soil volumes to be moved, treatment locations and capacity of those areas to receive the stockpiled materials.

Stockpiling may mean double-handling and increased earthmoving costs. It is important to account for the risk of wet weather and an increase in material volume upon excavation and plan contingencies to deal effectively with these issues.

Stockpiled ASS should be adequately neutralised and validated prior to re-use or

backfilling regardless of the duration of stockpiling.

2.8.2 Short-term stockpiling

The recommended maximum time period over which soils may be temporarily stockpiled before treatment commences to neutralise acidity is detailed in Table 3.

Table 3. Indicative maximum periods for short-term stockpiling of untreated ASS

Type of material		Maximum duration of stockpiling before the commencement of treatment	
Texture range (AS 1726–1993)	**Approx clay content (%)**	**Days**	**Hours**
Coarse texture **Sands to loamy sands**	≤5	Overnight	18 hours
Medium texture **Sandy loams to light clays**	5–40	2½ days	70 hours
Pyritic peat	NA	2 ½ days	70 hours
Fine texture **Medium to heavy clays and silty clays**	≥40	2½ days	70 hours

Note: *Excavated ASS requires treatment to neutralise acidity regardless of the duration of stockpiling. Table 3 is provided as a guide to the maximum period of time that should elapse before treatment to neutralise acidity commences.*

Note*: These timeframes do not apply to iron monosulfide sediments or gels (formerly known as monosulfidic black oozes). Iron monosulfide gels or sediments should not be stockpiled without a risk assessment and the implementation of strict environmental management protocols.*

At some sites, these figures may be too conservative, and in other circumstances not conservative enough (e.g. during hot weather some sands may begin to oxidise within a matter of hours, whereas complete oxidation of peat may take longer). Appropriate operational delay times should be determined well before the creation of the stockpile.

The use of a guard layer under the short-term stockpiles may be warranted in certain circumstances. Peaty soils containing pyrite should not be stockpiled without the use of a guard layer and adequate bunding.

The total volume of material placed in short-term stockpiles should not exceed 20 per cent of a day's total extraction. When undertaking short-term stockpiling of ASS materials, the stockpile should be monitored for signs of oxidation (e.g. colour changes, decrease in pH of more than half a pH unit). If stockpiled ASS materials are observed to have oxidised they will need to be treated with an appropriate amount of neutralising material before re-burial.

Due diligence is needed when stockpiling sandy soils with no acid buffering capacity (e.g. Bassendean sands), particularly when these soils are extracted from below the watertable. Reburial of untreated and acidifying sandy soils is not recommended.

2.8.3 Medium-term stockpiling

Situations where it is necessary to stockpile untreated ASS for moderate periods of time before treatment commences will need to be justified. Management to reduce the oxidation of sulfides and the collection and treatment of all leachate and run-off water will need to be implemented during the entire stockpiling period. The maximum time period which soils can be temporarily stockpiled in the medium-term before treatment commences is listed in Table 4.

Table 4. Indicative maximum periods for medium-term stockpiling of untreated ASS prior to the commencement of treatment

Type of material		Duration of stockpiling	
Texture range (AS 1726–1993)	**Approx clay content (%)**	**Days**	**Weeks**
Coarse texture **Sands to loamy sands**	≤5	14 days	2 weeks
Medium texture **Sandy loams to light clays**	5–40	21 days	3 weeks
Pyritic peat	NA	21 days	3 weeks
Fine texture **Medium to heavy clays & silty clays**	≥40	28 days	4 weeks

Note: *Excavated ASS requires treatment to neutralise acidity regardless of the duration of stockpiling. Table 4 is provided as a guide to the maximum period of time that should elapse before treatment to neutralise acidity commences.*

Depending on site-specific requirements, a risk assessment should be undertaken if soils are to be stockpiled for longer periods than those listed in Table 4. Neutralisation of the stockpiled materials may be necessary if it cannot be demonstrated that there is minimal risk of acidic leachate being generated by the stockpiles. Stockpiling of untreated ASS in the medium term should be a contingency measure rather than standard practice. Stockpiling of soils is not to be used as an alternative to soil neutralisation, and all soils that are to be replaced in an excavation should be appropriately treated.

The use of a treatment pad or 'guard layer' is needed in all circumstances beneath soil materials that are to be stockpiled in the medium term. Guard layers must be constructed according to specifications provided in 2.5.5 Treatment pad.

In addition, the following management strategies may need to be implemented to manage risk:

- The volume stockpiled should not exceed more than one week's volume of extraction.
- Leachate collection and treatment systems should be installed.
- The surface area of the stockpile should be minimised to reduce exposure to atmospheric oxygen. This may involve shaping the stockpile, and/or capping or lining it with a material that will minimise drying by wind and sun and prevent rainfall entering the stockpile. The cap or liner will need to cover the sides of the stockpile as well as the top.

- Keeping the surface of the material moist using a spray of iron-free water or neutralising solution. The spray should be carefully managed to prevent over-wetting the stockpiled material as this may produce leachate or runoff, and the spray should be a fine-mist to prevent desegregation of the soil from the stockpile surface.
- Erosion and sediment control structures should be constructed.

2.8.4 Long-term stockpiling

Long-term stockpiling prior to treatment is not recommended. Any stockpiling exceeding the time frames provided in Table 4 is considered long-term stockpiling and an appropriate management strategy is needed. The proposed management strategy for long-term stockpiling should be provided to DER for review and comment before the commencement of stockpiling.

The management strategy must document the alternatives considered and include a risk assessment and an environmental management plan. The environmental management plan should include, as a minimum, those management strategies outlined for medium-term stockpiles. The installation of a groundwater monitoring bore directly down hydraulic gradient of the stockpile may also be necessary. Failure to manage environmental risks posed by long term stockpiling may result in DER taking action under the *Environmental Protection Act 1986* and/or the *Contaminated Sites Act 2003*.

2.8.5 Stockpiling of topsoil

It is routine practice to scrape the topsoil before excavation and store it until it is needed for top-dressing. Some of the management options listed under medium-term stockpiles may be appropriate for managing topsoil stockpiles, especially if they contain low levels of sulfides. Low levels of sulfides may be intrinsic in topsoils or may occur as a result of 'over-stripping' during collection. It should be noted that:

- it is recognised that topsoil (A1 and A2 horizons) pH is generally less than pH 7 across Western Australia. A large proportion of topsoils (40 per cent) are in the range of pH 5.1–6.0. Bassendean sand type soils are typically in the range pH 5.1 to 5.7; and
- generally topsoils do not require treatment. However, if pH is less than 4.0, topsoils should be treated to revised validation criteria of pH 5. This level of treatment is considered appropriate as long as the validation testing demonstrates effective mixing and that, after stripping, the soil structure remains stable and non-acid forming.

2.9 Off-site ASS treatment and disposal

2.9.1 Off-site treatment at a licensed soil treatment facility

There are a number of licensed soil treatment facilities in the Perth Metropolitan area and in the south-west region which specialise in the treatment (neutralisation and validation) of ASS. The process undertaken in these facilities generally involves neutralising the ASS materials and then blending them with other materials to create compost or other soil amendment materials to be used for landscaping purposes.

Untreated ASS should only be taken to facilities which are licensed under the *Environmental Protection Act 1984* (approved) and have a DER approved ASS management plan.

ASS treatment facilities should be provided with full details of the materials they are being requested to accept so that they are able to appropriately manage the materials.

If off-site treatment of ASS is proposed, the proponent will need to provide receipts or other acceptance records from the relevant facility including details of the total amount of soil taken to the chosen facility within the initial closure report.

2.9.2 Off-site disposal at a licensed landfill facility

Anyone wishing to dispose of ASS to a licensed landfill facility should consult the *Landfill Waste Classifications Definitions 1996* (*as amended, Dec* 2009) to assist in the selection of an appropriate facility. The acceptance of materials for disposal to licensed landfill facilities must be in accordance with this document.

If disposal of ASS at a licensed landfill is proposed, the proponent will need to provide receipts or other acceptance records from relevant facility including details of the total amount of soil taken to the chosen facility within the an initial closure report.

2.9.3 Off-site re-use of treated ASS

DER’s preferred position is that treated (suitable neutralised and validated) ASS are managed for re-use. These materials should be considered a resource, not a waste. Consequently, disposal to a landfill facility should be considered as a last resort only.

Guidance for the re-use of treated ASS is contained within DER’s series of guidelines on waste-derived materials.

Note: Treated ASS may possess geotechnical characteristics or chemical properties that limit their suitability for re-use on some sites.

If off-site re-use of treated ASS is proposed, the proponent should provide receipts or other acceptance records from the receiving site including details of the total amount of soil taken to the chosen site within the an initial closure report.

3 Groundwater management

Activities that may cause the watertable to fall in areas underlain by ASS have the potential to cause sulfide minerals in the soil to oxidise and leach acidity, arsenic, metals and nutrients into groundwater. This may lead to the situation where groundwater becomes unsuitable for irrigation or other uses. Additionally, the discharge of acidic contaminated groundwater to nearby wetlands or waterways can adversely affect the health of these aquatic ecosystems and may also make these water features unsuitable for recreational use.

Activities that can cause the watertable to fall during construction activities and in areas of new development include (but are not restricted to):

- soil dewatering for the installation of underground infrastructure such as the installation of sewage pipe and pump station infrastructure) foundations, basements or elevator structures;
- pumping for the long-term control of water ingress to underground structures (including basement pumping);
- groundwater abstraction for dust suppression or the irrigation of open space during construction;
- installation of drainage systems (including sub-soil or open drains);
- excavation of wetland or lake features in new residential developments and the pumping

of groundwater to maintain lake levels;

- planting large numbers of trees; and
- excessive use of domestic or commercial bores.

Activities that have the potential to affect the elevation of the watertable are considered to be a form of soil disturbance and must be incorporated into an ASSMP.

3.1 Guiding principles

The management of groundwater in areas underlain by ASS should adhere to the following key principles which have been adapted from the principles for soil management set out in both the National Strategy for managing acid sulfate soils (ARMCANZ, 2000) and the proposed framework for managing ASS in Western Australia. The groundwater management principles are:

- wherever possible, iron sulfide minerals below the watertable *should not be disturbed by changes in the elevation of the watertable* to ensure that these minerals are not exposed to air and allowed to oxidise;
- where disturbance is unavoidable, the *disturbance should be minimised or otherwise managed* to prevent long-term environmental problems caused by the oxidation of iron sulfide minerals. Management measures may need to be implemented, not only in the immediate vicinity of pumping bores, but also throughout the area underlain by the cone of depression for the bores (which may extend beyond the development site); and
- where environmental problems have been caused by the oxidation of sulfide minerals resulting from either short-term or long-term changes in watertable elevation, these *problems should be remediated wherever possible*, or otherwise risk-based management strategies should be implemented to prevent potential impacts on human health and the receiving environment.

3.2 Minimising groundwater disturbance

ASS generally have a low load-bearing capacity, and these materials are commonly excavated and replaced with clean fill before building construction takes place on new urban development sites. This is particularly the case with peaty soils—in some parts of the Perth Metropolitan Region up to an eight-metre thickness of peat has been removed to facilitate development.

However, this method of developing land can lead to widespread groundwater contamination by acidity, arsenic, metals and nutrients if soil dewatering for excavation is poorly managed. It is therefore recommended that construction techniques that eliminate or minimise the need for soil dewatering be considered first, as outlined below.

3.2.1 Minimise groundwater fluctuations

Activities that result in fluctuations of groundwater and, in particular, permanent lowering of the watertable should be avoided as these may lead to the exposure of *in situ* sulfidic soils to oxygen. Acidic flushes can then be brought to the surface when the groundwater rises again or through evapotranspiration. The acid can cause a breakdown of the soil structure releasing contaminants which remain in the soil until rainfall or groundwater flow is sufficient to mobilise them. These contaminants ultimately cause detrimental environmental and economic impact to off-site sources such as groundwater aquifers and surface water bodies. There are also possible health effects caused by ASS impacts on groundwater, particularly arsenic contamination. For example, concentrations of arsenic, which potentially pose a risk to human health if groundwater is used for garden irrigation, have been identified in areas of Stirling, Perth. It is therefore preferable to maintain groundwater levels in a steady state to limit the impacts of groundwater abstraction.

3.2.2 Pile construction (driven, screw, extruded, poured)

Driven piles (or similar) are generally used when the surface soils have low load-bearing capacity and the weight of the building must be carried by deeper soils. Piles are long, load-bearing rods that are driven through soft soils into more consolidated material at depth. They provide support for surface structures to prevent subsidence problems. Driven piles have been used for building on ASS in the Netherlands since the 18th century.

In the past, timber piles were commonly used, but most modern piles consist of steel and concrete as reinforced concrete and pre-tensioned concrete or a variety of acid-resistant composite materials.

Specific guidance on the use of piles in soils that contain pyrite or are saline can be found in the Australian Standard AS2159-1995 *Piling Design and Installation* document. Piles have also been used on a number of projects within the Perth Swan River foreshore area to assist with ground support in soft ASS (landfill and alluvial mud) materials.

The major benefit of driven piles is that they negate the need for the removal of geotechnically unsuitable material and the disturbance of ASS. Therefore, treatment and management of ASS becomes unnecessary.

3.2.3 Sheet piling and diaphragm/slurry walls

Sheet piling is a form of driven piling using thin interlocking sheets of steel to obtain a continuous barrier in the ground. The main application of steel sheet piles is in retaining walls and cofferdams erected to enable permanent works to proceed.

Diaphragm or slurry walls are typically used to build tunnels, open cuts and subsurface foundations in areas of soft earth close to open water or with a high watertable. Diaphragm walls are impermeable (e.g. using concrete, bentonite or synthetic polymers) sub-surface structures constructed *in situ* with specialised equipment.

Sheet piles and diaphragm walls can be used in ASS areas to drastically reduce the extent of cone of depression of the watertable, thereby reducing the disturbance of ASS and the amount of dewatering effluent needing to be treated. In some instances, the use of sheet piling, slurry or diaphragm walls may greatly reduce the intensity and extent of required ASS investigations.

3.3 Management of dewatering

Provided that the cones of groundwater depression from groundwater pumping are kept to a minimum and effluent disposal is well managed, dewatering can be a viable option for lowering the watertable at a site to allow foundations and other sub-surface infrastructure to be built in areas where there is a high risk of ASS occurring.

The extent to which sulfide minerals (predominantly pyrite) will oxidise during dewatering depends on the extent of drawdown of the watertable (both vertical and lateral), and the permeability of the material that contains sulfide minerals. In general, pyritic sand will oxidise within hours to days of exposure to air, so it is very likely that this material will oxidise during a dewatering program.

However, before a dewatering program can be designed and implemented, it is essential that a site assessment has been undertaken in accordance *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015).

Under the *Rights in Water and Irrigation Act 1914* (RIWI Act), a groundwater abstraction licence may also be needed from the Department of Water (DoW) before dewatering can commence. If it is planned to discharge dewatering effluent, either directly or via the stormwater drainage system, into the Swan or Canning Rivers in the Perth Metropolitan area, the approval of the Swan River Trust, City Council and/or the Water Corporation may be required.

A dewatering and groundwater management plan with appropriate contingencies is essential for sites where ASS have been identified and may be affected by dewatering. The following sections outline the necessary components of a management plan for dewatering operations in ASS areas.

3.3.1 Hydrological assessment

A hydrological impact assessment should be conducted before the development of a dewatering and groundwater management plan. This should include, as a minimum:

- groundwater levels;
- groundwater flow patterns;
- identification of environmental receptors in the vicinity of the dewatering operations—particularly groundwater dependent wetlands, Class A conservation areas, Ramsar sites, etc;
- identification of groundwater users in the vicinity of the dewatering operations; and
- assessment of the hydrogeological regime of the local area.

The results of these investigations will:

- enable options to be assessed in relation to dewatering methodologies and the management, treatment and disposal of dewatering effluent;
- inform calculations and modelling of proposed groundwater disturbance from dewatering/drainage (e.g. required depth of groundwater drawdown, required pumping rates and volumes, required duration of groundwater pumping, estimates of radii of groundwater cones of depression);
- assess the potential for impacts to occur to surrounding environmental receptors;
- assess the potential for impacts to occur to surrounding groundwater users; and
- provide the ability to distinguish between seasonal variations in groundwater flows and depths as opposed to changes caused by groundwater abstraction.

3.3.2 Groundwater investigations

Groundwater should be investigated before the development of a dewatering and groundwater management plan to determine:

- vulnerability of the groundwater to acidification;
- groundwater levels, groundwater flow patterns and the hydrogeological regime of the local area; and
- baseline groundwater quality.

The results of these investigations will enable options to be assessed in relation to dewatering methodologies and the management, treatment and disposal of dewatering effluent.

When collecting baseline groundwater quality data it may be necessary to undertake more than one monitoring event to ensure the data are representative and to capture seasonal variations. The laboratory analytical suite should include:

- pH
- total acidity
- total alkalinity
- sulfate
- chloride
- sodium
- ammonia (as nitrogen)
- total dissolved solids (TDS)
- electrical conductivity (EC)
- total nitrogen
- total phosphorus
- dissolved aluminium (filtered)
- total aluminium
- dissolved arsenic (filtered)
- dissolved chromium (filtered)
- dissolved cadmium (filtered)
- total iron
- dissolved iron (filtered)
- dissolved manganese (filtered)
- dissolved nickel (filtered)
- dissolved selenium (filtered)
- dissolved zinc (filtered)

Measurements of pH, redox potential (Eh), dissolved oxygen (DO), total titratable acidity, total titratable alkalinity and conductivity should be made in the field during sampling. DER recommends low-flow sampling methods over the use of bailers for sampling groundwater.

Total alkalinity is an indicative measure of the buffering capacity of the groundwater. The lower the total alkalinity and the higher the total acidity, the more vulnerable groundwater is to acidification (reduced pH).

Table 5 provides a guide for the assessment of the buffering capacity of groundwater.

Table 5. Assessment of the buffering capacity of groundwater

Class	Designation	Alkalinity		pH	Description
		mg/L	meq./L		
1	Very high alkalinity	>180	>3	>6.5	Generally adequate to maintain acceptable pH level in the future.
2	High alkalinity	60–80	1–3	>6.0	Generally adequate to maintain acceptable pH level in the future.
3	Moderate alkalinity	30–60	0.5–1.0	5.5–7.5	Inadequate to maintain stable, acceptable pH level in areas vulnerable to acidification.
4	Low alkalinity	10–30	0.2–0.5	5.0–6.0	Inadequate to maintain stable, acceptable pH level.
5	Very low alkalinity	<10	<0.2	<6.0	Unacceptable pH level under all circumstances.

Note: *management should not be derived to rely on the natural buffering capacity and should seek to preserve and/or enhance buffering capacity where possible.*

(Adapted from Swedish EPA, 2002)

Chemical indicators that ***may*** indicate that groundwater is being affected by, or has already been affected by, the oxidation of sulfides include:

- an alkalinity:sulfate ratio of less than 5 (Swedish EPA, 2002);
- a chloride:sulfate ratio less than 2 (Mulvey, 1993) (**note:** this ratio has little relevance in a freshwater groundwater environment. The alkalinity:sulfate ratio is more relevant in freshwater environments);
- a pH of less than 5; and/or
- a soluble aluminium concentration greater than 1 mg/L.

The ratio of chloride (Cl) to sulfate (SO_4) (by mass) in seawater is generally constant, at approximately 7.2 (in seawater the concentration of chloride is approximately 19,400 mg/L and sulfate is approximately 2,700 mg/L). Estuaries can be expected to have a similar $Cl:SO_4$ ratio.

However, increased levels of sulfate relative to chloride and alkalinity, combined with low pH and high concentrations of iron and aluminium, are indicative of the oxidation of ASS. A $Cl:SO_4$ ratio of less than two is a strong indication of an extra source of sulfate from sulfide oxidation (Mulvey 1993). It is important to note that $Cl:SO_4$ ratio is less predictive in freshwater or in areas of interface between brackish and fresh water. In these environments the alkalinity:sulfate ratio is more relevant.

When undertaking water quality investigations standard QA/QC procedures should be followed, as outlined in *Assessment and management of contaminated sites* (DER 2014) http://www.der.wa.gov.au/images/documents/your-environment/contaminated-sites/guidelines/Assessment_and_management_of_contaminated_sites.pdf.

3.3.3 Dewatering techniques: well-points, sumps and spears

At sites where there is a substantial amount of sand interbedded with silty, peaty or clayey materials, dewatering is normally carried out with an array of dewatering 'well-points' or 'spears' which are connected to a common suction pump or vacuum extraction system. The well-point systems are normally sunk into a permeable sand unit below the base of the proposed excavation.

Alternatively, sumps with submersible pumps at their base may be used and are the preferred method of dewatering as they are cheaper to install and operate and their radius of influence is generally smaller than dewatering spears.

A dewatering array is normally constructed to encircle the proposed excavation site, and two or more stages of dewatering may be needed to lower the watertable to the required depth. Alternatively, when dewatering is needed for linear projects, such as sewer excavations, dewatering spears are typically installed only on one side of the excavation.

As discussed in 3.2.3 Sheet piling and diaphragm/slurry walls, the extent of the cone of depression can be restricted by using sheet piling or constructing diaphragm or slurry walls provided that there is an aquitard at a shallow depth that can form a base for these subsurface structures.

***Note**: Dewatering and excavation on some ASS sites may release a large amount of hydrogen sulfide gas from groundwater. This gas may reach toxic levels within excavations and in confined spaces. Therefore, it is strongly recommended that on-site gas monitoring and occupational health and safety measures are implemented to deal with this contingency during dewatering on such sites.*

3.3.4 Cone of depression of the watertable

Dewatering should be managed to confine drawdown from dewatering to within the site boundaries.

