



Australian Government Initiative

WATER QUALITY
AUSTRALIA

National Acid Sulfate Soils Guidance

Guidelines for the dredging of acid
sulfate soil sediments and associated
dredge spoil management

June 2018

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Cataloguing data

This publication (and any material sourced from it) should be attributed as: Simpson, SL, Mosley, L, Batley, GE and Shand, P 2018, *National Acid sulfate soils guidance: Guidelines for the dredging of acid sulfate soil sediments and associated dredge spoil management*, Department of Agriculture and Water Resources, Canberra, ACT. CC BY 4.0.

This publication is available at waterquality.gov.au.

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Acknowledgements

This document was externally reviewed by the National Committee for Acid Sulfate Soils (NatCASS). The case studies were contributed by Stuart Simpson, Luke Mosley and Peter Adkins.

The authors would like to thank the Department of Agriculture and Water Resources for overseeing the management of the guidelines, providing support throughout and reviewing; Dr Richard Bush and Dr Nicholas Ward, Southern Cross University, for comments and suggestions on the draft report; Steve Appleyard for a constructive review and advice and colleagues at WA Department of Water and Environment Regulation for generously sharing their knowledge and expertise on dewatering; Dr Peter Adkins and Ben Zammit for assistance with case studies; NatCASS for supporting and reviewing the project since its inception; and other reviewers for contributing insightful reviews on different aspects of ASS hazards. Funding for this guidance was provided by the Department of Agriculture and Water Resources with in-kind support from the CSIRO (EP158859).



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1 The purpose of this guidance

These guidelines have been written to provide technical and procedural advice to avoid environmental harm from acid sulfate soils (ASS) encountered during dredging projects. The guidelines concern the risks posed both during dredging operations (that is to the water column and surrounding aquatic environment) and during disposal of dredged spoil materials within water bodies (open-water disposal), including confined (dyked) disposal resulting in creation of new land or on existing land.

The guidelines describe a technical framework for evaluating the environmental acceptability of dredged material, management alternatives and means to minimise and manage potential impacts. This framework provides national guidance over a wide range of dredging scenarios and management options, and so flexibility and discretion is necessary. As a consequence, not all of the considerations will apply, or relative importance will vary, depending on the specifics of the dredging project being proposed. **It is essential that the reader consult relevant jurisdictional guidance and regulations and contact the relevant state or territory government department for specific local and regional information and advice.**

The guideline document is divided into four sections:

- 1) An introduction to dredging activities and the need for specific consideration of ASS.
- 2) An overview of the extent, risks, legacies and potential liabilities posed by ASS, and existing policy and regulatory environment with respect to dredging.
- 3) A guide to assessing risks and sound management principles and procedures for disposal of dredged spoil within water bodies and on land, including site selection, preparation, remediation and monitoring.
- 4) The development of management strategies and plans, including the development of an ASS Management Plan (ASSMP).

A series of appendices are provided that contain further information on a range of matters, including:

- several case studies that describe ASS management activities;
- dredged material characterisation; and
- ASSMP.

The guidelines are intended to provide good practice risk management for dredging activities, and include a tiered framework to provide a clear and transparent procedure for achieving a robust assessment and providing acceptable monitoring objectives.

The intent is to provide guidance that is ‘fit for purpose’. As the types of dredging activities covered will range in scale from very small (for example channels on farms) to very large (for example large regional port development) and from inland to coastal, the document will not be prescriptive except in cases where the information is to be applied universally (for example definitions of ASS). A general overview only is provided of other non-environmental factors to be considered in decision making, and there is no review or detailed advice provided for social, cultural and economic considerations.

This report does not review, describe or evaluate methods for dredging (for example appropriate equipment or operation techniques), or for the collection of sediment samples for assessment, which are adequately described elsewhere (for example DER, 2015a; Sullivan et al., 2018a-c; Simpson and Batley, 2016).

2 Introduction

2.1 Acid sulfate soils

Acid sulfate soils (ASS) is the term used to describe soils and sediments which either contain sulfide minerals, principally pyrite (FeS_2) and iron monosulfide (FeS), or have been impacted by severe acidification (pH less than 4) due to the oxidation of the sulfide minerals. These soils are generally present in low-lying areas of both coastal and inland landscapes across Australia, with an estimated area of around 4 million hectares.

A number of terms have been used to describe ASS, including actual/potential (Dear et al., 2014) and ripe/unripe (Dent and Pons, 1995), with the former being more common in Australia. Recent suggestions for improving the definition (Sullivan et al., 2009; 2010) have largely been incorporated into the latest classification scheme for Australian soils (Isbell, 2015). The definitions for types of ASS used in these guidelines are:

- Sulfidic: soils containing detectable sulfide, with the following sub-division.
 - Hypersulfidic: Sulfidic soil material that is capable of severe acidification (pH less than 4) as a result of oxidation of contained sulfides.
 - Hyposulfidic: Sulfidic soil material that is not capable of severe acidification (pH less than 4) as a result of oxidation of contained sulfides.

[Note: these materials were previously referred to as potential acid sulfate soils (PASS)].

- Sulfuric: Soil material that has a pH less than 4 (1:1 by weight in water, or in a minimum of water to permit measurement) when measured in dry season conditions as a result of the oxidation of sulfidic materials.

[Note: these materials were previously referred to as actual acid sulfate soils (AASS) previously].

- Monosulfidic: Soil material containing greater than or equal to 0.01% acid volatile sulfide (AVS). These materials are often referred to as monosulfidic black ooze (MBO) (Sullivan et al., 2018d).

The term 'acid sulfate soils' is generally used for sediments in wetlands (sub-aqueous soils) and regolith (the weathered material above bedrock). Acid sulfate soils form under anoxic conditions, typically in waterlogged or saturated environments along the coast or inland, within drains, rivers and wetlands. They do not generally pose a significant risk to human health or the environment if undisturbed, however, sulfide is unstable in the presence of oxygen (and other oxidising agents) reacting to generate sulfuric acid. Severe acidification may result if there is insufficient acid neutralising capacity (for example carbonate minerals) in the soil. A number of other hazards have been recognised in association with ASS, including deoxygenation, contaminant metal and metalloid release, malodours and nutrient release. Some of these hazards occur due to redox changes in the soil, and some may occur and even be enhanced under high pH conditions in systems that are well-buffered in terms of acid-neutralisation capacity. The disturbance of ASS has the potential to cause significant impacts, including fish kills, loss of biodiversity in wetlands, contamination of surface water and groundwater, and corrosion of steel and concrete structures. Some of the problems associated with ASS have been known for several centuries, for example during dewatering of the Dutch polders from the 17th century onwards (Dent and Pons, 1995).

Box 2.1 Management Principles.

1. The disturbance of ASS should be avoided wherever possible.
2. Where disturbances of ASS are unavoidable, preferred management strategies are:

- minimisation of disturbance;
- neutralisation of acidity (treatment);
- hydraulic separation of sulfides either on its own or in conjunction with dredging; and
- strategic reburial (reinternment, with treatment of any excess acidity).

Other management measures may be considered but must not pose unacceptably high risks.

3. Works should be performed in accordance with best practice environmental management when it has been demonstrated that the potential impacts of works involving ASS are manageable to ensure that the potential short- and long-term environmental impacts are minimised.
4. The material being disturbed (including the in situ ASS) and any potentially contaminated waters associated with ASS disturbance, must be considered in developing a management plan for ASS and/or in complying with the general environmental duty.
5. Receiving marine, estuarine, brackish or fresh waters are not to be used as a primary means of diluting and/or neutralising ASS or associated contaminated waters.
6. Management of disturbed ASS is to occur if the ASS action criteria listed by Dear et al. (2014) guidelines is reached or exceeded.
7. Stockpiling of untreated ASS above the permanent groundwater table with (or without) containment is not an acceptable long-term management strategy. For example, soils that are to be stockpiled, disposed of, used as fill, placed as temporary or permanent cover on land or in waterways, sold or exported off the treatment site or used in earth bunds, that exceed the ASS action criteria listed in Table 1 should be treated/managed.
8. The following issues should be considered when formulating ASS environmental management strategies:
 - the sensitivity and environmental values of the receiving environment. This includes the conservation, protected or other relevant status of the receiving environment (for example Fish Habitat Area, Marine Park, Coastal Management District and protected wildlife);
 - whether groundwaters and/or surface waters are likely to be directly or indirectly affected;
 - the heterogeneity, geochemical and textural properties of soils on-site; and
 - the management and planning strategies of local government and/or state government, including regional or catchment management plans/strategies and state and regional coastal management plans.

Note: Modified from Ahern et al. (1998) and Dear et al. (2014).

2.2 The problem

Dredging involves the excavation of bed sediment materials from waterways to result in the deepening or widening of the waterway, or creation of new waterways or channels (for example canals). The waterways may be temporarily dry at the time of the dredging with the activity still classed as dredging under legislation. The disturbance of ASS during dredging or disposal of ASS within waters and on land may result in acidification of soil, sediment, surface water and groundwater. The often acidic waters from disturbed ASS may contain high concentrations of metals, metalloids and nutrients that may adversely impact human health, aquatic communities, agricultural practices and engineering works. The dredging of ASS may result in aesthetic issues (for

example if spoil is placed on beaches), unpleasant odours (for example hydrogen sulfide release), high turbidity, deoxygenation of waters and fish kills (particularly when disturbing MBOs), and potentially acidification risks at the disposal site. Consequently, ASS hazards need to be assessed, managed and considered together with the other environmental hazards associated with dredging activities.

Beyond impacts from disturbing ASS, dredging activities can pose a wide range of concerns to the public that include environmental impacts due to the disturbance of sediments, and impacts due to the disposal of the dredged sediments. These may include immediate smothering impacts on benthic ecology, secondary effects due to changes to bathymetry and hydrodynamics, altering suspended solids concentrations, light penetration through the water column, and release of excessive concentrations of nutrients or potentially toxic substances (for example metal(loid)s or other contaminants).

The environmental issues due to contaminants are often greater when dredging occurs closer to regions with more intensive land use by urban populations, industries or farming. In some locations, sediment contamination may be sufficient to require the material to be classified as hazardous and be dealt with as a hazardous waste. In other cases, the levels of contamination may be low, but the process of disturbing the sediments can modify the properties and forms of the contaminants within the sediments and may potentially result in the creation of new hazards. As many waterways and surrounding lands are interconnected and have multiple uses (including as environmental habitats), impacts due to dredging may extend beyond the immediate dredging zone to areas that are less prominent to public observations. Dredged materials may be relocated within waterways and remain underwater, used to create new land beside or within a waterway, or placed on land.

2.2.1 Dredging activities

Dredging is an excavation activity or operation usually carried out at least partly underwater (generally in shallow water areas, less than 30 m deep) with the purpose of removing bottom sediments and relocating them. Dredging is frequently required to create or maintain shipping access to commercially and recreationally important waterways, including ports, harbours, rivers, lakes (USACE, 2003; OSPAR, 2009; PIANC, 2010; Ports Australia, 2014). Dredging also often occurs in the construction of artificial drains, urban and peri-urban stormwater retention ponds, irrigation channels, residential developments (including canal estates) that desire deep-water access for boats (marina facilities, construction of jetties), for the placement of subsea pipelines. Dredging is also used by extractive industries (that is sand and gravel, and mineral sand mining). Although some of these activities may be managed by legislation of standard dredging practices, the management of disturbances to ASS may still be important for these industries. The sediments targeted by dredging programs are typically underwater, but may also occur above the water surface, either associated with shorelines (for example river banks) or areas exposed during low water levels of rivers and lakes or intertidal areas of estuarine or coastal environments.

Shipping channel deepening and port development in the coastal environment are the most common and largest scale dredging requirements in Australia (Ports Australia, 2014). Here, dredging is primarily undertaken to increase the size (depth and/or width) of waterways for shipping and navigation purposes. Due to the large quantities of materials dredged, environmental impacts can potentially be very large, in terms of physical, chemical, or biological disturbances arising both from dredging operations (in water) and dredged material disposal. The scale of the impacts may be

strongly influenced by choices made during the planning and approval of dredging operations. The design choices and approval decisions need to cover the dredging (removal or excavation), together with the transport and placement of dredged sediments (USACE, 2003; USEPA/USACE, 2004; AINA, 2008; Bridges et al., 2008; Palermo et al., 2008; NAGD, 2009; EA, 2012; NIGD, 2012).

Maintenance dredging is undertaken within ports and river transport corridors to remove sediments that regularly accumulate in artificially deepened channels and berths because of moving currents, storm and tidal surges, and sediments from upstream during flooding (that is in previously dredged areas). The sediment being removed will have been transported by currents from nearby areas, for example upper regions of river systems or higher activity coastal environments, and are generally not expected to contain large quantities of ASS unless they have been then left undisturbed for a long period of time, where pyrite or MBOs can form in situ once sediments have been deposited. Capital dredging is undertaken for new developments or to expand existing infrastructure, and involves excavation of sediments to create deeper access within waterways for new or existing shipping channels and berths (Ports Australia, 2014). Capital dredging may frequently involve sulfidic sediments.

As shipping expands globally, resulting in greater ship numbers and greater sizes of ships, both the number and size of ports along Australia's coastline will expand. This expansion will result in increased needs for both capital and maintenance dredging and increased demand for dredged material placement areas. While dredging is more commonly undertaken in the coastal zone, inland dredging activities are also common and require guidelines for sound environmental management. Examples of inland dredging activities include construction and maintenance of navigation channels within rivers and lakes, farm irrigation channels or canals, dams, locks, weirs, draining and filling of wetlands and various forms of residential construction.

All forms of soil and sediment disturbance have the potential to cause environmental impacts, and as dredging operations typically result in large-scale changes within a localised area, there may potentially be impacts both within the vicinity of the dredging operation and further afield within the water body, or coastal environment. The disposal of dredged materials may lead to second-phase dredging impacts, after the dredging program has concluded. In the case of ASS, oxidation and formation of acidity can persist for years, creating legacy issues if not managed appropriately, and may be of greater environmental concern than issues at the time of dredging.

Once materials are excavated, they can be handled in a number of different ways. Dredged material may be relocated within a water body or transported and disposed of further afield. Guidance on unconfined ocean disposal of dredged materials is provided in Australia's National Assessment Guidelines for Dredging (NAGD, 2009). Land reclamation projects are often undertaken in parallel with dredging works (for example where dredged material is used as landfill), with the clean dredge spoil frequently used to provide fill material for raising land elevation. For transport within a water body, dredged materials may be loaded into a hopper or barge (part of the dredge itself or on a separate vessel) and transported to a disposal site where the contents of the hopper are emptied, or pumped via a pipeline directly from the dredge site to a disposal location. For transport to land, dredged materials are usually pumped via a pipeline to the desired location, where dewatering of the materials will usually occur. Materials dredged for the purpose of creating trenches are often placed temporarily on the adjacent seabed and then returned into the trench after the pipe has been laid (for example the burial of gas pipelines or telecommunication cables in waterway sediments). Spoil

from the dredging of smaller channels (for example irrigation intakes, drains) is often cast or mounded to the side of the channel.

2.2.2 General environmental considerations for dredging activities

Dredging can cause environmental impacts beyond those resulting from the immediate destruction or modification of benthic habitats caused by removal of materials or burial. Other general ecosystem changes may occur due to changes to hydrological characteristics that modify both water circulation and currents and potentially cause physical and structural changes to land integrity (for example changes in erosion rates). The habitat modifications may affect some species more than others (for example wading birds, certain fish species, benthic invertebrates, and other aquatic biota) or potentially introduce new species, including weeds and pest species. Noting that for many highly modified waterways (for example industrial harbours), the sediment to be dredged may be heavily contaminated and the associated ecological community depauperate (that is lacking variety) and unhealthy. Sacrificing communities in the relatively small areas impacted by dredging is often acceptable to the majority of stakeholders, given the ease with which sediments can be recolonised. These and other impacts are not addressed further in this document, but should be considered along with other broader environmental impacts, and relevant legislation (for example for marine conservation reserves, commercial recreational fisheries, contaminated sites and land management, and other public uses of the environment).

Within the surrounding environment, impacts may occur to water quality due to resuspended sediment and, if fine sediments are not contained (for example using silt curtains), these may be transported by water currents to potentially impact aquatic and benthic habitats further afield. Water column impacts may also occur due to contaminant and nutrient release and dispersion, or rapid changes in water quality associated with low dissolved oxygen concentrations. The Australian water and sediment quality guidelines (ANZECC/ARMCANZ, 2000) within the National Water Quality Management Strategy (NWQMS) and the NAGD (2009) provide guidance for many of these assessment issues. Particular considerations are the risks associated with resuspension, during dredging activities, of MBOs that may result in hypoxia and anoxia to the extent that fish kills occur. In waterways with limited water circulation or pH buffering, there is an increased likelihood of acidification due to oxidation of ASS.

Land-based placement of dredged materials requires environmental impact assessment relating to site location, containment and treatment of materials and will frequently require long-term monitoring of materials that may be transported off site (for example dust, leachates). The National Environmental Protection Measure (NEPM, 2013) provides guidance for many of the land-based assessment issues, where the presence of ASS may result in specific management actions, for example management of leachates. Of particular importance to assessments of risks posed by ASS is the issue of both short-term and long-term oxidation processes that may release acidity and contaminants, particularly metals. Additional tests, not common with other guidelines, may include oxidation-leach tests specifically designed for assessing these solid-phase oxidation risks.

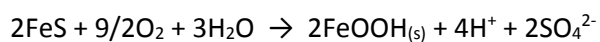
2.2.3 Contaminant release during dredging

To understand how dredging activities are likely to perturb contaminants, it is important to first discuss the chemical and physical properties of the sediments pre-disturbance. Sediments are typically composed of a range of grain sizes from sand- to clay- and silt-sized particles, the latter having the greatest surface area and hence more binding sites for contaminant adsorption. Metals

will be present in a range of chemical forms. Mineral forms (for example clay minerals, pyrites, et cetera) are typically inert and not bioavailable. During sediment diagenesis, deposition from overlying waters of metals associated with iron and manganese oxyhydroxides and natural organic matter will occur. Microbial decomposition of organic matter and sulfates will create sub-oxic, and at depth, anoxic conditions, leading to the formation of iron and manganese monosulfides (FeS, MnS – the major components of AVS and other less soluble metal sulfides such as pyrite (FeS₂) and trace-metal sulfides (for example CuS, ZnS).

The chemistry of pore waters will reflect the equilibrium solubility of metals in the oxic, sub-oxic and anoxic zones (Kristensen, 2000). Burrowing organisms will, however, lead to the introduction of oxic waters at depths of 1-10 cm depending on the organism type and size (Aller et al., 2001), and this will lead to localised disturbances to the redox equilibria and some oxidative dissolution of FeS and, to a lesser extent MnS, with a localised pH decrease (H⁺ production) arising from the overall reaction (Equation 2.1).

Equation 2.1 The oxidation of iron monosulfide (FeS).



The oxidation of FeS produces an insoluble iron(III) oxyhydroxide in estuarine and marine waters but does not directly proceed to sulfate and acid (H⁺) (Morse, 1994a, Morse and Rickard, 2004; Rickard and Morse, 2005). An intermediate sulfur species, presumed to be elemental sulfur, forms initially and its subsequent oxidation leads to the observed pH reduction (Burton et al., 2006; Hong et al., 2011). Others have suggested that sulfite and thiosulfate are the likely intermediates (Caetano et al., 2003).

The oxidation of AVS during resuspension in oxygenated waters can be very rapid (Simpson et al., 1998; Morse and Rickard, 2004; Rickard and Morse, 2005). The rates of FeS and MnS oxidation are pH dependent, with MnS oxidation kinetically slower than that of FeS (Morse, 1991, Stumm and Morgan, 1996). Dissolution of other trace metal sulfides such as CuS occurs more slowly (Simpson et al., 1998, 2000; Di Toro et al., 1996a, b). Slow diffusion of released metals ultimately to the overlying water occurs from pore waters, however, this can be accelerated by organisms irrigating burrows (Peterson et al., 1996; Remaili et al., 2016).

In fresh water environments, the release of elevated concentrations of sulfate into solution, as a result of sulfide oxidation may also cause local and downstream impacts on ecosystems (Smolders et al., 2006). In sensitive ecosystems, other impacts of increased sulfate concentrations may include phosphorus and ammonium-nitrogen release associated with the reformation of sulfides (Smolders et al., 2006) greater rates of mercury methylation (USGS, 2004) and the potential for sulfide toxicity to sensitive wetland plants as sulfate reduction takes place (Minnesota Pollution Control Agency, 2014).

Effect of sediment disturbance

During dredging operations, massive disturbance occurs that leads to the exposure of sub-oxic and anoxic sediments to oxygenated water, increasing the potential for the oxidation and dissolution reactions described in section 2.2.3. Disturbance of pore waters and the mixing of the oxic, sub-oxic and anoxic sediment zones may result in the release of metal(loid)s (Simpson and Batley, 2003) and nutrients (Morgan et al., 2012), although there are also many reactions that attenuate the release and influence the longer-term impacts (Calmano et al., 1994, 1998; Förstner and Calmano, 1998;

Vandenberg, et al 2001; Cantwell et al., 2002; Caetano et al., 2003; Eggleton and Thomas, 2004; Maddock et al., 2007; Hedge et al. 2009; Simpson et al., 2012).

The properties of the sediments and the dredging method being used will influence the degree of contaminant release. Where the sediment is relatively unconsolidated and is removed by cutter-suction dredging, processes will differ from those where sediments remain relatively consolidated and are removed by clam-shell or bucket dredging, where the exposed surfaces only will be subject to oxidation. It is important to note that coarser sediments are most likely to rapidly re-settle following disturbance. By contrast, finer sediments may remain aggregated and sink with minimal disintegration resulting in a localised benthic accumulation, or they may disperse as fine-sediment (colloid) plumes that may transport nutrients, contaminants and ASS materials far from the site of dredging.

A number of studies have reviewed the effect of resuspension events on metal release from sediment particles and these have varied from physically disturbing the surface of the sediments (Cantwell et al., 2002; Cantwell and Burgess, 2004, Kalnejais et al., 2007) to more extreme studies that evaluate the maximum possible releases based on mixing of sediment with oxygenated water (Simpson et al., 1998, 2000; Hong et al., 2011). Both approaches have provided data that could be used to predict the fate of metals during disturbance from dredging activities. The experiments with estuarine sediments by Simpson et al. (1998, 2000) showed that under certain conditions, there was rapid oxidation of FeS in less than one hour, while oxidation of metal sulfides such as CdS, CuS, PbS and MnS generally takes considerably longer (for example 8 h). A consequence is that a large portion of metals being released from sediment may have time to be scavenged through adsorption by other particles, including freshly formed iron hydroxide phases. However, metals weakly adsorbed by sediment particles (in the water column or deposited) may often be quite reactive and either re-dissolve or be bioavailable if ingested by organisms (Campana et al., 2012; Simpson et al., 2014). If there is a significant pH decrease as a consequence of the oxidation reactions, then it is likely to be associated with a similarly significant and geochemically related impact on metal release.