Appendix E outlines empirical methods which can be used to calculate the radial extent of the groundwater cone of depression as well as the estimated pumping rates and times necessary to achieve the required groundwater drawdown for dewatering operations. A web-based tool for conducting these calculations, based on the methods described in Appendix E, can be found at http://www.der.wa.gov.au/your-environment/acid-sulfate-soils/66-cone-of-depression.

DER will need a preliminary assessment of the radial extent of the cone of depression and of pumping rates and times (using methods outlined in Appendix E) for all dewatering operations in ASS areas.

(Linear disturbances should be assumed to consist of a number of rectangular dewatering areas that abut each other and that are pumped sequentially.)

In situations where the radius of influence of dewatering extends less than 50 metres from each dewatered excavation and/or pumping of each excavation is less than seven days in duration, DER may not require any further groundwater modelling. In these circumstances, Dewatering Management Level 1a or 1b, as outlined in 6.2.1 Dewatering Management Level 1a and 6.2.2 Dewatering Management Level 1b, will apply. This is conditional on there being no sensitive receptors (wetlands, waterways, Ramsar sites, Class A conservation reserves, public drinking water source protection areas) within the radius of influence of each dewatered excavation. In addition the cone of depression should not extend to any known or suspected contaminated sites. For more information on contaminated sites see DER's contaminated sites webpage at: http://www.der.wa.gov.au/contaminatedsites.

In other situations, DER may require that site-specific investigations and groundwater flow modelling are undertaken to better quantify the potential impacts of dewatering on the local groundwater flow regime. Under these conditions, proponents will need to implement measures to reduce the extent of the cone of depression of the watertable and reduce the duration of dewatering in any given excavation. Measures to achieve these objectives include:

- reducing the depth and/or size of the excavation or dewatering system so that the dewatering footprint does not affect sensitive receptors;
- dewatering in small cells to reduce the pumping rates needed to keep each excavation dry;
- use of sheet piling, slurry wall or soil grouting to constrain the lateral extent of the cone of depression of the watertable to the immediate vicinity of the excavation;
- use of groundwater recharge trenches[13] to constrain the lateral extent of the cone of depression of the watertable to the immediate vicinity of the excavation;
- use of strategic re-injection to maintain aquifer pressures and groundwater levels; and
- undertaking dewatering during summer months when the watertable is at seasonal low levels to reduce the amount of pumping needed.

Where it is not possible to reduce the size of the cone of depression sufficiently to prevent drawdown impacts on nearby environmental receptors, DER may require that proponents undertake a risk assessment in accordance with DER contaminated sites guidelines to demonstrate that potential environmental impacts of dewatering are manageable. In these circumstances, a more detailed assessment of potential impacts of dewatering as outlined in 6.2.3 Dewatering Management Level 2 will apply.

***Note**: Site-specific values of hydraulic conductivities in areas with ASS should be measured using borehole slug-tests or estimated using sediment grain-size analysis techniques for large dewatering projects. It is **NOT** appropriate to undertake pumping tests in areas where iron sulfide minerals are known to occur below the watertable, as the prolonged drawdown of the watertable may cause these minerals to oxidise over a wide area and release acidity, arsenic, metals and nutrients into groundwater.*

3.3.5 Containment, treatment and disposal of dewatering effluent

Although the discharge from groundwater pumping in ASS areas may have a moderate pH (typically 5 to 6), it may have a high total acidity due to high concentrations of dissolved iron and aluminium as well as large amounts of suspended iron floc. This can cause environmental problems if the water is discharged without treatment. Consequently, the management of dewatering effluent is a critical component of dewatering programs in areas underlain by ASS.

When water containing considerable soluble iron is discharged into waterways or wetlands, iron hydroxides precipitate out where the waters mix. These chemical reactions release large quantities of acid into the aquatic ecosystem and consume oxygen causing de-oxygenation of the water column. The combination of acid, iron floc and de-oxygenation can cause fish kills, reduced fish spawning and the destruction of benthic habitats for macro-invertebrates (Baldigo and Murdoch, 1996; Nordstrom *et al.*, 1999; Sammut and

[13] Infiltration capacity tends to decrease with time, as the infiltration surfaces of the recharge trenches become clogged with fine sediments or metal precipitates. Recharge trenches usually work well in shallow highly permeable aquifers with shallow watertables.

Lines-Kelly, 2000; Lydersen *et al.*, 2002; Russell and Helmke, 2002; Kroglund *et al.*, 2003). In some areas, other chemical species, such as organic acids and dissolved carbon dioxide, may be a significant component of acidity.

Aluminium is naturally present in soils and is released from soil if the pH of the soil solution declines to pH 4.5. Hence dewatering effluent in ASS areas typically contains high concentrations of aluminium. Monomeric and hydrolysed forms of aluminium (Al^{3+}, $Al(OH)^{2+}$, $Al(OH)_2^+$ and $Al(OH)_3$) are typically most toxic. (In general the higher the charge the more toxic the species.) The Al present in these forms is biologically available, i.e. is available for binding to gill surfaces leading to fish suffocation (Lydersen *et al.*, 2002; Kroglund *et al.*, 2003). Dissolved aluminium is most toxic to aquatic organisms in freshwater at pH values of 5 to 6. Additionally, the use of untreated discharge water containing high levels of soluble Al^{3+} for on-site or off-site irrigation may kill some sensitive plant species due to aluminium toxicity.

The generally preferred option for disposal of dewatering effluent is to re-infiltrate on-site via earthen basins or trenches. These infiltration structures may be placed strategically to mound groundwater and limit off-site impacts, particularly near protected or sensitive wetlands.

***Note**: Acidic water is generally defined as water with a pH of less than 6 where the total acidity exceeds the total alkalinity of the water.*

It is recommended that dewatering effluent be aerated in tanks or suitably sized treatment ponds to oxidise and precipitate dissolved iron (and other metals), then lime-treated and passed through a retention basin to settle out further precipitates before re-infiltration. A schematic representation of a simple dewatering effluent management system is shown in Figure 3.

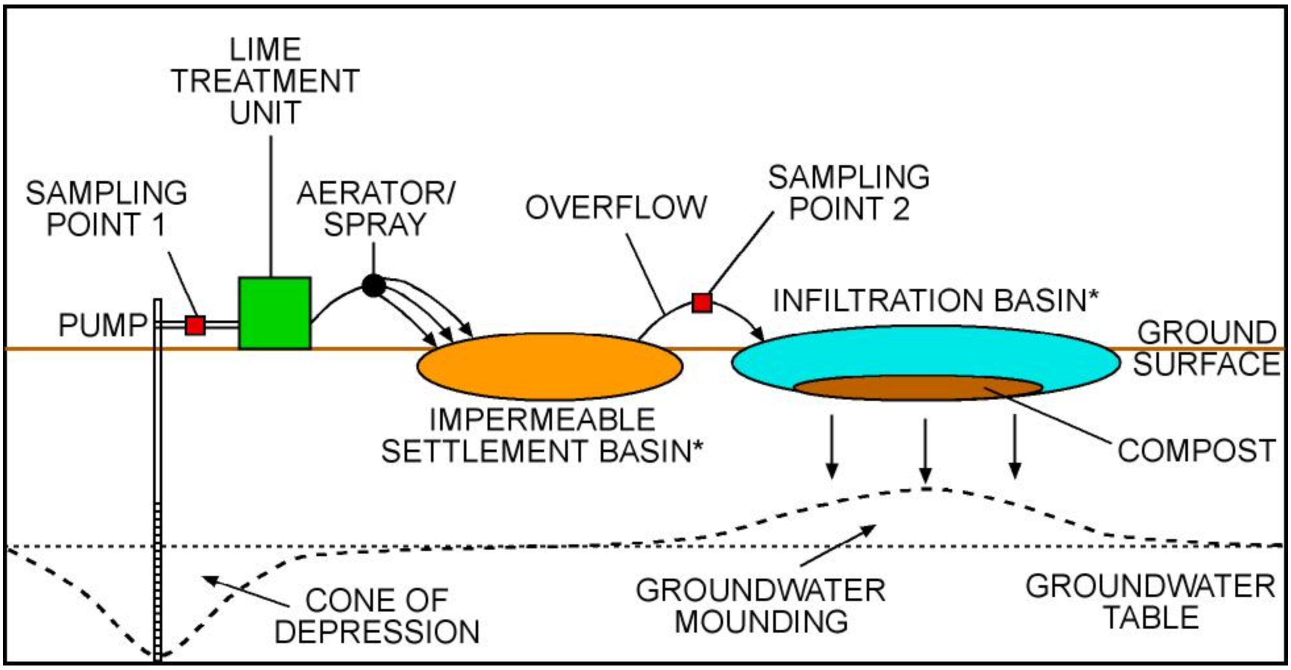

Figure 3 Schematic view of a basic dewatering effluent treatment system

The retention or settlement basins should be designed such that the dewatering effluent has a minimum of a six to 10-hour retention time, in order to settle sediment with a 0.015-millimetre target size.

A simple way to reduce the amount of oxygen in the treated effluent before re-infiltration is to add organic matter (such as hay bales) to the infiltration basins.

When the pH of dewatering effluent is below 4.5 it usually contains soluble iron and aluminium salts. When the pH is raised above 4.5 the iron begins to precipitate as a red-brown stain/scum/solid. In addition, the soluble aluminium is a good flocculant and may cause other minerals to precipitate and may cause suspended clay particles to flocculate.

It is important to let any suspended solids settle before using treated water (otherwise it will block pipes and pumps) or before discharging treated water (to avoid adverse aesthetic impacts and environmental harm). Chemical flocculants can be used to reduce the settlement time if it does not settle quickly enough for the staging of the works; however, care should be taken in choosing flocculating agents as these can also alter pH or cause other environmental impacts.

Although the treatment system depicted in Figure 3 will remove some of the iron oxy-hydroxide floc, if the water is to be re-used on-site or discharged off-site, more treatment will usually be needed. This may include filtration, flocculation and/or diversion to one or more settlement ponds to allow the remainder of the floc and suspended sediment to settle.

Dewatering effluent should be contained within treatment and infiltration basins or trenches at all times and the site should not be allowed to flood.

At completion of works, accumulated sediments at the bottom of treatment and infiltration basins/trenches, along with the top 30 centimetres of the underlying soil profile, should be sampled to determine appropriate decommissioning requirements, and then remediated and validated as required. Any material requiring remediation should be disposed of in accordance with *Landfill Waste Classification and Waste Definitions 1996 (as amended)* (DER 2009).

DER recommends that, wherever possible, dewatering discharge should first be disposed of or re-used on-site before off-site disposal options are considered. Possible on-site uses for the water include: disposal to ground via infiltration basins; irrigation (if sufficient land area is available); or use for dust control on construction sites. Off-site disposal options include irrigation on adjacent land (provided an agreement has been reached with the land owner); use in industrial or commercial processes; disposal to sewer (provided this has been approved by the Water Corporation (or other owner of the sewer) and the water meets Trade Waste acceptance criteria); and removal by liquid waste contractors.

Disposal of dewatering effluent to stormwater drains is generally not acceptable as these drains typically discharge to wetlands or waterways. If considering disposing dewatering effluent to a storm water drain, the same rules should be applied as for disposal to an aquatic ecosystem as outlined in 3.3.10 Discharging dewatering effluent to an aquatic ecosystem.

3.3.6 Neutralising acidic dewatering effluent

There is a range of neutralisation products available to treat acid waters. The rate of application of these products for treating acid water should be carefully calculated to avoid the possibility of ‘overshooting’ (i.e. making water too alkaline). Usually the optimum water conditions are pH 6.5–8.5 and total acidity < 40mg/L.

Aglime or crushed limestone ($CaCO_3$ – pH: 8.5 to 9.0) are two of the cheapest neutralising agents and are generally not harmful to plants, livestock, humans and most aquatic species. The limitation of their application is their insolubility in water (although it is more soluble in strongly acid water). Using aglime or limestone to increase the pH of water can be slow but will not cause pH overshoot.

Other cheaper, fairly soluble neutralising agents include hydrated lime ($Ca(OH)_2$ – pH: 12.5 to 13.5) and quick lime (CaO – pH: 12.5 to 13.5) can quickly increase the pH but they are difficult to manage and can result in excessively high pH and so should be used with caution. Specialist dosing equipment and expertise may be required.

When using strong alkaline materials, strict protocols must be established for their safe use, handling and monitoring, including monitoring of their effects on the receiving environment. Overdosing acidic waters, such that strongly alkaline conditions are created, can give rise to environmental risks similar to acidity and should be avoided.

Sodium bicarbonate ($NaHCO_3$ – pH~8.2) is highly soluble, quick to act and is not subject to pH overshoot. Where sodium bicarbonate has been used, any accumulated sediments within treatment systems will need to be disposed of off-site to an appropriate licensed landfill facility so as not to cause an increase in the salinity/sodicity of the local environment.

Note on the use of sodium-based compounds in ASS landscapes

Should sodium-based compounds, such as sodium hydroxide ($NaOH$), be considered as a neutralising material, precautions should be taken to ensure that salinity issues are not increased as a result of free sodium ions being introduced into the landscape. Sodium has a dispersive effect in soils and in water and its use needs should be carefully managed

The use of NaOH may not contribute to an increase in buffering capacity into the future.

The use of sodium-based compounds may:

- increase the salinity of any discharge waters;
- result in caustic waters being released to the environment; and/or
- contribute to adverse downstream impacts in sensitive fresh waterways.

The use of soda ash (Na_2CO_3) is particularly risky as it has a pH>11 and is highly soluble (one kilogram is soluble in 3.5 litres of water). Its use is not recommended as it releases heat on combination with water and is known to cause sodicity effects on soils.

If sodium-based compounds are used, sodium should be added to any water quality monitoring suite and precautions taken with regard to any precipitates/sludge in settlement/retention ponds. This sediment should be analysed and appropriately remediated or disposed of.

It should be noted that when neutralising acid water, no safety factor is used. Monitoring of pH and total titratable acidity needs to be carried out regularly during neutralisation procedures (see 3.3.7 Dewatering effluent monitoring) to verify that appropriate levels have been achieved and maintained.

Calculating the quantity of neutralising agent for acidic water

The quantity of alkaline neutralising agent needed **MUST** be determined by laboratory assessment of the total acidity of water by titration, as typically more than 80 per cent of the acidity of water is caused by its dissolved metal content rather than its pH. The amount of neutralising agent needed will depend on:

- the quality and purity of the neutralising agent being used;
- the particle size of the material and the degree to which the material becomes coated with iron and aluminium oxy-hydroxides;

- the effectiveness of the application technique; and
- the existence of additional sources of acid leaching into the water body that may further acidify the water.

Appendix A sets out the process for determining the necessary liming rates for acidic lakes and can be applied equally to the neutralisation of dewatering effluent ponds.

Methods of application of neutralising agents to dewatering effluent

Agricultural lime and some other materials used as neutralising agents have a low solubility in water and are often mixed with water to form slurries before application. Methods of application include:

- mobile lime or caustic-dosing unit;
- spraying the slurry over the water with a dispersion pump;
- pumping the slurry into the water body with air sparging (compressed air delivered through pipes) to improve mixing once added to water; and
- using mobile water treatment equipment to dispense neutralising agents.

In some circumstances a neutralising agent in its solid form can be used, for example by:

- placing it in a porous bag of jute or hessian and tying the bag to drums so that it floats in the water. The material will then gradually disperse. This technique should only be considered where there is significant water movement; or
- passing water across a bed or through a buffer of coarsely ground limestone ($CaCO_3$) or other granulated neutralising agent. However, this is unlikely to be effective in the long term as coarse particles of the neutralising agent may become coated with insoluble iron or other compounds and/or may be washed away or dissolved.

3.3.7 Dewatering effluent monitoring

Water quality should be monitored both before and after any treatment process. It is recommended that the water is sampled directly from the pipe as it comes out of the ground and then directly from the impermeable settling basin, before overflow, to provide consistent sampling locations and to avoid excessive interference from turbidity (see Figure 3).

Table 6 presents **minima** for trigger levels, corrective actions and associated monitoring for dewatering effluent where the radius of influence of dewatering extends greater than 50 metres from the dewatered excavation and the duration of groundwater pumping is greater than seven days.

Trigger values listed in the table apply to dewatering effluent as it comes out of the ground (i.e., untreated). If water quality has not improved post-treatment this is an indication that additional treatment is needed.

Table 6. Dewatering effluent monitoring matrix: radius of influence of dewatering > 50m and duration of groundwater pumping > 7 days

	Trigger	Action	Monitoring
1a.	**Total titratable acidity <40mg/L**, pH>6	Continue daily field measurements of pH and total titratable acidity.	**Daily**—field measurement: pH, redox (Eh), electrical conductivity (EC) and Total Titratable Acidity (TTA), total alkalinity (TAlk) **Fortnightly**—laboratory analysis: total acidity, total alkalinity, pH
2a.	**Total titratable acidity <40mg/L**, pH in range 4 to 6	Undertake neutralisation treatment (liming).	**Daily**—field measurement: pH, Eh, EC & TTA, TAlk **Weekly**—laboratory analysis: total acidity, total alkalinity,
3a.	**Total titratable acidity in range 40mg/L to 100mg/L**, pH>6	Effluent should be aerated to precipitate dissolved iron and directed to a series of settlement basins/trenches or other treatment system to allow removal of iron and other metals. Undertake neutralisation treatment (liming).	**Daily**—field measurement: pH, Eh, EC & TTA, TAlk, dissolved oxygen (DO), **Weekly**—laboratory analysis: total acidity, TAlk, pH
4a.	**Total titratable acidity in range 40mg/L to 100mg/L,** pH in range 4 to 6	Effluent should be aerated to precipitate dissolved iron and directed to a series of settlement basins/trenches or other treatment system to allow removal of iron and other metals. Undertake neutralisation treatment (liming).	**Daily**—field measurement: pH, Eh, DO,EC, TTA, TAlk **Weekly**—laboratory analysis: total acidity, TAlk, pH **Fortnightly**—laboratory analysis: total acidity, total alkalinity, pH, sulfate, chloride, sodium, total iron, dissolved iron (filtered), total aluminium, dissolved aluminium (filtered), total arsenic, total chromium, total cadmium, total manganese, total nickel, total zinc, total selenium, ammoniacal nitrogen, hydrogen sulfide*, EC, Total Suspended Solids (TSS), Total Dissolved Salts (TDS), Total Nitrogen (TN), Total Phosphorus (TP)

	Trigger	Action	Monitoring
5a.	**Total titratable acidity >100mg/L** or pH<4 or **total alkalinity <30mg/L**	Effluent should be aerated to precipitate dissolved iron and directed to a series of settlement basins/trenches or other treatment system to allow removal of iron and other metals. Increase neutralisation treatment (liming) rate. Advise DER immediately. Contaminated Sites Branch (CSB) may advise appropriate action which may include ceasing dewatering.	**Twice daily**—field measurement: pH, Eh, DO, EC, TTA, TAlk **Weekly**—laboratory analysis: total acidity, total alkalinity, pH, sulfate, chloride, sodium, total iron, dissolved iron (filtered), total aluminium, dissolved aluminium (filtered), total arsenic, total chromium, total cadmium, total manganese, total nickel, total zinc, total selenium, ammoniacal nitrogen, hydrogen sulfide*, EC, TSS, TDS, TN, TP May be needed to undertake investigations to determine the size of the 'acidic footprint' created and manage this impact appropriately.

Notes for use of Table 6:

1. Field measurements of pH, redox, total titratable acidity and total alkalinity are useful indicators of whether water quality has been affected by the oxidation of sulfide minerals and enable management responses to be made without waiting for laboratory analyses to be undertaken.

   Measurements of pH indicate the hydrogen ion concentration in water at any given time (i.e. the actual acidity in water), but this is usually only a very small proportion (less than 10 per cent) of the total acidity stored in the form of hydrolysable metals in water. This acidity may be released at some time in the future if water is released into the environment, and therefore must be assessed by using a titration test kit. It is recommended that this test is also carried out in the field to ensure that acidity in the form of dissolved carbon dioxide gas is measured in the titration and is not lost by volatilisation.

   Note that the pH scale is logarithmic and a variance of 1 equates to a 10-fold effective difference in the concentration of H^+ ions.

2. In addition to pH, total titratable acidity and total alkalinity, it is recommended that measurements of water conductivity, redox potential (Eh or ORP) and dissolved oxygen are also made in the field. Increases in these parameters may indicate that sulfide minerals are oxidising and increasing the solute load in water (i.e. an increase in Eh is an indication of conditions transitioning from reducing to oxidising).

3. Periodic chemical analyses should be carried out in a laboratory for a suite of metals and metalloids which are commonly leached into groundwater when sulfide minerals are oxidised and which can have significant environmental impacts on receiving environments.

   Measurement of metal concentrations in dewatering effluent should be as total concentrations from an unfiltered water sample. These concentrations should then be used to determine appropriate treatment options for the effluent, except where otherwise specified, and to identify any emerging trends in groundwater quality. It is not the intention that these values for total metals be directly compared against environmental or health-based criteria for dissolved metals. However, when determining treatment options, consider that:

- any metals contained within suspended solids have the potential to be mobilised if pH and/or redox conditions change (which is common in ASS environments); and
- if dewatering effluent is to be discharged into a receiving environment then these suspended solids will be discharged along with the water.