In estuarine sediments, the magnitude of the pH decrease is often limited, for example less than 1 pH units, largely as a consequence of the buffering by alkalinity in seawater (Simpson et al., 1998. Morgan et al., 2012), but is likely to be greater in freshwater systems. Field studies of pH changes associated with the dredging of estuarine sediments showed minimal changes in pH, attributed to effective water mixing in the release area (Morgan et al., 2012). Similarly, while laboratory studies showed significant reductions in dissolved oxygen saturation that increased with increasing sediment to water ratios (Morgan et al., 2012), only minor changes in dissolved oxygen concentrations were measured in field studies, again attributed to effective mixing. In less well-buffered systems, particularly in freshwaters, the pH decrease may be large (Simpson et al., 2010; Simpson et al., 2014).

The rate of oxidation of Fe(II) and Mn(II) increases significantly in the pH range 5-8, which covers most fresh and marine waters (Stumm and Morgan, 1996; Millero, 2001). In oxic waters in this pH range, iron solubility is extremely low and the dominant forms are colloidal iron oxyhydroxides. These scavenge any released heavy metals further reducing their bioavailability. Transport of these forms by bottom currents may mean that re-deposition in the sediments could occur at a distance from their source.

Pyrite, FeS₂, is a major constituent of anoxic sediments, and it too can be subject to oxidation, largely by oxygen, nitrate or MnO₂ and aerobic bacteria (Morse, 1994). Pyrite is an important binding phase for trace metals in anoxic systems (Huerta-Diaz and Morse, 1992; Morse, 1994b), and as such, a potential metal source during pyrite oxidation (Morse et al., 1994a). The very rapid release of dissolved iron during resuspension and pyrite oxidation is unlikely in the time scale because of its slower oxidation kinetics (Morse, 1991, Calmano et al., 1994; Rickard and Morse, 2005) and minimal time in entrainment, given the settling rates for sediments typical of shallow water bodies where dredging typically takes place (Caetano et al., 2003).

Release of nutrients

Dredging activities may release nutrients contained within pore water from dredged sediments (Morgan et al., 2012; Batley et al., 2015). For most dredging activities, the concentration of nutrients is not expected to be significant, but at some locations considerable amounts of nutrients may have accumulated and pose risks to the environment (Batley and Simpson, 2009), such as eutrophication beyond the dredging zone. Where dredging is to occur during seasons in which algal blooms are likely, the risk posed by nutrients released into the water column may increase dramatically and should be minimised and monitored. A review of the release of nutrients (nitrate, nitrite, ammonia and phosphate) during coastal dredging operations (Batley et al., 2015) found that ammonia release was the greatest concern. Ammonia and phosphate release has previously been observed during the dredging of FeS rich sediments, although iron (hydr)oxides formed from the oxidation of FeS tend to strongly limit the dissolved phosphate concentrations (Morgan et al., 2012).

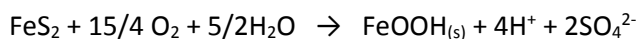
When dredging takes place in fresh water environments, the release of sulfate may also create elevated concentrations in local and downstream environments. In estuarine and marine waters sulfate concentrations are naturally high (for example approximately 2.7 g/L). Elevated sulfate concentrations in freshwaters may cause direct toxicity to sensitive organisms (Wang et al., 2016), or impact the ecosystems indirectly through the influence on other nutrients or sulfide formation, for example phosphorus and ammonium-nitrogen release associated with the reformation of sulfides (Smolders et al., 2006). Low sulfate concentrations are frequently the primary limiting factor for sulfide formation in freshwater environments, and release of at one location (for example due to dredging) may result in impacts further afield (including nutrient cycling).

2.2.4 Contaminant release from acid sulfate soils

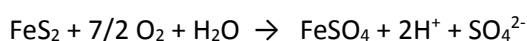
Many soils, especially in coastal regions contain appreciable concentrations of iron sulfide minerals, especially FeS and FeS₂ in deeper strata. These are formed from the bacterially mediated reduction of sulfate, present in elevated concentrations together with iron in marine and estuarine waters. Bacteria also require a source of organic matter associated with aquatic ecosystems. While these sulfide minerals occur in many coastal soils and sediments, they are also present in inland regions.

Exposure of iron sulfide minerals to oxygen or other oxidants involves oxidation of both sulfide and Fe(II) with the formation of Fe(III) (for example iron oxyhydroxides) and sulfate and, most importantly, hydrogen ions, as shown for pyrite (FeS₂) oxidation (Stumm and Morgan, 1996; Millero, 2001) (Equation 2.2).

Equation 2.2 The oxidation of pyrite (FeS₂).



The first step in this process involves release of Fe(II):



which is then further oxidised (Fanning et al., 2002).

Oxygen reaches sulfide minerals by diffusion. In drying sediments, the development of a porous structure, driven by shrinkage and cracking, enhances the penetration of oxygen to the deeper deposits. This might occur when water bodies dry up after prolonged droughts. Mechanical disturbance will have the same effect. Re-flooding releases the generated acid which will interact with metals released from the pyrite or other soil minerals leading to their dissolution. The presence

of carbonate minerals will react with any acid that has formed from sulfide oxidation, buffering the pH and reducing metal mobility. During re-flooding of oxidized ASS, porewater concentrations of metals are likely to remain well in excess of water quality guideline values (WQGVs) with the prospect for interactions with biota (Baker et al., 2011; Fitzpatrick et al., 2008a,b, 2009, 2012; Mosley et al., 2014; Shand et al., 2010; Simpson et al., 2008, 2010;). Porewater concentrations of metals may remain highly elevated for many days in moderately well-flushed waterbodies (for example estuaries), and potentially for months to years in waterbodies with low water exchange (for example lakes) (Baker et al., 2011; Fitzpatrick et al., 2011, 2012). Burton et al. (2008) examined the profiles of metals and arsenic during rewetting of a coastal ASS. They showed that while porewater concentrations of zinc, nickel, aluminium and manganese were initially high and the porewater pH was 3.5, within 10 days the pH had risen to 6.5 and metal concentrations had dropped significantly. In the case of zinc, the initial concentration of 2 mg/L dropped to 0.5 mg/L after 10 days but took 50 days to decrease below 5 µg/L. The initial and 10-day concentrations exceed the water quality guideline value (ANZECC/ARMCANZ, 2000). Interestingly, after 30 days, AVS (FeS) began to be formed through reduction of Fe(III) and sulfate leading to either precipitation of metal sulfides or scavenging of released metals by iron(III) oxyhydroxides thereby reducing the concentrations of soluble porewater metals. Overall the results indicated a subtle balance between oxidative processes and sulfate reduction that ultimately controls metal dissolution.

Simpson et al. (2008, 2010) observed similar metal releases following rewetting of sulfidic materials from the Murray River and associated lakes in South Australia. In particular, laboratory studies showed that concentrations of Zn, Cu, Ni, Cd, Mn and Al measured after a 24 hour mixing experiment exceeded water quality guideline values for ecosystem protection by as much as 100 times. At least half of the 24 hour release concentrations were usually achieved within 10 minutes. Released metal concentrations were greatest where the pH of the solution after mixing for 24 hours was less than 4. Field measurements during rewetting showed a similar pH dependence (Shand et al. 2010; Mosley et al. 2014a,b,c).

During mixing of pore waters with overlying water, be it rainwater, river water or estuarine waters, there are a number of attenuating processes that modify both the dissolved metal concentrations and the fractions of these that are bioavailable to aquatic organisms. These include:

- high suspended sediment concentrations that provide potential metal binding sites;
- metal-binding colloidal iron and aluminium oxyhydroxide species released from ASS or, in the case of iron, precipitated during oxidation of Fe(II) and binding to sulfide in anoxic environments (sulfate reduction to sulfide and FeS formation); and
- natural organic compounds, either dissolved or associated with iron, manganese and aluminium species, that can adsorb and complex metals in colloidal or particulate forms that are not bioavailable, particularly at pH greater than 5.

The metal(loid) release data obtained by both Burton et al. (2008) and Simpson et al. (2008), have been assessed in terms of long-term exposure using WQGVs based on chronic toxicity over 3 to 21 days (depending on the test species). At the high initial metal(loid) concentrations (released during resuspension), that occur over shorter periods than 3 days, toxic effects due to metal(loid)s are likely to be seen for some species. Typically the metal concentrations at which toxic effects occur are an order of magnitude above water quality guideline values. The actual risk of effects will depend on sediment type, acidity of the initial release waters, properties of the receiving water (for example

temperature, buffering capacity) and subsequent kinetics of attenuation reactions for dissolved metals.

Oxygen consumption resulting in hypoxia or anoxia within waters may occur rapidly during oxidation of monosulfides such as MBOs (for example FeS), but more slowly for oxidation of disulfides such as pyrite (FeS₂), resulting in de-oxygenation of the re-flooded pore waters. The hydrodynamics of the local environment will strongly influence when hypoxia or anoxia develop, which is more likely in low energy freshwater systems that have low rates of water exchange. When forms of sulfide such as MBOs are physically disturbed and potentially mixed into the overlying water, the potential for oxygen depletion is greatest (EPHC/NRMMC, 2011).

2.3 Characterising ASS encountered during dredging

Many of the existing National and state or territory guidelines for dredging (for example NAGD, 2009; Western Australia EPA, 2011; DEP (Tasmania), 2013; Victoria EPA, 2001) provide frameworks for assessing general risks posed by dredging and those related to contaminants, but provide limited guidance on risks posed from dredging ASS. In the case of the guidance for ocean disposal of dredged materials (NAGD 2009), due to the extensive volume and pH buffering capacity provided by seawater, the disposal of sediments classified as containing ASS in the open marine environment is unlikely to significantly alter the acidity and release of quantities of metal(loid)s to the extent that water quality guideline values are exceeded in the water column. In well-flushed open waters the risks posed by disposal of sediments classified as containing MBOs may also be relatively small. However, many freshwater and marine sediments naturally contain sufficient quantities of ASS that may pose risks to the environment during dredging and disposal within confined waterways or following placement on land.

There are a wide range of issues that need to be considered and potentially addressed in regard to management of ASS that are disturbed during dredging activities. The risks posed by ASS generally increase with increased exposure to oxygen, and ASS exposed to the atmosphere undergoes greater rates of oxidation than ASS underwater (Figure 2.1). The increased risks posed by ASS due to excavation, dewatering, and drying which may occur if ASS are placed on land, together with storage and treatment methods, are discussed in section 4.5.2. When ASS are below the water table, they are generally considered harmless, but on exposure to oxygen the sulfides in the ASS rapidly react producing acid. Water movement increases the supply of dissolved oxygen (DO) to ASS at the sediment-water interface, and ASS placed undisturbed within still waters (Figure 2.1b) are a lower risk than in moving waters (Figure 2.1c). ASS that is resuspended into the water column will represent a considerably greater risk of rapid oxidation (Figure 2.1d). Four principal objectives exist for the management of ASS:

- identify and characterise the ASS present;
- avoid or minimise disturbance of ASS;
- mitigate impacts when ASS disturbance is unavoidable; and,
- rehabilitate disturbed ASS and associated impacts (for example acid drainage).

When assessing risks posed by ASS dredging and dredge material disposal, considerations will likely include:

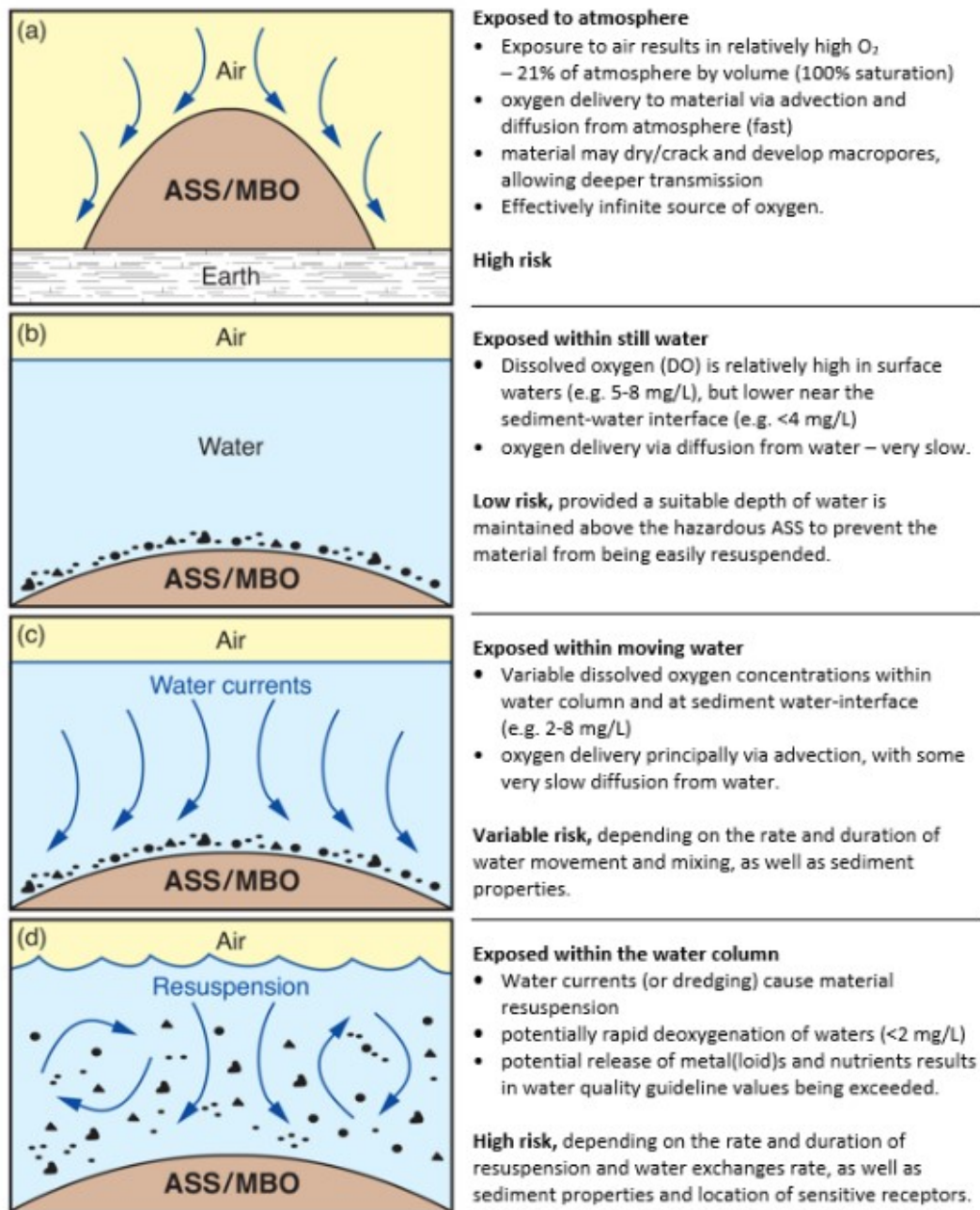
- the total volume of ASS potentially disturbed

- the characteristics of the ASS material (sulfidic, sulfuric materials or MBOs);
- the spatial distribution and variability (maps) of the ASS (influencing avoidance strategies);
- the potential for oxidation of ASS in the dredged materials or within sediment disturbed by the dredging or disposal activities (for example adjacent to the dredged areas or disposal sites);
- the potential acidity of dredged or disturbed sediments or soils if they were oxidised;
- the potential for deoxygenation of waters due to rapid oxidation MBOs (highly labile sulfide phases);
- the potential release of metals, metalloids or nutrients that may affect water quality around the dredging or disposal areas;
- neutralisation treatments (for example low to very high liming rates for disposal on land);
- the containment and treatment of site waters (runoff, effluents, leachates) at the excavation and treatment sites;
- the location of the proposed dredge or disposal sites in relation to sensitive receptors (for example important aquatic ecosystems, water supplies et cetera);
- monitoring, verification and reporting requirements;
- general site activities (for example stockpiling of neutralising agents); and,
- the quality of dredged sediment and decant water in dredge spoil receiving ponds with respect to ASS; and,
- prevailing environmental/climatic conditions.

The following guidance documents should also be consulted when considering what sediment analyses may be necessary when assessing risks posed by dredging ASS materials:

- Australia and New Zealand Water and Sediment Quality Guidelines (ANZECC/ARMCANZ, 2000)
 - Sediment quality guidelines and proposed revisions (Simpson et al., 2013; 2016).
- Acid Sulfate Soils Guideline Series (DER, 2015a,b; and updates Sullivan et al., 2018a-d).
 - Assessment criteria for ASS: Identification and Investigation of Acid Sulfate Soils and Acidic Landscapes, and Department of Environment and Conservation (DER, 2015a), and Treatment and Management of Soils and Water in Acid Sulfate Soils Landscapes (DER, 2015b).
- Queensland Acid Sulfate Soil Technical Manual: Soil Management Guidelines (Dear et al., 2014).
- National Environment Protection Measure - Assessment of Site Contamination (NEPM, 2013)
 - Ecological Investigation/Screening Limits (EIL/ESL)
 - Health Investigation Limit (HIL C) and Soil Health Screening Levels for Direct Contact (HSL-C) (for Public Open Space).

Figure 2.1 Schematic representation of the level of risk associated with exposure of ASS and MBO materials as a results of dredging activities.



Note: Modified from in Dear et al., (2014) concerning stockpiling ASS. Exposure scenarios: (a) above the water; (b) under still water; (c) under moving water; and, (d) resuspended within the water column. Confined storage of ASS/MBO materials on land or near shore (isolated from waters of dredging activity) and acidity treatment needs are described in section 4.5.2.

3 The extent, risks, legacies and potential liabilities of dredging ASS

3.1 ASS occurrence and risks

In Australia, Acid Sulfate Soils (ASS) are frequently found in low-lying coastal areas, and generally below the more recent historical (post-glacial Holocene) higher sea-level ranges, for example below 5 m Australian height datum (AHD) in northern Queensland, and often mostly below 0.5 to 2 m in coastal areas with smaller tides. When ASS are encountered at higher elevations, they are usually associated with bottom sediments in drains, dams, constructed and natural waterways, swamps and billabongs, periodically stagnant creeks and places with perched water tables. Within freshwater environments, that may be encountered at considerably higher elevations. Stormwater detention systems in urban and peri-urban drainage systems represent a common example of where ASS may be encountered and require management in freshwater environments (for example Liege Street case study at the end of this report). The existence of ASS at higher elevations is primarily due to the presence of an aqueous environment where sulfate-reducing bacteria are provided with organic matter (their energy source) and available sulfate ions. Acid sulfate soils in non-coastal areas are commonly referred to as 'inland ASS' or 'upland ASS' (EPHC/NRMMC, 2011; Dear et al., 2014; DER, 2015a,b). While most coastal ASS is geologically young (less than 10,000 years old), inland ASS can be found in much older sediments. These occurrences are not limited by stratigraphy or age, and may originate from minerals other than soils.

Methods of managing ASS in coastal and inland regions have many commonalities. Investigations of maintenance dredging of ASS and legacy environmental impacts have become well-documented. The environmental issues for ASS dredge material will vary depending largely on whether the material is to be disposed to land, or returned to another location within the water body. For onshore disposal, the ASS are usually more accessible to management and remediation. For ASS disposal back to the water body, the release of nutrients into the water column, leading to excessive algal growth is a moderate risk. This is because elevated concentrations of nutrients (notably NH_4^+) and iron in the water column are routinely reported to be generated from disturbed ASS at a very localised scale (within 100 m of spoil placement). These impacts are largely acute. The more direct risks of placing dredge material back to the water body are the smothering and alteration of benthic habitat. For disposal in near-shore coastal environments, it is possible that some seagrasses will be present and productive on spoil bank area during the dredging program. Seagrasses in the areas of deposition may be affected if the sediment layer is greater than approximately 2 cm thick (deeper than petiole length).

The assessment of risks posed by MBOs explicitly, has generally only been considered more recently (Sullivan et al., 2018d). Examples include the maintenance dredging of sediments within the Peel Region for the Western Australian government authorities (Sullivan et al., 2006). In general, the materials routinely dredged in the Peel Harvey Estuary are black oozes to a depth of at least 30 cm (the depth of sampling). They typically have low trace metal concentrations yet high contents of inorganic sulfur (the chromium-reducible sulfur (CRS) concentration was 1.6% S and acid volatile sulfide (AVS) was 0.6%). The metal sulfide contents of these materials exceed their inherent acid neutralising capacity (ANC), with a propensity to generate an excess of up to 400 mol H^+ /tonne

(equivalent to a reduced S concentration of 0.54% S). This explains why those sediments have developed into extreme examples of ASS where they have been disposed to shorelines and used for land reclamation. The sediments are dominated by fine silt and clay particles (less than 63 µm). Morgan et al. (2012) measured mean total nitrogen and total phosphorus concentrations within the black muds at approximately 8500 and approximately 740 mg/kg respectively. Acidification and mobilisation of aluminium and iron when disposed to land are the major environmental issues that have been reported for the Peel Estuary. The potential influence of nutrient release and iron on aquatic productivity (in the water column) and algal blooms have also been considered. The sediments at both the disposal site and collected in the channel are confirmed as hazardous ASS.

Although acid-base accounting laboratory analyses may often show that there are significant amounts of ANC in sediments, in coastal ASS much of it often exists as shell fragments. Shell grit material is generally an inefficient neutralising agent due to its low surface area and tendency to be 'armoured' with metal oxides and gypsum (Mosley et al. 2014d). Therefore, lime treatment of the material in the case of the Peel Harvey Estuary is now considered necessary to safeguard against acidification where the sediment is disturbed and is to be placed in an oxidising environment long-term.

3.2 Regulation and management of dredging activities

Each of the states and territories have a range of legislation that requires consideration when assessing and providing approvals (consents) for dredging activities. This legislation varies greatly between the different Australian states and territories, and different pieces of legislation generally apply to offshore dredging, to coastal and estuarine dredging, and to dredging in inland waterways. The acts and their regulations that apply will be primarily determined by the location of the proposed activity (for example inland or coastal, private or crown land, including reserves and national parks). The state or territory acts are also impacted by federal acts such as the Environmental Protection and Biodiversity Conservation Act (1999) (the EPBC Act). This act establishes an environmental assessment and approval system that is separate from, and in addition to, state/territory systems. Under the EPBC Act, a person must not take an action that has, will have, or is likely to have a significant impact on a matter of national environmental significance, except where certain processes have been followed and/or certain approvals obtained. Included are World Heritage areas, wetlands of international importance (for example Ramsar wetlands), listed threatened species and communities, listed migratory species, and Commonwealth marine areas.

Project proposals (and their consent) will also need to consider any local management plans and systems, such as development plans, catchment management plans/strategies and coastal management plans, resource management and planning system (RMPS).

3.2.1 Relevant policy and guidances applying to dredging

Many of the existing national and state or territory guidelines for dredging (for example NAGD, 2009; DEP, 2013; Vic EPA, 2001; WA EPA, 2011) provide frameworks for assessing general risks posed by dredging, but provide limited guidance on risks posed from dredging ASS. Guidance on the environmental risk assessment of contaminants associated with dredging activities, and their potential impacts on water, sediment and soil quality is provided under the National Water Quality Management Strategy (NWQMS) (for example ANZECC/ARMCANZ, 2000; NEPM, 2013).