4. Chemical analysis should be carried out for the major ions sulfate, chloride and for alkalinity. Increases in sulfate or the sulfate/chloride ratio (i.e. a decrease in the chloride/sulfate ratio) often indicate that water is being affected by the oxidation of sulfide minerals, and a decrease in alkalinity indicates that the buffering capacity of water is decreasing.
5. The disturbance of ASS materials may also lead to the oxidation of organic matter and increased leaching of nitrogen (particularly in the form of dissolved ammonium ions) into groundwater.
6. Under very acidic conditions, phosphorus may also be leached from soils into groundwater.
7. If dewatering effluent is to be discharged via irrigation or used for dust suppression purposes the proponent needs to demonstrate that it is of suitable quality for this purpose. Similarly, if dewatering effluent is to be discharged via infiltration the proponent needs to demonstrate that it is of suitable quality for this purpose. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand (ANZECC & ARMCANZ, 2000) may provide more guidance in this regard.
8. If there are *naturally* acidic wetlands in the vicinity of the project area it may be more appropriate to adopt a trigger value for pH of 5.5 rather than 6.0. However, this approach should be applied with caution as the low pH of many wetland areas in Western Australia is not natural but rather has been caused by human activities in the surrounding area.
9. The measurement of hydrogen sulfide is only needed when discharging effluent to the natural environment.

When undertaking dewatering effluent monitoring, standard QA/QC procedures should be followed, as outlined in 2.5.6 Validation of soil treatment.

In situations where the radius of influence of dewatering extends less than 50 metres from each dewatered excavation and/or pumping of each excavation is less than seven days in duration, the risk of soil and groundwater acidification is reduced. Accordingly, the groundwater monitoring requirements can potentially be relaxed. In these situations, it is expected that the water quality of the dewatering effluent will approximate the general groundwater quality within the radius of influence of dewatering.

Table 7 presents **minima** for trigger levels, corrective actions and associated monitoring for dewatering effluent where the radius of influence of dewatering extends less than 50 metres from each dewatered excavation and/or the duration of groundwater pumping is less than seven days.

Trigger values listed in the table apply to dewatering effluent as it comes out of the ground (i.e., untreated). If water quality has not improved post-treatment this is an indication that additional treatment is needed.

Table 7. Dewatering effluent monitoring matrix: radius of influence of dewatering < 50m and/or duration of groundwater pumping <7 days

	Trigger	Action	Monitoring
1b.	**Total titratable acidity <40mg/L,** pH>6	Continue daily field measurements of pH and total titratable acidity.	**Daily**—field measurement: pH, Eh, DO, EC, TTA, TAlk **Fortnightly**—laboratory analysis: TTA, TAlk, pH
2b.	**Total titratable acidity <40mg/L,** pH in range 4 to 6	Undertake neutralisation treatment (liming)	**Daily**—field measurement: pH, Eh, DO, EC, TTA, TAlk **Weekly**—laboratory analysis: TTA, TAlk, pH
3b.	**Total titratable acidity in range 40mg/L to 100mg/L,** pH>6	Effluent should be aerated to precipitate dissolved iron and directed to a series of settlement basins/trenches or other treatment system to allow removal of iron and other metals Undertake neutralisation treatment (liming).	**Daily**—field measurement: pH, Eh, DO, EC, TTA, TAlk **Weekly**—laboratory analysis: TTA, TAlk, pH
4b.	**Total titratable acidity in range 40mg/L to 100mg/L,** pH in range 4 to 6	Effluent should be aerated to precipitate dissolved iron and directed to a series of settlement basins/trenches or other treatment system to allow removal of iron and other metals Undertake neutralisation treatment (liming).	**Daily**—field measurement: pH, Eh, DO, EC, TTA, TAlk **Weekly**—laboratory analysis: TTA, TAlk, pH **Fortnightly**—laboratory analysis: total acidity, total alkalinity, pH, sulfate, chloride, sodium, total iron, dissolved iron (filtered), total aluminium, dissolved aluminium (filtered), total arsenic, total chromium, total cadmium, total manganese, total nickel, total zinc, total selenium, ammoniacal nitrogen, hydrogen sulfide*, EC, total suspended solids (TSS), total dissolved salts (TDS), total nitrogen (TN), total

	Trigger	Action	Monitoring
			phosphorus (TP)
5b.	**Total titratable acidity >100mg/L** or pH<4 or **total alkalinity <30mg/L**	Effluent should be aerated to precipitate dissolved iron and directed to a series of settlement basins/trenches or other treatment system to allow removal of iron and other metals. Increase neutralisation treatment (liming) rate. Advise DER immediately. CSB may advise appropriate action which may include ceasing dewatering.	**Daily**—field measurement: pH, Eh, DO, EC, TTA, TAlk **Weekly**—laboratory analysis: total acidity, total alkalinity, pH, sulfate, chloride, sodium, total iron, dissolved iron (filtered), total aluminium, dissolved aluminium (filtered), total arsenic, total chromium, total cadmium, total manganese, total nickel, total zinc, total selenium, ammoniacal nitrogen, hydrogen sulfide*, EC, TSS, TDS, TN, TP May be needed to undertake investigations to determine the size of the 'acidic footprint' created and manage this impact appropriately.
6b.	**Total titratable acidity >100mg/L and 25% higher than baseline values**	Upgrade to 'Dewatering Management Level 2' including implementation of groundwater quality monitoring program	**Monitoring requirements:** Dependent upon value of total titratable acidity and pH as per guidance above
7b.	pH decrease >1 pH unit from baseline values	Upgrade to 'Dewatering Management Level 2' including implementation of groundwater quality monitoring program.	**Monitoring requirements:** Dependent upon value of total titratable acidity and pH as per guidance above.

Notes for use of Table 7:

1. Field measurements of pH, total titratable acidity and total alkalinity are useful indicators of whether water quality has been affected by the oxidation of sulfide minerals and enable management responses to be made without waiting for laboratory analyses to be undertaken.

   Measurements of pH indicate the hydrogen ion concentration in water at any given time (i.e. the actual acidity in water), but this is usually only a very small proportion (less than 10 per cent) of the total acidity stored in the form of hydrolysable metals in water. This acidity may be released at some time in the future if water is released into the environment, and therefore must be assessed by using a titration test kit. It is recommended that this test is also carried out in the field to ensure that acidity in the form of dissolved carbon dioxide gas is measured in the titration and is not lost by volatilisation.

Note that the pH scale is logarithmic and a variance of 1 equates to a 10-fold effective difference in the concentration of H^+ ions.

2. In addition to pH, total titratable acidity and total alkalinity, it is recommended that measurements of water conductivity, redox potential (Eh or ORP) and dissolved oxygen are made in the field. Increases in these parameters may indicate that sulfide minerals are oxidising and increasing the solute load in water (i.e. an increase in Eh is an indication of conditions transitioning from reducing to oxidising).
3. Periodic chemical analyses should be carried out in a laboratory for a suite of metals and metalloids which are commonly leached into groundwater when sulfide minerals are oxidised and which can have significant environmental impacts on receiving environments.

   Measurement of metal concentrations in dewatering effluent should be as *total* concentrations from an *unfiltered* water sample. These concentrations should then be used to determine appropriate treatment options for the effluent, except where otherwise specified, and to identify any emerging trends in groundwater quality. It is not the intention that these values for total metals be directly compared against environmental or health-based criteria for dissolved metals. However, when determining treatment options, consider that:
   a) any metals contained within suspended solids have the potential to be mobilised if pH and/or redox conditions change (which is common in ASS environments); and
   b) if dewatering effluent is to be discharged into a receiving environment then these suspended solids will be discharged along with the water.

4. Chemical analysis should be carried out for the major ions sulfate, chloride and for alkalinity. Increases in sulfate or the sulfate/chloride ratio (i.e. a decrease in the chloride/sulfate ratio) often indicate that water is being affected by the oxidation of sulfide minerals, and a decrease in alkalinity indicates that the buffering capacity of water is decreasing.
5. The disturbance of acid sulfate soil materials may also lead to the oxidation of organic matter and increased leaching of nitrogen (particularly in the form of dissolved ammonium ions) into groundwater.
6. Under very acidic conditions, phosphorus may also be leached from soils into groundwater.
7. If dewatering effluent is to be discharged via irrigation or used for dust suppression purposes the proponent needs to demonstrate that it is of suitable quality for this purpose. Similarly, if dewatering effluent is to be discharged via infiltration the proponent needs to demonstrate that it is of suitable quality for this purpose. The *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand (ANZECC & ARMCANZ, 2000) may provide more guidance in this regard.
8. If there are *naturally* acidic wetlands in the vicinity of the project area it may be more appropriate to adopt a trigger value for pH of 5.5 rather than 6.0. However, this approach should be applied with caution as the low pH of many wetland areas in Western Australia is not natural but rather has been caused by human activities in the surrounding area.
9. *The measurement of hydrogen sulfide is only needed when discharging effluent to the natural environment.

When undertaking dewatering effluent monitoring standard QA/QC procedures should be followed, as outlined in 2.5.6 Validation of soil treatment, Quality assurance/quality control (QA/QC).

3.3.8 Groundwater monitoring

In situations where dewatering is undertaken for more than seven days or where the predicted radius of the cone of depression of the watertable is greater than 50 metres, or where the site is located near wetlands or in any other environmentally sensitive area, groundwater bores should be installed and groundwater monitored to determine if dewatering is affecting groundwater quality (see 3.3.9 Dewatering in proximity of surface water bodies and 6.2.3 Dewatering Management Level 2).

A minimum of three (3) groundwater bores, ideally arranged in a triangle, should be installed. **Their position in relation to the proposed works must be carefully considered to enable them to be used to assess any impacts of dewatering on groundwater.**

Note: If a closure report does not adequately demonstrate the monitoring of groundwater relative to an area of works (including staged works), DER may be unable to provide the required clearance advice.

A suggested **minimum** groundwater-monitoring program is outlined in Table 8.

Table 8. Minimum groundwater-monitoring program

1.	Baseline laboratory groundwater quality data to be collected before the commencement of dewatering operations (this should include more than one monitoring event to ensure the data are representative and to capture seasonal variations).
2.	Water table level monitoring to ensure that watertable drawdown does not exceed 10cm at a distance of 100m from the dewatered excavation.
3.	pH, standing water levels, Eh, DO, EC, total titratable acidity (TTA) and total alkalinity (TAlk) to be monitored in the field every second day during the dewatering operation and continued until it can be shown that groundwater levels have returned to normal elevations.
4.	Samples to be collected for laboratory analysis at fortnightly intervals during the dewatering operation.
5.	Laboratory groundwater quality analytical suite to include: total acidity, total alkalinity, pH, sulfate, chloride, dissolved aluminium (filtered), dissolved arsenic (filtered), dissolved chromium (filtered), dissolved cadmium (filtered), dissolved iron (filtered), dissolved manganese (filtered), dissolved nickel (filtered), dissolved zinc (filtered), dissolved selenium (filtered), ammonia-nitrogen , total nitrogen, total phosphorus, filterable reactive phosphorus (FRP), EC and TDS.
6.	Laboratory groundwater quality data to be collected after finalisation of dewatering operations.
7.	Results of the groundwater and effluent water quality and water level monitoring program to be reported within an initial closure report (8.2.1 Initial closure report) for the project along with a discussion of any environmental impacts observed (potential requirements for continued monitoring and/or remediation will be assessed after

	review of this initial closure report by DER).
8.	Groundwater samples to be collected from all groundwater monitoring bores for laboratory analysis at intervals of one month to two months for a period of at least six months. This must include at least one groundwater monitoring event taken at the time of seasonal groundwater high, following completion of dewatering operation (period of monitoring needed will increase with increasing magnitude of the dewatering operation).
9.	Results of the post-dewatering groundwater quality monitoring program to be reported within a post-dewatering monitoring closure report (8.2.2 Post-dewatering monitoring closure report) for the project along with a discussion of any environmental impacts observed (potential requirements for continued monitoring and/or remediation will be assessed by DER after a review of this post-dewatering monitoring closure report).

When undertaking groundwater monitoring standard QA/QC procedures should be followed (as outlined in 2.5.6 Validation of soil treatment).

Note: When sampling for metals and metalloids, a comparison between unfiltered and filtered samples can also be used as a form of quality assurance for groundwater sampling procedures. Large discrepancies (more than a factor of 10) between the two analytical results typically indicate that sampling was carried out under very high pumping rates that have triggered oxidation and precipitation of metal hydroxides and oxides within the water column. DER may require proponents to resample and validate chemical analyses in situations where there are large discrepancies between filtered and unfiltered metal analyses.

Where dewatering is undertaken in an area underlain by ASS with a total radial extent of groundwater cone of depression of less than 50 metres or for a total duration of less than seven days, groundwater monitoring wells should be installed as outlined above. However, the requirements for groundwater monitoring can be relaxed. These requirements are described as Dewatering Management Level 1a and 1b and are outlined in in 6.2.1 Dewatering Management Level 1a and 6.2.2 Dewatering Management Level 1b. In these cases the groundwater monitoring program can be limited to measurements of watertable level to ensure that the actual radial extent of the groundwater cone of depression is not greater than predicted from calculations. If monitoring shows that the actual total radial extent of the groundwater cone of depression is greater than 50 metres and the duration of dewatering exceeds seven days, the additional dewatering management measures outlined in 6.2.3 Dewatering Management Level 2 will need to be implemented and DER should be advised of the dewatering program.

3.3.9 Dewatering in proximity of surface water bodies

Where dewatering operations, or any other groundwater disturbances, are to be undertaken in an area underlain by ASS in close proximity (i.e. within 500 metres) of a surface water body with environmental value (e.g. river, estuary, marine environment, conservation category wetland, resource enhancement wetland), management measures will need to be undertaken to protect the environmental values of the water body.

Baseline laboratory water quality data should be collected from the surface water body before the commencement of dewatering operations (this may involve more than one monitoring event to ensure the data are representative and to capture seasonal variations). Standing water levels within the surface water body prior should also be measured before the commencement of dewatering operations.

Dewatering, or any other groundwater disturbance, should not be allowed to cause any lowering of the level of water within the water body itself and should not be allowed to lower the level of groundwater immediately next to the water body by more than 10 centimetres.

When undertaking water quality monitoring of surface water bodies standard QA/QC procedures should be followed, as outlined in 2.5.6 Validation of soil treatment.

If groundwater monitoring shows deterioration in groundwater quality, additional monitoring should be undertaken to determine the extent of the impact and determine whether the water quality within the surface water body has also deteriorated or is at risk of deterioration. In this case the following additional management measures should be undertaken:

- pH, EC, DO, Eh, total titratable acidity and total alkalinity of the surface water body should be monitored in the field every second day during dewatering operations.
- Laboratory water quality data should be collected from the surface water body at fortnightly intervals during dewatering operations.
- The laboratory analytical suite for surface water quality monitoring should include: total titratable acidity (TTA), total alkalinity, pH, sulfate, chloride, dissolved aluminium (filtered), total aluminium, dissolved arsenic (filtered), dissolved chromium (filtered), dissolved cadmium (filtered), total iron, dissolved iron (filtered), dissolved manganese (filtered), dissolved nickel (filtered), dissolved zinc (filtered), dissolved selenium (filtered), ammoniacal nitrogen, EC, TDS, total nitrogen, total phosphorus, filterable reactive phosphorus (FRP).
- Measurement of standing water levels within the surface water body should be carried out before the commencement of dewatering operations and at twice weekly intervals throughout the duration of the dewatering operation (to ensure that water levels are not lowered as a result of the groundwater disturbance).
- Measurement of groundwater levels immediately next to the surface water body should be carried out before the commencement of dewatering operations and at twice weekly intervals throughout the duration of the dewatering operation (to ensure that groundwater water levels are not lowered by more than 10 centimetres as a result of the groundwater disturbance).
- Dewatering operations must cease immediately if monitoring results show any decline in water levels within the surface water body or a decrease of more than 10 centimetres in groundwater levels immediately next to the surface water body.
- Dewatering operations must cease immediately if results of the water quality monitoring program for the surface water body and adjacent groundwater indicate any deterioration in water quality.
- Results of water quality and water level monitoring program for the surface water body must be reported within an initial closure report for the project along with a discussion of any environmental impacts observed.
- Laboratory water quality data should be collected from the surface water body at intervals of one month to two months for a period of six to 12 months (depending upon the magnitude of the dewatering operation) following completion of the dewatering operation.
- Results of the post-dewatering water quality and water level monitoring program for the surface water body should be reported within a post-dewatering monitoring closure

report for the project along with a discussion of any environmental impacts observed. Potential requirements for continued monitoring and/or remediation will be assessed after DER reviews this post-dewatering monitoring closure report.

- Remedial actions should be undertaken to restore the water quality of the surface water body if needed.

3.3.10 Discharging dewatering effluent to an aquatic ecosystem

Discharge of dewatering effluent to wetlands or waterways should only ever be considered as a last resort when planning dewatering operations. It is only acceptable if:

- the authority in which the waterway or wetland is vested (e.g. local government authority, Swan River Trust or Department of Parks and Wildlife) has approved the discharge;
- the discharge meets water quality criteria that will protect the environmental values of the receiving water body(s); and
- there is a contingency plan in place to alternatively manage the discharge if water quality deteriorates during the dewatering program.

Where dewatering effluent is to be discharged to a wetland or waterway, the monitoring program outlined in Table 9 should be carried out as a minimum requirement.

Table 9. Minimum surface water monitoring program where dewatering effluent is to be discharged, directly or indirectly, to a wetland or waterway

1.	Dewatering effluent is monitored in accordance with measures described in 3.3.6 Neutralising acidic dewatering effluent of Table 6.
2.	Baseline laboratory water quality data are collected from the surface water body before the commencement of dewatering operations (this should be a comprehensive measure of background water quality and should involve more than one monitoring event to capture seasonal variations and to ensure the data are representative). Where the duration of discharge is significant the proponent will need to continue to monitor and evaluate background water quality. As metal concentrations in freshwater bodies often show large diurnal variations in concentration (Gammons et al, 2015), it is important that water samples are collected at approximately the same time each day.
3.	Field water quality parameters of the surface water body should be monitored in the field at daily intervals during discharge.
4.	Laboratory water quality data should be collected from the surface water body at weekly intervals during discharge.
5.	Laboratory water quality data should be collected from the surface water body after finalisation of dewatering operations (this may involve more than one monitoring event to capture seasonal variations and to ensure the data are representative).
6.	Results of the water quality monitoring program for the surface water body should be reported within an initial closure report for the project along with a discussion of any environmental impacts observed (potential requirements for continued monitoring and/or remediation will be assessed by DER after a review of this an initial closure report).

7.	Laboratory water quality data should be collected from the surface water body at intervals of one month to two months for a period of six to 12 months (depending upon the magnitude of the dewatering operation) after completion of the dewatering operation.
8.	Measured field water quality parameters should include: pH, EC, Eh, DO, TDS, total titratable acidity and total alkalinity.
9.	The laboratory analytical suite for water quality data should include: total acidity, total alkalinity, sulfate, chloride, dissolved aluminium (filtered), total aluminium, dissolved arsenic (filtered), dissolved chromium (filtered), dissolved cadmium (filtered), total iron, dissolved iron (filtered), dissolved manganese (filtered), dissolved nickel (filtered), dissolved zinc (filtered), dissolved selenium (filtered), ammoniacal nitrogen, total nitrogen, total phosphorus, filterable reactive phosphorus (FRP).
10.	Results of the post-dewatering water quality monitoring program for the surface water body should be reported within a post-dewatering monitoring closure report for the project along with a discussion of any environmental impacts observed (potential requirements for continued monitoring and/or remediation will be assessed after DER reviews this post-dewatering monitoring closure report).

Where dewatering effluent is to be discharged to a wetland or waterway, **including indirect discharge via the storm water or associated drainage network systems**, the trigger/action levels outlined in Table 10 should be adopted as a **minimum requirement**. The trigger/action levels have been adopted for the protection and conservation of environmental and ecological values and human health.

Table 10. Minimum trigger/action levels to be used where dewatering effluent is to be discharged directly, or indirectly, to a sensitive wetland or waterway

1.	pH should remain within the range of 6.5 to 8.5 and should remain within 1 pH unit of that of the receiving environment in order to minimise stresses on the aquatic ecology of the receiving environment.
2.	In the absence of comprehensive data for background water quality of the receiving environment, contaminant concentrations in effluent must meet relevant criteria specific to the receiving environment as outlined in ANZECC & ARMCANZ, 2000[14]; (Note that a minimum protection level of 95 per cent applies to the Swan and Canning River Systems).
3.	Where the background water quality of the receiving environment has been conclusively established, concentrations of metals and organics in discharge should not exceed background concentrations of the receiving environment.
4.	Total iron concentrations in the effluent should not exceed 1.0mg/L and iron should not be allowed to cause floc formation in the receiving environment.
5.	Total aluminum concentrations in the effluent should not exceed 0.15mg/L (150µg/L) and the concentration of aluminium in the receiving environment should not be allowed

[14] *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand (ANZECC & ARMCANZ, 2000).

	to exceed 0.15mg/L.
6.	Nutrients: • Swan and Canning Rivers and catchments—nutrient concentrations in discharges should comply with the Swan River Trust long-term nutrient concentration targets specified in the Healthy Rivers Action Plan (i.e. total nitrogen of 1.0mg/L and total phosphorus of 0.1mg/L). • Discharges to any other surface water bodies should aim to meet default trigger values for nutrients as outlined in ANZECC & ARMCANZ 2000 (Tables 3.3.4 and 3.3.6).
7.	Salinity should not be more that 10 per cent of the receiving environment (a salinity concentration of less than that of the receiving environment is generally acceptable if this is not likely to cause detrimental impacts).
8.	Discharge should not cause an objectionable odour.
9.	Discharge should not contain any floating matter.
10.	Temperature should not vary by more than 2°C from that of the receiving environment.