The NAGD (2009) was developed for coastal dredging (for example ports) that propose unconfined sea dumping of dredged material (NAGD, 2009). They were prepared in order to meet the Australian

Government's obligations as a signatory to the London Dumping Convention (1972) and Protocol (1996) to "protect and preserve the marine environment from pollution relating to ocean disposal, minimising impacts on marine living resources, human health and other uses of the marine environment". The NAGD (2009) primarily focus on contaminant impacts. Due to the extensive scale of the open marine environment, many of the issues associated with the disposal of ASS are considered a negligible risk. The volume and pH buffering capacity provided by seawater make changes in acidity unlikely, and deoxygenation of the water column is also unlikely to occur or be significant due to dumping of MBOs. The NAGD (2009) does not provide guidance on sound practice for disposal, within waterways or on land, of dredged materials that contain significant amounts of ASS. There are no national or state-based guidelines for inland (freshwater) dredging activities.

3.2.2 Relevant policy guidelines applying to ASS

In addition to the national guidance documents (for example EPHC/NRMMC, 2011), each of the states and territories has various forms of guidance specific to ASS management: New South Wales (Tulua, 2007); Victoria (Victoria, 1999); VCASSIC, 2010; Vic EPA, 2009; Tasmania (DIIPWE, 2010); Western Australia (DER, 2015a,b; WA EPA 2011); South Australia (DPTI, 2012); and Queensland (Ahern et al., 2004; Dear, 2014).

4 Proposed assessment framework and ASS management plan

To avoid environmental harm from Acid sulfate soils (ASS) encountered during dredging projects, it is recommended that a tiered assessment framework be adopted through which technical and procedural guidelines can be implemented. A proposed framework is shown in Figure 4.1.

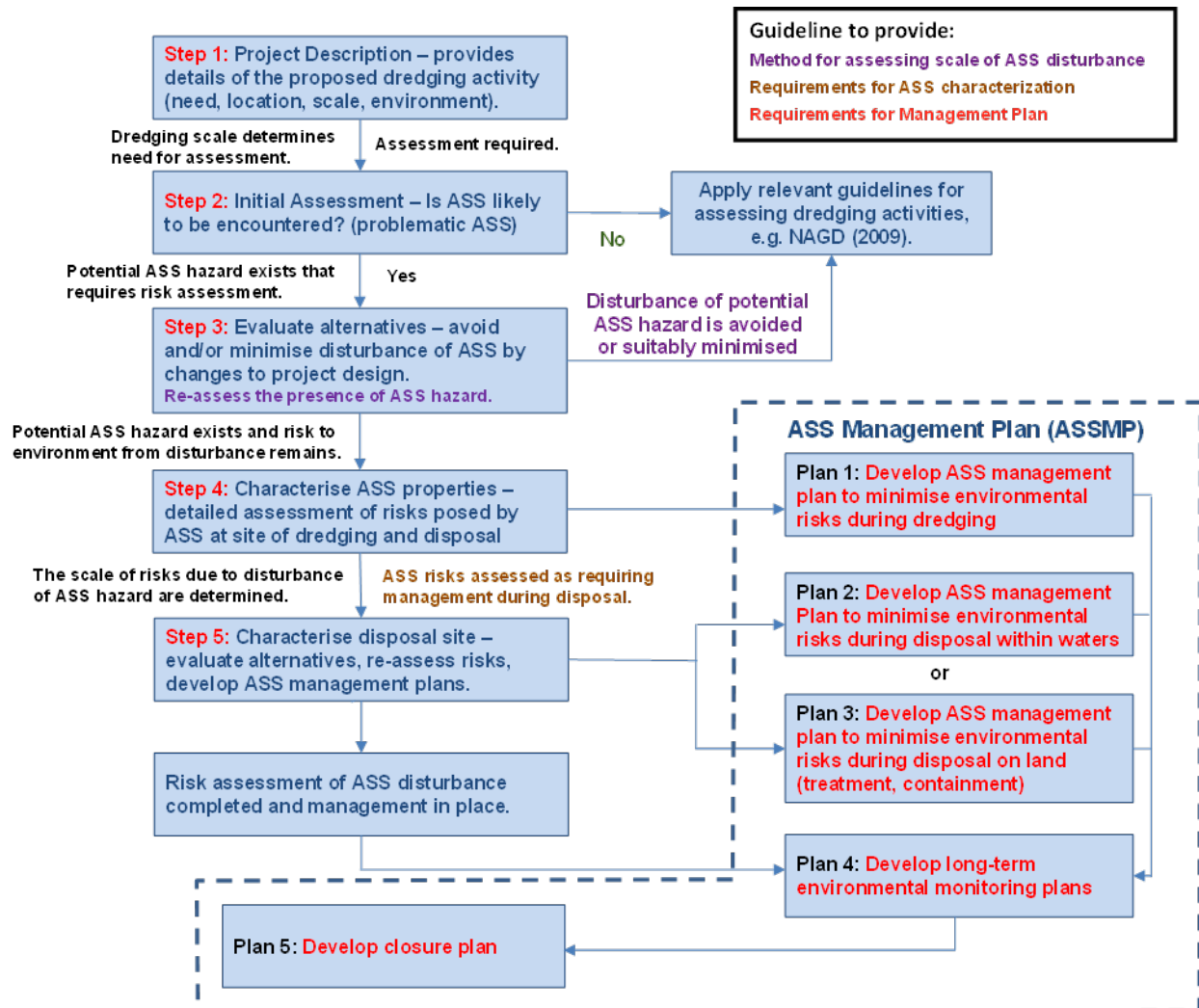
The proposed assessment framework is intended to provide a step-wise decision process that proponents and regulators who are considering dredging activities can work through to provide adequate information when applying for approvals/consents. Where ASS are likely to be encountered, the framework leads to the preparation of an ASS Management Plan (ASSMP) that is broken into a series of sub-plans that expand on the specific components or considerations necessary for ASS management, including environmental monitoring and closure plans. The proposed steps within the framework include:

- 1) Providing a project description that includes details of the proposed dredging activity (the need, location, scale, environment and timing). This will outline the social-economic aspects of the project, and provide details on aspects such as community consultation, values for protections, and be consistent with the (National Water Quality Management Strategy (NWQMS).
- 2) Assessing the likelihood that ASS will be encountered and pose an environmental risk (hazardous ASS), and if clearly not likely (that is strong evidence to indicate so), then ASS assessment will not be necessary and the proponent will consider the relevant guidelines for assessing dredging activities (for example NAGD, 2009). This is contingent on no error entering into judgement or interpretation, faulty equipment, or testing procedures that lead to a wrong assessment. The assessment of ASS hazard requires careful consideration of the ASS properties and the scale of ASS requiring management.
- 3) Where potential ASS hazards exist at a scale requiring management of risks from disturbance (relating to quantity and properties), then an evaluation of alternatives should be made to avoid and/or minimise disturbance of the ASS. Then re-assess, as in Step 2, to determine whether any significant ASS hazard remains present.
- 4) Where potential ASS hazards remain following consideration of measures to avoid and minimisation disturbance, then a full characterisation of the ASS properties and an assessment of risks posed by ASS at site of dredging and disposal will be required. This step will determine the needs for management during dredging operations (Plan 1), for disposal within a water body (Plan 2), for disposal on land (Plan 3), monitoring (Plan 4) and closure (Plan 5).
- 5) Where the proposed disposal site is on land, there is a need to characterise the site, and to evaluate alternatives and re-assess risks posed by ASS if modifications are made to the proposed site. An ASSMP should then be developed to minimise environmental risks during disposal (treatment, containment) (Plan 3).

These steps within the framework are intended to provide strategies, processes, protocols and actions to identify and define the management problem, to avoid and minimise disturbance, to mitigate and limit impacts when disturbance is unavoidable or has already occurred, and to rehabilitate sites and affected areas to 'fit for purpose' use where there has been impacts from disturbance. This approach is consistent with existing guidance documents (for example decision trees in ANZECC/ARMCANZ (2000) and NAGD (2009), and will provide a risk-based approach to

minimising the impacts on water quality from dredging of ASS. Where impacts cannot be avoided, the framework directs the proponent to minimise impacts, and develop clear management and monitoring plans, with justification specific to the project needs and any constraints.

Figure 4.1 Flowchart for proposed assessment framework.



For the purpose of this framework, the ASS hazard may represent one or a combination of sulfidic materials, sulfuric materials or MBOs (see section 2.1 for definitions). Appendix C: The ASS Management Plan provides a more detailed discussion of what may be included in the ASSMP.

4.1 Project description (Step 1)

The project description should be the first and ‘minimum requirement’ for proposed dredging activities that may disturb ASS. It should describe the need for the proposed dredging activity and the intended management of the dredging and disposal of the dredged material (including longer-term monitoring).

It will outline the social and economic aspects of the project, and provide details on community consultation, and the values for protection, and be consistent with the NWQMS.

The application of sound principles should form the basis for all aspects of the project description, including the proposed design, selection of methods and proposed environmental management and monitoring. It should clearly describe and demonstrate consideration of options to avoid impacts to

the environment, including aquatic and benthic receptors. The project description should include, depending on the nature and scale of the proposed dredging operation:

- purpose, context and description of the dredging operation, including a clear rationale for the location and scale (for example potential volume of material), together with information on all of the proponents;
- a site map with proposed dredging and disposal areas, and location of any other relevant points of interest/potential impact (for example Aboriginal heritage areas, sensitive/important aquatic ecosystems, water offtakes, native vegetation), together with proposed staging or timeframes for dredging and disposal activities;
- a list of the potential stakeholders (community, government, industry, NGOs) and potential consultation or intended discussions;
- alternatives to undertaking dredging (including environmental, social and economic impacts of each alternative);
- significant natural and cultural features of the sites (where both dredging and disposal occur);
- a description of the material and the physical constraints at the site (such as water depth, sediment type, dredging extent);
- environmental impacts of the project on air, soil and water quality (groundwater and surface water);
- the proposed dredging technique, source of dredge equipment, disturbed sediment and pest management strategies;
- a description of opportunities for beneficial use of dredged materials, including treatment to create beneficial uses;
- proposed and possible disposal sites;
- options to prevent oxidation of ASS (for example keep dredged material underwater/saturated);
- spoil management and other waste prevention strategies to reduce or remove the hazardous constituents (for example sediment/turbidity, contaminants, ASS), preventing acidification and hazardous leachates (mitigation or remediation measures, and methods for monitoring the effectiveness of those measures);
- other waste management and disposal options;
- a cost-benefit analysis of alternative management options;
- outline of the uncertainties, particularly around heterogeneity of dredged materials (for example ASS properties, geochemical and textural) and dredging and disposal site conditions;
- possible contingency needs and arrangements (corrective actions and contingency plans should undesirable or unforeseen impacts occur);
- a monitoring program for dredging operations and disposed materials;
- a review and auditing plans (standards, timing and responsibilities); and
- closure considerations.

Smaller-scale projects would only contain a sub-set of these assessments.

The strategies for management of environmental impacts of ASS dredging should include a consideration of the environmental values of the receiving environment, and the sensitivity of these values to the activities being proposed. Environmental considerations for on-land disposal activities

will extend to groundwaters and surface waters that may potentially be affected directly or indirectly through overland flow or infiltration. The management strategy must consider how the proposed activities and management strategies meet the requirements of other policies or legislation at the local and/or state and territory government level.

Checklist – Project description (Step 1 from Figure 4.1)

Provide an overview of the project, that includes a description of the nature, scale and location of the proposed dredging activities, the stakeholders, significant attributes of sites where activities may take place and the surrounding environment, and initial high-level project design and management considerations.

4.2 Initial assessment of the likelihood of encountering ASS (Step 2)

A desktop review may be suitable for determining the likelihood for ASS hazards to exist in the proposed dredging area (for example DER, 2015a). Maps exist for many regions of Australia that indicate the likelihood of encountering ASS (e.g. Naylor et al., 1998). For example, in WA ASS risk maps are accessible via Landgate's Shared Land Information Platform (SLIP) (DER, 2015a). The Atlas of Australian Acid Sulfate Soils also provides information on the distribution and properties of ASS across Australia. The atlas is available on the Australian Soil Resource Information System (ASRIS). If no background information exists, or poor quality predictions are suspected, for the inclusion or exclusion of ASS hazards, then analyses should be included in the initial site characterisation as necessary to adequately inform the project description.

This review or site characterisation should seek to determine if the sediment in the proposed dredged area contains or is likely to contain significant quantities of ASS. The identification of ASS materials represent a potential major source of acidity that may release significant quantities of heavy metals or metalloids to the water column or during disposal on land. The monosulfidic black ooze (MBO) in soil or sediment also represent a risk for rapid oxidation resulting in deoxygenation of the water column during dredging, and metal contaminant release. Where these forms of hazardous ASS are determined to be present in sediments, the assessment should extend to quantifying the risk that these materials represent.

Initially, a field investigation with the appropriate field tests (Sullivan et al., 2018b,c) may indicate the areas with the greatest ASS hazard. However, it is important to note that the field test are just indicators of ASS, and need to be confirmed using appropriate laboratory tests. The pH of a moist spoil in the field (pH_F) and the field pH following oxidation with hydrogen peroxide (pH_{FOX}) are commonly used field tests in the field assessment of ASS. DER (2015a) provides a good summary of potential indicators for ASS hazards.

Field indicators of sulfuric materials include:

- pH_F in soil and drains less than 4 (classification for acidic waters: pH_F less than 5.5);
- water clarification and colour changes;
- orange and yellow mottles on exposed areas of the landscape;
- fish kills and disease; and
- corrosion of concrete and steel structures.

Field indicators of sulfidic materials include:

- blue-greenish grey colour;
- rotten-egg gas (H_2S) odour; and,
- vigour of reaction with hydrogen peroxide (H_2O_2).

Sulfidic soils may be indicated by the following:

- A reaction with 30% H_2O_2 , where the strength of the reaction with peroxide is a useful indicator, but cannot be used alone. Organic matter and other soil constituents such as certain forms of iron and manganese minerals can also cause a reaction. Care should be exercised in interpreting a reaction on surface soils and high organic matter soils such as peats and some mangrove/estuarine muds and marine clays. This reaction should be rated, for example L = low reaction, M = medium reaction, H = high reaction, X = extreme reaction, V = volcanic reaction.
- The actual value of pH_{FOX} , where if pH_{FOX} less than 3, and a significant reaction occurred, then it strongly indicates the presence of hypersulfidic materials. The more the pH_{FOX} drops below 3, the more likely the presence of inorganic sulfides. pH values in the range of 3–4 may also indicate hypersulfidic materials are present but laboratory tests are required to confirm the presence of sulfides.
- A much lower (greater than 1 pH unit) pH_{FOX} than field pH_{F} , where the lower the final pH_{FOX} value and the greater the difference between the pH_{FOX} compared to the pH_{F} , the more indicative of the presence of hypersulfidic materials. This difference may not be as great if starting with an already mildly acid pH_{F} (close to 4), but if the starting pH is neutral or alkaline then a larger change in pH should be expected. Where fine shells, corals or carbonates are present the change in pH may not be as large due to buffering. The ‘fizz test’ (effervescence with dilute acid, for example 1 M HCl, should be used to test for carbonates and shells.

Based on these field tests, the following interpretation may be used for ranking the presence of hypersulfidic materials (and sulfuric materials):

- strong Indicator of hypersulfidic materials: All three indicators present (pH_{FOX} less than 3; M to H reaction, $\text{pH}_{\text{F}} - \text{pH}_{\text{FOX}}$ greater than 3);
- moderate Indicator of hypersulfidic materials: pH_{FOX} greater than 3 and the remaining two indicators are positive; and,
- low Indicator of hypersulfidic materials: pH_{FOX} greater than 3 and one or none of the remaining indicators are positive.

Field indicators of MBOs (Sullivan et al., 2018b-d) include:

- dark black amorphous gels (Figure 4.2);
- sulfide odours emitted in local environment;
- sulfide odour release upon reaction of sediment with dilute hydrochloric acid (achieved using small amounts of material outdoors and appropriate personal protective equipment);
- water deoxygenation; and,
- fish kills.

Figure 4.2 Photograph of monosulfidic black ooze (MBOs).



A positive field MBO identification needs to be confirmed by measuring the AVS content in the laboratory (Sullivan et al., 2018b-d).

Where hazardous ASS has been determined to exist, the next step should be to avoid or minimise disturbance. Where disturbances cannot be completely avoided, then a full characterisation should be undertaken of the ASS that may be disturbed.

If hazardous ASS is determined to be not present in the proposed dredged materials, or present at levels that do not require management, then the ASS assessment will be determined to be complete and additional step in the framework will not apply. The proponent will continue to apply other relevant guidelines, for example those applicable to assessing general dredging activities (e.g. NAGD, 2009), water quality (for example ANZECC/ARMCANZ, 2000) and lands (for example NEPM, 2013).

Checklist – Initial Assessment of ASS Risks (Step 2 from Figure 4.1)

Undertake a desktop assessment of the likelihood of the project encountering ASS, which may utilise maps, soils atlas, or other forms of existing information on soil and sediment properties at the proposed dredging and possible disposal sites. Where insufficient background information is available, an initial site characterisation should be undertaken, which may include the use of relatively simple field indicators for the presence of ASS.

4.3 Evaluating alternatives to disturbing ASS (Step 3)

The first principles for ASS management are those of avoiding and minimising disturbance. The term disturbance in these guidelines refers to any movement, excavation or drainage of ASS. As dredging is often a costly activity, dredging proponents usually have a strong economic incentive to minimise dredging. The consideration and options available for avoiding and minimising dredging or disturbance of ASS will be both project and location specific (for example inland river or lake, estuarine river, or coastal). In some cases, there may be an option to change major components of

initial project designs (for example location of dredging or disposal), while for other projects the options may be highly constrained (for example due to small waterways and limited land options).

4.3.1 Avoiding and minimising disturbance to ASS

The avoidance or minimisation of disturbance of ASS are the most preferred management strategies to avoid environmental harm (for example Ahern et al., 1998; Dear et al., 2014; DER, 2015b). Both during dredging operation (for example within water bodies) and disposal on land, minimising the disturbance of ASS is likely to provide both economic and environmental benefits. Just because ASS are under water does not necessarily mean that there is no hazard, as water can contain and transport dissolved oxygen. Where possible, avoidance is also often the cheapest option, because of the costs associated with long-term discharge of acid and metals or metalloids if the materials become oxidised. The risks of impacts from disturbed ASS will depend on both the properties of the ASS and the receiving environment, and will increase as the quantities of disturbed ASS increase. There exist a wide range of measures that may be considered for minimising and mitigating dredging-related impacts, many of which are beneficial to minimising risks due to ASS. Such measures include those to:

- reduce or avoid a dredging requirement (modify position of channel);
- increase natural sediment transport (thus reduce or avoid dredging requirement);
- reduce impacts of dredging (reduce area or depth of material dredged, modify dredging technique and rate);
- prevent dispersion of sediment (for example use of silt curtain);
- reduce short-term impacts to the water column (for example aeration to improve DO levels);
- reduce impacts of dredging on biological receptors (for example adapt dredging programme);
- offset dredging impact by replenishing lost sediment or beneficial use of dredged material elsewhere;
- reduce impacts of disposal: prevent dispersion of sediment; improve DO concentrations (increased surface water mixing – air exchange, whilst monitoring impact on oxidation that leads to harmful levels of acidification); minimise impacts to biological receptors (modify disposal timing);
- avoid or reduce impacts of disposal: prevent (for example treatment of acidity through liming) or contain the extent of release of contaminants into the water column for example contain silt within silt curtain or other separation techniques); and,
- offset disposal impact: re-establish characteristic biota (fish and plants habitats).

The most important measures that are specific to ASS include:

- avoiding areas with high existing and/or potential acidity;
- avoiding ASS in sensitive environments;
- keeping hazardous ASS water-saturated (under water, inundated) to minimise oxidation; and,
- covering and containing disturbed hazardous ASS to minimise oxidation and water movement (runoff, leachates, effluents).

If changes to project design result in ASS being avoided or the disturbance minimised to the extent that there is no longer any hazardous ASS, the ASS assessment will be determined to be complete

and additional steps in the framework will not apply (as per Step 2). Where hazardous ASS are determined to exist), then the assessment proceeds through to Step 5.

The proponents for dredging ASS should demonstrate that all alternatives have been evaluated, with discussion of the environmental, social and economic impacts of all options (why they are suitable/unsuitable).

4.3.2 Beneficial re-use and waste

Note: Relevant state or territory regulatory requirements relating to beneficial re-use and waste must be consulted alongside this national guidance.

The re-use options for dredged material should be considered early within the proposal and planning stages (Lukens, 2000). Possible beneficial uses may include land reclamation (fill materials for infrastructure projects or upland habitats), agriculture (nourishment of farm land), or habitat construction within waterways (for example wetlands, nesting islands). The properties of the dredged materials (both physical and chemical) will strongly influence the choices available for re-use, recovery and disposal. Sands and gravels may provide opportunities for re-use as secondary aggregates, whereas the more organic-rich water retaining silts may provide opportunities for backfilling or beneficial conditioning agricultural lands or ecological improvements. A combination of different uses and disposal routes may achieve more environmentally acceptable solutions. Examples of common beneficial uses for dredged materials include:

- engineered uses - land creation and improvement (for example construction and industrial use, including port development, airports, urban, and residential), coastal nourishment (beaches, shoreline stabilisation and erosion control, offshore berms, capping material and fill;
- agricultural and aquaculture uses – land spreading, aquaculture, construction material, liners; and
- environmental enhancement - habitat restoration and improvements (for example wetlands, shore land, islands) for nesting animals and fisheries.

The technical aspects of beneficial uses are well-established and described in the literature (USEPA/USACE, 2004; NAGD, 2009; DEP (Tasmania), 2013; Victoria EPA, 2001). Most dredged materials will require some form of treatment (for example dewatering as a minimum) before they can be reused directly. For materials that contain ASS, this treatment would typically involve a neutralising agent such as fine limestone. However, even treated ASS may not be suitable for use as construction fill because the reaction of sulfate with calcium carbonate or with concrete can produce material with inadequate properties. For example, guidelines produced by the British Concrete Paving Association (Britpave, 2005) indicate that pyrite concentrations as low as 0.25% (commonly measured in dredge spoil) may result in materials that swell with time if treated with lime due to the formation of minerals like gypsum and ettringite. Therefore, proponents should seek expert geotechnical advice when considering reuse of dredged materials that contain ASS for construction purposes. It is generally preferable that ASS-containing materials not be used on construction sites.

The beneficial use of materials will often require some form of feasibility analysis to assess the appropriateness of the material for the proposed use, together with costs and time required to process the material into a form that can be used effectively for environmental benefit. Transportation costs will generally limit beneficial reuse to occur at locations that are not long distances from the dredging operations. As land disposal is often expensive where risks are identified

due to contamination (including ASS), disposal within waterways (for example sea disposal) is often the preferred option where this results in lower or similar levels of environmental risks.

For the dredged materials that have no beneficial use, that is where all or some component of the material requires disposal through some means, it may be necessary to assess materials against a 'waste hierarchy' to identify and rank options in order of environmental impact. Waste classification guidelines applicable to the jurisdiction may be used to classify as inert, contaminated and non-hazardous/hazardous categories. A waste hierarchy that may be applicable to dredging may specify an order of preference for dealing with materials as:

- 1) Elimination – which may include not dredging.
- 2) Reduce – modify the dredging specifications to reduce the volume (changing depth or width of dredged area).
- 3) Re-use – maximise the beneficial use of dredged materials, for example in construction, agriculture or habitat creation.
- 4) Recycle – sort the waste into the various fractions, where some may be re-used.
- 5) Disposal – considered as a last resort, when Steps 1 to 4 have been exhausted.