Any variation from the above discharge quality guidance will only be considered if an appropriate risk assessment is conducted, trigger values are derived and reporting demonstrates that the discharge quality will not cause any harm to human health or the environment.

Dewatering discharge must cease immediately if the results of the water quality monitoring program for the surface water body at any time indicates deterioration in water quality or any deleterious impacts on ecology. Any dewatering management plan should include contingencies for such an event.

If any of the triggers in Table 10 are exceeded, DER and the relevant Department of Water licensing office must be advised immediately. (SRT should be advised of exceedences within the Swan and Canning River systems). DER may then require appropriate action to be undertaken which may include ceasing dewatering discharge.

4 Water management in ASS areas

The progressive urbanisation of previously undeveloped land generally increases groundwater recharge due to land clearing and a reduction in the amount of water that is returned from soil to the atmosphere by transpiration. Consequently, the watertable often rises in new urban areas, and in some areas the rise in watertable can be sufficiently large to make new developments susceptible to flooding. As a result, extensive urban drainage schemes are often needed to lower the watertable to manage the flooding risk.

Additionally, the construction of bores for watering gardens and public open space and the planting of trees in parks may also lead to a lowering of the watertable in some areas, so that watertable contours and groundwater flow patterns often become more complex with time in urban areas. After a period of time, urban developments may be underlain by a patchwork of areas where the watertable is substantially higher than pre-development levels next to areas where the watertable is at least periodically well below pre-development levels. In regions underlain by pyritic soils, this local lowering of the watertable can lead to pyrite oxidation and groundwater being impacted by soil acidification products (Figure 4).

Consequently, it is important to continually manage groundwater recharge and abstraction in urban development on ASS to minimise the risk of groundwater being impacted by metals and arsenic that may be leached as a result of pyrite oxidation. The following sections provide guidance for ongoing groundwater management in urban areas that are underlain by ASS.

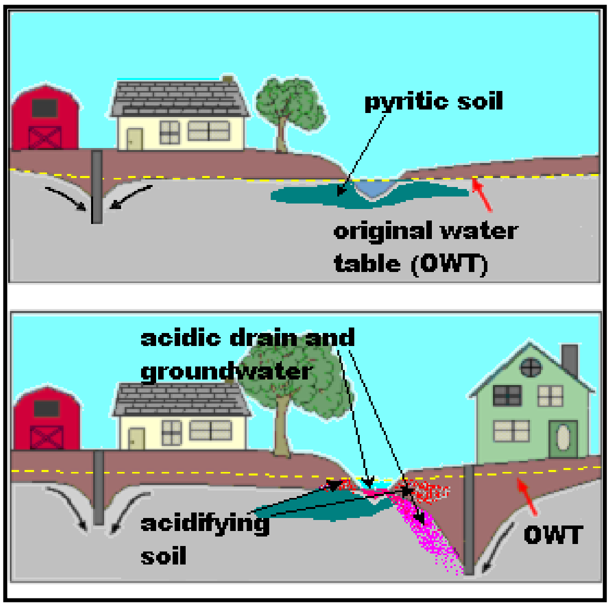

Figure 4 Local acidification of groundwater caused by increasing groundwater abstraction in a new urban area

4.1 Assessment and management of lakes and drains in areas vulnerable to acidification

The construction of drains and lakes in urban areas overlying potential ASS is a significant source of groundwater acidification that may cause ongoing problems for local government authorities, state government and private landowners.

4.1.1 Environmental problems caused by acidic urban drains

Poorly constructed and managed urban drains may export large amounts of toxic acidification products (especially dissolved aluminium) to receiving waterways or wetlands that may trigger fish kills or lead to a loss of biodiversity in the water bodies that receive the discharge. These drains may continue to discharge acidity to the environment for many decades after construction and, although discharge water can be treated or managed, it may not be possible to entirely eliminate the discharge of acidity to drains when the process of sulfide oxidation is well established in soils.

Figure 5 indicates how drainage in areas with ASS can cause significant environmental impacts and the process is described below.

During dry weather, the continuous process of sulfide mineral oxidation generates a large reservoir of soluble acidification products in the soil profile. Some of this acidity is discharged in seepage into drains and may generate substantial amounts of iron staining on drain walls and dense iron oxy-hydroxide floc in drain water. The process of ferrous iron oxidation and hydrolysis may also reduce the dissolved oxygen content of the drain water while decreasing pH. Some of the dissolved ferrous iron also reacts with organic carbon and sulfate under reducing conditions to form iron monosulfide black oozes which accumulate as a jet-black oily looking material consisting of poorly crystalline iron monosulfide minerals in a matrix of organic matter that settles to the bottom of the water bodies.

The hydrolysis of dissolved aluminium occurs much more slowly than iron and a substantial amount of aluminium may remain in solution as Al–hydroxy ions that are highly toxic to aquatic ecosystems. Consequently, the discharge of drainage to a receiving water body during dry weather may cause detrimental impact but the effects are likely to be very localised. Additionally, the precipitation of iron floc may smother the benthic environment and impact benthic animals (particularly macro-invertebrates, juvenile fish and crustaceans) in the immediate vicinity of the discharge point.

The situation can change dramatically when it rains. Infiltrating rainwater can release a slug of stored acidity from the soil into drainage water and increasing flow rates in drains may pick up monosulfidic black ooze from drain floors and carry this material in suspension to drain outlets. This material has a very high chemical oxygen demand and can rapidly remove dissolved oxygen from the water column in the receiving water body (Bush *et al.*, 2002; Sullivan *et al.*, 2002). This factor coupled with high aluminium concentrations can be fatal to aquatic organisms, including fish, near the drains. De-oxygenation caused by the drain discharge can also cause phosphorus to be released from benthic sediments and trigger algal blooms, which, in turn may lead to impacts on fish including fish kills.

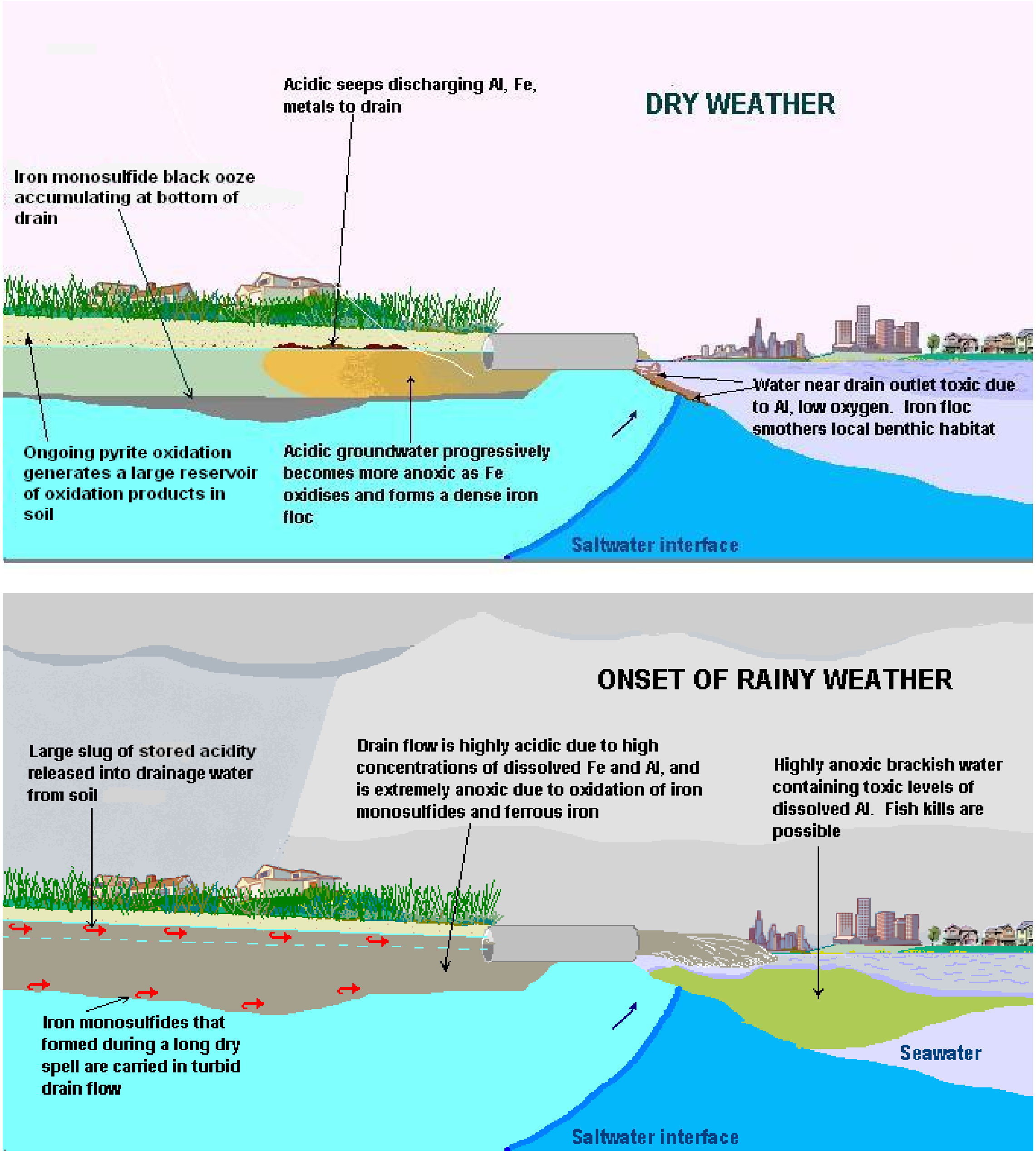

Figure 5 Process of soil acidification and contaminant discharge in urban drains in ASS in dry weather and wet weather following a long dry period

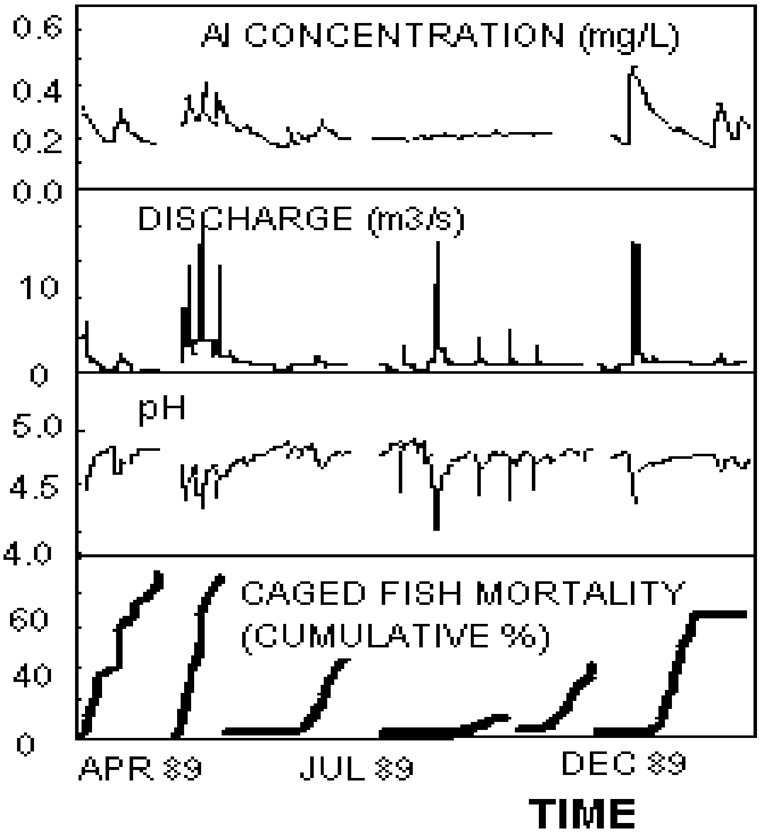

Figure 6 Variation of drain acidity and toxicity with flow rate (after Baldigo and Murdoch, 1996)

Although the environmental impacts of drain discharge may be particularly severe after a prolonged dry spell, further rainfall events will likely release further pulses of acidity in drainage water (Figure 6) which may cause ongoing environmental problems in the receiving water bodies due to aluminium toxicity (Baldigo and Murdoch, 1996). The short-term episodic nature of these acidity discharges also makes measurements difficult without intensive monitoring.

4.1.2 Lime filter drainage

Perth's declining rainfall pattern and increased groundwater abstraction have caused some deep drainage systems to become conduits for acidified waters to be discharged to wetlands and waterways. Neutralising agents can be incorporated into drainage lines to aid the neutralisation of acidic storm water runoff and from acidified groundwater inflows. Such design measures will prevent development of highly acidic waters and the transport of mobilised metals. By treating acid as close to its source as possible, the volumes of contaminated waters requiring treatment should be minimised. This reduces treatment costs and environmental risks.

Consideration should be given to the type of drain and potential flow rates in determining the particle size of the neutralising agent and how it will be applied. Options include fine aglime applied directly to the drain base (in a sand mixture) or the use of coarser limestone blends. The neutralising agent will need to be replenished if it is scoured from the drain (into other treatment areas) or as it develops gypsum, iron and/or aluminium coatings that reduce its neutralising efficiency by preventing contact with water.

As contact of acidified water with the neutralising agent will cause precipitation of metals from solution, consideration should be given to capturing and removing such metals, for example, by constructing settlement ponds or silt fences across drains at intervals. These will require periodic cleaning and maintenance.

It is inappropriate to apply neutralising agents into natural watercourses or water bodies unless carefully planned and approved by the relevant authorities. This is particularly important for waters where pH-sensitive wildlife may be present such as in wetland ecosystems.

4.1.3 Problems caused by the acidification of excavated lakes in urban areas

Currently there is a high demand for water features in public open space in new residential areas to provide an amenity for nearby residents. In many cases, urban lakes are created by deepening existing wetlands and are, therefore, likely to disturb ASS.

If the wetlands are underlain by potential acid sulfate soil materials, the process of excavation may cause lakes to become highly acidic. Wetlands with pH values as low as 2.5 have been recorded in the Perth metropolitan area (Appleyard *et al.*, 2002). Groundwater flow may continue to transport acidity into lakes for many decades. This may be the result of the disposal of acidifying material upstream or poor management of groundwater up-gradient of the lakes. Consequently, the addition of lime or other neutralising materials to ameliorate acidic conditions in such lakes may only be a temporary remedial measure (Figure 7).

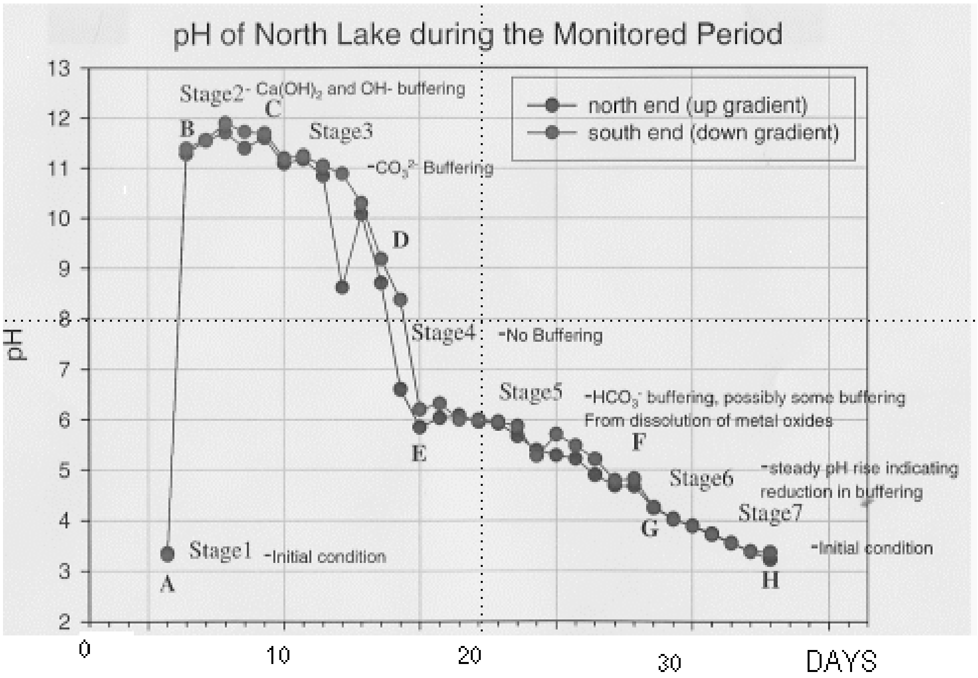

Figure 7 Variation of pH with time in an acidified urban lake in the City of Stirling after the addition of 5 tonnes of calcium hydroxide (Willis-Jones, pers. comm., 2003)

Visual indicators that a lake may be acidifying include:

- the disappearance of fringing vegetation and the appearance of clear 'beaches' around the lake;
- increasing iron staining around the margins of the lake and the appearance of yellow crusts of secondary iron and aluminium sulfate minerals in sediments near the water line in summer months;
- decreasing diversity of macro-invertebrates in the lake and the increasing abundance of acid-tolerant fauna such as water boatmen (*Notonecta glauca)* and mosquito larvae;

and/or

- increasing water clarity in the lake and the increasing abundance of filamentous algae and iron precipitates on the lake bottom.

Chemical indicators that a lake is acidifying include:

- sudden decreases in pH, generally during summer months. During the early stages of acidification, pH values may moderate during winter. However, over time, low pH values may become a permanent feature of the lake water;
- large diurnal fluctuations in pH, with changes of up to 2 pH units occurring within a 24-hour period (Helfrich *et al.*, 2001);
- decreasing alkalinity values in lake water;
- increasing values of the sulfate/chloride ratio in lake water; and/or
- increasing concentrations of soluble iron and aluminium in lake water.

4.1.4 Management and remediation measures for drains and urban lakes in areas with acid sulfate soils

Measures to prevent or minimise acidification problems in drains and lakes constructed in urban areas where there is a high risk of ASS being exposed:

- **Avoid construction in critical areas**—the most effective way of preventing acidification problems in drains and excavated lakes is to avoid constructing these features in areas underlain by ASS at shallow depth. Inappropriate construction of drains and lakes can create expensive and long-term management problems.
- **Construct shallow instead of deep drains**—in situations where ASS materials are located at some depth below the watertable, it may be possible to construct drains that do not disturb these materials. In general, broad shallow-drains are less likely to have acidification problems than narrow deep-drains. Wherever possible, the base of a drain should be constructed to be at least 0.5 metres above any sulfidic material (Dear *et al.*, 2002). In situations where sulfides cannot be avoided, sufficient neutralising materials should be used during drain construction.
- **Adopt water sensitive urban design management principles**—adopting design features in urban subdivisions that minimise surface runoff and maximise the infiltration of rainfall throughout an urban catchment can be an effective strategy for minimising the disturbance of sulfidic materials caused by the construction of stormwater drains.

In cases where drains and lakes are undergoing acidification, there are a number of possible remediation options that can be implemented to manage the acidity problem:

- **Redesign existing drains**—in areas where existing drains have been constructed into sulfide layers and are exporting acid, it may be possible to redesign the drainage network to reduce acid discharge. This may include reassessing the network with a hydrological study to decide whether all the drains are necessary, filling in superfluous drains (reducing the drainage density will often reduce the net export of acid from a catchment) and neutralising acidic spoil. Existing drains can be modified by neutralising existing acidity in drain walls, raising the base of the drains and broadening drains to allow them to carry the same volume of water without disturbing sulfidic material.
- **Passive treatment systems**—a variety of techniques have been developed by the mining industry for treating acidity and high metal concentrations in acid mine drainage

(AMD) using naturally occurring chemical processes, and many of these techniques could be used to manage drainage from disturbed ASS. The more commonly used techniques are briefly outlined in 5.3.1 Passive techniques for treating acidic drainage.

- **Lime treatment**—often the simplest way to neutralise an acidic drain or lake is to add an appropriate amount of lime (as described in Appendix A). This method, however, may only provide a temporary neutralising effect as described in 4.1.3 Problems caused by the acidification of excavated lakes in urban areas. Continual, periodic monitoring, following the addition of lime, will be necessary to ensure the drain or lake does not revert to acidic conditions with time.

4.2 Management of groundwater abstraction bores

Bores are commonly installed for garden watering in residential areas underlain by sandy soils and fresh groundwater, particularly in areas where the watertable is shallow and is readily accessible by either hand-dug or drilled bores. Areas with a very shallow watertable and sandy soils are also often very susceptible to water quality problems caused by pyrite oxidation as they are often underlain by organic-rich (often peaty) wetland sediments that create suitable conditions for the *in situ* formation of pyrite below the watertable. The sandy soils also generally have a very low capacity to neutralise acidity generated by the oxidation of pyrite when the watertable is drawn down by groundwater abstraction.

The vulnerability of groundwater in these areas to acidification depends to a large extent on the chemical composition of the groundwater, particularly on the relative proportion of bicarbonate to sulfate and chloride ions in groundwater and the overall alkalinity of the water.

4.2.1 Indicators of groundwater acidification

In areas with existing bores, visual indicators of possible groundwater acidity problems include:

- extensive iron staining of fences, walls and footpaths;
- very strong 'rotten egg' odour from hydrogen sulfide when bores are pumping;
- plants are burnt when watered with sprinklers;
- white '"fluffy' salt crusts appear where water evaporates from concrete surfaces;
- iron clogging of bores and irrigation systems; and
- milky white colour of pumped water caused by aluminium hydroxide precipitates.

Chemical indicators that ***may*** indicate that groundwater at the watertable is being affected by the oxidation of sulfides include:

- a sulfate: chloride mg/L ratio greater than 0.5 (Mulvey, 1993);
- a pH of less than 5; and/or
- a soluble aluminium concentration greater than 1 mg/L.