The waste classification of dredged materials will mostly be influenced by the degree of contamination (for example inert or hazardous), with consideration of the physical properties (for example water content). Where hazardous ASS is present, while the dredged material may not be contaminated, the exposure of these materials to air may lead to the production of sulfuric acid and the release of toxic quantities of aluminium and metal(loid)s. Note that although the metal contaminant concentrations may not exceed soil or sediment quality guideline values (SQGVs, Simpson et al., 2013), significant risks may exist due to disturbance of the materials. For example, if the pH was to decrease below pH 5 it is likely that, potentially hazardous concentrations of metal(loid)s may be released into the dissolved phase despite the particulate metal(loid) concentrations being below SQGVs (Simpson et al., 2010). The land placement of problematic ASS materials will therefore require detailed planning (for example assessment of material properties) and design of containment, treatment, and longer-term management and monitoring strategies will be necessary to minimise impacts associated with acidic water discharges.

In summary, the 'hazard classification' for the dredged materials should consider both the physical properties and their constituent contaminants, together with the type of ASS hazard. For the broader classification of wastes, the appropriate national, state/territory and regional guidance documents should be consulted.

Checklist – Evaluating Alternatives to Disturbing ASS (Step 3 from Figure 4.1)

Once hazardous ASS at scale have been determined as likely to exist, steps should be taken to avoid and/or minimise the disturbance. This is the first principle of ASS management. The choice of alternative locations for dredging and disposal sites may significantly minimise, and potentially eliminate, ASS risks. The beneficial reuse of materials should be considered, including reuse of ASS material following treatment to stabilise and eliminate undesirable properties.

4.4 Characterising ASS properties and assessing risks (Step 4)

Note: Relevant state or territory guidelines and regulatory requirements must be consulted alongside this national guidance when characterising ASS properties and assessing risk.

4.4.1 General characterisation of dredging materials

For most disposal options, the general physical characteristics of the dredged material to be determined will include particle-size distribution, water content or percent solids, specific gravity of solids, and plasticity characteristics. For all materials, there will be a need to undertake analyses of a broad suite of contaminants and compare these to appropriate guidelines to provide initial screening and identification of the likelihood of unacceptable impacts to the environment. As the risks posed by ASS often relate to transformations following disturbance (for example oxidation), and some of these transformations may take a considerable period of time to occur, additional tests may be necessary to provide screening-level information on these processes. Examples of potentially useful tests may include oxidation-leach test to assess risks of contaminant mobilisation in ASS that are different to other materials commonly assessed under NEPM (2013).

Both the physical and chemical testing will need to be tailored to the dredging and disposal site. They should consider both the short-term and long-term physical behaviour of the material. The contaminant testing should consider all pathways where contaminants may be of environmental concern, including effluent, leachates and surface runoff from land-based sites, groundwater impacts, and any that may lead to contaminant uptake by plants or animals (including humans), including air-related pathways (dust or gaseous release).

This step will also lead to the development of a management plan to minimise environmental risks during dredging (Plan 1, Figure 4.1).

4.4.2 Characterising ASS properties

Quantifying the risk posed by disturbing problematic ASS

Whether disturbed within the water column during dredging or disposal, or on land during disposal, ASS will require clear management actions. Management will include monitoring and measures to prevent potential impacts of stressors in the water column (pH, dissolved oxygen, suspended solids, and sediment/water contaminants). Failure to incorporate these two principles (monitoring and measures) into dredging plans may result in unacceptable risks to waterways (marine, estuarine, or fresh) or land resources. Seawater environments are likely to have greater capacity than freshwater environments to buffer acidity and dilute inputs from disturbed ASS. However, there should not be reliance on the natural capacity of systems to buffer effects of ASS or dilute contaminants released from project sites. A thorough characterisation of the risks will be necessary for the cumulative impacts of proposed dredging activities (that is dredged materials and at the disposal site).

Maps (or other forms of conceptual site models) of the hazardous ASS should be developed to enable strategies for avoidance or minimisation of disturbance to be considered. Where avoidance is not possible, the risks and remediation measures will need to be quantified. A standard operating procedure (SOP) should specify both the methods and the data quality objectives (for example a QA/QC schedule) for collecting, analysing and reporting these data.

Several technical guideline manuals exist that outline procedures for assessing ASS (for example Ahern et al., 2004; Dear et al., 2014; DER, 2015a; Sullivan et al., 2018a-d). These methods have been endorsed by the National Committee for Acid Sulfate Soils (NatCASS) for use Australia-wide and may

be updated from time to time. Acid-base accounting is used to assess both the potential of a soil material to produce acidity from sulfide oxidation and also its ability to neutralise any acid formed. The net acidity is a measure of this potential. It provides a quantitative assessment of the acidity risk, and also permits the determination of, for example liming rates, and validation of the treatment.

All methods have limitations, and the acid-base accounting methods are not intended to assess indirect effects of disturbing ASS that may include:

- soluble and flocculated iron;
- soluble and flocculated aluminium;
- other metals and metalloids (for example As, Cd, Co, Cr, Cu, Ni, Mn, Zn);
- deoxygenating compounds (monosulfides, organic complexes); and,
- noxious gases.

The acid-base accounting does not take into account the kinetics of either the acidification or neutralisation processes, and additional testing and monitoring approaches may be necessary for some sites. In addition, differences in effective neutralisation may occur in the field compared to laboratory tests (for example due to presence of shells which may be measured as neutralising capacity in the laboratory but may be less effective in situ).

Influence of soil properties on acidity risks (texture, buffering and acid-neutralising capacity)

Soil texture or sediment particle-size distribution also affects the disturbance risk (Ahern et al., 1998; Dear et al., 2014; Sullivan et al., 2018b,c). Coarse-textured sulfidic sands are particularly vulnerable to rapid oxidation due to their relatively higher permeability and often negligible buffering capacity. Fine-textured soils such as medium to heavy clays or silty clays tend to oxidise at a slower rate than sandy soils but may contain a larger amount of pyrite. The combined use of material type and acidity data should be used to develop initial action criteria relating to risk posed by hazardous ASS that may be encountered (Table 4.1).

Table 4.1 Texture-based ASS action criteria

Type of material		Sum of existing and potential acidity: acid generating potential (AGP)			
Texture range (NCST, 2009)	Approximate clay content %	1–1000 tonne (t) material disturbed		> 1000 t material disturbed	
		% S-equiv.	mol H ⁺ /t	% S-equiv.	mol H ⁺ /t
Fine: medium to heavy clays and silty clays	>40	0.1	62	0.03	18
Medium: sandy loams to light clays	5–40	0.06	36	0.03	18
Coarse: sands to loamy sands and peats	<5	0.03	18	0.03	18
Draft action criteria for poorly buffered sands - Coarse: sands, poorly buffered	<5	0.01	6	0.01	6

Note: modified from Ahearn et al., 2004; Dear et al., 2014. Concentrations provided on an 'oven-dried basis'

With respect to dredging, it is important to recognise that the receiving waters, whether marine, estuarine, brackish or fresh, are not to be used as a primary means of diluting and/or neutralising ASS or associated contaminated waters. However, soils and sediments may contain a significant

buffering capacity, which represents the degree to which a material can intrinsically resist pH change to either a more acidic or more alkaline state. The acid-neutralising capacity (ANC) of material is essentially a subset of its buffering capacity, being the ability of the soil to resist becoming more acidic.

Risk categorisation to guide management planning

The risks posed by sulfuric and hypersulfidic materials are usually described and quantified using terms that describe the complex forms of acidity associated with ASS. The acidity can be operationally defined using particular laboratory tests and throughout this document the acidity is described using the units of % S and mol H⁺/tonne. The first, % S, is an 'equivalent sulfur unit', describing forms of acidity in terms of the percentage of oxidisable inorganic sulfur by weight in a dry soil or sediment. The units of mol H⁺/tonne is an 'equivalent acidity unit', describing forms of acidity in terms of the number of moles of H⁺ produced per tonne of dry soil or sediment. Care must be taken to convert test results accurately into the same units (Ahern et al., 1998; Sullivan et al., 2018b,c).

Once the amount of acidity has been quantified, this information may be used to develop 'Action Criteria' (risk/treatment categories) for the materials and to determine the specific treatment requirements necessary to minimise risks associated with the acidity. Examples of Action Criteria may include:

- sum of existing plus potential acidity (excluding acid neutralising capacity) of less than 18 mol H⁺/tonne (0.03 S%); and,
- a neutralising capacity of more than 1.5 times the sum of existing plus potential acidity, all measured in the same units (and using a minimum safety factor of 1.5).

Numerous literature sources exist for estimating treatment levels and the associated liming rates (for example Ahern et al., 1998; Table 4-2 in Dear et al., 2014; Sullivan et al., 2018b,c). This is discussed further in Section 3.5.2.

The categorisation of the risk should consider the amount of hazardous ASS material, and the risk may be categorised as low when, for example, the excavation is small, for example less than 10 m³. No specific guidance is provided on what this limit should be, however, volume classifications of 100 m³ and 500 m³ have been used for certain guidelines dealing with ASS management (for example Tasmanian Acid Sulfate Soil Management Guidelines, DEP, 2009).

Checklist – Characterising ASS Properties and Assessing Risks (Step 4 from Figure 4.1)

Once a requirement for managing hazardous ASS has been determined, an ASSMP will need to be developed (Appendix 3). Detailed characterisation of the dredged materials and of soil and sediment disturbed at the disposal site is necessary to prepare an ASSMP. This assessment should enable risks categories to be devised for various materials that will be used to inform treatment and containment strategies.

4.5 Characterising the disposal site (Step 5)

There are various options available for disposal of dredged materials, including:

- recycling/reuse (including creation of new shoreline – land);
- burial (or sub-burial) below the water table on land;
- disposal to land (including river banks and land-spreading);

- disposal to landfill; and,
- disposal within water (including dispersive and non-dispersive sites, and also hydrodynamic dredging to move materials downstream).

When evaluating the various disposal options, it will be necessary to consider which option minimises the impacts to the environment of acidity generation, dissolved oxygen depletion, nutrient releases, contaminants, and other physico-chemical stressors.

Most of the land-based options, whether buried or unburied, will require some form of application of neutralization materials (for example lime) to reduce the acidity.

The process of selecting the disposal site will need to consider the nature and scale of the proposed dredging operation and provide many items of information in common with the project description (see list in Section 3.1). This will include consideration of all the other potential users or uses for the area and the economical and operational feasibility. Considerable background information may need to be gathered in order to adequately assess both potential direct and indirect impacts to the physical environment and habitats.

The selection of disposal sites will lead to the development of a management plan to minimise environmental risks during disposal of dredged material within waters (Plan 2, Figure 4.1) or on land (Plan 3, Figure 4.1). The characteristics of these management plans are expanded on in the following section.

4.5.1 Disposal into waters

When considering unconfined disposal of dredged material in freshwater rivers or lakes, or in estuaries or other coastal waters, the site characteristics may strongly influence the risks posed by the dredged materials. In particular, the proximity to sensitive ecosystems, and multiple hydrological and meteorological considerations (for example tides, currents, storms). It is likely that surveys of physical, chemical and biological characteristics of the water column and benthic habitat will be necessary to create maps to provide details of:

- bathymetry, hydrology (currents, temperature, dissolved oxygen), and sediment properties (for example grain size analysis);
- extent and condition of existing habitats (water column and benthic, potentially shoreline and deep water), proximity to critically important habitats (spawning, feeding, nursery, recruitment, migration), and other areas of special conservation value (biological importance - protected areas, sanctuaries or reserves); and,
- whether the disposal site will be predominantly retentive or dispersive. At retentive sites the impacts to benthic organisms will be high initially, and time scales for recovery may be important. At dispersive sites, the likelihood of impacts and the scales, outside the primary zone of dumping should be considered and estimates of the broader dispersal zones and of time scales of impacts within that.

In evaluating sites, consideration will be given to both potential direct and indirect impacts, particularly those associated with changes in:

- water transparency (decreases), suspended particulate matter (increases), sedimentation (rates increasing);
- bathymetry (altered current directions, velocities, wave patterns, increased erosion elsewhere);

- sediment composition (high silt, organic matter, seagrass);
- ability for recovery to occur (recolonisation by benthic organisms);
- introduction of pest species (associated with dredged materials); and,
- dissolved oxygen concentrations that may lead to acute or chronic anoxia or hypoxia (associated with MBOs and high nutrient inputs).

This background information will be utilised together with the other characterisation steps to enable the risk posed by the proposed project to be assessed.

Checklist – Characterising the Disposal Site (Step 5 from Figure 4.1)

The ASSMP will need to consider a range of treatment and containment options for the dredged materials at the disposal site (Appendix 3). For both land-based and within water disposal sites, a range of potential impacts will need to be minimised. At this step, alternative disposal sites may again be considered. The risk categories for the ASS derived in Step 4 will be used to develop suitable treatment and containment measures.

4.5.2 Disposal onto land

Land-based placement options, beyond those of beneficial reuse, may include both nearshore and on-land containment. In this document, these are referred to as confined-disposal facilities (CDF), which is consistent with international terminology. A great many site characteristics may influence the risks posed by the dredged materials, including the proximity to sensitive ecosystems, topography and soil properties, surface and groundwater flow paths, multiple meteorology considerations (for example rainfall, storms, tides/currents and water levels when adjacent to the coast or rivers), and long term site properties (erosion). There will be a need to consider direct physical impacts to the land (including surface and subsurface hydrology) and the ability to contain materials (pads, bunding, capping). The assessment should consider risks posed by the material placement within the containment zone (target zone for dispersal during placement), off site transport (beyond the target zone), long term properties (erosion of structure), and the ability to monitor off-site movement (dust, runoff, effluents, leachates).

Other attributes requiring consideration will include the likely fluctuations between states of materials being water-logged/reduced/anoxic and those being exposed/oxidising, and how these states may influence runoff, effluences and leachates and any potential receptors in the surrounding environment (aquatic and terrestrial). The placement of material on land may alter the position of the groundwater table beneath the placed materials (changes in potentiometric head (pressure)) and may modify the needs for groundwater monitoring bores and drainage management over time.

The placed materials will usually involve the use of a dedicated placement area or storage facility. These areas may require a pad to be created and bunding to contain the materials. For example, dredged materials containing high concentrations of MBOs, it may be feasible to use of geotextile tubes for disposal of spoil (for example see Case Study 3). Major considerations for the placement of dredged materials on land include:

- site location (for example may be very large volumes of wet materials) and construction of pad, bunding for materials, and maintenance (for example capping or drains);
- potential impact on receptors at the disposal site (for example native vegetation);

- material handling and transport between the site of dredging to the site storage (for example piped or trucked);
- dewatering (for example to stabilise poorly consolidated materials);
- treatment (for example liming to lower acidity, odour control, contaminants; and,
- long-term site management (for example monitoring programs).

Disposal of ASS materials below the water table on land, and capping with non-ASS material), is another option for reducing oxidation of dredged material (see Case Study 1. Dredging and on-land disposal, Western Basin Reclamation Area, Gladstone, Queensland). Use of organic mulches may also be beneficial on top of, or mixed into, spoil piles as they can lessen the rate of oxidation of pyrite (by competing for oxygen and providing food for microbes) (Yuan et al. 2016). Revegetation of spoil areas may also be beneficial in reducing runoff and providing organic carbon inputs.

Each of these considerations is overlain by the broader social and economic considerations (for example future land users), with ongoing consideration of project safety. Following each consideration, there may be an opportunity to modify the project design or dredging plans to achieve improved outcomes for the project and the environment.

Handling of dredged materials

There will need to be considerations for handling of dredged materials to the site of disposal (for example barge, pipeline). In general, the bulk sediment transportation method will need to consider the economics and requirements to contain the dredge material until its delivery to the disposal site.

The liquid content of waste dredge spoil (for example entrained or pore water and leachates) may need to be reduced before material can be held in a stabilised form on land (including landfill disposal). Dewatering sites may be separate to the final disposal site and may require separate construction. Design and management of dewatering activities for dredged materials should consider a range of factors relating to the sites location and potentially beneficial re-use of waters. Important aspects relating to the location may include:

- minimal impact to valued ecosystem (both at site or adjacent risks);
- ability to return to past state (rehabilitation access);
- suitability (size, containment), security (occupational/workplace health and safety, animals, birds) and ability to monitor (for example drying rates);
- being as close as practicable to the dredge site to minimise need for transport infrastructure (for example may be piped); and,
- residues (salts et cetera) and off-site discharges (including dust).

Treatment of hazardous ASS materials

Untreated ASS that is stockpiled on land may develop into a long-term management problem due to oxidation leading to very low pH. Effective management strategies need to be developed based on appropriate measures and considerations during the project planning stages.

The requirements for any treatment of the dredged materials on land will depend on the physical properties, levels of contamination and ASS properties. It is recommended that all dredged materials be initially considered within a waste hierarchy that successively considers options for prevention, re-use, recycling, and other recovery methods before disposal (see Section 3.3.2). Treatment options

may result in materials becoming suitable for beneficial reuse elsewhere, or may solely be for the purpose of stabilising for containment purposes.

Treatment measures may be necessary to achieve volume reduction, including the physical/chemical separation of solid and liquid components, or physical/chemical stabilisation of components. Any treatment should aim to achieve a reduction in the material volume, reduce its hazardous nature, facilitate its handling, or enhance its recovery. The treatment may enable material to be reclassified for beneficial reuse in preference to disposal at an approved landfill site. Historically, the most common method of treatment of dredged materials has been physical stabilisation achieved by mixing the sediment with a product such as lime, cement or fly ash. These methods are considered as simple processes which generally produce an acceptable material, but there exist disadvantages that include increased volume of material and environmental and economic aspects related to energy requirements and potentially additional sources of contamination and processes to manage.

For any treatment activities, consideration should be given to the proximity to surrounding water systems and the specification of exclusion zones. For example, treatment should not be carried out within 10 m of any watercourse, or within 200 m of any borehole or, spring used for the supply of water for domestic, food production, or other human consumption purposes. Even if bores are not used for domestic supply water purposes, an exclusion zone is recommended. Exclusion zones (distances) may also be specified for other areas requiring protection (for example specified distances from creeks and rivers, or from marine protected area).

Classifying ASS treatments to manage acidity

The treatment chosen should consider the ASS acidity hazard and quantity, with the net acidity being the main driver for most classification systems. These categories should indicate the neutralisation requirements of the hazardous ASS (Noting there is no requirement to specific area or volume of material). Dear et al. (2014) describe five treatment categories that are considered effective for this purpose (summarised briefly here):

- 1) Low level of treatment – Category L: For disturbances of ASS requiring treatment with less than 0.1 tonnes (dry wt) of fine CaCO_3 .
- 2) Medium level of treatment – Category M: For disturbances of ASS requiring treatment with 0.1 to 1 tonnes of fine CaCO_3 .
- 3) High level of treatment – Category H: For disturbances of ASS requiring treatment with greater than 1 to 5 tonnes of CaCO_3 .
- 4) Very high level of treatment – Category VH: For ASS disturbances requiring treatment with greater than 5 to 25 tonnes of fine CaCO_3 .
- 5) Extra high level of treatment – Category XH: For ASS disturbances requiring treatment with more than 25 tonnes of CaCO_3 .

For each of these categories Dear et al. (2014) also provided useful points for management of site waters (runoff, leachates), treatment pads and bunding, groundwater and monitoring needs. In this report, the advantages or disadvantages of various neutralising technologies (for example Aglime, lime, hydrated lime) are not discussed.

Safety note; most neutralization agents represent significant health hazards and some require extreme care when handling and applying. An over-application of neutralising agents may also harm the environment due to direct toxicity to aquatic plants and organisms for soils or leachate with pH

greater than 9. The use more caustic agents (for example $\text{Ca}(\text{OH})_2$) may result in both increased human health hazards and risk of resulting in overly high soil and leachate water pH.

Containment measures for dredging materials on land

Containment requirements may be minimal if the materials do not contain or are unlikely to release significant concentrations of contaminants or ASS, for example materials that are predominantly sand, gravel, and/or rock or other previously undisturbed geological materials which have low ASS and have not been exposed to modern sources of contamination. Where this is not the case, additional containment measures may be necessary. If the materials are contaminated, various local, state or national waste regulations may also apply. Forms of containment may be necessary to:

- minimise exposure to air from the surface that may result in undesired oxidation (for example ASS), odours, dust, et cetera;
- minimise exposure to rainfall that may promote transport of contaminants to the groundwater in the form of leachates or off-site runoff of liquids; and,
- stabilise the materials (for example while dewatering) and prevent off-site runoff of suspended solids.

A range of measures will usually be necessary to both prepare the site and facilitate the containment of the materials. These many include:

- pads, footing or liners on which the materials will sit to prevent or reduce migration of contaminants from the dredged material;
- surface covers to prevent or reduce exposure to rain and air and reduce material runoff, volatilisation and dust, and also to prevent interaction with plants, animals and humans;
- bunding and slurry walls to prevent or reduce offsite migration of materials or waters;
- surface drainage, seepage and leachate containment, pumping and treatment;
- groundwater pumping and subsurface drainage containment controls; and,
- stabilisation controls, including liming to neutralise existing or potential acidity associated with ASS materials, or solidification to immobilise materials.

Land-based containment options

In evaluating the suitability of different land-based containment options, it is important to consider all the transport pathways (water, solid, gaseous) through which contaminants or non-contaminant stressors (TSS, odours) may require containment and all of the environments (surface, sub-surface, air) and receptors (plants, animals; benthic, pelagic) they may potentially impact if not contained.