An example of groundwater data from an acidified area is shown in Table 11Table. The table shows how the acidity, metal and arsenic concentrations generally decrease with increasing depth below the watertable. The data indicate that the surface of the aquifer has become acidified with subsequent mobilisation of elements such as arsenic, aluminium and iron and that decreasing pH is proportional to increased concentrations of these elements.

Table 11. Chemical data from investigation borehole SLA5 in the Perth suburb of Stirling showing high acidity, metal and arsenic concentrations at the watertable that decrease with increasing depth in the superficial aquifer

	Depth (metres below surface)				
Analyte	3.6	6.6	9.6	12.6	15.6
pH	2.6	3.4	3.8	5.6	4.4
EC (mS/m)	504	381	429	142	147
As (µg/L)	7300	280	17	24	25
Al (mg/L)	230	160	200	0.21	2.8
Cd (µg/L)	72	<5	<5	<5	<5
Cr (µg/L)	310	140	100	<20	<20
Pb (µg/L)	17	2	5	<0.5	7
Ni (µg/L)	150	130	290	<10	50
Fe (mg/L)	1200	1000	1200	110	180
Acidity (mg/L as $CaCO_3$)	5700	2700	2900	200	330

4.2.2 Management of groundwater abstraction bores

The management of groundwater quality in urban areas mapped as having a 'Moderate to Low' or 'High' risk of being underlain by ASS should be in accordance with the principles outlined in 3.2 Minimising groundwater disturbance. That is, wherever possible, reductions in the watertable elevation beyond normal seasonal variations should be avoided to prevent sulfide oxidation taking place and, if disturbance is unavoidable, active groundwater management measures should be implemented to minimise declines in the elevation of the watertable beyond normal seasonal variations. It is also recommended that the same management approach be adopted in other areas where investigations have detected significant amounts of iron sulfides below the watertable that may be affected by groundwater drawdown.

In general, there is no licensing requirement for garden bores, and so it is usually not possible to prevent groundwater use by these bores in established urban areas where groundwater is easily accessible and is of a suitable quality for irrigation. In some cases it may be possible to prevent the installation of garden bores in new residential subdivisions through the use of covenants that may be administered by local government authorities.

Under provisions of the *Contaminated Sites Act 2003*, memorials can also be placed on land titles to advise where groundwater has been contaminated as a result of ASS disturbance or due to previous land uses and to restrict groundwater use.

Measures that can be used to minimise the drawdown of the watertable caused by pumping of garden bores:

- **Decrease pumping rates**—reducing pumping rates will reduce the size of the cone of depression caused by groundwater abstraction. This will also mean that the time needed to water a domestic garden will increase and may require the irrigation system to be redesigned to ensure an even water coverage with the lower pumping rate. On larger properties, it may be possible to trickle-pump water into a holding tank which can be then used to distribute water for irrigation at a higher rate.
- **Reduce water use in gardens**—gardens irrigated with domestic bores often use twice as much water as those irrigated with scheme water and much of this extra water is wasted by evapotranspiration. Increasing the efficiency of water use in gardens through 'WaterWise' gardening techniques will reduce the amount of groundwater pumped.
- **Increase urban density**—increasing the density of urban development reduces the total area of gardens that are watered. This is occurring already in many suburbs but could be encouraged as a management measure in areas where there is a high risk that iron sulfide minerals will oxidise if the watertable falls.
- **Use alternative water sources**—alternatives to shallow groundwater for irrigating gardens, parks and open space include stored rainwater, grey water from bathrooms and laundries in houses, treated sewage and scheme water (not preferred). Treated sewage may be beneficial in areas where soil and shallow groundwater has been affected by acidification as this effluent has a high acid neutralisation capacity and may help reverse acidification at the watertable. However, excessive use of sewage can also increase nitrate concentrations in groundwater. The advice of the Department of Health (DoH) should be sought in relation to the use of grey water and treated sewage.

In areas where groundwater acidification is known to have taken place, it is recommended that advice should be sought from DER or DoH before using bores with a total acidity >25mg/L as $CaCO_3$ (equivalent to a pH of 5 and an iron concentration of >5mg/L) or an aerated pH of less than 5 (see below) as a source of drinking water. Chemical analysis for metals and metalloids including aluminium, arsenic, cadmium, chromium, copper, iron, lead, nickel, selenium and zinc is recommended. This is because groundwater of this acidity may affect human health if used on a long-term basis as a source of drinking water. This water may also affect the health of pets that drink the water and may kill sensitive garden plants or fish in ponds due to aluminium toxicity. Contact with the water may cause skin and eye irritation due to acidity, for example, running through sprinklers or walking barefoot on lawn irrigated with this water.

Note: *The Department of Health (DoH) advises that untreated groundwater from garden bores is unsuitable for drinking or for filling swimming pools because of the risk of microbial and chemical contamination that might affect human health (see DoH pamphlet 'Using bore water safely' on their website www.health.wa.gov.au).*

5 Remediation

5.1 Remediation of acidified soils

The most common technique for remediating acidified soils is neutralisation with alkaline materials. Soil neutralisation methodologies are described in 2.3.4 Piling and diaphragm walls.

5.2 Remediation of groundwater

In cases where groundwater has been acidified and poses a risk to human health, the environment or environmental values, remediation may be needed. Groundwater remediation is expensive and time-consuming, hence good management is extremely important in ASS areas to avoid creating a problem that requires remediation.

If significant oxidation of sulfide minerals has occurred, then one or more of the following management/remediation measures may be needed.

5.2.1 Placing of hardstand areas (buildings, car parks etc.) over the area where the watertable has been disturbed

Hardstand greatly reduces the amount of local recharge and the amount of soluble contaminants that can be flushed out of the soil profile into groundwater. This helps reduce the extent to which groundwater may be impacted by iron sulfide oxidation products, but does ***NOT*** prevent groundwater impact taking place. If this management measure is used for stored acidity in soil above the watertable, it is extremely important that runoff from roofs and paved areas is not discharged to ground near where oxidised sulfides are known or suspected to occur to prevent the leaching of sulfide-oxidation reaction products to groundwater.

5.2.2 Use of permeable reactive barriers (PRBs)

Permeable reactive barriers (PRBs) or 'treatment walls' are permeable subsurface structures that treat impacted groundwater that flows through the structure (Figure 8). As PRBs are permeable, they have limited impact on local groundwater flow systems. A variety of materials can be used within the structure to treat groundwater. PRBs used to treat acidic groundwater commonly contain a large amount of organic matter or iron filings. The reaction of acidic groundwater with this material causes sulfate reduction to take place, creates alkalinity and precipitates metals as sulfide minerals within the organic matrix. The material within PRB structures has a finite life which is dependent on the groundwater flow rates and the total acidity of groundwater. It is important that sufficient field and laboratory work is undertaken before the installation of a PRB to ensure that it has adequate capacity to treat acidity for a period of at least 20 years. It is also important that soils around the PRB are adequately managed to prevent sulfide oxidation during the installation of the structure. Monitoring bores should be installed up and down hydraulic gradient of the PRB to monitor its effectiveness during the lifespan of the structure.

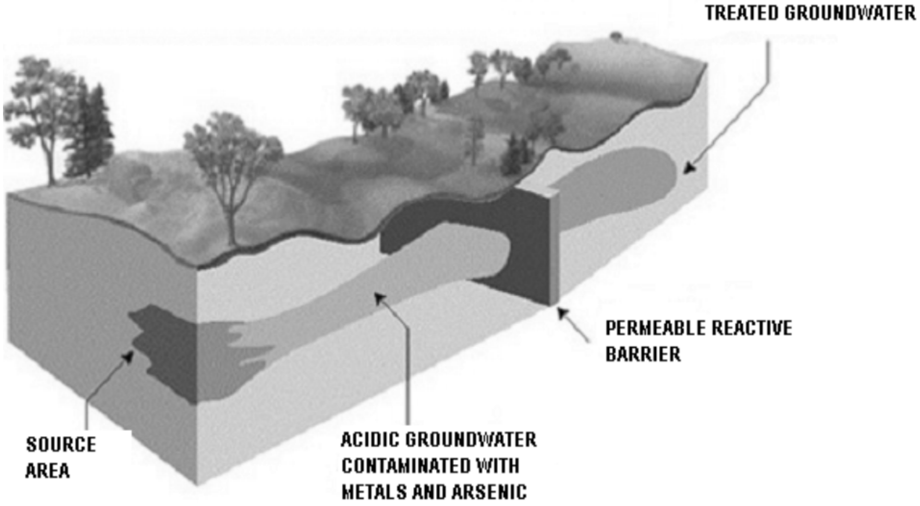

Figure 8 Use of a permeable reactive barrier to treat acidified groundwater contaminated by metals and arsenic

5.2.3 Use of sub-surface slurry walls to contain impacted groundwater

If groundwater has become severely impacted as a result of dewatering activities, it may be possible to construct a slurry wall to prevent the impacted groundwater from flowing towards nearby sensitive wetlands or groundwater abstraction bores. This approach will only be effective if there is a shallow aquitard which can form the base of the sub-surface containment structure and if the contained area is covered with a well-drained impermeable surface to prevent the infiltration of rainwater and the watertable within the structure rising to the ground surface. However, this may reduce the level of water in wetlands and local groundwater flow, creating a new set of problems. Slurry walls can be used in conjunction with PRBs to funnel contaminated groundwater into a narrower area for treatment.

5.3 Remediation of drains and surface water bodies

5.3.1 Passive techniques for treating acidic drainage

There are a number of passive drainage treatment techniques that are commonly used in the mining industry to reduce the acidity and metal content of acid rock drainage (ARD) discharging from some mine sites and many of these systems can be used to treat water discharging from disturbed ASS. The term ‘passive’ can be misleading as, although these systems do not require the addition of chemicals for treating drainage, they are NOT maintenance-free treatment systems.

The selection and sizing of a particular passive treatment system must be made after assessing the composition of the drainage as different treatment technologies vary considerably in their effectiveness, depending on the quality of the water that needs to be treated. A number of different treatment systems may be needed, operating in tandem as a ‘treatment train’, to manage acidic and metal rich drainage in a specific setting.

The features of the most commonly used passive treatment systems are outlined below together with a description of the chemical conditions for which they are most effective. More detailed information about the design and management of these systems can be found in Piramid Consortium (2003).

Aerobic wetlands

Aerobic wetlands are one of the most commonly used passive treatment techniques as they are simple to construct and can be used to develop public amenities and wildlife sanctuaries in areas where soil and water have become acidified. They consist of a large area of reeds (often *Typha* or *Phragmites* species are used) planted in an organic-rich substrate (Figure 9). Their role is to provide sufficient oxygen and residence time to allow iron and some other metals to be precipitated as oxyhydroxides. These systems are most effective for water that has a high iron content but a low acidity. Often, drainage is first passed through settling ponds to precipitate some iron before discharge to aerobic wetlands to ensure that the wetland is not rapidly smothered with precipitates. Reeds and sludge have to be periodically harvested from aerobic wetlands to maintain their effectiveness.

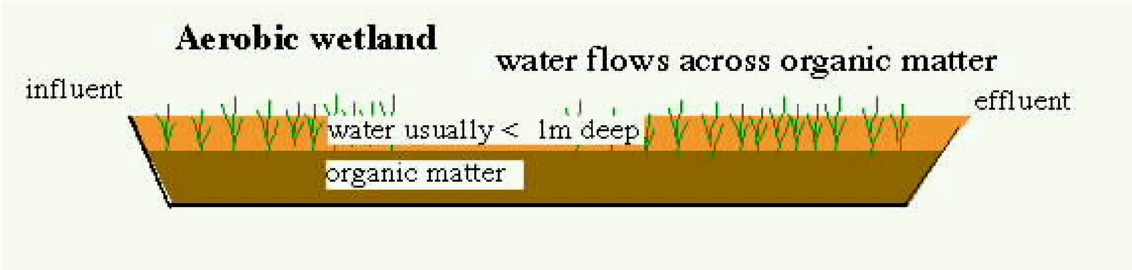

Figure 9 Schematic representation of an aerobic treatment wetland

Compost wetlands

Compost wetlands differ from aerobic wetlands in having very thick (>30cm) substrates of various forms of organic matter. The substrate encourages bacterial activity which reduces sulfate to sulfide, generating alkalinity in the process. Additional alkalinity can be generated by mixing crushed limestone with the organic substrate. Iron and some other metals are removed from solution by the formation of insoluble sulfide minerals within the organic matter. Aluminium accumulates as a precipitate of aluminium hydroxide on the top of the compost material.

The organic sludge in the wetlands has to be periodically removed to maintain the effectiveness of the system. As the material accumulates sulfide minerals, it should be handled and treated as ASS.

Anoxic limestone drains (ALDs) and oxic limestone drains (OLDs)

Both ALDs and OLDs utilise the dissolution of calcium carbonate in limestone to raise pH, neutralise acidity and generate bicarbonate alkalinity. Limestone is widely used in passive treatment systems for this purpose because it has a low cost and is non-hazardous. However, limestone is also prone to being coated with iron oxy-hydroxide ochres which greatly reduces its effectiveness. This often hinders the use of OLDs and open drains lined with limestone.

The problem of coating of limestone can be greatly reduced (but not necessarily prevented) by maintaining anoxic conditions in the drainage. This can be done by burying the drain beneath a cover of soil to make ALDs (Figure 10).

Limestone drains can effectively treat highly acidic water but may suffer from iron coating and clogging problems if the drainage contains high concentrations of dissolved iron.

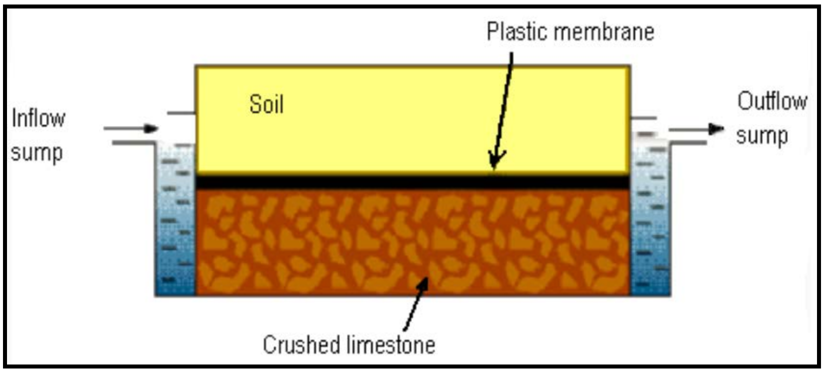

Figure 10 Schematic representation of an anoxic limestone drain (ALD)

Reducing and alkalinity producing systems (RAPS)

RAPS have been developed to overcome the iron coating problems that hinder the performance of anoxic limestone drains (ALDs). A RAPS is essentially an ALD overlain by a compost bed which removes oxygen from the inflowing drainage and helps ensure that iron in the ferric oxidation state is reduced and kept in solution in the ferrous form. The water then flows through a limestone bed where alkalinity is generated (Figure 11). RAPS work effectively where water contains high concentrations of dissolved oxygen and iron, and may only require 20 per cent of the treatment area of a compost wetland. The main limitation of the system is that the rate of treatment is slow due to the low permeability of the compost layer and that public access to the site must be restricted as the material behaves like quicksand and will not support the weight of a child. Additionally, high concentrations of aluminium in water may cause clogging of pore spaces and reduce the effectiveness of the system.

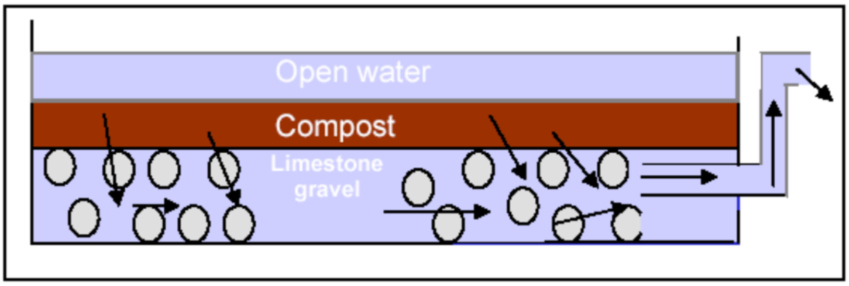

Figure 11 Conceptual diagram of a reducing and alkalinity producing system (RAPS) (after Piramid Consortium, 2003)

5.3.2 Neutralising acidic bodies of water

There is a range of neutralisation products available that can be used to treat acid waters. The rate of application of these products for treating acid water should be carefully calculated to avoid the possibility of 'overshooting' (i.e. making water too alkaline). Usually the optimum water condition is pH 6.5–8.5 and total acidity < 40mg/L.

Aglime is the cheapest neutralising agent and is generally not harmful to plants, livestock, humans and most aquatic species. The limitation of its application is its insolubility in water, although it is more soluble in strongly acid water. Using aglime to increase the pH of water can be slow and costly.

More soluble neutralising agents such as sodium bicarbonate[15] ($NaHCO_3$) are quick to act

[15] Sodium bicarbonate should be used with caution so as not to cause an increase in the salinity/sodicity of the local environment.

and not subject to pH overshoot. Other cheaper, fairly soluble neutralising agents include hydrated lime ($Ca(OH)_2$) and quick lime (CaO) but they are difficult to manage and can result in excessively high pH. When using these strongly alkaline materials, strict protocols must be established for their safe use, handling and monitoring to prevent adverse effects on the receiving environment.

Soluble or caustic neutralising agents such as hydrated lime or sodium hydroxide (pH 12–14), can quickly increase the pH and should be used with caution. Overdosing natural waterways with hydrated lime can cause similar environmental impacts to acid conditions. There is potential to damage estuarine and wetland ecosystems as some metals and metalloids are as soluble in very alkaline conditions as under acidic conditions.

It should be noted that when neutralising acid water, no safety factor is used. Monitoring of pH and total titratable acidity should be carried out regularly during neutralisation procedures and for a suitable period afterwards to verify the appropriate levels have been achieved and maintained.

Calculating the quantity of neutralising agent for acidic water

The quantity of alkaline neutralising agent needed must be determined by laboratory assessment of the total acidity of water by titration after treatment with hot hydrogen peroxide (Kirby and Cravotta 2005) as typically more than 80 per cent of the acidity of water is caused by its dissolved metal content rather than its pH. The amount of neutralising agent needed will depend on:

- the quality and purity of the neutralising agent being used;
- the particle size of the material and the degree to which the material becomes coated with iron and aluminium oxy-hydroxides;
- the effectiveness of the application technique; and
- the existence of additional sources of acid leaching into the water body that may further acidify the water.

Methods of application of neutralising agents to acidic water bodies and drains

Treatment of water in drains and lakes with acid neutralising reagents is an effective way of managing acidity but is not a permanent solution as the treatment will have to be carried out on an ongoing basis. The most suitable material for neutralising water acidity is agricultural lime (calcium carbonate) as it is inexpensive, will not make water excessively alkaline if applied in excess and will help increase the acid-base buffering capacity of the water. Although more caustic chemicals such as calcium hydroxide are more effective neutralising reagents, it is recommended that they should ***NOT*** be used because of the risk of making water highly alkaline if used in excess. This can create a health and safety risk for workers applying the chemicals to lakes and drains and for the public who may come into contact with the highly alkaline water. Very alkaline water may also severely damage aquatic organisms in lakes and fringing vegetation and may affect the health of water birds. The most effective way of applying the lime to lakes and drains is to mix finely ground limestone with water to make a milky suspension that is sprayed onto the lake surface. Appendix A sets out the process for determining the necessary liming rates for acidic lakes (artificial or natural water bodies) in urban areas.

Agricultural lime and some other materials used as neutralising agents have a low solubility in water and are often mixed with water to form slurries before application. Methods of application include:

- spraying the slurry over the water with a dispersion pump;
- pumping the slurry into the water body with air sparging (compressed air delivered through pipes) to improve mixing once added to water;
- pouring the slurry out behind a small motorboat and letting the motor mix it in;
- incorporating the slurry into the dredge line (when pumping dredge material); or
- using mobile water treatment equipment such as the 'Neutra-mill', 'Aqua Fix' and 'CRAB' (Calibrated Reagent Application Blender) to dispense neutralising agents to large water bodies.

In some circumstances a neutralising agent in its solid form can be used, for example by:

- placing it in a porous bag of jute or hessian and tying the bag to drums so that it floats in the water. The material will then gradually disperse. This technique should only be considered where there is significant water movement; or
- passing water across a bed or through a buffer of coarsely ground limestone $CaCO_3$ or other granulated neutralising agent. However, this is unlikely to be effective in the long term as coarse particles of the neutralising agent may become coated with insoluble iron or other compounds, washed away or dissolved.

When the pH of ASS leachate is below 4.5, it usually contains soluble iron and aluminium salts. When the pH is raised above 4.5, the iron precipitates as a red-brown stain/scum/solid, which can coat plants, monitoring equipment, the floors or walls of dams, drains, pipes, piezometers and creeks. In addition, the soluble aluminium is a good flocculant and may cause other minerals to precipitate or for suspended clay particles to flocculate. It is important to let any sludge settle before using treated water (otherwise it will block pipes and pumps) or before discharging treated water (to avoid adverse aesthetic impacts and environmental harm). Chemicals can be used to reduce the settlement time if it does not settle quickly enough, however care should be taken in choosing flocculating agents as these can also alter pH or cause other environmental impacts.

Large-scale dosing of waters to alter the chemical characteristics, such as may be the case in the mining industry, is a specialised and highly technical task that requires considerable expertise and experience. Professional guidance should be obtained in these situations.

The pH and total titratable acidity of the water should be checked daily during the first two weeks following application or until the pH and acidity has stabilised and then on a regular basis. The pH should be checked at least daily if there is any discharge from the site and preferably more frequently depending on the environmental sensitivity of the receiving environment.

6 Management of typical land development projects

Wherever possible, the disturbance of ASS should be avoided. Wherever ASS are to be disturbed, comprehensive management measures will need to be implemented based on the level of risk associated with the disturbance. Factors that may influence the level of risk include the nature, magnitude and duration of the proposed ASS disturbance, the soil characteristics and the sensitivity of the surrounding environment.

The disturbance of ASS during typical land development projects (e.g. residential developments) should be staged so that the area disturbed at any one time is limited and the potential effects are easily managed. The essential components of a management strategy for the disturbance of ASS during typical land development projects are outlined below.

N.B. Monitoring programs—it is important to note that the purpose of the monitoring requirements described below is to provide ongoing management information. The reporting of the monitoring programs should therefore not be seen as purely an administrative task.

There needs to be ongoing review and interpretation (by suitably qualified personnel appointed by the project's proponent) of data collected during site works to ensure early detection of trends so that management can be adapted and/or contingency measures implemented. If trend analysis of monitoring data indicates deterioration in soil, surface water or groundwater quality further disturbance/dewatering should cease immediately and DER should be informed.

6.1 Soil

Soil management measures will need to be undertaken where the volume of ASS to be disturbed is greater than 100m^3. For disturbances of ASS (greater than 100m^3) the management should include:

- staging of disturbance such that the potential effects on any area disturbed at any one time are limited and easily managed;
- staging of earthworks program to minimise the amount of time that ASS are exposed to the atmosphere (i.e. minimise the time that excavations are left open);
- provision of bunding of the site using non-ASS material to collect all site runoff during earthworks;
- management of stockpiles of excavated soils;
- monitoring of pH and total acidity of any pools of water collected within bunds and treatment of water to keep the pH in the range 6.5–8.5 and acidity < 40mg/L $CaCO_3$, with reference to see 3.3.7 Dewatering effluent monitoring of this guideline;
- treatment of soils according to their existing (actual) plus potential acidity with the appropriate amount of neutralising material;
- validation of soil treatment;
- development of an ASS management plan (ASSMP) and submission of the ASSMP to DER for approval before the commencement of site works **(please allow 45 days for DER to complete its review and provide comment on the ASSMP; ASS-disturbing site works should not commence until DER comment has been received);**
- submission of an initial closure report to DER; and

- remedial actions to restore soil quality, if needed.

6.2 Dewatering

6.2.1 Dewatering management level 1a—radial extent of groundwater cone of depression <50m

Where dewatering will be undertaken in an area underlain by ASS where the predicted radius of the cone of depression of the watertable is less than 50 metres, the management measures that should be implemented include (but are not necessarily limited to):

- staging of earthworks and dewatering program to minimise the duration and magnitude of dewatering (to limit the amount of time that ASS are exposed to the atmosphere);
- management of dewatering effluent in accordance with Table 7;
- watertable level monitoring to ensure that the actual radial extent of the groundwater cone of depression is less than 50 metres;
- if the actual radial extent of the groundwater cone of depression exceeds 50 metres and the duration of the dewatering operation exceeds seven days, the additional dewatering management measures outlined in 6.2.3 Dewatering Management Level 2 (DER should be advised in this case);
- development of an ASSMP and submission of the ASSMP to DER for approval before commencement of site works (please allow 45 days for DER to review and provide comment on the ASSMP; site works cannot commence until the ASSMP has been approved by DER);
- submission of an initial closure report to DER; and
- remedial actions to restore groundwater quality, if needed.

6.2.2 Dewatering management level 1b—duration of dewatering less than seven days

Where dewatering will be undertaken in an area underlain by ASS for a total duration of less than seven days, the management measures that should be implemented include (but are not necessarily limited to):

- staging of earthworks and dewatering program to minimise the duration and magnitude of dewatering (to limit the amount of time that ASS are exposed to the atmosphere);
- management of the dewatering program to minimise the lateral and vertical extent of groundwater drawdown (to limit the volume of ASS exposed to the atmosphere (see 3.2 Minimising groundwater disturbance));
- calculation of the radius of the groundwater cone of depression;
- management of dewatering effluent in accordance with Table 7;
- watertable level monitoring to ensure that the actual radial extent of the groundwater cone of depression is not more than that predicted from calculations;
- if the actual duration of dewatering exceeds seven days and the radial extent of the groundwater cone of depression is greater than 50 metres, as the additional dewatering control measures outlined in 6.2.3 Dewatering Management Level 2 (DER should be advised in this instance);

- development of an ASSMP in accordance with 7 Preparation of an ASSMP and submission of the ASSMP to DER for approval before commencement of site works **(please allow 45 days for DER to complete its review and provide comment on the ASSMP; site works that might disturb ASS materials should not commence until DER comment has been received);**
- submission of an initial closure report to DER; and
- remedial actions to restore groundwater quality to be undertaken if needed.

6.2.3 Dewatering management level 2—duration of dewatering greater than seven days with a radial extent of the cone of groundwater depression greater than 50 metres

Where dewatering will be undertaken in an area underlain by ASS for a total duration of greater than seven days or where the predicted radius of the cone of depression of the watertable exceeds 50 metres, the management measures that should be implemented include (but are not necessarily limited to):

- staging of disturbance such that the potential effects on any area disturbed at any one time are limited and easily managed;
- staging of earthworks and dewatering program to minimise the duration and magnitude of dewatering (to limit the amount of time that ASS are exposed to the atmosphere);
- management of the dewatering program to minimise the lateral and vertical extent of groundwater drawdown (to limit the volume of ASS exposed to the atmosphere, see 3.2 Minimising groundwater disturbance);
- calculation and modelling of the radius of the groundwater cone of depression;
- limiting the radius of the groundwater cone of depression to less than 100 metres;
- baseline laboratory groundwater quality data collected before the commencement of dewatering operations (this may involve more than one monitoring event to ensure the data are representative and to capture seasonal variations);
- installation of groundwater monitoring bores up-gradient and down-gradient of dewatering location (bores must be appropriately positioned to enable them to be used to assess any impacts of dewatering on groundwater level and quality);
- management of dewatering effluent in accordance with Table 6;
- watertable level monitoring to ensure that watertable drawdown does not exceed 10 centimetres at a distance of 100 metres from the dewatering location;
- groundwater pH, standing water levels, EC, redox, DO, total titratable acidity and total alkalinity monitored in the field every second day during the dewatering operation and continued until it can be shown that groundwater levels have returned to normal elevations;
- groundwater samples collected for laboratory analysis at fortnightly intervals during the dewatering operation;
- laboratory groundwater quality analytical suite including: total acidity, total alkalinity, sulfate, chloride, dissolved aluminium (filtered), dissolved arsenic (filtered), dissolved chromium (filtered), dissolved cadmium (filtered), dissolved iron (filtered), dissolved manganese (filtered), dissolved nickel (filtered), dissolved zinc (filtered), dissolved selenium (filtered), ammoniacal nitrogen, TDS, total nitrogen, total phosphorus, filterable reactive phosphorus (FRP);

- development of an ASSMP and submission of the ASSMP to DER for approval before commencement of site works **(please allow 45 days for DER to complete its review and provide comment on the ASSMP; ASS-disturbing site works should not commence until DER comment has been received);**
- immediate cessation of dewatering operations if the results of groundwater and/or dewatering effluent monitoring indicate any deterioration in groundwater quality;
- remediation of groundwater if the results of the groundwater quality monitoring program indicate that any environmental impact has occurred as a result of project works;
- laboratory groundwater quality data collected after finalisation of dewatering operations;
- results of the groundwater and effluent water quality and water level monitoring program reported within an initial closure report for the project along with a discussion of any environmental impacts observed;
- groundwater samples collected from all groundwater monitoring bores for laboratory analysis at intervals of one month to two months for a period of at least six months, including at least one groundwater monitoring event taken at the time of highest seasonal groundwater levels following completion of the dewatering operation (the period of monitoring needed will increase with increasing magnitude and duration of the dewatering operation);
- results of the post-dewatering groundwater quality monitoring program reported within a post-dewatering monitoring closure report for the project along with a discussion of any environmental impacts observed (potential requirements for continued monitoring and/or remediation will be assessed after DER reviews this post-dewatering monitoring closure report); and
- remedial actions undertaken to restore groundwater quality, if needed.

6.3 Contingency planning

Contingency planning involves outlining mitigation measures to prevent predicted impacts. The planned contingency measures should be risk-based and practical and will be linked with water quality trigger levels for management responses. If there is significant delay between a trigger level being reached and the mitigation measures being implemented, this could result in unacceptable damage to sensitive receptors. The proposed mitigation measures should be established with consultation with DER at an earlier stage before site work commences so that they can be implemented without delay.

Groundwater trigger levels may vary throughout the project due to changes in groundwater quality caused by seasonal variations.

If statistical techniques are adopted to determine acceptable trigger levels (e.g. using mean and/or standard deviations), sufficient background monitoring data should be collected to develop a good understanding of the groundwater system. If the measured values of a certain parameter shows an increasing trend (i.e. decline in groundwater quality) over the monitoring period, the trigger level should be based on the ‘best case’ results or should not be established using this data until the trend is normalised.

7 Preparation of an ASSMP

An ASSMP should outline the strategies that will be used to manage potential impacts of development works that have the potential to disturb disturb ASS materials on a site. The

ASSMP should be structured to address the key environmental management measures that will be used to mitigate or manage ASS disturbance both on-site[16] and in proximity to the site for the life of the development. The ASSMP should be accompanied by the results of the ASS investigations and should include contingency measures.

The ASSMP should be prepared and submitted to DER for review and approval before the commencement of any acid sulfate soil disturbing site works.

To assist in planning project timelines, it is recommended that the project manager allow at least 45 days for DER to complete its review of an ASSMP and provide comment.

7.1 Purpose of an ASSMP

The objective of an ASSMP is to outline a strategy to effectively manage the potential extent and severity of impacts of ASS disturbance on the project site in relation to the proposed scope of works. An ASSMP should provide for ongoing management and monitoring of the effects of disturbance of ASS through the entire construction or operation period of a project and describe the construction schedules and environmental management procedures.

An ASSMP must provide:

- evidence of practical, achievable and auditable plans for the management of the project to ensure that environmental impacts are minimised—this requires an integrated plan for comprehensive monitoring and control of construction and operational impacts;
- a framework to confirm compliance with approval conditions stipulated by the relevant regulatory authorities; and
- evidence that the project management will be conducted in an environmentally acceptable manner.

7.2 Format of an ASSMP

The following is a suggested format for an ASSMP. The format is designed to ensure adequate detail has been provided to demonstrate that the proposed management strategies will result in appropriate mitigation of potential impacts.

An ASSMP should detail the following:

- an overview of the physical characteristics and environmental attributes of the site, including:
  - site identification details and the current certificate of title,
  - a description of the geology (stratigraphy, lithology), geography (topography, climate) and hydrogeology (groundwater flow and direction) of the site,
  - the presence of sensitive environmental receptors including surface water bodies and groundwater abstraction bores within a one-kilometre radius of the site or within the area of groundwater drawdown, should the dewatering proposed at the site cause a cone of depression of the watertable that exceeds this distance, and

[16] To simplify and expedite the DER review process, please ensure that both the soil and water management components of the ASSMP are submitted within the one document. Submitting these separately causes delays in the review process.

- a description of current and historical land use on the site and in the vicinity of the site;

- details of ASS investigations undertaken in accordance with *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015);
- details of any additional soil and/or water ASS investigations undertaken to support the ASSMP, including:
  - sampling methodologies (sampling density, field and laboratory quality assurance and quality control details, analysis suites, field instrument calibration details),
  - bore installation details and bore logs,
  - justified assessment criteria, and
  - tabulated field and laboratory analysis results;
- a description and two-dimensional diagram (cross-section) of the occurrence of ASS on the site, including:
  - vertical and lateral distribution of both AASS and PASS according to the depth of occurrence to three metres or to one metre below the depth of proposed disturbance, whichever is greater, and
  - a map of the distribution of ASS at the site;
- an overview of the proposed development works including:
  - nature of development (e.g. residential estate, ornamental lake etc),
  - location, volume and depth of the proposed soil excavation,
  - location, volume, vertical and lateral extent of the proposed dewatering program, and
  - location, vertical and lateral extent of any proposed drainage strategies;
- details of the potential on-site and off-site effects of the disturbance of the soil and/or groundwater;
- a description of the management strategies proposed to minimise impacts from the site works including:
  - strategies for preventing the oxidation of iron sulfides, including avoiding the disturbance of ASS by redesigning the layout of the excavations,
  - the soil excavation strategy,
  - treatment strategies for excavated ASS, including neutralisation of ASS, neutralisation material and calculations, use of lime/limestone barriers, burial of potential ASS,
  - details of temporary storage of excavated ASS,
  - re-use/disposal plans for excavated ASS,
  - containment strategies to ensure that all contaminated stormwater and acidic leachate associated with the oxidation of ASS are prevented from entering the environment both in the short and long term,
  - details of dewatering methodologies,
  - strategies for management of the watertable level both on and off site both during and post construction,

  - delineation of any clay and peat lenses and horizons that may affect dewatering or excavation of soil,
  - details of dewatering effluent treatment, management and disposal, and
  - contingency measures.
- timing (milestones) of site works and environmental management initiatives;
- performance criteria to be used to assess the effectiveness of the ASS management and monitoring measures;
- a comprehensive monitoring program for soils and surface water and groundwater quality, designed to enable the effectiveness of the management strategy to be assessed—depending on the type and scale of the proposal and sensitivity of the location, the following should be included:
  - monitoring locations,
  - monitoring frequency,
  - sampling and analytical parameters, and
  - procedures to be undertaken in the event the monitoring indicates exceedence of trigger values;
- description of the pilot project or field trial (if conducted) to:
  - prove the effectiveness and the feasibility of the selected management procedures to deal with ASS and their environmental impacts,
  - demonstrate that the proponent has the capability to implement those management procedures effectively, and
  - demonstrate the ability to comply with agreed standards and performance targets;
- description of the contingency procedures to be implemented on the site to deal with unexpected events or in the event of failure of management procedures, including a remedial action and restoration plan related to:
  - any failure to implement any proposed ASS management strategies, and
  - any situation where mitigation strategies that are implemented prove to be ineffective, with the result being that the project fails to meet agreed standards or performance levels;
- outline of internal and external reporting procedures and frequencies for meeting environmental performance objectives and demonstrating quality assurance to relevant authorities and the community;
- management summary detailing site responsibilities of the environmental consultant, the site manager and the site contractors, including details of whom is responsible for any associated contractor training—the parties responsible for informing DER of changes to the ASSMP or contingencies being employed should also be identified;
- a commitment to submit a closure report, at the conclusion of site works, detailing:
  - management measures undertaken at the site,
  - total volumes and extent of disturbed soil and water,
  - the results of all monitoring programs,
  - a discussion of the effectiveness of management strategies employed at the site,

- a discussion of any potential risks to human health or the environment,
- proposed future monitoring and/or reporting programs, and
- proposed remediation measures if needed; and

• a commitment to submit a post-dewatering monitoring closure report (if needed), detailing:
  - the results of all groundwater and surface water monitoring programs,
  - a discussion of the effectiveness of management strategies employed at the site,
  - a discussion of any potential risks to human health or the environment,
  - proposed future monitoring and/or reporting programs, and
  - proposed remediation measures if needed.

It is imperative that the management plan be reviewed and periodically updated to reflect knowledge gained during the course of operations and to reflect new scientific advances and changed community standards/values.

Changes to the management plan should be developed and implemented in consultation with relevant authorities.

For further information, please refer to the *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015) and the contaminated sites management guidelines.

8 Reporting requirements

8.1 General reporting requirements

A checklist is provided in Appendix B outlining the information which should be considered when preparing an ASSMP for submission to DER.

DER acknowledges that the level of information needed for reporting is site-specific and relates to a number of variables such as the nature of the proposed development, soil type, groundwater depth, surrounding sensitive receptors, and the complexity of the issues.

Some information is, however, mandatory, regardless of the site. Mandatory requirements are noted within the checklist provided in Appendix B. Where a practitioner chooses to deviate from the mandatory information requirements of the checklist, the deviations should be highlighted and clear reasons should be given for the deviation from the standard format.

DER requires the certificates of title (hardcopy) and the co-ordinates of site boundaries (eastings/northings) to establish a legal description of a site. If this information is not provided, assessment of the report(s) may not proceed.

Inclusion of the information listed in the checklist will facilitate consistent reporting and aid in the efficient and accurate assessment and management of existing and potential acidity in the landscape.

Where data reporting is not considered consistent with this guideline, in either content or format, DER may return the report without assessing the information and the proponent will be requested to re-submit the report with the missing data included. This will increase the time taken for DER to provide a review and comment on the report.

When submitting any report to DER, all components of the report must be submitted as a hard copy. Email submissions or digital copies will not be accepted.

More information in relation to the content, compilation and presentation of site management plans can be found in the DER contaminated sites management guidelines available at www.der.wa.gov.au/contaminatedsites.

8.2 Closure reporting

8.2.1 Initial closure report

After completion of site works a closure report should be prepared and submitted to DER.

The report should detail, but not necessarily be limited to:

- the soil and water management measures undertaken at the site;
- the volume of soil and groundwater treated at the site;
- the amount of neutralising agent used during works;
- the results of soil validation and monitoring programs;
- the results of dewatering effluent monitoring programs;
- the results of the groundwater monitoring program (plus surface water body monitoring program where applicable), with particular emphasis on trends in water quality (graphs of water quality data should be presented to aid the identification of trends);
- a discussion of the effectiveness of management strategies employed at the site;

- a discussion of any potential risks to human health or the environment; and
- a discussion of any remedial measures needed.

A checklist is provided in Appendix C outlining the information which should be considered when preparing an initial closure report for submission to DER.

DER acknowledges that the level of information needed for reporting is site-specific and relates to a number of variables such as the nature of the proposed development, the requirements of the management plan, surrounding sensitive receptors, and the complexity of the issues.

Some information is, however, mandatory, regardless of the site. Mandatory requirements are noted within the checklist provided in Appendix C. Where a practitioner chooses to deviate from the mandatory information requirements of the checklist, the deviations should be highlighted and clear reasons should be given for the deviation from the standard format.

The potential requirement for further investigative or remedial works will be assessed by DER should the results of the initial closure report indicate any residual risks.

Review of this report can be used to determine whether the project was undertaken in accordance with the approved management plan. Hence, review of this report can be used to determine whether a statutory or regulatory condition which requires that an approved ASSMP be implemented for the project has been met.

If information provided in the initial closure report indicates contamination, or potential contamination, in soil, groundwater, or surface water is attributable to site works, the site may be classified accordingly under the *Contaminated Sites Act 2003*.

8.2.2 Post-dewatering monitoring closure report

Where groundwater monitoring is to continue after completion of the dewatering operation, a further post-dewatering monitoring closure report should be submitted after completion of the monitoring period.

This post-dewatering monitoring closure report should contain, but not necessarily be limited to:

- the results of the groundwater monitoring program (plus surface water body monitoring program where applicable), with particular emphasis on trends in water quality (graphs of water quality variations with time should be presented to aid the identification of trends);
- a further discussion of the effectiveness of management strategies employed at the site;
- a further discussion of any potential risks to human health or the environment; and
- a discussion of any remedial measures needed.

A checklist is provided in Appendix D detailing the information which should be considered when preparing a post-dewatering monitoring closure report for submission to DER.

DER acknowledges that the level of information needed for reporting is site-specific and relates to a number of variables such as the nature of the proposed development, the requirements of the management plan, surrounding sensitive receptors, and the complexity of the issues.

Some information is, however, mandatory, regardless of the site. Mandatory requirements are noted within the checklist provided in Appendix D.

Where a practitioner chooses to deviate from the mandatory information requirements of the checklist, the deviations should be highlighted and clear reasons should be given for the deviation from the standard format.

The potential requirement for further investigative or remedial works will be determined by DER should the results of the post-dewatering monitoring closure report indicate any residual risks.

If the information provided in the post-dewatering monitoring closure report indicates contamination, or potential contamination, in soil, groundwater, or surface water is attributable to site works, the site may be classified accordingly under the *Contaminated Sites Act 2003*.

9 More information and acknowledgments

It is recommended that reference also be made to guidelines and manuals developed by the NSW and Queensland state governments, in particular:

- *Queensland Acid Sulfate Soil Technical Manual 2014 – Soil Management Guideline v4.0.* Department of Science, Information Technology, Innovation and the Arts, Queensland Government;
- *Acid Sulfate Soils Laboratory Methods Guidelines* In *Queensland Acid Sulfate Soils Manual* (Ahern *et al.*, 2004). Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia;
- *Guidelines for Sampling and Analysis of Lowland Acid Sulfate Soils in Queensland* (Ahern *et al.*, 1998), Queensland Acid Sulfate Soils Investigation Team; and
- *New South Wales Acid Sulfate Soil Manual 1998*, Acid Sulfate Soil Advisory Committee.

Department of Environment Regulation acknowledges the guidelines and manuals produced by the following committees and organisations that were used in the development of this guideline:

- Queensland Acid Sulfate Soils Investigation Team;
- Queensland Acid Sulfate Soil Management Advisory Committee;
- NSW Acid Sulfate Soils Management Advisory Committee;
- National Committee for Acid Sulfate Soils; and
- Southern Cross University.