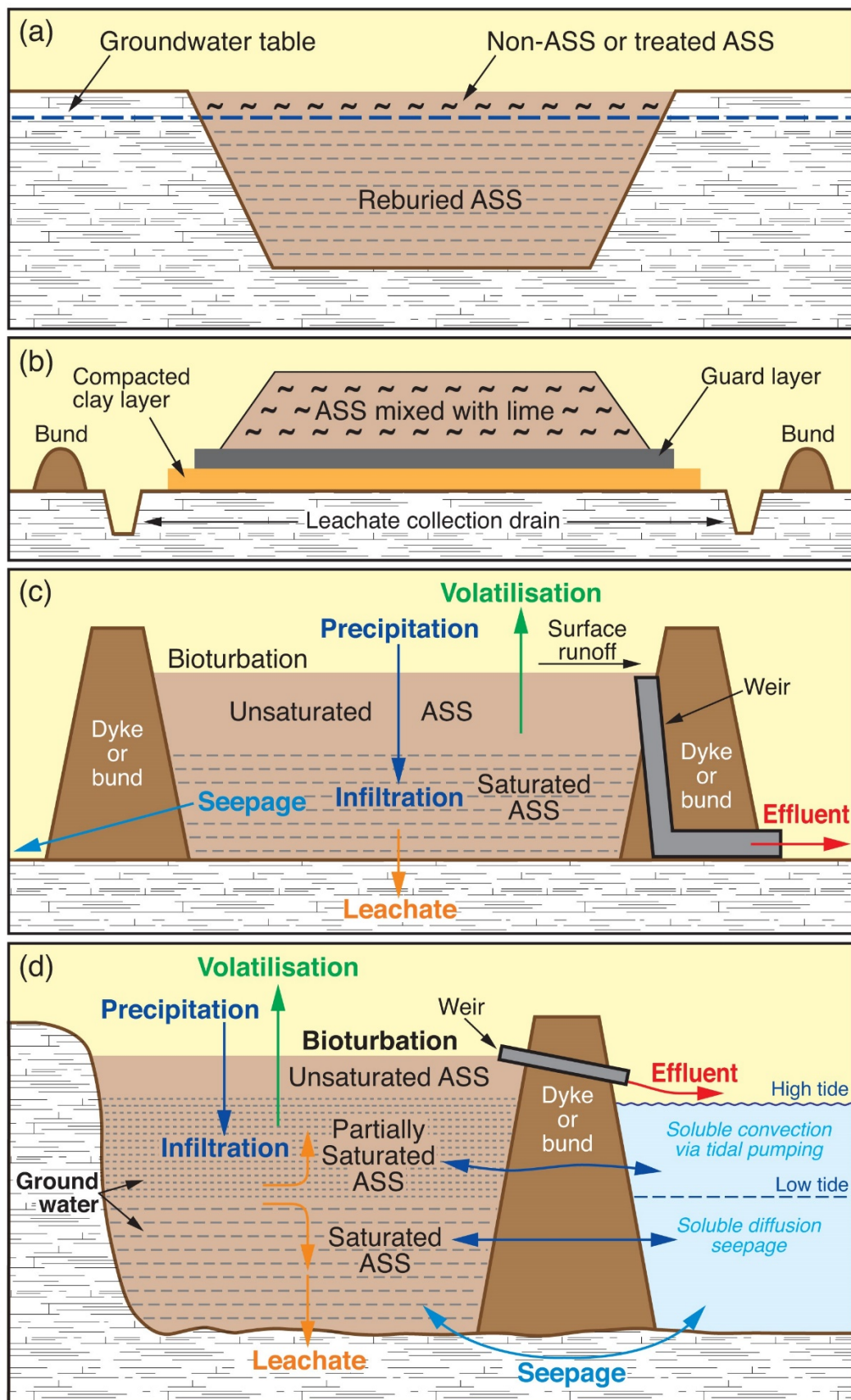
On-land containment of ASS may occur below ground, by way of strategic reburial (with material above or below the water table) (Figure 4.3a), above ground (Figure 4.3b,c) or in shoreline structures (Figure 4.3d). Strategic reburial often seeks to contain the ASS under anaerobic (reducing) conditions at the base of a void, where sulfide oxidation and hence acid generation are minimised (Figure 4.3a). Cover layers for buried ASS may include non-ASS materials or ASS-material that have been treated to minimize acidification risks (for example mixed with lime).

Possible transport pathways of contaminants from land-based containment structure are illustrated in Figure 4.3a-c (USEPA (2004)). The pathways to surface waters include uncontrolled runoff or seepage and controlled effluent discharges during the development stages (filling, settling and dewatering) and during operation (contained surface runoff, and leachates). The pathways to

groundwaters will mostly be leachates from the original materials and those generated from rainfall-infiltration and subsequent reactions and seepage of those waters into deeper aquifers. The pathways to the atmosphere will include evaporation of liquids, volatilisation of gaseous substances and dust.

For near-shore containment (Figure 4.3d), many of the transport pathways for contaminants are similar. Changes in water levels adjacent to a near-shore CDF may facilitate and transport soluble contaminants or other potential stressors (TSS escape) directly through the bunding and also disturb the groundwater environment and seepage rates.

Figure 4.3 Examples of land-based containment options and contaminant pathways.



(a) strategic reburial, (b) and (c) on-land with different treatment and containment measures, and (d) shoreline containment (modified from USEPA, 2004; Dear et al., 2014). Note that other containment structure may also exist.

Geochemical changes that influence contaminant transport processes on land

Most of the transport pathways indicated in Figure 4.3 may potentially lead to impacts on the surrounding environment. The importance of the pathways may also change with time, where pathways important during the development stages (filling, settling and dewatering) cease, and longer-term processes relating to physical and/or chemical changes within the placed materials occur, including oxidation, which is very important when considering ASS.

The dredged material may be largely anoxic initially (reduced, with little oxygen), and may oxidise as dewatering is completed and the dredged material dries out and cracks developing increasing oxygen permeability. These processes are expected to result in increased accumulation of salts on the surface of the dredged material and especially on the edge of the cracks. Rainfall events will tend to dissolve the salts and increase the acidity, salinity and metal concentrations in surface runoff and potentially groundwater. The drying process will also facilitate the oxidation and decomposition of organic matter.

The containment structures may contain dry unsaturated materials (totally above the water table), partially or intermittently saturated materials, and totally saturated materials (Figure 4.3). The unsaturated materials are likely to oxidise more rapidly than the saturated material, and the latter may remain anaerobic and reduced if suitably capped or oxygen permeability is low. Reducing conditions will favour the immobility of many metal contaminants, but not necessarily metalloids such as arsenic. The partially or intermittently saturated materials will transition and potentially fluctuate between reduced and oxidised states and may facilitate long-term releases from materials in this zone. Reduced metal species (Fe^{2+} , Mn^{2+}) can also be present in high concentrations in groundwater affected by ASS. These species are mobile in groundwater, and oxidation and hydrolysis reactions (for example as anoxic groundwater enters oxygenated surface water) can result in lower pH and create impacts some distance from the site of disposal (Mosley et al. 2014).

Additional tests to assess short and long term risks of contaminant mobilisation for hazardous ASS on land

There are a range of tests that may be undertaken that provide additional information on the risk of mobilisation of contaminants associated with ASS or dredged materials due to both the short-term and long-term dewatering, drying, oxidation and rewetting. Appropriate tests may include incubation tests (for example 2 mm thick slabs for soil, chip-tray incubation – see Sullivan et al., 2009; 2018b,c). There are currently no recommendations for leaching-type tests that may provide information similar to the simplified laboratory runoff procedure (SLRP) and the rainfall simulator/lysimeter system (RSLs) recommended by the USACE (2003) for similar purposes. The SLRP laboratory test creates leachates from wet, unoxidised and dry, and oxidised sediment for a range of suspended solid concentrations, where air-drying is for 3 weeks, chemical oxidation uses 30% H_2O_2 . The RSLs test uses a custom field-based soil lysimeter to expose the materials and allow natural drying and oxidation processes to occur, and then they are subjected to rainfall simulations at a standard rainfall intensity and duration. In this manner site-specific conditions including precipitation intensity, duration, vegetative cover, physical disturbance, et cetera may all be simulated. The SLRP used in the USA is described as more conservative test procedures than RSLs tests, with respect to the predicted contaminant release to the dissolved phase because the procedure exposes all particles in the test sample to the extraction, while the RSLs only exposes the surface of the sediment sample to the runoff simulation. If more accurate data are considered necessary prior to a decision, the RSLs procedure can then be conducted.

Long-term oxidation kinetic test methods, similar to those used by the mining industry, may also provide valuable information about the rate of oxidation of dredge spoil and about how the quality of leachate changes over time (Shi et al., 2015). Such tests can take many months to carry out, and may only be applicable to very large dredging operations where there is a considerable amount of forward planning that takes place before the approvals process commences.

Elutriate tests may also be requested for larger scale dredging projects that are disposing on land.

This guidance document does not discuss methods for the following aspects of contaminant mobilisation:

- assessment or treatment procedures for surface water runoff, effluents, leachate, or removal of solids;
- assessment or simulation of the formation of test runoff, leachates, or effluents; and,
- evaluation of volatile gaseous emissions, groundwater/sub-surface processes and transport within or beyond CDFs.

Checklist – The ASS Management Plan (ASSMP) (from Figure 4.1)

For larger projects, the ASSMP may be more easily developed and better communicated if it is separated into a series of discrete plans for the dredging, disposal, monitoring of impacts, and closure. For small projects, where ASS risk are low, it may be possible to create a single management plan. Long-term environmental monitoring plans will differ from the short term monitoring during dredging and initial disposal. Closure plans are intended to demonstrate that the residual risks are low and from which point no further monitoring of the project is required.

5 Management strategies and management plans

A core objective of developing an Acid Sulfate Soils Management Plan (ASSMP) is to provide details of approval conditions and management actions for the proposed activities. It should allow adaptive management and monitoring strategies to be implemented at spatial and temporal scales that enable effective outcomes. It should establish an agreed outline for the management of disturbed materials, including environmental management triggers and response requirements that is transparent to stakeholders.

5.1 General components of management plans for dredging

In managing risk and selecting preferred management strategies, it is the responsibility of the proponent to ensure that the work can be conducted in a way that will not result in environmental harm. There exist a wide range of mitigation and abatement measures that may be used to protect the aquatic environment during dredging operations (for example containment structures such as silt curtains, or sheet piling) and on-land measures may include neutralisation and containment (for example bunding, reburial) and monitoring, prevention and treatment of offsite transport of solids or leachates. General considerations for dredging project management plans include:

- water quality monitoring and management criteria (for example pH, turbidity, dissolved oxygen, contaminants);
- riparian and foreshore vegetation preservation;
- threatened species protection;
- stockpile location and management;
- introduced marine pest and cyst management strategies;
- sediment and erosion control measures;
- weed control and equipment wash down procedures;
- stormwater management;
- noise, air quality (including dust and odour) management;
- handling, removal and disposal of waste, including contaminated wastes;
- transport and access issues;
- cultural and heritage issues;
- navigation and safety (if boats/barges/platforms are used for construction);
- maintenance of public access;
- emergency response, including oil spills and fires;
- site security; and,
- water-dependent ecosystems.

5.2 Minimising risk during dredging projects

A wide range of considerations may be necessary to adequately minimise risks that occur during dredging operations, including:

- minimisation of the need for dredging, considering the environmental setting and operational safety requirements;
- minimisation of the dredge area with direct and indirect impacts on key benthic habitats (for example design and locate marine infrastructure to avoid or reduce impacts on sensitive habitats);
- minimise the release of sediments and dispersal of turbid plumes into the water column as much as practicable (specialised dredging equipment), particularly where sediment-sensitive benthic communities exist (reduce dispersal of turbid plumes in sensitive environments). For example, use of dredges equipped with sediment management devices where these are found to minimise sediment generation and dispersion, and use of silt curtains where they are operable and likely to be effective in controlling turbidity release and dispersion.
- the time of year of dredging and disposal to avoid critical life-cycle phases within the ecosystem, for example coral spawning, and animal migration, breeding, nesting or birthing periods;
- the use of suitable equipment and monitoring procedures during use; and
- the application of near real-time data collection and interpretation methods (particularly for turbidity) to support environmental management of dredging.

There is a range of advantages and disadvantages associated with dredging in summer or winter that may influence the risks posed by the activities. These may relate to area usage, weather conditions or more specific factors that may influence risks opposed by acid sulfate soils (ASS), such as naturally higher dissolved oxygen concentrations in waters during cooler temperature months.

The project description will have provided details of the purpose, location (grid references) and details specific to the dredging operations, and disposal plans (locations). Important operational details include, the proposed dredge footprint (m^2), quantities of materials to be dredged (volumes (m^3), areas), dredging schedule (timing – summer/winter) and rates (duration), the methodology for dredging (dredge types) and material transport, and specific management operational controls during the dredging process such as silt controls.

The method of dredging and management of the dredged solids and overflow waters during loading vessels for transport purposes may have a large influence on impacts to the water column. Overflow waters may be discharged at water level or below, and should be evaluated to minimise turbidity and impacts associated with deoxygenation. Overflow water may contain significant concentrations of fine solids, and the discharge to deeper waters where dissolved oxygen concentrations are lower may reduce the risks associated with oxidation of PASS or monosulfidic black ooze (MBO) contributing to water column acidification or deoxygenation. Consideration should also be given to how weather conditions influence the controls in place for silt, for example silt curtains may become ineffective in high wave or current conditions.

Further guidance on these general dredging requirements is provided elsewhere (for example Palermo, 2008; NAGD, 2009). Additionally, this document does not provide guidance on environmental monitoring of contaminants during dredging operations as these issues are not specific to ASS management and suitable guidance is provided elsewhere (ANZECC/ARMCANZ, 2000; Simpson et al., 2013). Dealing with ‘hot spots’ of contamination is a challenge for many dredging

projects, and may also be a consideration for ASS. In the case of ocean disposal of dredged materials, it is permissible to dump contaminated material with uncontaminated material if the two combined materials meet the guideline values (average composition) (NAGD, 2009).

5.3 Acid sulfate soil management plans

The ASSMPs should cover all aspects of the ASS management. While a single plan may be appropriate for some projects, there is less potential the finer details of ASS management to be missed or inadequately considered if the plans are broken down into clear components. For this reason, it is recommended that the ASSMP is prepared as a series of plans that clearly separate these different components, or sub-plans (Figure 3.1):

- 1) Minimising environmental risks during dredging (Plan 1).
- 2) Minimising environmental risks during disposal within waters (Plan 2).
- 3) Minimising environmental risks during disposal on land (Plan 3).
- 4) Long-term environmental monitoring plan (Plan 4).
- 5) Closure plan relating to ASS disturbance and management (Plan 5).

The likely requirements for each of the ASSMP components are expanded upon within the Appendices. The broader ASSMP reporting requirements will likely include:

- an introduction that provides background information to the proposed works and occurrence of hazardous ASS;
- a description of the hazardous ASS present at the site which is subject to disturbance (the characterisation, that may also consider past site disturbance and possible future dredging operations) (initial maps and conceptual site model);
- a description of the water body to be dredged and the scale (area, volumes) and items of environmental significance;
- general methodologies and management strategies for the dredging areas;
- plans to minimise disturbance and general methodologies for the dredging areas;
- description of the disposal site (on land or within water) – expanded below;
- treatment, monitoring, validation of treatment, performance indicators, responsibilities, contingencies, reporting and administration of the plan;
- management of dredging and dredged material placement is transparent to all stakeholders (including roles and responsibilities); and,
- guidance to the approval holder and the dredging contractor with regard to dredging and management activities, including environmental management triggers and response requirements.

The principal management strategies will often concern treatment of ASS (neutralisation), the containment (reburial of potential ASS to minimise oxidation and acidity generation, containment of MBOs – for example within geotextile tubes), and control or treatment of leachates. The assessment will outline residual environmental risks following ASS treatment and containment (for example neutralisation and reburial procedures).

The residual risk (RR) will vary for each management strategy, and is likely to be unacceptable for some. Higher RR may be expected for hazardous ASS materials that are stockpiled above ground than those that are strategically reburied despite containing residual acidity.

Appendix A: Case studies

Several case studies are provided to highlight the issues and mitigation measures needed when encountering real-world examples of dredge operations in acid sulfate soil.

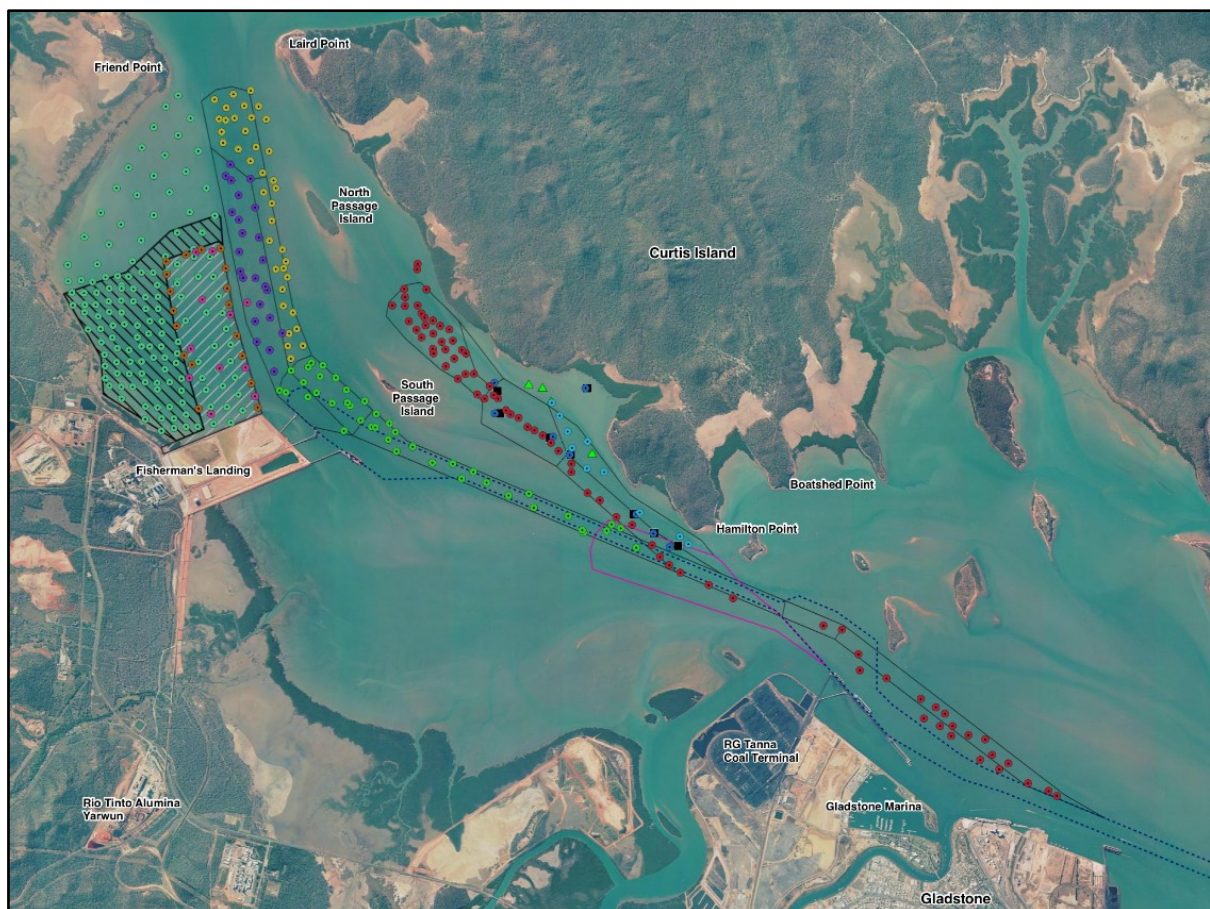
- 1) Case Study 1. Dredging and on-land disposal, Western Basin Reclamation Area, Gladstone, Queensland
(prepared by Stuart Simpson, CSIRO).
- 2) Case Study 2. Dredging acid sulfate soils during the drought in the Lower Lakes, South Australia
(prepared by Luke Mosley, University of Adelaide, and Ben Zammit, Department for State Development, SA).
- 3) Case Study 3. Removal and dewatering of pyritic sediment from a wetland (Western Australia)
(prepared by Peter Adkins, Department of Parks and Wildlife, WA (previously within 'Swan River Trust').

Case Study 1. Dredging and on-land disposal, Western Basin Reclamation Area, Gladstone, Queensland

NOTE: This case study reflects ASS assessment and management practices that were current at time of the original reclamation proposal. The 2018 ASS guidance material contains updated protocols for several matters compared to those in the case study (e.g. new protocols for defining net acidity). Readers should refer to the 2018 ASS protocols for currently recommended practice in ASS assessment and management, rather than those specified in the case study.

The Western Basin Reclamation Area comprised a subtidal expanse of waters, adjacent to the northern side of the existing Fisherman's Landing Reclamation, situated in the Port of Gladstone, 10 km north of Gladstone, Queensland (Map A1). The dredging comprised deepening and widening of existing channels and swing basins, and the creation of new channels, swing basins and berth pockets to enable access to new port facilities. The disposal of dredged materials occurred in the Western Basin Reclamation Area.

Map A1 Western Basin Reclamation Area.



Note: Area is adjacent to Fisherman's Landing Reclamation, and zones of staged dredging, Port of Gladstone, Gladstone, Queensland.

Source: GHD, 2009.

A1.1 Assessment of acid sulfate soils

The action levels for the assessment were from Dear et al. (2002). The assessment commenced with a desktop study and continued to a detailed assessment for all dredging areas (GHD, 2009, Appendix i). This quantified the amounts of hazardous ASS (sulfidic and sulfuric materials) at 189 locations within the dredging area and 100 locations in the reclamation area. The ASS assessment found that some locations within the dredging area may require management based on elevated amounts of net acidity (greater than or equal to 18 mol H⁺/tonne, the action criterion), with soft silt/clay materials typically having a net acidity of 200 to 500 mol H⁺/tonne (or 0.05% up to 0.8%S). However acid neutralising capacity (ANC) analyses indicated that the majority of the sediments would potentially self-neutralise within the reclamation area, reducing the potential impact of the acid-producing fraction. Owing to possible separation of the potential acid-producing fraction (pyritic material) and the neutralising fraction (calcium carbonate) which may occur during dredged material placement, a moderate degree of liming was considered likely during the placement of the dredged materials. Within the reclamation area, the majority of the sediments that may be disturbed during the construction of the bund wall contained excess sulfur acidity and net acidity at varying depths, and insufficient ANC to self-neutralise.

Following the delineation and quantification of hazardous ASS materials, management principles were developed that included: minimisation of rehandling of sediments identified as containing potential or actual acidity above the action criteria, to reduce the potential of dispersal of sulfide fines; and, no dredging of identified hazardous ASS.

The potential for oxidation of hazardous ASS was identified should they become unsaturated during any project stages. If this was to occur, the release of acidic groundwater containing elevated concentrations of metals from the reclamation site into the harbour was identified as a potential impact. To minimise the risk posed by the ASS, mitigation measures were implemented that included:

- Optimising excavation techniques to ensure that the remaining material was inundated each tidal cycle and dredged material was kept in a saturated state through to placement;
- Excavation, relocation and placement materials from the reclamation area that may become inundated during works to permanently below the water table within the bunded area (with turbidity/siltation controls);
- Verification sampling conducted during placement of the dredged material to confirm the sediments do not produce acidity in high enough concentrations to cause environmental harm, with neutralisation treatment by mixing with lime if necessary.

A1.1.1 Management plans

The Environmental Management Plan for the Western Basin Dredging and Disposal Project included the following elements: marine water quality; marine and terrestrial flora and fauna; sediment quality; ASS; coastal processes; groundwater; hydrology and stormwater; social impact; noise and vibration; air quality; visual amenity; traffic and site access; health and safety; mosquito and biting midge presence; environmental emergency procedures; and cultural heritage.

An ASS Management Plan (ASSMP) was prepared that outlined the principles of ASS management for bund construction and dredging, the Reclamation Area, and validation testing and monitoring for each of those activities (GHD, 2009, Appendix E). Strategic placement of non- hypersulfidic materials was used to assist in 'sealing' in the hypersulfidic materials. Neutralisation treatment of all sulfuric

materials was undertaken together with and verification testing to confirm successful treatment before placement of sulfuric materials in the Reclamation Area.

The placement of sediments with net acidity greater than or equal to 18 mol H⁺/tonne (and ANC less than 1.5× %S concentrations) was undertaken without neutralisation when strategic burial (sub-aqueous placement) was possible up to a level not exceeding mean sea level, and with neutralisation treatment when above this level. Buried hypersulfidic material was capped by non-ASS material in order to exclude oxygen.

The placement of sediments with net acidity greater than or equal to 18 mol H⁺/tonne and ANC 1.5 to 3× %S concentrations was undertaken without neutralisation, sub-aqueously where possible, but otherwise above the mean seal level. Materials with greater ANC tended to be placed above the mean seal level. All of these upper materials received an appropriate level of neutralisation treatment. A range of laboratory testing was undertaken to reduce the risk of uncertainty surrounding successful neutralisation.

Mixing of sediment in the reclamation cell was undertaken to maximise the potential for shell fragments to settle with sulfides, and to minimise the potential for the formation of pockets of sulfides without, or with limited, ANC. Buried hazardous ASS was capped by non-ASS material in order to exclude oxygen and to promote the formation of a permanent water table above the level of the top of the placed hazardous ASS. Siltation and erosion controls were utilised during and following the project operations.

For completed reclamation cells, verification testing was undertaken (for example SPOCAS testing), with frequency in the range 1 test per 1,000 m³ to 1 test per 10,000 m³, to demonstrate effective neutralisation of acid (less than 18 mol H⁺/tonne), with provision for additional neutralisation treatment if sediments fail the verification testing. Monitoring was undertaken of water pH in selected drains and at the final discharge point (daily), with the provision to neutralise to pH 6.5-8.5. Groundwater monitoring bores were installed for early detection of acid generation (pH and electrical conductivity testing, and provision for analyses of heavy metals) and to confirm groundwater levels.

A1.2 References

Dear, SE, Moore, NG, Dobos, SK, Watling, KM & Ahern, CR 2002, *Soil Management Guidelines*, in: *Queensland Acid Sulfate Soil Technical Manual*, Department of Natural Resources & Mines, Indooroopilly, Queensland.

DOE 2013, *Independent Review of the Port of Gladstone: review report*, Department of the Environment (DOE), Commonwealth of Australia, Canberra, Australian Capital Territory.

GHD 2009 [Appendix E – ASS Management Framework. Western Basin EIS – Supplementary Document ASSS](#), Document 42/15386/56/402603.

GHD 2009, [Acid sulphate soils assessment: Western Basin Dredging and Disposal](#). Document 42/15386/44/393367, Appendix i.

Case Study 2. Dredging acid sulfate soils during the drought in the Lower Lakes, South Australia

The latter part of the “Millennium” drought from 2007 to 2010 in the Murray-Darling Basin resulted in extreme low river flows and water levels below Lock 1 of the Murray River at Blanchetown to the barrages in the Lower Lakes (Albert and Alexandrina) of South Australia. The unprecedented low water levels exposed large areas of acid sulfate soils on the lake margins, resulting in large-scale soil and water acidification (Fitzpatrick et al., 2010; Mosley et al., 2014). The rapidly falling water levels also meant that dredging was required to maintain: (i) irrigation water supplies (Figure A1), (ii) vessel navigation, (iii) water connections between Lake Alexandrina and Lake Albert, and (iv) removal of regulating structures. In South Australia dredging is considered development and as such requires approvals from the relevant planning authority. The South Australian Environment Protection Authority (SA EPA) managed the licences required for such an activity and the conditioning of the disposal and/or treatment of the spoil. These dredging operations and their management will be further described later on in this document.

Figure A1 Example of a dredged channel.



A2.1 Irrigation water supplies

Due to the need for emergency action to prevent irrigation channels being stranded from the river's edge, off-river lagoons and lakes, a fast-track approval process was developed between local Council

and State Government agencies. This process enabled the relevant regulatory agencies to truncate or waive the normal processes of assessment and issue rapid approvals/exemptions or permissions, subject to the dredging application being consistent with the purpose of the emergency measures. This included the issuing of previously accredited and recognised contractors and dredging operators a multi-site license (rather than a license per site as traditionally done). A standard application form was developed that included check boxes for all the required information. Screening for ASS was required as part of the process. Soil samples (at 0-30 cm intervals to maximum depth of dredging) were taken along a transect at regular intervals (10-30 m apart depending on length of channel and additional transects undertaken if greater than 15 m width of dredging). Samples were immediately delivered in sealed plastic bags or vials (with no air gap) to a laboratory for pH_{water} and pH_{ox} testing and government scientists assisted with the interpretation of the results to determine a course of action.

If the initial screening indicated that hazardous ASS material was present (that is pH_{water} or pH_{ox} less than 4) then acid-base accounting was undertaken. Based on the results, if neutralisation was required limestone was mixed with the dredged material at the rate calculated in the acid-base accounting results (including a 1.5 safety factor). In low risk scenarios, typically found in the Lower Lakes, and given the difficulties in transporting spoil to shore across often soft and waterlogged sediments, spoil was typically side cast (spread thinly) to the side of the dredged channel with a silt curtain used during dredging at the end of the channel to prevent export of sediment (Figure A2).

Figure A2 Aerial view of dredged channel.



A2.2 Vessel navigation

Many marinas and jetties were stranded in the drought and required dredging. The assessment process was used. In addition, dredging of the channel used by the Narrung Ferry (between Lake Albert and Lake Alexandrina) was used to keep the ferry in operation. Some material was kept underwater with disposal away from the channel being dredged. Silt curtains were used around the

dredging and disposal sites but proved difficult to keep in place due to the strong winds and current on the lakes. Land-based disposal was also undertaken in a flat area adjacent to the ferry terminus. Dredged material was placed on a base for dewatering. The base was prepared by compacting a layer of limestone (100 mm thick) as a 'guard layer' to neutralise any acidic drainage. The spoil was tested and treated in proportion to the lime requirements calculated from the acid-base accounting results (with a 1.5 safety factor applied), and later disposed of off-site in accordance with waste derived fill criteria.

A2.3 Connection between Lake Albert and Lake Alexandrina

A large-scale dredging operation was also investigated in the Narrung Narrows connecting the Lower Lakes. This was to involve a large barge mounted cutter-suction dredge and land disposal of large quantities of acid sulfate soils. The proposal involved a lime slurry to be injected into the disposal line at the time of dredging at a rate determined by the acid-base accounting. This management action did not proceed based on a cost-benefit analysis compared to other options.

A2.4 Removal of regulating structures

Following recovery of water levels a number of temporary earthen structures built in and around the lower lakes were removed as required under the conditions of construction. This included the excavation and dredging of imported fill material as well as the lake bed sediments displaced by the construction activities. Prior to the decommissioning of structures, testing for ASS was undertaken on the fill material and the displaced sediments to determine the most appropriate methods for removal treatment and disposal. Testing determined that the imported fill material was inert and met the waste fill criteria which was removed via excavator and recycled as fill material. The mixed fill and lake sediment was considered to be a moderate risk, and the sediments were removed using a cutter suction dredge and deposited in a series of settlement ponds constructed on the bank near the site.

The ponds were constructed with a compacted limestone base and the material was allowed to dewater with the decanted water tested for pH and acidity and alkalinity before being allowed to drain back to the Lake. The structure materials were again subjected to acid-base accounting which determined that the mixed sediments posed a low risk and were cleared for use as local agricultural fill material. The displaced lake bed sediments were considered too high risk of acidification and contaminant release if disposed of onshore and were disposed of in the lake. The material was used to fill the void left by the fill material and in a number of local low spots. The spoil was disposed of within a silt curtain and water quality testing was undertaken throughout the operation to ensure that background levels outside of the disposal areas were not compromised.

A2.5 References

Fitzpatrick RW, Grealish, G, Chappell, A, Marvanek, S & Shand, P 2010, *Spatial variability of subaqueous and terrestrial acid sulfate soils and their properties, for the Lower Lakes South Australia*, CSIRO Land and Water Report, Urrbrae, South Australia.

Mosley, LM, Zammit, B, Jolley, A & Barnett, L 2014, 'Acidification of lake water due to drought', *J. Hydrol.*, vol. 511: pp. 484-493.

Case Study 3. Removal and dewatering of pyritic sediment from a wetland

Constructed in 2004, the one hectare Liege Street Stormwater Treatment Wetland is located in Cannington, Western Australia, approximately 10 km south-east of the Perth CBD. The wetland, which receives drainage runoff from a 530 ha mainly commercial and residential catchment, was designed to improve water quality in stormwater from summer/autumn storm events prior to this runoff being discharged into the Canning River. The wetland is also located in the Canning River Regional Park and therefore protection and enhancement of habitat values was seen as a critical component during planning and implementation of this project.

Initially, the wetland was performing well, reducing nutrients and other contaminants from stormwater flows. However, since its construction, macrophyte coverage in wetland areas has reduced by more than 70%, significantly impacting the wetlands ability to improve water quality. High organic and nutrient loading received from influent drainage, combined with available sulfate and iron resulting from local aquifers, under permanently inundated highly reducing conditions have caused the development of pyritic sediments, which have in turn led to the decline in macrophyte coverage across the wetland.

To remedy this issue, the pyritic sediments were removed from the wetland using a micro-dredge and Geopro Desludging Tubes (Figure A3 and Figure A4). Owned and operated by Apex Envirocare, the micro-dredge was a compact dredge (6.4 × 1.8m) that was launched from a trailer. The micro-dredge can pump at a rate of 6,800 L/min, operating in as little as 400mm of water, and is driven by a double-pulley hydraulic windlass with two hydraulic motors. The suction cutter head was 1.65 m × 0.36 m and can dredge up to a depth of 5 m.

Figure A3 Micro-dredge in operation.



Figure A4 Desludging tubes.



The use of the micro-dredge and desludging tubes, assisted by earthmoving plant, allowed removal of approximately 200 tonnes (dry weight) of pyritic sediment from the wetland such that the sediment could be dried and treated in a limestone-bunded area adjacent to the wetland with a relatively small footprint, limiting impacts on the existing vegetation.

Initially the micro-dredge only removed a portion of the pyritic sediment, with a significant volume of sediment remaining post-dredge due to underwater obstructions which limited access, and irregular shaped wetland areas where the micro-dredge reach was limited by the location of its guide wires. The water column in the vicinity of the dredge was also quite turbid during dredging, which is likely to have added to the volume of sediment left in the wetland post-dredge once these fines settled.

Following the initial dredge, the micro-dredge returned to the wetland to remove the remaining sediment which had been moved by earth moving plant into more accessible deeper ponds in the wetland. The movement of this sediment was facilitated by the planned spreading of sand on the wetland base, to decrease sumpland depths. Unfortunately, some of this sand mixed into the sediment, causing frequent blockages in the dredge pipework, limiting the volume of material the dredge could effectively remove. The sand also reduced the efficiency of the desludging tubes at removing fines, as sand settled at the inlet of the tubes, forming a mound as can be seen in Figure A5. Dredge effluent sprayed off this mound resulting in turbid water exiting the tubes, until the tubes were inflated higher than the mound negating this issue.

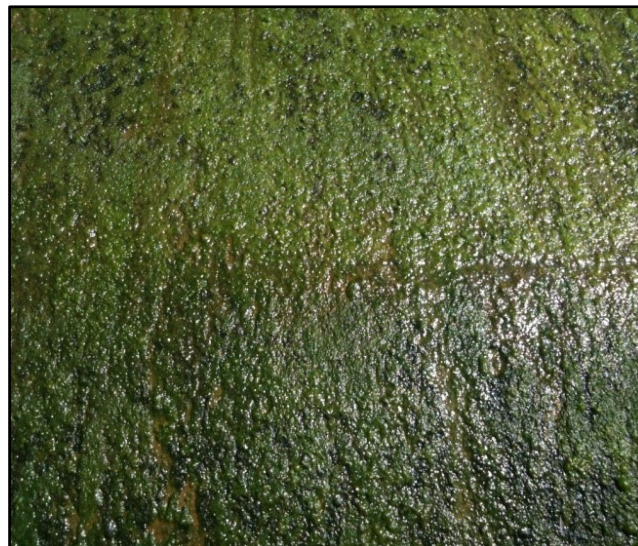
Although the micro-dredge is small and manoeuvrable in a limited area, which may suit other projects quite effectively, the non-geometric shapes of the wetland and the introduced sand did not suit this approach; however, dredged sediment was removed wet, which was critical in avoiding oxidation of the pyritic sediment. The use of in-line coagulant dosing followed by discharge into the desludging tubes was a very successful way to dewater the dredged sediment in a limited area, although the sand component in the dredge material did cause issues with water quality released from the tubes. When there was no sand in the dredge material and the tubes were able to release water without interference from the sand mound, the tubes only released a small quantity of fines with an internal layer of sediment quickly developing. This internal layer of sediment provided a secondary filtering mechanism, returning water that was clear of fines and, which after it had passed through the limestone bunded storage area, was of a suitable quality to discharge back into the wetland (Figure A5). The initial dredging took place over the late summer period, where during this

time the desludging tubes also developed a substantial biofilm cover likely assisting their water quality improvement function (Figure A6).

Figure A5 Dredge effluent pre and post dosing.



Figure A6 Biofilm on desludging.



Although pyritic sediment still remained submerged in some of the deeper ponds of the wetland, removal of material from the wetland sumplands, combined with decreased sumpland depths and changes to operational water levels will allow the wetland to seasonally dry-out in certain areas. These changes, combined with planting of tubestock, will promote vegetative growth, improving wetland function and discouraging the accumulation of pyritic sediments in vegetated areas of the wetland, which will also reduce the frequency and possibly the need for similar future maintenance activities.

Appendix B: Dredged material characterisation

B1.1 Sampling site locations and numbers

The choice of sampling locations and number of samples taken for a dredging project may significantly influence the assessment outcomes. The sampling and analyses required will vary from project to project, but should adequately represent the area under consideration. It will involve collecting many samples to cover both the location area and depth of dredging. A rationale for the sampling site selection and analyses at each site should be provided.

Sampling (material characterisation) should include the full depth of the proposed dredging (and often a buffer to allow for dredging inaccuracy, for example 1 m below the proposed level). The intensity of sampling relates in part to the statistical power required to calculate mean properties and 95% confidence limits. This creates a basic need for a minimum of three samples (results) per dredged volume, and an increasing number as the volume of the material increases.

It is recommended that a scheme similar to that adopted by the NAGD (2009) be used to determine the number of samples required to characterise the material being taken from a proposed dredging site (Appendix D, NAGD, 2009) (Table B1).

Table B1 Suggested number of sediment sampling locations when characterisation results are achieved^a.

Volume of material to be dredged (m3)	Number of sampling locations
0–10 000	6
10 000–17 000	7
17 000–23 000	8
23 000–30 000	9
30 000–37 000	10
37 000–43 000	11
43 000–50 000	12
50 000–58 000	13
58 000–67 000	14
67 000–75 000	15
75 000–83 000	16
83 000–92 000	17
92 000–100 000	18
100 000–141 000	19
141 000–182 000	20
182 000–223 000	21
223 000–264 000	22
264 000–305 000	23
305 000–346 000	24

Volume of material to be dredged (m ³)	Number of sampling locations
346 000–386 000	25
386 000–427 000	26
427 000–468 000	27
468 000–509 000	28

^aModified from NADG (2009).

However, for projects where adequate information is available to indicate the sediment materials being considered for dredging are relatively homogenous, or existing information is available on the sediment composition, then the number of additional samples may be reduced. As a minimum requirement, it is recommended that the number of samples taken be as described in Table B2. More sample locations may be desirable where the sediment composition or distribution of ASS and contamination is potentially very variable, or when the dredge area is geographically complex.

Sediment cores will comprise a large number of the samples when assessing material to be dredged, with surface grabs being another major component (cheaper, but providing limited information on deeper sediment properties). The depth of the sediment cores, and layers to be analysed from these cores, should be targeted to the proposed depth of the dredging. For large dredging projects, a pilot survey may be useful to define areas and sequences for dredging. For a pilot survey, it is suggested that 5 to 10 % of the samples required for a full-scale study be taken.

Table B2 Suggested minimum number of sediment samples to be taken and results achieved.

Volume of material to be dredged (m ³)	No. of samples required at dredging site (composite samples may be acceptable)
up to 25,000	3
25,000 – 100,000	4–6
100,000 – 500,000	6–10
500,000 – 2,000,000	10–20
for each 1,000,000 above 2,000,000	additional 10

As ASS materials are very susceptible to oxidation, care should be taken to avoid unnecessary exposure of the samples collected to air (for example immediately after sampling place sub-samples in jars or zip lock bags with no headspace, place on ice or refrigerate at 4°C until analysis).

B1.2 Sample characterisation requirements

The characterisation will include analyses to describe the material's physical characteristics, and chemical characteristics in relation to ASS (Sullivan et al., 2018b,c) and contaminants (as per the existing guidelines for soil (NEPM (2013) and sediment quality guidelines (ANZECC/ARMCANZ, 2000; Simpson et al., 2013; Simpson and Batley, 2016). Simple field tests (for example peroxide tests) may be used to determine which sediments from a large range may be most appropriate to submit to full ASS characterization (including acid-volatile sulfide (AVS) analyses to assess MBOs). However, the field test are not a replacement for the full characterisation, which should be completed for a suitably representative number of samples (for example sufficient to calculate 95% UCLs et cetera).

To determine appropriate action levels for contaminants and properties including ASS to be used for the assessment of dredged material, the default will usually be those specified under the NWQMS

(for example ANZECC/ARMCANZ, 2000; NAGD, 2009; Simpson et al., 2013). Typically, at least three action levels will be needed to be specified to enable management action to be implemented:

- 1) Action Level 1: In general, ASS properties (including MBOs) and contaminant concentrations, or levels of other stressors in dredged material below Action Level 1 are of no concern and are unlikely to influence the environment (during dredging or during disposal).
- 2) Action Level 2: Dredged material with ASS properties, contaminant concentrations, or levels of other stressors above Action Level 2 are considered unsuitable for disposal within a water body or on-land. (Note: This is likely to apply to only a part of a proposed dredging area, and the total dredging area may become mapped to specify areas that can be dredged and others that cannot, or others that require various forms of treatment during disposal or potentially require to be classified for landfill).
- 3) Between Action Levels 1 and 2: Dredged material that is classified as between Action Levels 1 and 2 may require further consideration and possible further testing before a decision will be made.

(Note: This may be the case where only a few of the many parameters being assessed fail the criteria by a relatively small margin).

For each action level, guideline values should be provided for physical and chemical stressors based on readily measurable parameters or characteristics. Collectively the action levels should enable assessment of the risk associated with the ASS (acidity generation and associated metal release, dissolved oxygen depletion), and with contaminants, nutrients, and other physico-chemical stressors.

The actions levels may be based on bulk properties of the materials (for example levels of PASS and MBOs, concentration of contaminants), or may be based on test results for materials that have been manipulated, for example elutriate tests, short-term and long-term drying/oxidation/rewetting tests, oxygen depletion upon resuspension of MBOs. The need for action levels based on such tests may proceed using a tiered, decision-tree approach, in keeping with the risk-based approach introduced in the water and sediment quality guidelines ((ANZECC/ARMCANZ, 2000; Simpson et al., 2013).

B1.2.1 Characterisation of ASS

The characterisation of the dredged material for ASS will likely include a desktop review of published information together with sampling and analyses to provide supplementary and more detailed information.

Sullivan et al. (2018b,c) provides guidance on ASS identification and laboratory methods.

The sampling and testing program will likely include measurements made in the field and laboratory. For example, field-pH measurements may be used to classify soils: pH_F or pH_{KCl} less than 5.5 (acidic soil; field pH wet with deionised water or with KCl), pH_F or pH_{KCl} less than 4.0 (AASS), pH_{ox} less than 3.0 (PASS; after sample is fully oxidised using 30% H_2O_2 solution of initial pH 4.5-5.5). Laboratory-based testing should follow the latest recommendations on ASS testing, and the characterisation is recommended to include the chromium or the SPOCAS “full acid-base accounting” suite of tests (Ahern et al., 2004). The National Acid Sulfate Soils Identification and Laboratory Methods Manual (2017) provides full descriptions of these methods, for the interpretation and reporting of results. This testing will provide information on the net acidity that may potentially be mobilised through measurements of existing acidity, potential sulfidic acidity, and acid-neutralising capacity (ANC).

Additionally, if MBOs are observed, it is recommended that testing also involve measurement of Acid Volatile Sulfide (AVS).

This characterisation should be sufficient to allow maps of the ASS to be constructed that describe the locations and volumes of AASS and PASS, along with other material properties necessary for management. Descriptions may also include areas with elevated Net Acidity (for example greater than 18 mol H⁺/tonne).

B1.2.2 Classification criteria for ASS

A series of classification criteria need to be developed that classify the materials being proposed for dredging as low, medium or high hazard, for example potentially capable of causing adverse effects in the environment without additional management measures. These criteria will be used to develop the performance criteria for material disturbance (during dredging) and placement (on land or within waters). The classifications will likely include materials as non-ASS, self-neutralising ASS, and PASS based on criteria set out in currently accepted ASS testing guidelines (check for updates). For example, action criteria may include:

- Sum of existing plus potential acidity (excluding acid neutralising capacity) of less than 18 mol H⁺/tonne (0.03 S%);
- An acid neutralising capacity of more than 1.5 times the sum of existing plus potential acidity, all measured in the same units; and
- An AVS content greater than 0.01 %.

The classification criteria will then be applied to the classification data to enable plans to be developed for the proposed dredging and disposal options (for example monitoring, treatment or containment requirements; controls and verification) as per the ASSMP [Appendix C].

Appendix C: The ASS Management Plan

A core objective of developing an ASSMP is to provide details of approval conditions management actions for the proposed activities that may disturb ASS (see Figure 3.1).

C1.1 Environmental Management Plan (EMP)

An EMP will exist that provides guidance for the entire project, including to the approval holder and the dredging contractor with regards to the dredging and management activities, and any additional environmental management criteria and response requirements beyond the ASSMP. The EMP will likely consider / include:

- the ASSMP (focus of this report);
- cultural heritage, community engagement, emergency responses, and future scenarios (for example climate change);
- broader water quality aspects of dredging and disposal (including bathymetry, hydrodynamics);
- land site characteristics (location, land-uses, topography, geology, hydrogeology, et cetera);
- ecology (flora and fauna – environmental receptors);
- surface water (contaminants of concern);
- groundwater (contaminants of concern);
- other soils (contaminants of concern);
- risk assessment (framework, problem identification, receptor-exposure-toxicity and risk characterisation);
- hydrology;
- erosion and sediment control;
- waste classifications;
- air quality;
- noise and vibration (terrestrial and underwater for dredging);
- hazardous materials management and emergency preparedness;
- containment risks management;
- monitoring and inspection plan;
- compliance audits;
- incident reporting and complaints; and
- records management.

As a consequence, the EMP may provide the performance criteria for each activity (dredging, disposal) that allow effective management of risks posed by the disturbance of the ASS, together with other activities, over the short and longer term (for example target levels for pH, suspended solids and dissolved oxygen concentrations of waters). Details should be provided on the methods to be used, the frequency of sampling and analyses, and associated performance criteria for the methods. Other criteria may also exist relating to on-land placement of materials that are more general than those relating to the ASSMP (for example dust, odour). To complement these

performance criteria, the management or contingency measures should also be indicated for situations when the criteria are not met (non-conformance).