10 References

Ahern, C.R., Ahern, M.R., and Powell, B., 1998, Guidelines for sampling and analysis of Lowland Acid Sulfate Soils (ASS) in Queensland 1998, Department of Natural Resources, Indooroopilly, Queensland, Australia.

Ahern, C.R., McElnea, A.E., and Sullivan, L.A., 2004, Acid Sulfate Soils Laboratory Methos Guidelines, Queensland Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia.

Ahern, C.R., Stone, Y. and Blunden, B., 1998, Acid Sulfate Soils Management Guidelines, Acid Sulfate Soil Management Advisory Committee, Wollongbar, New South Wales, Australia.

Ahern, C.R., and Watling, K.M., 2000, Basic Management Principles: Avoidance, Liming and Burial, In Acid Sulfate Soils: Environmental Issues, Assessment and Management, Technical Papers, Ahern CR, Hey KM, Watling KM Eldershaw VJ (eds), Brisbane, 20 – 22 June, 2000, Department of Natural Resources, Indooroopilly, Queensland, Australia.

Appleyard, S., 2004, Acid, arsenic, rust and red-slime: Risks of not adequately managing the disturbance of acid sulfate soils on the Swan Coastal Plain, Western Australia, In Proceedings of Iron and Sulphur Bacteria Workshop, Scott, W (ed), Perth, 11 – 14 February, 2004, Murdoch University, Western Australia, Australia.

APPLEYARD, S.J., WONG, S., RALSTON, A., ANGLEONI, J., and WATKINS, R., 2002, Groundwater acidity and arsenic contamination caused by urban development on acid sulfate soils in Perth, Western Australia, Proceedings of the 5th International Acid Sulfate Soil Conference 'Sustainable Management of Acid Sulfate Soils', August 2002, Tweed Heads, New South Wales.

Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ), 2000, National Strategy for the Management of Coastal Acid Sulfate Soils, ARMCANZ Discussion Paper, 39 pp.

AUSTRALIAN STANDARD, 1993, AS 1726 – 1993, Geotechnical site investigations.

BALDIGO, B.P., and MURDOCH, P.S., 1996, Effect of stream acidification and inorganic aluminium on mortality of brook trout (*Salvelinus fontinalis*) in the Catskill Mountains, New York: Canadian Journal of Fisheries and Aquatic Science, 54, pp.603-615.

BUSH, R.T., FYFE, D., and SULLIVAN, L.A., 2002, Distribution and occurrence of monosulfidic black ooze (MBO) in coastal acid sulfate soil landscapes, Proceedings of the 5th International Acid Sulfate Soil Conference 'Sustainable Management of Acid Sulfate Soils', August 2002, Tweed Heads, New South Wales.

DAVIDSON, W.A., 1995, Bulletin 142: Hydrogeology and Groundwater Resources Of The Perth Region, Western Australia, Geological Survey Of Western Australia.

DEAR, S.E., MOORE, N.G., DOBOS, S.K., WATLING, K.M., and AHERN, C.R., 2002, Queensland Acid Sulfate Soil Technical Manual: Soil Management Guidelines, Queensland Department of Natural Resources Technical Report. Available at web site http://www.derm.qld.gov.au/land/ass/index.html

DEPARTMENT of ENVIRONMENT, 2004, Is my house built on Acid Sulfate Soils? (Draft).

DEPARTMENT of ENVIRONMENT, 2004, Proposed Framework for Managing Acid Sulphate Soils.

DEPARTMENT of ENVIRONMENT, 2009, Landfill Waste Classification and Waste Definitions 1996 (as amended).

DEPARTMENT of ENVIRONMENT and CONSERVATION, May 2009, Identification and Investigation of Acid Sulfate Soils and Acidic Landscapes.

DEPARTMENT of ENVIRONMENTAL and CONSERVATION, 2010, Assessment levels for Soil, Sediment and Water, Contaminated Sites Management Series.

DEPARTMENT of ENVIRONMENTAL PROTECTION, 2001, Development of Sampling and Analysis Plans, Contaminated Sites Management Series.

DEPARTMENT of ENVIRONMENTAL PROTECTION, 2001, Reporting on Site Assessments, Contaminated Sites Management Series.

EUROPEAN STANDARD, 2005, EN14679:2005 Execution of Special Geotechnical Works – Deep Mixing.

ENVIRONMENTAL AGENCY UK, April 2007 – Hydrogeological impact appraisal for dewatering abstractions, Science Report SC040020/SR1, ISBN: 978-1-84432-673-0.

HELFRICH, L.A., NEVES, R.J., and PARKHURST, J., 2001, Liming Acidified Lakes and Ponds, Virginia Cooperative Extension Publication Number 420-254, Virginia State University.

Available at web site http://www.ext.vt.edu/pubs/fisheries/420-254/420-254.html.

KROGLUND, F., ROSSELAND, B., TEIEN, H., SALBU, B., HANSEN, T., and KROGLUND, M., 2003, Aluminium toxicity in coastal/brackish waters, Proceedings of the 5th Keele Meeting on Aluminium.

Lydersen, E., Øxnevad, S., Østbyte, K., Andersen, R.A., Bjerkely, F. Vøllestad, L.A., and Poleo, A.B., 2002, The effect of ionic strength on the toxicity of aluminium to Atlantic salmon (*Salmo salar*) under non-steady state conditions: Journal of Limnology, 61, pp.69-72.

MULVEY, P., 1993, Pollution prevention and management of sulfidic clays and sands, in: R. Bush (Ed.) Proceedings of the National Conference on Acid Sulfate Soils, Coolangatta 1993, pp.116-129.

Nordstrom, D.K., Alpers, C.N., Coston, J.A., Taylor, H.E. McCleskey, R.B., Ball, J.W., Ogle, S., Costifas, J.S., and Davis, J.A., 1999, Geochemistry, toxicity and sorption properties of contaminated sediments and pore waters from two reservoirs receiving acid mine drainage, US Geological Survey Technical Paper.

PRAKONGKEP, N, GILKES, B., SINGH, B 2009, Understanding soil processes controlling landscape acidity and heavy metal mobilisation in Aquic Podosols on the Swan Coastal Plain.

PIRAMID Consortium, 2003, Engineering Guidelines for the Passive Remediation of Acidic and/or Metalliferous Mine Drainage and Similar Wastewaters, European Commission 5th Framework RTD Project no. EVK1-CT-1999-000021 'Passive *in-situ* remediation of acidic mine / industrial drainage' (PIRAMID). University of Newcastle Upon Tyne, Newcastle Upon Tyne UK. 166pp.

Queensland Government, 2002, Department of Local Government & Planning and Department of Natural Resources and Mines, State Planning Policy Guidelines 2/02.

Queensland Governmnet, 2014, Queensland Acid Sulfate Soil Technical Manual – Soil Management Guideline v4.0

RUSSELL, D.J., and HELMKE, S.A., 2002, Impacts of acid leachate on water quality and fisheries resources of a coastal creek in northern Australia: Journal of Marine and Freshwater Research, 53, pp.19-33.

SAMMUT, J., and LINE-KELLY, R., 2000, An Introduction to Acid Sulfate Soils, Booklet published by the National Committee for Acid Sulfate Soils, the National Heritage Trust and Environmental Australia.

SOMMER, B., and HORWITZ, P., 2001, Water quality and macro-invertebrate response to acidification following intensified summer droughts in a Western Australian wetland: Marine and Freshwater Research, 52, pp 1015-1021.

State of Western Australia, 1914, *Rights in Water and Irrigation Act 1914*, State Law Publisher.

State of Western Australia, 1986, *Environmental Protection Act 1986*, State Law Publisher.

State of Western Australia, 2003, *Contaminated Sites Act 2003*, State Law Publisher.

Stone, Y., Ahern, C.R., and Blunden, B., 1998, Acid Sulfate Soils Manual 1998, New South Wales Acid Sulfate Soil Management Advisory Committee, Wollongbar, NSW Agriculture.

Swedish ENVIRONMENTAL PROTECTION AGENCY, 2002, Alkalinity and Acidification in Groundwater, Technical guidance document published by the Swedish EPA.

SYDNEY COASTAL COUNCILS GROUP, 2006, Groundwater Management Handbook First Edition – A Guide for Local Government.

Virginia Water Resources Research Center, 1993, Guidelines for Liming Acidified Lakes and Ponds. Publication of the Virginia Polytechnic Institute and State University.

Wendling, L., G. Douglas, S. Coleman and Z. Yuan, 2010. Assessment of the Ability of Low-Cost Materials to Remove Metals and Attenuate Acidity in Contaminated waters, September 2010. CSIRO: Water for a Healthy Country National Research Flagship:

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Appendices

Appendix A Determining liming rates for acidic urban lakes

The following chemical models for determining lake liming rates have been adapted from *Guidelines for Liming Acidified Lakes and Ponds* published by the Virginia Water Research Center (1993). The model assumes that the water quality targets in lime-dosed lakes are a pH of about 6.5.

Model A—Iterative liming

This is the simplest method of applying lime and relies on measurements of pH and alkalinity being made in the field to test the effectiveness of the liming. It is recommended that pH is measured with a pH meter and that alkalinity is measured in the field with a proprietary test-kit. The lime dosing process is outlined in the following figure.

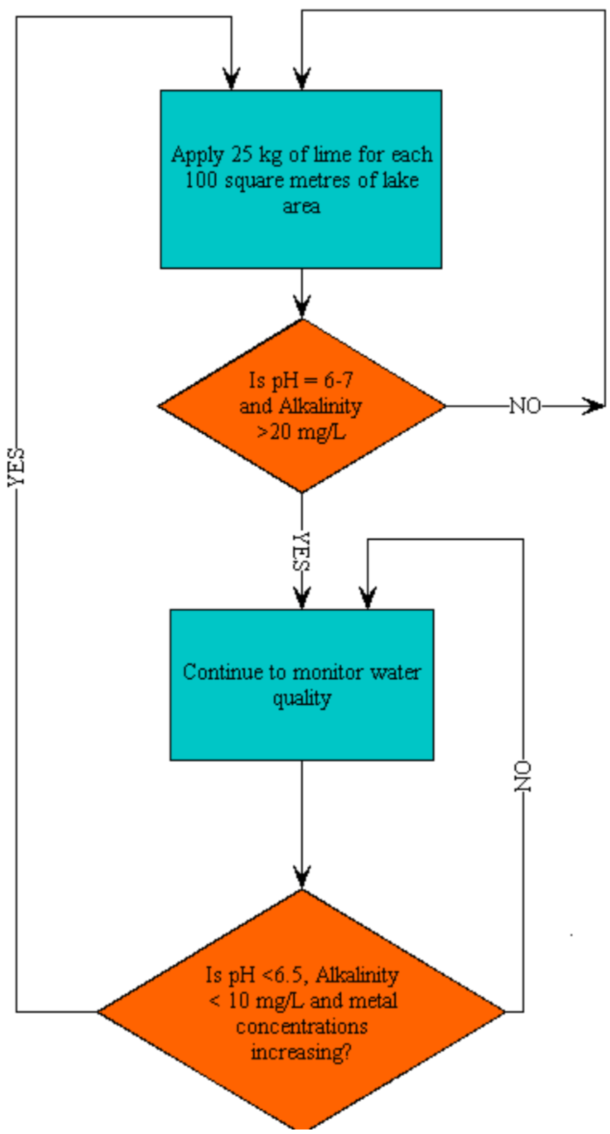

Figure A1 Model A—Lime dosing accounting for the chemical quality and particle size of the lime

The liming process outlined in Model A is a 'trial and error' procedure and it may require a long time to achieve the correct lime dose. Although the process set out below is more involved, it will give an estimate of the total amount of limestone needed to neutralise an acidic lake accounting for the quality of the limestone used and the average particle size of the crushed material.

Model B

The following information is needed to calculate the lime-dosing rate:

- lake pH before liming;
- lake retention time (units of years)—this is the average time needed for the water body in a lake to be completely renewed by groundwater (or surface water) input and discharge from the lake. The residence time is equal to the lake volume divided by the flow rate of water through the lake. It can be determined by undertaking detailed hydrogeological investigations near lakes. The residence time can also be estimated by monitoring the rate at which the pH of a lake recovers after it has been dosed with lime;
- lake volume (units of cubic metres);
- average limestone particle size (units of μm); and
- calcium content of limestone (as percentage of CaO).

The lime dosing rate is determined by undertaking the following four steps:

Step 1: Estimate the unadjusted dose factor, D_1 (i.e., does not take into consideration characteristics of the specific limestone used as a source of lime).

Use Figure A2 to determine the unadjusted dose factor D1 using the initial pH of the lake and the lake retention time.

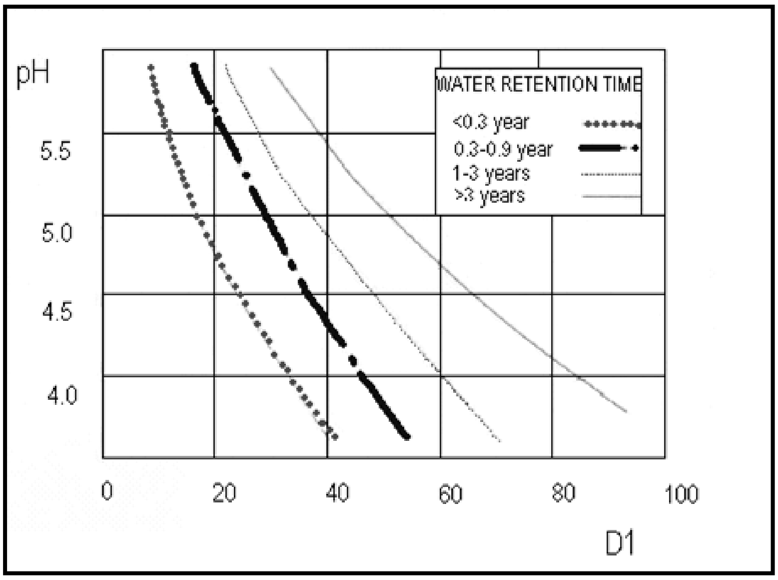

Figure A2 Graph for determining the unadjusted dose factor, D_1 from the initial lake pH and the lake retention time

Step 2: Modify the dose for the limestone calcium content.

The calcium content of the limestone used as a source of lime, C (as % CaO) is entered into Equation 1.

$D_2 = D_1 \times 60/C$ Equation 1

Where D_2 = dose factor adjusted for calcium content

D_1 = unadjusted dose factor

C = is the percent calcium as CaO

Step 3: Modify the dose for limestone particle size.

The lime dissolution factor (F) is determined from the average particle size using Figure A3. This factor is entered into Equation 2 to determine the lime dose adjusted for particle size.

$D_3 = D_2/F$ Equation 2

Where D_3 = dose factor adjusted for both lime content and particle size (g m^{-3})

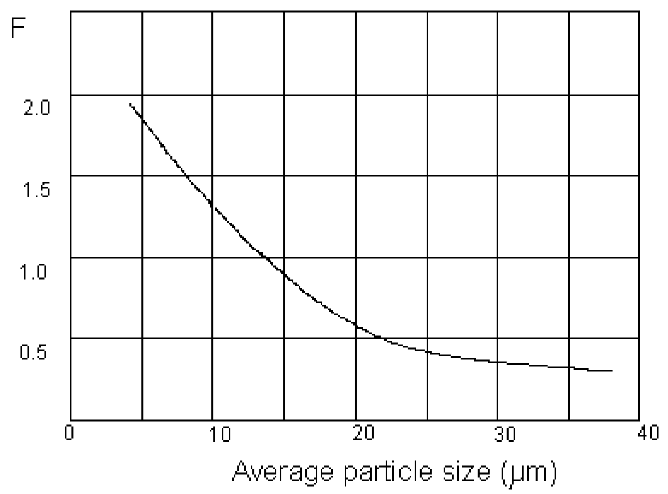

Figure A3 Calculation of lime dissolution factor F from the average particle size

Step 4: Calculate the limestone dose needed to treat the lake

The required mass of limestone needed to treat the lake is calculated from Equation 3

$D_{TOTAL} = D_3 \times V/1,000,000$ Equation 3

Where D_{TOTAL} = tonnes of limestone needed to treat the lake

V = lake volume (m^3)

Model C—Determining lime requirements by titration

The lime requirement to neutralise acidic water can be determined by titration with sodium hydroxide using phenolphthalein indicator. This method is further described in the *Acid Sulfate Soil Laboratory Method Guidelines Version 2* – May 2004.

Reference

Virginia Water Research Center, 1993, Guidelines for Liming Acidified Lakes and Ponds.

Appendix B ASS management plan checklist of reporting requirements

Acid Sulfate Soil management plan

Acid Sulfate Soil management plan		
Report sections	Information to be included, where relevant	Comments
1 Executive summary	• Background • Objectives of the Acid Sulfate Soil Management Plan (ASSMP) • Scope of work • Summary of ASS investigations • Summary of ASSMP	**Mandatory information**
2 Scope of work	• Clear statement of the scope of work	**Mandatory information**
3 Site identification	• Street number, lot number, street name and suburb • Common title/name of site (e.g. Sparkling Waters Residential Estate) • Certificates of title (copy of document including survey plan) • Co-ordinates of site boundaries (Northings/Eastings—specify datum set) • Locality map • Current site plan showing any existing infrastructure, scale bar, north arrow, local environmentally significant features, 'stages' of development • Local government authority	**Mandatory information**
4 Details of land development	• Full description of proposed development • Site lay-out plans and cross-sectional diagrams for proposed development • Full description of proposed ground disturbing activities including both soil and water disturbance (including volumes, depths, duration, locations etc) • Details of proponent and Project	**Mandatory information**

Acid Sulfate Soil management plan		
Report sections	Information to be included, where relevant	Comments
	Manager • Details of planning conditions including full and clear identification of section of the development project for which clearance of conditions is sought—i.e. site plans clearly showing cadastral boundaries, 'stage' boundaries, spatial co-ordinates, gazetted roads etc, (where applicable) • List of all other names under which the development has been known (where applicable)	
5 Site history	• Land use - previous, present and proposed, focusing on history of ground disturbance on site or in vicinity of site (e.g. disposal of dredge spoil, mineral sand or peat mining, previous dewatering, drainage or deep excavation) • Local usage of ground/surface waters, and location of groundwater bores	**A brief summary of the site history is adequate if detailed information was provided to DER in a referenced previous report**
6 Site Conditions and surrounding environment	• Topography • Drainage/hydrology • Characteristic indicators of AASS and/or PASS (soil, water, vegetation and infrastructure) • Flood potential • Preferential pathways for contaminants, e.g. drains • Residents in close proximity to site • Details of any relevant local sensitive environment, e.g. water courses, wetlands, local habitat areas • Photographs of site and surrounds • Photographs of characteristic indicators of AASS and/or PASS (where applicable)	**A brief summary of the site conditions is adequate if detailed information was provided to DER in a referenced previous report**

Acid Sulfate Soil management plan		
Report sections	Information to be included, where relevant	Comments
7 Geology and hydrogeology	• DER ASS risk mapping • Published geological mapping • Soil stratigraphy using recognised geological classification method • Location and extent of imported and locally derived fill • Site borehole logs or test pit logs showing stratigraphy • Detailed description of the location, design and construction of on-site groundwater bores • Description and location of springs and wells within a 1km radius of the site • Known or expected depth to groundwater table • Presence of multi-layered aquifer (investigations may result in cross-contamination of aquifers if detailed knowledge of site conditions and contaminants are not known) • Direction and rate of groundwater flow • Permeability of strata on the site • Direction of surface water runoff • Groundwater discharge location • Groundwater quality • Groundwater/surface water interaction • Groundwater conditions (e.g. unconfined, confined, ephemeral or perched) • Beneficial use of groundwater in the vicinity such as public drinking water supply and source areas, domestic irrigation, aquatic ecosystems, and the potential impacts on these uses • Location and use of groundwater bores within a 1km radius of the site	**A brief summary of the geology & hydrogeology is adequate if detailed information was provided to DER in a referenced previous report**

Acid Sulfate Soil management plan		
Report sections	Information to be included, where relevant	Comments
	• Location of sensitive receptors/users • Preferential migratory pathways	
8 Basis for adoption of assessment criteria	• Table listing all selected assessment criteria and references • Rationale for and appropriateness of the selection of criteria • Assumptions and limitations of criteria	**Mandatory information**
9 Results	• Details of initial ASS investigations • Details of any additional soil and/or water ASS investigations undertaken to support the ASSMP (where applicable) • Summary of all soil results in accordance with *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015) • Table with observations and data, similar to Table 8 within *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015), to include: - the full grid reference of each borehole using Australian Metric Grid - an exact description of the vertical dimensions of the borehole relative to existing surface height in both metres below ground level (mBGL) and metres above AHD - soil texture, grain size, roundness, sorting and sphericity using the Australian Soil and Land Survey Field Handbook (McDonald *et al.*, 1990) as a guide - colour using a Munsell colour chart - mottling, organic matter, moisture content, watertable level and other diagnostic features (e.g. jarosite, shell) - results from field soil pH_F and pH_{FOX} tests, including the pH of water and	**Mandatory information**