C1.2 ASS Management Plan (ASSMP)

Like the EMP, the ASSMP should allow adaptive management and monitoring strategies to be implemented at spatial and temporal scales that enable effective environmental management outcomes. It should establish an agreed outline for the management of disturbed materials which is transparent to stakeholders, including environmental management criteria and response requirements.

The ASSMP is often prepared as a single document, attempting to cover all aspects of ASS management, while at the same time being linked to the dredging plan methodology and sequencing. While this may be appropriate for some activities, there is also potential for many of the finer details of ASS management to be missed, or inadequately considered with the broader scope of dredging plans. For this reason, it is recommended that the ASSMP is prepared as a series of plans that clearly separate the different components (Figure 4.1):

- 1) Minimising environmental risks during dredging (Plan 1);
- 2) Minimising environmental risks during disposal within waters (Plan 2);
- 3) Minimising environmental risks during disposal on land (Plan 3);
- 4) Long-term environmental monitoring plan (Plan 4); and
- 5) Closure plan relating to ASS disturbance and management (Plan 5).

The likely requirements for each of the ASSMP components are expanded in the following sections. The broader EMP and ASSMP reporting requirements will likely include:

- an introduction that provides background information to the proposed works (purpose and scope) and occurrence of ASS;
- a conceptual model;
- a description of the ASS present at the site(s) which is subject to disturbance (the characterisation, classification of AASS and PASS) (as described in Appendix 2);
- the sites and proposed activities (preferred and options);
- a description of the water body to be dredged and the scale (area, volumes) and items of environmental significance;
- the general methodologies and management objectives and strategies for the dredging areas;
- plans to minimise disturbance and general methodologies for the dredging areas;
- a description of the disposal site (on land or within water) – expanded below;
- treatment, monitoring, validation of treatment, performance indicators, responsibilities, contingencies, reporting and administration of the plan; and
- the management of dredging and dredged material placement is transparent to all stakeholders.

While the focus of this document, is on the ASSMP, the components/plans described below will always have significant overlap with the EMP. A number of factors considered in the EMP will influence the ASSMP, but additional methods may not need to be specified if they duplicate the EMP

requirements (for example .water hydrodynamics/ particle dispersion measurements, leachate monitoring techniques).

C1.2.1 Plan 1: Minimising environmental risks during dredging

Background information should be provided as to the proposed works and occurrence of ASS, including the amount and general characteristics of material being dredged. This component of the management plan should also provide:

- a description of the ASS present at the dredging location or disposal site which is subject to disturbance (the characterisation, classification);
- a description of the water body to be dredged (area, volumes) and items of environmental significance;
- a description of the potential impacts and risks (for example water deoxygenation, turbidity, acidity, contaminants, nutrients);
- the general methodologies and management strategies for the dredging areas;
- plans to minimise disturbance and general methodologies for the dredging areas;
- the dredging procedures and ability to achieve the dredging aims, particularly if intending to surgically remove/separate sediment strata containing different classification of ASS (for example PASS, non-PASS);
- a description of the disposal site (on land or within water) and methods for transportation of dredged spoil to this site – expanded in section C1.2.2 Plan 2: Minimising environmental impact during disposal within waters and C1.2.3 Plan 3: Minimising environmental impacts during disposal on land (treatment, containment);
- treatment and monitoring undertaking during the dredging operation, including, validation of treatment, performance indicators; and
- responsibilities, contingencies, reporting and administration of the plan.

The project design may be the main factor influencing the ability to minimise risks, and choices may be necessary with respect to dredging areas and depths to achieve lower risks, that is avoiding disturbance of problematic ASS materials and retaining them in situ. The main concerns that are specific to ASS will be risk associated with deoxygenation or acidification of the water column due to dredging activities. These risks will be minimised by understanding the materials that are most likely to create them (risk rankings based on characteristics), and minimising the total suspended solids (TSS) within the water column (silt controls). In both cases, it would be useful to provide estimates of likelihood of deoxygenation or acidification occurring, and create action levels appropriate for these risk, for example a maximum amount of TSS (mg TSS/L) within the water column before dredging must be suspended due to unacceptable risks of adverse effects due to deoxygenation or acidification occurring. Similar action levels may exist for other stressors, or surrogates, if they can be monitored in real time.

Specific considerations for minimising risk during dredging projects are described in Section 5.1. Engineering-based approaches will often be the most effective measure for minimizing risks, such as the isolation of dredge area (for example using sheet piles or cofferdams) or reducing transport of silt and suspended solids from the site (for example using silt curtains or screens). The timing works to avoid sensitive ecological windows will also be important for many projects (for example breeding, spawning or larval stages of threatened or vulnerable species, or to coincide with weather and tidal conditions that will minimise the transport of suspended material).

Performance criteria

A series of performance criteria for dredging operations will need to be developed that allow effective management of risks during the proposed dredging activities. Criteria likely to be essential for the ASSMP are likely to include:

- Dissolved oxygen – real-time monitoring and management triggers/actions;
- Water clarity (turbidity, TSS) – real-time monitoring and management triggers;
- Acidity – real-time monitoring and management triggers/actions; and
- Contaminants and nutrient concentrations (field-based analyses of ammonia; laboratory analyses of others).

C1.2.2 Plan 2: Minimising environmental impact during disposal within waters

The site selection of appropriate disposal sites and methods within waters (rivers, lakes, estuaries, coastal waters) is important for avoiding unacceptable, adverse impacts on the environment and other amenities. Effects may be minimised by selecting a site where the dredged material and the sediments in the receiving area are similar. In most cases, blanketing of a comparatively small area of seabed may be considered (by stakeholders) to be an acceptable environmental consequence of disposal (in order to achieve the project need). To avoid excessive degradation of the waterway as a whole, the number of sites should be limited as far as possible and each site should be used to the maximum extent that will not interfere with navigation. For some sites, where reasonably clean, finer-grained dredged material is concerned, impacts may also be reduced if the material disperses (potentially deliberately) to prevent or reduce blanketing, particularly of a smaller site. For some environments, the rate of deposition of dredged material may have a strong influence on the impacts at the disposal site, and may be controlled to achieve improved outcomes.

Sufficient information should be assembled about the disposal site so that reasonable assurance can be provided to stakeholders that the desired values and project outcomes are achieved. In general, the total area covered and impacted by the dredged spoil should be minimised. The identification of areas that are potentially suitable as underway disposal sites will require broad considerations and considerable engagement with all stakeholders. For example, in most waterbodies the considerations will include:

- whether the material can be reasonably transported and disposed of at the proposed site (taking into account economic and operational feasibility);
- conservation and special purpose areas (for example marine protected areas, Ramsar sites);
- areas of significant archaeological, cultural or historical or scenic importance;
- recreational areas (including beaches);
- fishing (commercial and recreational); shell-fishing grounds; spawning, feeding and nursery grounds; migration routes of important fisheries;
- marine mammals and birds;
- aquaculture;
- engineered sites that may contain (for example) cables and pipelines, renewable energy sites (wind, wave);
- industry uses, for example aggregate extraction, water extraction for cooling, desalination and aquaculture;

- shipping lanes or anchorage zones; and
- military exclusion zones or past munitions disposal sites.

To assess potential physical impacts and contaminant impacts at underwater disposal sites, a broad knowledge of site characteristics is necessary, which may include the following:

- hydrology (water depth and bathymetry, currents, tides and waves);
- weather (storms);
- bottom sediment physical characteristics (for example grain-size differences) and sediment deposition/erosion rates;
- water salinity, temperature, dissolved oxygen and turbidity (background and variability);
- biological/ecological characteristics of the site (for example, presence and tolerance of the benthic organisms and plants to sediment deposition, presence of rare or endangered, or unique species);
- potential for site recovery (biological recolonisation);
- site history and access (previous uses, including disposal operations);
- ability to adequately monitor the site, and modify operations;
- ability to control placement of the material (dispersive, non-dispersive);
- site capability (maximum allowable TSS and volume limits for material disposed as mounds); and
- the interaction of these characteristics with broader site considerations and the acceptability of site uncertainties and risks to all stakeholders.

The physical conditions in the vicinity of the disposal site will influence the transport and fate of the dredged material. Open-water disposal sites may be classified as predominantly nondispersive or predominantly dispersive. At predominantly non-dispersive sites, most of the disposed material should remain on the bottom following placement, and may form mounds that can potentially be capped. At predominantly dispersive sites, most of the disposed material should be dispersed either during placement or eroded from the bottom and transported away from the disposal site by currents and/or wave action within a predicted time frame. The site characterisation will therefore need to consider whether the site is dispersive or non-dispersive and how this influences other aspects of the assessment, for example how redistribution of sediments may impact the surrounding environment.

Within-water disposal may also include confined disposal facilities (CDFs – Section 3.5.2 of main document), in which case the term refers to both nearshore and upland constructions. The physical and chemical properties of the materials will influence the design-factors and engineering necessary for containment or isolation of the dredged materials. An important consideration for ASS-containing dredged materials will include the impact of the natural drying on the mobilisation of acidity and contaminants and the potential for hazardous leachates.

The biological community composition and distribution at the site will influence the nature of the effects that are to be expected, and potentially the biological assessments that need to be undertaken. It is recommended that baseline information is gathered to facilitate future monitoring studies.

The physical, chemical and biological (including toxicological) characteristics of the material needs to be determined as part of the disposal site characterisation process (in situ and as the material is disposed). The site evaluation should consider the potential for adverse effects across spatial and temporal scales, and cover both the entire potentially disturbed waterway (for example river, lake or seabed) (topography, geochemical and geological characteristics, benthic communities, fisheries resources, prior disposal activities) and the water column (suspended matter, pH, salinity, dissolved oxygen, nutrients, primary productivity, contaminant concentrations).

The assessment of the risk of biological and ecological effects of the dredged material (toxicological and bioaccumulation effects, changes in community structure, disruption of ecological processes, degradation of water and sediment quality and alteration of sediment characteristics) should be evaluated according to the NWQMS. This assessment will determine whether the proposed/planned impact are acceptable for unacceptable.

Early discussions with all stakeholders are recommended to ensure that they are involved in the process of identifying an area which is suitable for a new disposal site.

In general, this component of the management plan may have considerable overlap with Plan 1, where many of the potential impacts and risks relate to changes in water quality (for example dissolved oxygen, pH, suspended solids, and contaminant and nutrient concentrations). Components may include:

- a description of the ASS present in the material being disposed;
- a description of the disposal site and items of hydrological or environmental significance;
- a description of the potential impacts and risks (for example water deoxygenation, turbidity, acidity, contamination);
- the general methodologies and management strategies to minimise potential impacts;
- the procedures for disposal and monitoring;
- the performance criteria for the management actions required when criteria are not met (for example non-conformance with desired turbidity targets for water quality); and
- responsibilities, reporting and administration of the plan.

Performance criteria

A series of performance criteria for dredged material disposal will need to be developed that allow effective management of risks during the proposed disposal activities. Criteria likely to be essential for the ASSMP are likely to be similar to those used during the dredging activities, for example criteria for:

- Dissolved oxygen: real-time monitoring and management triggers/actions;
- Water clarity (turbidity, TSS): real-time monitoring and management triggers;
- pH: real-time monitoring and management triggers/actions; and
- Contaminants and nutrient concentrations (field-based analyses of ammonia; laboratory analyses of others).

C1.2.3 Plan 3: Minimising environmental impacts during disposal on land (treatment, containment)

The selection of appropriate land-based disposal sites is important to avoiding unacceptable, adverse impacts on the environment and other amenities. The site selected should have little existing value (current and projected for future) or the value is expected to be improved through the planned disposal. It should also be acceptable that the site remain in a potentially degraded state for the project life if an extended period for drying or remedial works are expected (for example 12 months to years).

Sufficient information should be assembled about the site so that reasonable assurance can be provided to stakeholders that the desired values and project outcomes will be achieved. Land-based sites should be as close as possible to the site of dredging, and generally within approximately 1 km of the dredging activity, or within 3 km if the additional expense of a booster station is justified when pumping. If material treatment is required, this should be undertaken a suitable distance (for example 30 to 50 m) from waterways, to allow for adequate containment structures, interception, and monitoring. To assess potential physical impacts and contaminant impacts at land-based disposal sites, a broad knowledge of site characteristics is necessary, which may include the following:

- available area, storage capacity, configuration and access for the required life of the site;
- broad land use considerations (including real estate) and contamination history;
- site accessibility (tracks, piping, drainage) and security (access by public, or animals);
- proximity to sensitive ecological environments or important habitats;
- topography, water runoff patterns and adjacent drainage;
- ability to dewater, and for the dredged material to eventually dry and oxidise;
- groundwater (levels, flow and direction, and potential impact on groundwater discharge and recharge);
- weather (meteorology and climate);
- soil properties and stratigraphy;
- biological receptors (land, water, groundwater) on site and adjacent to site;
- potential for effluent, leachate, and surface runoff impacting adjacent ground and surface water resources;
- potential for movement of contaminants off site and biological/ecological or human health impacts; and
- potential for release of volatiles (contaminants, odours), dust, or noise.

Likely reporting requirements for the site management plan will include:

- an overview of the project that summaries the key dredging aspects relating to the dredging scale (volumes, area) and methods of dredging and material transport, and of the general land disposal location (current use, values, et cetera);
- site description (topography, geology, hydrology, ecologically sensitive surrounding areas);
- detailed maps of soils (including ASS), contaminants, water, groundwater;

- comprehensive description of the dredged materials, including physical properties of the soils, sediments, ASS, contaminants, (field and laboratory test results);
- methodology for classifying ASS (field screening tests, action Levels, et cetera);
- avoidance and beneficial reuse;
- site preparation (for example construction, pads, bunding) and related environmental measures;
- treatment site and procedures (for example methodology and liming rates for PASS, performance criteria and verification testing) and location (treatment site preparation and management);
- dewatering and disposal of waters (possibly returned by pipe to dredging location);
- other hazard mitigation strategies (for example silt controls, minimising oxidation of PASS, leachates), including testing and verification;
- runoff, effluent leachate interception (for example silt ponds, barriers, drains);
- other monitoring plans (for example water quality, dust, odours);
- groundwater monitoring, including bore hole plans;
- contingency plans (for example acidic leachate detected);
- monitoring and reporting requirements;
- safety (chemical storage, for example lime, and spill response);
- review, validation testing, reporting and auditing (for example of performance criteria).
- community / stakeholder liaison; and
- closure.

Performance criteria

A series of performance criteria for dredged material placement on land will need to be developed that allow effective management of risks posed by the materials in the short and longer term.

Criteria pertinent for the ASSMP will likely include:

- Those to validate the ASS-neutralisation, for example from Dear et al. (2014):
 - The neutralising capacity of the treated soil must exceed the existing plus potential acidity of the soil by at least a safety factor of 1.5;
 - Post-neutralisation, the soil pH (pH_{KCl}) is to be greater than 6.5; and
 - Excess neutralising agent should stay within the treated soil until all acid generation reactions are complete and the soil has no further capacity to generate acidity. Note: This generally precludes the use of materials with appreciable soluble alkalinity (for example burnt lime, quicklime) for permanent soil amelioration.
- All waters that enter and exit the site (runoff, effluents, leachates) – pH, turbidity, contaminants, for example:
 - pH of effluent waters are within target range for receiving environment (for example 6.5-8.5);
 - Turbidity of effluent waters are within target range for receiving environment (for example less than 50 mg TSS/L); and
 - No contaminant concentrations exceed the water quality guideline values (ANZECC/ARMCANZ, 2000).

The rate of verification testing should be specified, and will be site specific. The success of the ASS-neutralisation can only be verified with a full acid-base account (chromium or SPOCAS suite including retained acidity); pH testing alone is not sufficient. These performance criteria equate to there being no positive calculated net acidity (using acid base accounting) in the soil following treatment. Soil that has been treated by neutralisation techniques and has not met these criteria should be re-treated and re-tested until the performance criteria are met.

Characterisation of the land site

This aspect of the assessment is not covered in this report, and separate guidance should be sought, including guidelines for contaminated sites NEPM (2009), NWQMS (for example ANZECC/ARMCANZ (2000)), the procedures for assessing impacts of disturbing ASS on land (for example Dear et al., 2014), and other relevant national, state/territory or regional guidelines. For this assessment the recommendation may differ considerably from those provided here for assessing potential impacts of placing dredged materials on land. For example, there are numbers of samples required for site characterisation (McDonald et al., 1990), where the minimum number of sampling sites for extensive projects are specified based on area: 4 sites when less than 1 hectare, then 2 per additional hectare.

Treatment and containment

The design and use of treatment pads for neutralising materials, guard layers, bunding, covers or other containment structures, and drainage systems are not described in this review. Dear et al. (2014) provides a suitable discussion of important considerations.

C1.2.4 Plan 4: Long-term environmental monitoring plan

The monitoring program should be designed to ascertain that changes in the receiving environment are within the areas and magnitudes predicted. The monitoring program may be designed to determine whether:

- 1) the zone of impact differs from that projected; and
- 2) the extent of change protected outside the zone of impact is within the scale predicted.

The requirements for monitoring are likely to be site and project specific. The monitoring program should be developed in conjunction with stakeholders. There are two types of monitoring:

- compliance monitoring (measures compliance with the approved project and permit conditions)
- field monitoring (measures the condition, and changes in condition, of the receiving environment).

Monitoring in relation to disposal of dredged material (in waters or on land) will mostly comprise measurements for compliance purposes (assessed against action levels or other permit requirements). The monitoring of effects of dredged material disposal in waters will require selection of representative monitoring sites, from which extrapolation to other areas will be necessary. The effect is likely to be similar in many areas, and it is not feasible to monitor every location receiving small quantities of dredged material. More detailed investigations at a few carefully chosen sites that are subject to large inputs of dredged material is likely to provide suitable information for understanding processes and effects.

Likely reporting requirements for environmental monitoring plans may include:

- water management (including surface and groundwater quality, and leachate control);

- wastewater management;
- soil management;
- noise management (including noise and vibration);
- air management (including dust and odour control);
- waste management (including solid/liquid waste, and special waste (medical, radioactive, chemical));
- hazardous materials management (including scheduled wastes, resource storage, pest control, household chemicals, compressed/liquid gas); and
- flora and fauna.

Water quality monitoring

Dredging operations and material placement projects will require monitoring of water quality. During dredging operations, monitoring should include turbidity, TSS, salinity, pH, temperature and dissolved oxygen. For most of these parameters automated approaches can be used with data loggers and telemetry and complemented by collection of discrete samples for confirmation of some predicted parameters (for example TSS predicted from monitoring of turbidity). Crucial parameters in the case of PASS are pH and dissolved oxygen, however, a model of rates of MBO oxidation and deoxygenation of the water column may be possible to be developed based on monitoring of TSS and knowledge of MBO properties. In some cases, it may be possible and necessary to monitor receptors over longer time frames (for example for corals and seagrass).

Following placement of dredged materials, the monitoring requirements will be more case specific, but may include those same water quality parameters in adjacent water bodies that may be potentially impacted from effluents and ground waters. Possible requirements may include:

- the standard of any site water to be discharged into the environment must meet Australian guidelines to avoid deleterious effects on water quality of the receiving environment;
- specify performance criteria that include targets for pH (for example 6.5 – 9.0), dissolved oxygen (greater than 3 mg/L, greater than 50% saturation), turbidity (for example less than 50 mg/L TSS), and contaminants (for example below WQGVs specific in ANZECC/ARMCANZ, 2000);
- specify monitoring frequency, parameters, techniques/training;
- review of data; and
- corrective actions in response to exceedance of target criteria ranges.

Site emissions

The emissions of substances from the site that are not controlled by emission limits should not cause contamination of areas beyond the site. Consequently, appropriate measures (and potentially an approved emissions management plan) should be taken to prevent or where that is not practicable, to minimise, those emissions.

Examples of appropriate measures include the ‘secondary containment’ of all liquids whose emission to water or land could cause pollution, unless other appropriate measures are in place to prevent leakage and spillage from the primary container.

Any emissions from the site activities should be free from odour at levels likely to cause pollution outside the site. What comprises an odour is different for different people. Consequently,

appropriate measures (and potentially an approved odour management plan), should be taken to prevent or where that is not practicable, to minimise, those odours.

Similar measures may be necessary for site noise and vibration, and all measures should have acceptance criteria and notification procedures for breaches.

C1.2.5 Plan 5: Closure plan

Here, the closure plan relates to the specific project and impacts from the dredging of ASS-containing materials. The intent of the plan is to demonstrate that the residual risks are low. A closure report for ASS is likely to only be required when material have been present that require higher levels of treatment or management. The details of the closure plan may be less where lower amounts and smaller hazards were identified. For projects requiring a very high level of ASS treatment and management, a closure report may include recommendations for independent handover testing. Likely requirements for closure plans that may apply to contaminated sites or an ASSMP may include the following introductory information:

- a summary of the history of the site with respect to project-related impacts, the extent of any remediation, and relevant monitoring or management;
- a summary of the history of community engagement relating to the consultation process for the project, and any agreed consultation over future site use;
- the objectives for the site and surrounding environment following closure;
- the rationale and justification for any clean-up levels or permanent containment systems (for example residual barriers);
- a discussion of current risks, and any ongoing monitoring, mitigation or other management activities (to reduce risks);
- the rationale for the selection of the recommended closure plan option(s), with justification over other options;
- possible contingency planning to address possible failure of critical components influencing closure plan (for example issue with long-term any remaining management strategies);
- a description of other final decision-making processes relating to evaluation of success or effectiveness of measures taken (for example achievement of clean-up levels);
- a description of the reporting and review requirements, including the final assessment of closure success, and explanations for any failure to meet targets (this requirement may indicate need for any additional work to be completed to achieve closure objectives);
- independent review and verification of compliance with closure plan and regulatory requirements of relevant environment protection authorities and other local, state or national regulatory agencies (documentation, certification); and
- proposed timing and final delegation for completion of closure plan.

Detailed information, relating specifically to ASS (from Dear et al., 2014), may including:

- total final volumes and dimensions of disturbed ASS;
- details of soil management strategies undertaken at the site (including evidence of specific management measures such as waste tracking, photographic evidence of neutralisation and of bunded treatment pads);
- location of any offsite treatment and/or disposal of ASS and evidence of treatment off site;

- summary of verification testing results for material treated either on or off site;
- location and maps of areas used for burial of fines from sluicing; and
- location and maps of areas used for strategic burial of potential ASS, depth below finished surface and details of safety margin below the permanent water table.

Detailed information relating specifically to general impacts may include:

- where dewatering was involved, final location, extent and duration of dewatering and details of groundwater management strategies applied;
- details of water management strategies undertaken at the site;
- summary of monitoring results for surface water and groundwater (with an emphasis on trends in water quality).

In addition, a closure report will likely require:

- appendices that contain full results of monitoring and verification testing regimes;
- a discussion of the effectiveness of management strategies employed at the site;
- details of any incidence of nonconformity with the environmental management plan and corrective actions taken;
- a discussion of any potential risks to the environment or human health;
- proposed future monitoring and/or reporting programs;
- proposed remediation measures if needed (for example handover testing); and
- if handover testing is required as part of a closure report for an 'extra high' level disturbance, summarise and discuss handover testing results, making reference to any failures and corrective actions.

Monitoring and rehabilitation of sites and effected areas

It is the responsibility of the proponent to ensure that the management strategies have been achieved, and that no environmental harm has occurred, or will not occur in the future, beyond that agreed/accepted before dredging and disposal activities commence. For example, additional responsibilities may include:

- revegetation of dredge spoil disposal areas (for example seagrass in shallower waters, planting on land);
- revegetation of stockpile areas;
- stabilisation of batters of reclaimed areas with "rip raps"; and
- reinstatement of public access, parking or thoroughfare.

Glossary

Term	Definition
Acid base account (ABA)	A simple equation used to combine the results of several laboratory soil tests to produce a consistent and comparable measure of net soil acidity. The accounting system includes measures of freely available (actual) acidity, acidity released from low solubility chemical compounds (retained acidity) and sulfides vulnerable to oxidation (potential acidity), balanced against any acid-neutralising capacity (ANC) if present in the soil. Except where the neutralising material in the soil is very fine, ANC on fine-ground laboratory samples is usually an overestimate of effective ANC compared to its field reactions and kinetics. Hence a compensating 'fineness factor' is employed in the equation.
Acid-neutralising capacity (ANC)	The ability of a soil to counteract acidity and resist the lowering of the soil pH. In an ASS context, acid-neutralising capacity is considered negligible if the soil's pH_{KCl} after processing (according to the latest Laboratory Methods Guidelines) is less than 6.5. Above pH 6.5, ANC is defined and measured according to the latest Laboratory Methods Guidelines (or AS 4969).
Acid sulfate soils (ASS)	Soils, sediments or other materials containing iron sulfides and/or acidity generated by their breakdown. These materials are environmentally benign when left undisturbed in an aqueous, anoxic environment but when exposed to oxygen the iron sulfides break down, releasing large quantities of sulfuric acid and soluble iron.
Action criteria	For ASS, the measured level of potential plus existing acidity beyond which management action is required if a soil or sediment is to be disturbed. The trigger levels vary for texture categories and the amount of disturbance. The extent of management required will vary with the level of acidity and the volume of the disturbance, among other factors.
Actual acid sulfate soils (AASS)	Soil or sediment containing highly acidic soil horizons or layers affected by the oxidation of soil materials that are rich in iron sulfides, primarily pyrite. This oxidation produces hydrogen ions in excess of the sediment's capacity to neutralise the acidity, resulting in soils of less than pH 4. These soils can often be identified by the presence of jarosite (a yellow coloured mineral).
Aglime	A neutralising agent used to treat acidic soils; by composition high quality aglime may be 98% calcium carbonate (CaCO_3) and hence has a neutralising value of 98%; it is mildly soluble in pure water, with a pH of approximately 8.3; application rates will depend on the purity and fineness of the product. Some commercially available lime(s) have much lower neutralising values.
Algae	Aquatic plants that do not have root structures or flowers. Microalgae (also called phytoplankton) are microscopic. Macroalgae can be seen without magnification.
Algal bloom	A large population density of a phytoplankton. Such blooms are normal, but become of concern when the species in bloom is toxic.
Alkaline	Description of a substance with a pH greater than 7 when dissolved in or mixed with water.
Amorphous	Lacking a clear shape; when referring to ionic solids, it describes a lack of long-range ordered crystalline structure.
Anaerobic sediments	Sediments lacking oxygen. They usually contain high levels of iron sulfide, causing them to be black in colour. Anaerobic sediments release hydrogen sulfide (rotten-egg gas) when exposed to air.
Anoxic	An environment where oxygen is intrinsically rare or absent.
ANZECC	Australian and New Zealand Environment and Conservation Council.
Aquatic ecosystem	Any water environment, from an ephemeral pond to the ocean, in which plants and animals interact with the chemical and physical features of the environment.
Aqueous	Composed of or pertaining to water.

Term	Definition
Aquifer	Layers of rock, sand or gravel that can contain free water and allow it to flow. An aquifer acts as a groundwater reservoir when the underlying rock is impermeable.
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand.
Aquatic environment	The geochemical environment in which dredged material is submerged under water and remains water saturated after disposal is completed.
ASSMP	The approved Acid Sulfate Soil Management Plan, including any amendments or addendums that may be approved from time to time.
Attenuation	A reduction in concentration of a contaminant with increasing distance from the source. Attenuation is specifically used in this document to describe reductions in leachate concentrations as a result of mixing with groundwater, adsorption of contaminants in foundation soils, degradation, volatilisation, and precipitation.
Available lime	The amount of reactive lime.
Australian height datum (AHD)	The datum used for the determination of elevations in Australia. The determination uses a national network of benchmarks and tide gauges, and sets mean sea level as zero elevation.
AVS	Acid volatile sulfides; the dilute acid-soluble sulfide concentration in an aquatic sediment.
Background	Environmental conditions that commonly occur, or concentration of a substance (ASS or contaminant) that is commonly found, in the local concentration environment at the site being considered.
Beach renourishment	The process of adding sand to a beach to alleviate erosion or to improve an amenity.
Beneficial uses	Placement or use of dredged material for some productive purpose. Beneficial uses may involve either the dredged material or the placement site as the integral component of the beneficial use.
Benthic community	The assemblage of organisms that live in and on the sediments below the waters (for example of rivers, lakes, estuaries, marine coastal waters).
Best practice environmental management (BPEM)	The management of an activity to achieve a continuing minimisation of the activity's environmental harm, through cost-effective measures, assessed against the measures now used nationally and internationally for the activity. See Section 21 of the Federal Environmental Protection Act 1994.
Binder	A single reagent or mixture of reagents and additives used to stabilise/solidify soil or waste.
Bioaccumulation	The accumulation of contaminants in the tissues of organisms through any route, including respiration, ingestion, or direct contact with contaminated water, sediment, or dredged material.
Bioavailable	Able to be taken up by organisms.
Biodiversity	The variety and variability of living organisms and the ecological complexes in which they occur.
Buffering capacity	The ability of a mixture or solution to resist pH change – in an ASS context, this may refer to surface or groundwaters, or to the soil solution, or to the soil itself.
Bund	A wall constructed to retain spoil, generally as an elongated earth mound used to direct and/or contain the flow of water.
Capital dredging	The removal of material to create a greater depth than had previously existed (usually for construction or navigational purposes), in an area or down to a level (relative to Ordnance Datum) not previously dredged during the preceding 10 years.
Capping	The controlled, accurate placement of contaminated material at an open-water site, followed by a covering or cap of clean isolating material.
Cement	A hydraulic binder.

Term	Definition
Chromium suite	In acid sulfate soils analysis, a suite of tests used to characterise the net acidity of a soil. The suite centres on the use of the chromium-reducible sulfur measure for potential acidity, along with a number of tests for other forms of acidity depending on the soil pH (TAA for actual acidity, S_{NAS} for retained acidity, and a choice of several ANC methods for acid neutralising capacity). See the latest version of the Laboratory Methods Guidelines or AS 4969 for further information.
Coastal zone	Includes coastal waters and the adjacent shorelands designated by a State as being included within its approved coastal zone management program. The coastal zone may include open waters, estuaries, bays, inlets, lagoons, marshes, swamps, mangroves, beaches, dunes, bluffs, and coastal uplands. Coastal-zone uses can include housing, recreation, wildlife habitat, resource extraction, fishing, aquaculture, transportation, energy generation, commercial development, and waste disposal.
COC	Contaminant of concern.
Conceptual model	A simplified representation of how a real system is believed to behave based on a qualitative analysis of data. A quantitative conceptual model includes preliminary calculations for key processes.
Confined disposal facility (CDF)	An engineered structure for containment of dredged material consisting of dikes or other structures that enclose a disposal area above any adjacent water surface, isolating the dredged material from adjacent waters during placement. Other terms used for CDFs that appear in the literature include "confined disposal area," "confined disposal site," and "dredged material containment area."
Confined disposal	Placement of dredged material within dyked (embankment) nearshore or upland confined disposal facilities (CDFs) that enclose the disposal area above any adjacent water surface, isolating the dredged material from adjacent waters during placement. Confined disposal does not refer to subaqueous capping or contained aquatic disposal.
Contaminants	Biological or chemical substances or entities, not normally present in a system, capable of producing an adverse effect in a biological system, seriously injuring structure or function.
Contaminated sediment	A sediment containing chemical substances at concentrations above background concentrations and above the guideline values. For contaminated dredged materials are defined as those that have been demonstrated to cause an unacceptable adverse effect on human health or the environment.
Community	An assemblage of organisms characterised by a distinctive combination of species occupying a common environment and interacting with one another.
Control	Part of an experimental procedure that is ideally exactly like the treated part except that it is not subject to the test conditions. It is used as a standard of comparison, to check that the outcome of the experiment is a reflection of the test conditions and not of some unknown general factor.
Control sediment	A sediment that is sufficiently free of contaminants that it will not cause effects to test organisms. Generally, a control sediment will have physico-chemical parameters similar to those of the test sediments.
COPC	Contaminant of potential concern.
Detection limit	Method detection limit is the concentration of a substance which, when processed through the complete analytical method, produces a signal that has a 99% probability of being different from the blank.
Dewatering	The process of extracting water from a saturated soil or sediment.
Diffusion	The transport of contaminants by random molecular motion and turbulence, usually from an area of high concentration to an area of low concentration.
Dissolution	In chemistry, the process by which a solid material forms a homogenous mixture with a solvent.
Dispersion	The transport and dilution of contaminants and/or suspended particles in air or water by the combined effects of shear and diffusion.

Term	Definition
Disturbance	In terms of this document, disturbance includes dredging, and consists of (a) excavating or removing the soil; or (b) exposing the soil to air; or (c) changing the level of the groundwater.
Disposal site or area	A precise geographical area within which disposal of dredged material occurs.
DO	Dissolved oxygen.
DOC	Dissolved organic carbon.
Dredged material	Material which has been dredged from a water body, while the term sediment refers to material in a water body prior to the dredging process.
Dredging	An excavation activity or operation usually carried out at least partly underwater (generally in shallow water areas) with the purpose of removing bottom sediments and relocating them.
Effluent	Water that is discharged from a confined disposal facility during and as a result of the filling or placement of dredged material.
Eh	Redox potential.
Environmental harm	Any adverse effect or potential adverse effect (whether temporary or permanent and of whatever magnitude, frequency or duration) on an environmental value, and includes environmental nuisance.
Environmental management plan	A document detailing the management procedures for a development with the goal of meeting the general environmental duty under an Environmental Protection Act. While non-statutory, these may be requested by an assessment manager as a condition of development approval.
Existing acidity	In acid base accounting, a collective term that includes actual acidity and retained acidity.
Geomorphology	The science that treats the general configuration of the Earth's surface; specifically, the study of the classification, description, nature, origin, and development of present landforms and their relationship to underlying structures, and of the history of geologic changes as recorded by these surface features.
Groundwater	Subsurface water in the zone of saturation, including water below the watertable and water occupying cavities, pores and openings in underlying soil and rock.
Guideline	Numerical concentration limit or narrative statement to support and maintain a designated water use.
Habitat	The specific area or environment in which a particular type of plant or animal lives. An organism's habitat provides all of the basic requirements for the maintenance of life. Typical coastal habitats include beaches, marshes, rocky shores, bottom sediments, mudflats, and the water itself.
Hydrated lime	The results of the controlled slaking of quicklime to produce a dried powder. They may also be referred to as calcium hydroxides or slaked limes.
Hydrogen sulfide	A gas with the formula H_2S , released from anaerobic systems as a metabolic by-product. Commonly known as 'rotten egg gas' due to its smell.
Hydrology	The characteristics of water and the study thereof.
Hypersulfidic	In relation to ASS, refers to sulfidic soil material that is capable of severe acidification (pH less than 4) as a result of oxidation of contained sulfides.
Hyposulfidic	In relation to ASS, refers to sulfidic soil material that is not capable of severe acidification (pH less than 4) as a result of oxidation of contained sulfides. Materials were previously referred to as potential acid sulfate soils (PASS) previously.
Impact	Environmental change (usually biological) that has occurred as a result of dredging activity. The extent of the change may be considered unacceptable and may require some intervention by regulatory authorities.

Term	Definition
Index (indices)	Composite value(s) that can give a quick ranking to a waterbody or other ecosystem feature, derived via a formula that combines measurements of important ecosystem characteristics; typically used to rank 'health' or naturalness.
Indicator	Measurement parameter or combination of parameters that can be used to assess the quality of water.
Infauna	Aquatic animals, such as clams or burrowing worms, which live in the sediment.
Infrastructure	The basic facilities and support systems underpinning urban areas, for instance water, power, sewerage and transport networks. Infrastructure can include services and institutional arrangements, but in the context of this document only refers to physical structures like roads and pipelines.
Leachate	Water or any other liquid that may contain dissolved (leached) soluble materials, such as organic salts and mineral salts, derived from a solid material. For example, rainwater that percolates through a confined disposal facility and picks up dissolved contaminants is considered leachate.
Level of protection	The acceptable level of change from a defined reference condition.
Lime	A general term for the various forms of calcium oxide and/or hydroxide.
Maintenance dredging	Dredging that is required to maintain water depths in areas where sedimentation occurs (for example in ports and marinas to maintain safe, navigable channels and berths). It involves the removal of recent unconsolidated sediments, such as mud, sand and gravel. It generally consists of cycles or a series of repeat dredges. It is usually from an area where the level of the river or seabed to be achieved by the dredging proposed is not lower (relative to Ordnance Datum), than it has been at any time during the preceding 10 years; or from an area for which there is evidence that dredging has previously been undertaken to that level (or lower) during that period.
Measurement parameter	Any parameter or variable that is measured to find something out about an environment or ecosystem.
Milk of lime	A suspension of hydrated lime and water.
Mobilise (of metals)	Where the naturally occurring metals in soil or sediment are changed from an insoluble to a soluble state.
mol H ⁺ /tonne	A measure of acidity, expressed as the number of moles of hydrogen cations per tonne of oven-dry soil material. A mole is 6.022x10 ²³ atoms of a given substance. The term can also be used as an 'equivalent acidity unit' when comparing the results of tests expressed in other units, such as when doing acid base accounting.
Monosulfidic	In relation to ASS, refers to soil material containing greater than or equal to 0.01% acid volatile sulfide (AVS).
Monosulfidic black ooze (MBO)	Amorphous gels that contain high concentrations of iron monosulfide minerals (general formula FeS). These minerals form in the base of low-flow surface water bodies in acid sulfate soil-influenced environments. MBOs are highly reactive in the presence of oxygen, breaking down in a matter of minutes to produce free iron and acidity. The reactions are controlled by the presence of oxygen in the water, and their disturbance can cause significant deoxygenation events in natural waters, killing aquatic life. MBOs may sometimes be referred to as iron monosulfides, monosulfides or acid volatile sulfides. MBO formation is considered a precursor to biogenic pyrite formation, and thus formation of ASS.
Neutralising	The process whereby acid produced (by the oxidation of iron sulfides) is counteracted by the addition of an ameliorant such as lime (CaCO ₃); there are formulae for calculating the amount of ameliorant needed.
NEPM	National environmental protection measure.
NTU	Nephelometric turbidity units, the most commonly used units for measurement of turbidity.
NWQMS	National Water Quality Management Strategy.

Term	Definition
Open-water disposal	Placement of dredged material in rivers, lakes, estuaries, or oceans via pipeline or surface release from hopper dredges or barges.
Organism	Any living animal or plant; anything capable of carrying on life processes.
Overlying water	The water above the sediment at a collection site or in a test chamber.
Oxidation	The combination of oxygen with a substance, or the removal of hydrogen from it; or, more generally, any reaction in which an atom loses electrons.
Oxidised	A process of chemical change involving the addition of oxygen following exposure to air.
Pathway (abiotic)	A route by which contaminants may move through the environment.
Pathway (biotic)	A route by which contaminants may be taken up by plants or organisms.
Pollution	Human introduction, directly or indirectly, of substances or energy into aquatic environments resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities such as fishing, the impairment of quality for use of the water and the reduction of amenities.
Potential acidity	Acidity associated with the complete oxidation of sulfides (mainly pyrite) – that is, the maximum theoretical amount of acidity that could be produced if all the pyrite in the soil oxidised. In an acid sulfate soils context, potential acidity is operationally defined by either the chromium-reducible sulfur method or the peroxide-oxidisable sulfur method.
Potential ASS (PASS)	See Hyposulfidic.
pH	The intensity of the acidic or basic character of a solution, defined as the negative logarithm of the hydrogen ion concentration of a solution. Used as a measure of the acidity or alkalinity of a soil or water body on a logarithmic scale of 0 to 14; a pH less than 7 is acid, pH 7 is neutral, and pH greater than 7 is alkaline. Note that one unit change in pH is a ten-fold change in acidity.
pH _{KCl}	The pH (measure of acidity or alkalinity) of a suspension prepared in the laboratory involving 1:40 (weight/volume) soil in a solution of 1 M potassium chloride.
Phase	Distinct state of matter (solid, liquid or gas) which in aquatic systems comprises sediment, water and air.
Pore water	The water that occupies the space between and surrounding individual sediment particles in an aquatic sediment (often called interstitial water).
Potential acid sulfate soils (PASS)	See Sulfuric.
Proponent	The agency or organisation proposing any dredging or disposal operation.
Pyrite	pale-bronze or brass-yellow, isometric mineral: FeS ₂ ; the most widespread and abundant of the sulfide minerals.
QA/QC	Quality assurance/quality control.
Quality assurance (QA)	The implementation of checks on the success of quality control (for example replicate samples, analysis of samples of known concentration).
Quality control (QC)	The implementation of procedures to maximise the integrity of monitoring data (for example cleaning procedures, contamination avoidance, sample preservation methods).
Quick lime	consists mainly of calcium oxide and magnesium oxide produced by calcination of limestone and/or dolomitic rock.
Receptor	A plant or animal that may be exposed to a stressor.
Recolonisation	A manipulative field experiment to test location-specific relationships, studying the organisms that colonise sediments that have previously been defaunated.
Redox	Simultaneous (chemical) reduction and oxidation; reduction is the transfer of electrons to an atom or molecule, whereas oxidation is the removal of electrons from an atom or molecule.

Term	Definition
Redox potential	A measure of the oxidation–reduction potential (ORP) of sediments. The redox potential is often reported as Eh (versus the normal hydrogen electrode).
Reference condition	An environmental quality or condition that is defined from as many similar systems as possible (including historical data) and used as a benchmark for determining the environmental quality or condition to be achieved and/or maintained in a particular system of equivalent type.
Risk	A statistical concept defined as the expected frequency or probability of undesirable effects resulting from a specified exposure to known or potential environmental concentrations of a material, organism or condition. A material is considered safe if the risks associated with its exposure are judged to be acceptable. Estimates of risk may be expressed in absolute or relative terms. Absolute risk is the excess risk due to exposure. Relative risk is the ratio of the risk in the exposed population to the risk in the unexposed population.
Runoff	The liquid fraction of dredged material or the surface flow caused by precipitation on upland or nearshore dredged material disposal sites.
% S	A measure of reduced inorganic sulfur (using the S_{CR} or S_{POS} methods) expressed as a percentage of the weight of dry soil analysed. Can also be used as an 'equivalent sulfur unit' when comparing the results of tests expressed in other units, or when doing acid base accounting.
Salinity	The presence of soluble salts in water or soils.
Sediment	Unconsolidated mineral and organic particulate material that has settled to the bottom of aquatic environments. The term dredged material refers to material which has been dredged from a water body, while the term sediment refers to material in a water body prior to the dredging process.
Soil and sediment	The natural accumulation of unconsolidated mineral particles (derived from weathered rocks) and organic matter that covers much of the earth's surface. The chemical and physical composition varies greatly between soil and sediment types. Clays, silts, sands, gravels, peats, muds and indurated sands (for example 'coffee rock') are all examples of soil and sediment.
Solidification	The addition of reagents to a contaminated material to impart physical/dimensional stability to contain contaminants in a solid product and reduce access by external agents (for example air, rainfall). It may not involve chemical interaction between contaminants and the solidification agent.
Solubility	In chemistry, how easily a substance will dissolve into a homogeneous solution, and also how much of a substance can dissolve into a solvent before saturation is reached. Solubility in water is the most common measurement, and the most relevant to ASS management.
Speciation	Measurement of different chemical forms or species of an element in a solution or solid.
Species	Generally regarded as a group of organisms that resemble each other to a greater degree than members of other groups and that form a reproductively isolated group that will not normally breed with members of another group. (Chemical species are differing compounds of an element.).
SPOCAS	The 'suspension peroxide oxidation combined acidity and sulfur' method, a peroxide- based method of measuring the acid-generating potential of an acid sulfate soil. The SPOCAS suite is a set of analytical results and derived calculations from the method that allow calculation of net acidity. An alternative to the chromium suite. See the Laboratory Methods Guidelines or AS 4969 for more information.
Spoil	Material obtained by dredging.
Spoil ground	Location at which dredged material is disposed in an aquatic environment.

Term	Definition
Stabilisation	It involves the addition of reagents to a contaminated material (for example soil or sludge) to produce more chemically stable constituents. It may not result in improved physical material characteristics, but the toxicity or mobility of the hazardous constituents will have been reduced.
Statistical power	The ability of a statistical test to detect an effect given that the effect actually exists.
Stressors	The physical, chemical or biological factors that can cause an adverse effect on an aquatic ecosystem as measured by the condition indicators.
Sulfide	A compound containing the –S functional group, or the S ²⁻ anion itself. The terms ‘sulfides’ and ‘sulfidic’ are used more generally throughout this document to refer to all the inorganic sulfur-containing minerals and precipitates involved in acid sulfate soils chemistry.
Sulfidic	In relation to ASS, refers to soils containing detectable sulfide, with the following sub-division.
Sulfuric	In relation to ASS, refers to soil material that has a pH less than 4 (1:1 by weight in water, or in a minimum of water to permit measurement) when measured in dry season conditions as a result of the oxidation of sulfidic materials. Materials were previously referred to as actual acid sulfate soils (AASS).
Sulfuric acid	A compound with the formula H ₂ SO ₄ . A strong mineral acid that is highly soluble in water, it is a principal breakdown product of the oxidation of pyrite.
Suspended solids	Organic or inorganic particles that are suspended in water. The term includes sand, silt, and clay particles as well as other solids, such as biological material, suspended in the water column.
TOC	Total organic carbon.
Toxicant	A chemical capable of producing an adverse response (effect) in a biological system, seriously injuring structure or function or producing death. Examples include pesticides, heavy metals and biotoxins.
Toxicity	The inherent potential or capacity of a material to cause adverse effects in a living organism.
Treatment pad	Area where soils are treated during neutralisation on which a guard layer is spread before the placement of the soils or sediment.
Turbidity	An optical measure of the amount of material suspended in the water (water clarity). Increasing the turbidity of the water decreases the amount of light that penetrates the water column.
Uptake	A process by which materials are absorbed and incorporated into a living organism.
Vadose zone	A subsurface zone that is unsaturated and aerobic, containing capillary water and air or gases at atmospheric pressure.
Volatiles	Chemical substances which move from solid or liquid substrates into the atmosphere.
Wetlands	Areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support and that, under normal circumstances, do support a prevalence of vegetation typically adapted for life in saturated-soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.
WQGV	Water quality guideline value.
Zoning	To designate, by ordinances, areas of land reserved and regulated for specific land uses.

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