Acid Sulfate Soil management plan		
Report sections	Information to be included, where relevant	Comments
	peroxide used (where conducted) - tabulated summary of results of laboratory analyses in %S units - all results exceeding the adopted assessment criteria highlighted • Summary of all water quality results—in a table that shows essential details such as sampling locations and depths, assessment criteria and highlights all results exceeding the adopted assessment criteria • Assessment and discussion of baseline groundwater quality results (where groundwater is proposed to be disturbed) • Calibration certificates or calibration results • Cross-sections of the soil profile beneath the study area • Copies of original laboratory result certificates including NATA accreditation details • Discussion of any discrepancy between field observations and laboratory analyses results • Site plan showing all sample locations, sample identification numbers and sampling depths • Interpretation of results to create detailed 3-dimensional maps and cross-sections of ASS occurrence/absence at the site, including soil type and oxidisable sulfur (%) content by depth • Overlays for ASS maps and ASS cross-sections clearly showing the lateral and vertical extent of the proposed soil and groundwater disturbance in relation to the occurrence of ASS at the site • Site plan showing extent of groundwater acidity and/or metal contamination beneath site (where applicable)	

Acid Sulfate Soil management plan		
Report sections	Information to be included, where relevant	Comments
	• Photographs of the soil profile, identifying each stratum	
10 Risk assessment	• Receptor identification • Assessment of receiving environment's sensitivity • Exposure assessment • Discussion of potential risk of harm to human health and/or the environment associated with disturbance of the site • Discussion of assumptions • Risk management decisions based on outcome of the assessment	**Mandatory information**
11 Evaluation of ASS management options	• Identify management goals and environmental performance objectives • Rationale for why the disturbance of ASS has not been avoided (where applicable) • Discussion of how the development has been designed to minimise or avoid the disturbance of ASS • Discussion of possible management options and how risk can be reduced • Confirmation that the material being disturbed (including the *in situ* ASS) and any potentially contaminated waters associated with ASS disturbance have been considered in developing the ASS management plan • Rationale for the selection of recommended management option	**Mandatory information**
12 Community consultation	• Details of stakeholders (individuals and groups) consulted • Summary of information provided to stakeholders (e.g. minutes of meetings, informative flyers) • Input and comments received from stakeholders • Details of how stakeholder input was	**Include information where community consultation was undertaken**

Acid Sulfate Soil management plan		
Report sections	Information to be included, where relevant	Comments
	considered in decision-making • Brief description of community consultation undertaken during previous stages of site investigation if details have already been submitted to DER in previous report(s) • Refer to DER Contaminated Sites guidelines	
13 ASS Management Plan	• Staging of disturbance such that the potential effects on any area disturbed at any one time are limited and easily managed • Staging of earthworks program to minimise the amount of time that ASS are exposed to the atmosphere (i.e. minimise the time that excavations are left open) • Contingency plan if the selected management strategy fails • Site management plan (operational phase), including stormwater management, soil management, groundwater management, surface water management, noise control, dust control, odour control, occupational health and safety • Site maps clearly showing locations of management infrastructure (e.g. water treatment ponds, stockpile locations) • Consideration of baseline groundwater quality results in determining appropriate groundwater management strategy • Details of application(s) for license(s) to take groundwater (where applicable) • Details of application(s) for license(s) to discharge effluent (where applicable) • Soil treatment validation program (where applicable) • Decommissioning of soil and/or water	**Include information, where applicable**

Acid Sulfate Soil management plan		
Report sections	Information to be included, where relevant	Comments
	treatment areas (where applicable) • Soil, groundwater and surface water monitoring programs • Description of the pilot project or field trial (where applicable) • Earthworks schedule • Hours of operation • Contingency plans to respond to site incidents, to obviate potential effects on surrounding environment and community • Identification of regulatory compliance requirements such as licences and approvals (local and state level) • Proximity to exposure receptors/populations • Contingency plan for receptors if management plan fails • Names and phone numbers of appropriate personnel to contact during remediation • Community relations plans (where applicable) • Staged progress reporting (where applicable) • Closure reporting • Long term site management plan • Details of responsibilities of site personnel • Outline of internal and external reporting procedures	

Appendix C ASS initial closure report checklist of reporting requirements

Acid sulfate soil initial closure report

Acid sulfate soil initial closure report		
Report sections	Information to be included, where relevant	Comments
1 Executive summary	• Background • Objectives of the Acid Sulfate Soil Management Plan (ASSMP) • Scope of work • Summary of ASS investigations • Summary of site works • Summary of ASSMP	**Mandatory information**
2 Scope of work	• Clear statement of the scope of work	**Mandatory information**
3 Site identification	• Street number, lot number, street name and suburb • Common title/name of site (e.g. Sparkling Waters Residential Estate) • Certificates of title (copy of document including survey plan) • Co-ordinates of site boundaries (Northings/Eastings—specify datum set) • Locality map • Current site plan showing any existing infrastructure, scale bar, north arrow, local environmentally significant features, 'stages' of development • Local government authority	**Mandatory information**
4 Details of land development	• Full description of proposed development • Site lay-out plans and cross-sectional diagrams for proposed development • Details of proponent and Project Manager • Details of planning conditions including full and clear identification of section of	**Mandatory information**

Acid sulfate soil initial closure report		
Report sections	Information to be included, where relevant	Comments
	the development project for which clearance of conditions is sought—i.e. site plans clearly showing cadastral boundaries, "stage" boundaries, spatial co-ordinates, gazetted roads etc, (where applicable) • List of all other names under which the development has been known (where applicable)	
5 Geology and hydrogeology	• Description of geology and hydrogeology encountered during ground disturbing activities • Discussion of any discrepancies between the geology and hydrogeology expected to be encountered and that which was encountered (where applicable) • Depth to groundwatertable • Direction and rate of groundwater flow • Direction of surface water runoff • Groundwater discharge location • Groundwater quality • Groundwater/surface water interaction • Groundwater conditions (e.g. unconfined, confined, ephemeral or perched) • Beneficial use of groundwater in the vicinity such as public drinking water supply and source areas, domestic irrigation, aquatic ecosystems, and the potential impacts on these uses • Location and use of groundwater bores within a 1km radius of the site • Location of sensitive receptors/users • Preferential migratory pathways encountered during ground disturbing activities	**Mandatory information**
6 Details of site	• Full description of ground disturbing	**Mandatory**

Acid sulfate soil initial closure report		
Report sections	Information to be included, where relevant	Comments
works	activities which were undertaken, including both soil and water disturbance (including volumes, depths, duration, locations etc) • Volume of soil and groundwater treated at the site • Amount of neutralising agent used during works • Details and verification of off-site treatment of soils (where applicable)	**information**
7 Adherence to ASS Management Plan	• Details of whether environmental performance objectives were met • Details of ASS management strategy implemented at the site including confirmation that the site works were carried out in accordance with the DER-approved ASS Management Plan • Identification of and justification for any deviations from the DER approved ASS Management Plan (where applicable) • Details of the implementation of any contingency plans (where applicable) • Verification of compliance with regulatory requirements such as licences and approvals (local and state level) • Photographs of site works confirming adherence with ASS Management Plan (e.g. photos of excavation, soils being stockpiled and treated, water treatment systems, effluent disposal, etc)	**Mandatory information**
8 Basis for adoption of assessment criteria	• Table listing all selected assessment criteria and references • Rationale for and appropriateness of the selection of criteria • Assumptions and limitations of criteria.	**Mandatory information**

Acid sulfate soil initial closure report		
Report sections	Information to be included, where relevant	Comments
9 Monitoring results	• Results of all soil, groundwater and surface water monitoring programs. • Summary of all monitoring results - in a table that shows essential details, such as sampling locations and depths, assessment criteria and highlights all results exceeding the adopted assessment criteria • Site plans showing the location of all monitoring points, showing their relation to ground disturbing activities and soil and water treatment and disposal areas • Full discussion of the results of the groundwater monitoring program (plus surface water body monitoring program where applicable) with particular emphasis on trends in water quality (graphs of water quality data should be presented to aid the identification of trends) • Results of soil treatment validation program (where applicable) • Results of validation of soil and water treatment areas after decommissioning (where applicable) • Calibration certificates or calibration results • Copies of original laboratory result certificates including NATA accreditation details • Discussion of any discrepancy between field observations and laboratory analyses results • Site plan showing all sample locations, sample identification numbers and sampling depths • Site plan showing extent of groundwater acidity and/or metal contamination beneath site (where applicable)	**Mandatory information**

Acid sulfate soil initial closure report		
Report sections	Information to be included, where relevant	Comments
10 Risk assessment	• Receptor identification • Assessment of receiving environment's sensitivity • Exposure assessment • Discussion of the potential risk of harm to human health and/or the environment associated with the ground disturbing works undertaken with reference to the results of the monitoring programs • Discussion of assumptions used in reaching the conclusions • Extent of uncertainties in the results • Discussion, justification and remedial measures proposed if environmental performance objectives were not met • Risk management decisions based on outcome of the assessment	**Mandatory information**
11 Community consultation	• Details of stakeholders (individuals and groups) consulted • Summary of information provided to stakeholders (e.g. minutes of meetings, informative flyers) • Input and comments received from stakeholders • Details of how stakeholder input was considered in decision-making • Brief description of community consultation undertaken during previous stages of site investigation, if details have already been submitted to DER in previous report(s) • Refer to DER Contaminated Sites Management guidelines	**Include information where community consultation was undertaken**
12 Ongoing monitoring	• Ongoing soil, groundwater, and/or surface water monitoring requirements • Details of party(s) responsible for ongoing monitoring program	**Mandatory information where applicable**

Acid sulfate soil initial closure report		
Report sections	**Information to be included, where relevant**	**Comments**
	• Commitment to and timing of submission of results of monitoring programs	
13 Conclusions and recommendations	• Brief summary of all findings • Full discussion of the effectiveness of management strategies employed at the site • Discussion of any potential risks to human health or the environment (where applicable) • Assumptions used in reaching the conclusions • Extent of uncertainties in the results • Discussion of any remedial measures required (where applicable) • Recommendations for further sampling (where applicable) • Long term site management plan (where applicable) • A statement detailing all limitations and constraints on the use of the site (where applicable) • Clear statement from the consultant as to whether the site should be reported as a known or suspected contaminated site under the *Contaminated Sites Act 2003*	**Mandatory information**

Appendix D ASS post-dewatering monitoring closure report checklist of reporting requirements

Post-dewatering monitoring closure report

Post-dewatering monitoring closure report		
Report sections	Information to be included, where relevant	Comments
1 Executive summary	• Background • Objectives of the monitoring program • Scope of work • Summary of ASS investigations • Summary of site works	**Mandatory information**
2 Scope of work	• Clear statement of the scope of work	**Mandatory information**
3 Site identification	• Street number, lot number, street name and suburb • Common title/name of site (e.g. Sparkling Waters Residential Estate) • Certificates of title (copy of document including survey plan) • Co-ordinates of site boundaries (Northings/Eastings—specify datum set) • Locality map • Current site plan showing any existing infrastructure, scale bar, north arrow, local environmentally significant features, "stages" of development • Local government authority	**Mandatory information**
4 Details of land development	• Full description of proposed development • Details of proponent and project manager • Details of planning conditions including <u>full</u> and <u>clear</u> identification of section of the development project for which clearance of conditions is sought—i.e. site plans clearly showing cadastral boundaries, 'stage' boundaries, spatial co-ordinates, gazetted roads etc, (where	**Mandatory information**

Post-dewatering monitoring closure report		
Report sections	Information to be included, where relevant	Comments
	applicable) • List of all other names under which the development has been known or referred to as (where applicable)	
5 Geology and hydrogeology	• Description of geology and hydrogeology • Depth to groundwater table • Direction and rate of groundwater flow • Groundwater discharge location • Groundwater quality • Groundwater/surface water interaction • Groundwater conditions (e.g. unconfined, confined, ephemeral or perched) • Beneficial use of groundwater in the vicinity such as public drinking water supply and source areas, domestic irrigation, aquatic ecosystems and the potential impacts on these uses • Location and use of groundwater bores within a 1km radius of the site • Location of sensitive receptors/users • Preferential migratory pathways encountered during ground disturbing activities	**Mandatory information**
6 Details of site works	• Description of ground disturbing activities which were undertaken, including both soil and water disturbance	**A brief summary of the Site Works is adequate if detailed information was provided to DER in a referenced previous report**
7 Basis for adoption of assessment criteria	• Table listing all selected assessment criteria and references • Rationale for and appropriateness of the selection of criteria	**Mandatory information**

Post-dewatering monitoring closure report		
Report sections	**Information to be included, where relevant**	**Comments**
	• Assumptions and limitations of criteria	
8 Monitoring results	• Results of all groundwater and surface water monitoring programs • Summary of all monitoring results—in a table that shows essential details such as sampling locations and depths, assessment criteria, highlights all results exceeding the adopted assessment criteria • Site plans detailing the location of all monitoring points and showing their relation to ground disturbing activities, soil and water treatment and disposal areas • Full discussion of the results of the groundwater monitoring program (plus surface water body monitoring program where applicable), with particular emphasis on trends in water quality (graphs of water quality data should be presented to aid the identification of trends) • Calibration certificates or calibration results • Copies of original laboratory result certificates including NATA accreditation details • Discussion of any discrepancy between field observations and laboratory analyses results • Site plan showing extent of groundwater acidity and/or metal contamination beneath site (where applicable)	**Mandatory information**
9 Risk assessment	• Receptor identification • Assessment of receiving environment's sensitivity • Exposure assessment • Discussion of the potential risk of harm to human health and/or the environment	**Mandatory information**

Post-dewatering monitoring closure report		
Report sections	Information to be included, where relevant	Comments
	associated with the ground disturbing works undertaken with reference to the results of the water monitoring program • Discussion of assumptions used in reaching the conclusions • Extent of uncertainties in the results • Risk management decisions based on outcome of the assessment	
10 Community consultation	• Details of stakeholders (individuals and groups) consulted • Summary of information provided to stakeholders (e.g. minutes of meetings, informative flyers) • Input and comments received from stakeholders • Details of how stakeholder input was considered in decision-making • Brief description of community consultation undertaken during previous stages of site investigation, if details have already been submitted to DER in previous report(s) • Refer to *Community Consultation* (DEC 2006) guideline	**Include information where community consultation was undertaken**
11 Conclusions and recommendati-ons	• Brief summary of all findings • Full discussion of the effectiveness of management strategies employed at the site • Discussion of any potential risks to human health or the environment (where applicable) • Assumptions used in reaching the conclusions • Extent of uncertainties in the results • Discussion of any remedial measures required (where applicable) • Recommendations for further sampling	**Mandatory information**

Post-dewatering monitoring closure report		
Report sections	Information to be included, where relevant	Comments
	(where applicable) • Long term site management plan (where applicable) • A statement detailing all limitations and constraints on the use of the site (where applicable) • Clear statement from the consultant as to whether the site should be reported as a known or suspected contaminated site under the *Contaminated Sites Act 2003*	
12 Ongoing monitoring	• Ongoing soil, groundwater and/or surface water monitoring requirements • Details of party(s) responsible for ongoing monitoring program • Commitment to and timing of submission of results of monitoring programs	**Mandatory information where applicable**

Appendix E Empirical methods for dewatering calculations

Empirical methods for calculating the radial extent of the groundwater cone of depression as well as the estimated pumping rates and times necessary to achieve the required groundwater drawdown for dewatered excavations.
A web-based tool for conducting these calculations, based on the methods described below, can be found www.der.wa.gov.au/ass.

Calculation methods

Dewatering of a rectangular excavation with dimensions **a** metres wide and **b** metres long can be approximated as pumping from a large-diameter bore with an equivalent radius of $\mathbf{r_e}$ metres, where:

$$r_e = \sqrt{\frac{ab}{\pi}}$$

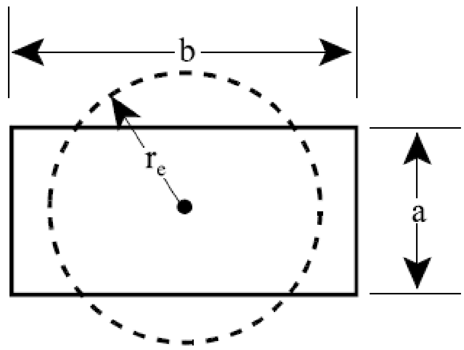

Figure E1 Equation No 1

The radius of influence of this large-diameter bore (i.e radius of the cone of depression of the watertable) can be approximated using Sichardt's equation:

$$R_o = 3000(H - h)\sqrt{K}$$

$$R_o = 3000 \text{ x } s \text{ x}$$

Figure E2 Equation No 2

Where: R_o = radius of influence of an equivalent pumping bore (m)

s = maximum groundwater draw down (m)

K = hydraulic conductivity of aquifer matrix (units of m/s)

In the absence of site-specific hydraulic data, Table 5A below lists default hydraulic conductivity values (K) for a variety of Western Australian soil types.

Table 5A. Default hydraulic conductivity values (K) for a variety of Western Australian soil types

Lithology	Hydraulic conductivity (m/s)
Sand	
Very coarse to gravel	0.002847
Very coarse	0.002361
Coarse	0.000845
Medium to coarse (moderately sorted)	0.000579
Fine to gravel (poorly sorted)	0.000116
Medium	0.000191
Fine to medium	9.49×10^{-5}
Fine	4.75×10^{-5}
Fine to very fine	1.97×10^{-5}
Very fine	9.26×10^{-6}
Silty	4.63×10^{-5}
Clayey	1.16×10^{-5}
Clay	4.63×10^{-6}
Sand and limestone: Ascot Formation	9.26×10^{-5}
Limestone and calcarenite: Tamala Limestone	0.001157 to 0.011574

Adapted from Davidson, 1995.

As a first approximation, changes in watertable elevation caused by dewatering are related to the pumping rate, hydraulic conductivity of the aquifer matrix and radius of influence of pumping by the equation:

$$H^2 - h^2 = \frac{nq}{\pi k}\left(\ln R_o - \ln r_e\right)$$

Figure E3 Equation No 3

Where: H = saturated thickness of the aquifer undisturbed by pumping (m)

h = saturated thickness of the aquifer at maximum drawdown (m)

k = hydraulic conductivity of aquifer matrix (units of m/s)

R_o = radius of influence of an equivalent pumping bore (m)

r_e = effective radius of an equivalent pumping bore (m)

q = pumping rate of individual dewatering well points (m^3/s)

n = number of well points used to dewater the excavation

In the absence of site-specific information, the saturated thickness of superficial aquifers may be obtained from:

- the '*Groundwater Atlas'* (for sites in the Perth metropolitan region); or
- information held by the Department of Water (for sites elsewhere in the state).

The pumping time needed for the cone of depression of the watertable to extend out to R_o is given by the Cooper-Jacob empirical relationship.

$$\mathbf{R_o = ((2.25\ k\ h\ t)/S)^{0.5}}$$

Figure E4 Equation No 4

Where: t = pumping time (seconds)

S = specific yield of aquifer sediments

Other parameters as previously defined

In the absence of site-specific hydraulic information, assume a specific yield of 0.1.

The following example demonstrates how these equations can be used to estimate the radius of influence of a dewatering program and the pumping rate and time needed to lower the watertable by a specified amount in the area of excavation:

Example 1

A dewatering program is planned at a site underlain by sandy sediments where the saturated thickness of the superficial aquifer is 45 metres. It is planned to lower the watertable by 5 metres in a rectangular area of dimensions 30 metres by 15 metres. It is proposed to use 26 well points around the rectangular area to lower the watertable to the base of the excavation.

Solution:

Firstly, use Sichardt's equation (Equation No 2) to determine the radius of influence (i.e. radius of ultimate cone of depression) if one large pumping bore is used to dewater the excavation:

$R_o = 3000 \times 5 \times (3.5 \times 10^{-4})^{0.5}$
= 281 metres

The equivalent radius of this pumping bore is determined using Equation No 1.

$r_e = (30 \times 15/\pi)^{0.5}$
= 12 metres

The pumping rate to dewater the excavation can be determined using Equation No 3:

$$(45)^2 - (40)^2 = \frac{nq}{\pi \times (3.5 \times 10^{-4})} \times ((\ln(281) - \ln(12))$$

i.e. $nq = 0.15\ m^3/s$

Given that there are 26 well points in use to dewater the excavation, the pumping rate of each well point must be $0.15/26\ m^3/s$, or about **5.8 L/s**.

The pumping time needed is given by the Cooper-Jacob equation (Equation No 4)

$281 = ((2.25 \times 3.5 \times 10^{-4} \times 40)/0.1)^{0.5} \times (t)^{0.5}$

i.e. $281/0.56 = (t)^{0.5}$

i.e. t = 251789 seconds or about **70 hours** or **3 days**

DER requirements for assessing dewatering operations

DER will need a preliminary assessment using the above calculation methods of the radial extent of the cone of depression and of pumping rates and times for all dewatering operations where there is a risk of disturbing ASS materials or of intercepting contaminated groundwater. Linear disturbances should be assumed to consist of a number of rectangular dewatering areas that abut each other and that are pumped sequentially.

In situations where the radius of influence, R_o, of dewatering extends less than 50 metres from each dewatered excavation and/or pumping of each excavation is less than seven days in duration, DER will not require any further assessment of dewatering other than requiring a standard monitoring program to be undertaken during the dewatering program. This is conditional on there being no sensitive receptors (wetlands, waterways, conservation reserves, abstraction bores and contaminated sites) within 50 metres of each dewatered excavation.

Otherwise, DER may require that site-specific investigations and groundwater flow modelling are undertaken to better quantify the potential impacts of dewatering on the local groundwater flow regime. Under these conditions, proponents will need to implement measures to reduce the extent of the cone of depression of the watertable and reduce the duration of dewatering in any given excavation. Measures to achieve these objectives include:

- reducing the size of each excavation to reduce the groundwater pumping rate needed to keep each excavation dry;
- use of sheet piling or soil grouting to constrain the lateral extent of the cone of depression of the watertable to the immediate vicinity of the excavation; and/or
- use of groundwater recharge barriers to constrain the lateral extent of the cone of depression of the watertable to the immediate vicinity of the excavation.