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Department of **Water and Environmental Regulation**

Department of **Primary Industries and Regional Development**

Sediments of the Vasse Estuary exit channel

A study of the characteristics and feasibility of removing sediments

Revitalising Geographe Waterways

VASSE taskFORCE

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Department of Water and Environmental Regulation

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Cover photograph: Aerial view of the Vasse estuary and surge barrier looking west towards Busselton.

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The *Sediments of the Vasse Estuary exit channel* study was initiated in response to concerns regarding the potential role of accumulated sediment as a contributing factor to poor water quality, unpleasant odour and mass fish kills within the Vasse Estuary exit channel. The study was undertaken by the Department of Water and Environmental Regulation (DWER) as part of the Revitalising Geographe Waterways program, which aims to improve the water quality, waterway health and management of Geographe waterways.

The aims of the study were to:

1. Determine the volume and composition of sediment within the Vasse Estuary exit channel by field investigations.
2. Evaluate the feasibility of removing sediment from portions of the channel using a range of sediment removal techniques.
3. Evaluate a trial technique under consideration via a small-scale case study of sediment removal upstream of the Vasse surge barrier by the Water Corporation.

Field investigations

The key findings from the sediment field investigations undertaken in the Vasse Estuary exit channel were as follows:

- A layer of sulfidic black ooze[1] was identified along the length of the exit channel but the depth of this layer was highly variable. Throughout much of the channel, this layer was only 10–20 cm deep; however, the accumulation was deeper in two main areas:
    - About 300 m^3 of sulfidic black ooze immediately upstream of the Vasse surge barrier. This layer occupied a small area but ranged in depth from 60 cm to 1 m deep.
    - About 3000 m^3 of sulfidic black ooze at the opposite end of the channel near Estuary View Drive. This was a 30 cm layer but occupied a large area of the channel. A clay layer of equivalent thickness and volume was also found below the sulfidic black ooze layer. The layer of clay was not considered to be problematic.
- While sediments in the channel that were characterised as sulfidic black ooze had the potential to form sulfuric acid when exposed to oxygen, they also had a high acid

[1] The term black sulfidic ooze has been used in this report rather than monosulfidic black ooze (MBO). The term black sulfidic ooze refers to black sediment with a high acid volatile sulfur (AVS) content and a fine grain size. The measurement of AVS includes different sulfide species and, although monosulfides typically represent a large fraction of this group, other unstable species such as dissolved sulfides may also be present in significant amounts (Rickard 2005).

neutralising capacity arising from materials such as carbonates and seawater. While precautionary liming of these sediments would be recommended if they were to be removed (resulting in exposure to air), only a low level of treatment would be required.

- The chemical analysis results did not raise any significant contamination issues. The concentration of metals, polyaromatic hydrocarbons and pesticides were either not detectable or below thresholds required for disposal to a Class 3 landfill facility, and were below the Australian and New Zealand Environment and Conservation Council's 'ISQG-low' criteria for estuarine sediments. If disposal of sediment to a Class 2 landfill facility were required, further leachate testing will be needed. The City of Busselton waste disposal facility at Vidler Road, Naturaliste, is currently transitioning from a Class 2 to a Class 3 facility.
- The sulfidic black ooze upstream of the surge barrier had characteristics that were likely to lower dissolved oxygen in the water column and could contribute to hydrogen sulfide odour in the area. Furthermore, these sediments were also likely to release dissolved inorganic phosphorus into the water when oxygen levels were low. Data from regular monitoring indicated that these sediments appeared to adversely affect water quality near the surge barrier.
- The sulfidic black ooze layer near Estuary View Drive had characteristics that were likely to contribute to hydrogen sulfide odour in the area. This is likely to be exacerbated when water levels are low enough to expose sediments. Other sources of odour, such as floating algae that rots at the edge of the water nearby, are unlikely to be resolved by removal of sediment. These processes may have contributed to the accumulation of sulfidic black ooze near Estuary View Drive and are expected to continue regardless of whether sediment is removed or not.
- It was unclear whether sediments near Estuary View Drive contributed to low oxygen conditions in the water column since very shallow water conditions have prevented regular measurement of dissolved oxygen at this location.

Feasibility assessment

Seven sediment removal techniques were evaluated for their potential to remove sediment from the Vasse Estuary exit channel. The seven options included:

  - Dredge to geotextile bags
  - Drainage and excavation
  - Dredge to sand dam
  - Dredge to drying ponds
  - Mechanically suspend and flush to the ocean via Wonnerup Inlet
  - Dredge directly to Geographe Bay
  - Suction pump to tankers and transport to the wastewater treatment plant (WWTP)

Characteristics of the Vasse Estuary exit channel that require specific consideration when evaluating the feasibility of sediment removal were:

- Physical space available for dewatering sediment – there is generally limited space on the foreshore of the channel.
- Ecological sensitivity and the Ramsar obligations – the channel forms part of the Ramsar listed area of the Vasse Wonnerup wetlands. Works that cause substantial disturbance to waterbirds or impact on the character of the wetlands would require formal assessment under the *Environmental Protection and Biodiversity Conservation Act 1999*.
- The need to minimise the risk of fish kills resulting from sediment removal works – that is, prevent further deterioration of water quality during summer and autumn and enable free movement of fish during the same season. The risk of a fish kill at this time of year is generally higher.
- Potential impacts on neighbours – although adjoining neighbours may be supportive of attempts to address water quality and odour problems in the estuary, they may also be unsupportive of techniques that result in excess noise, infrastructure, traffic disruption and odour during the works.

Sediment removal options were examined using criteria that included environmental risk, potential impacts on neighbours and technical feasibility. The preferred option for future sediment removal was identified as dredging to geotextile bags. This option was preferred as environmental risks were considered manageable for small projects, and there are likely to be fewer technical constraints and impacts on neighbours. A winter removal option would be available with this technique; however, the only available space to lay geotextile bags for dewatering is the public foreshore area of James Richardson Park, which adjoins Estuary View Drive.

An informal community meeting was held with residents of Estuary View Drive in May 2018 to gauge potential community response to the concept of using James Richardson Park for dewatering of sediments with geotextile bags. Attendees were generally positive, although some commented that their support was dependent on the works actually solving odour issues at this location.

Case study

In May–June 2017, the Water Corporation responded to the results of the field investigations that showed sulfidic black ooze sediments at the surge barrier were likely to be negatively impacting on water quality.

$100 000 was committed for removal of a small volume (< 300 m^3) of sediment at the Vasse surge barrier. A suction pump mounted on a floating pontoon was used to pump sediment slurry into tankers for transport to the Busselton wastewater treatment plant. Here, it was added to sewage effluent ponds for drying and disposal. There were no negative water quality or social impact consequences observed from these works.

Unfortunately, a low efficiency of removal was achieved with the use of the sump pump since a large amount of water was transported with the sediment. The Water Corporation completed their own pre- and post-sediment surveys and estimated that 119 m^3 of sludge was removed from an estimated original volume of 216 m^3. The balance of the 300 m^3

sediment is believed to have shifted in distribution when the prop gates were opened in May 2017.A small dredge is likely to achieve an improved removal efficiency, although dredging could also result in a higher degree of turbidity and possibly lower oxygen levels in the channel during the works.

Key recommendations

The following key recommendations arise from the need to slow down the formation and accumulation of sulfidic black ooze, monitor potential water quality and odour issues, and enact management of existing sulfidic black ooze accumulations where there are likely to be clear benefits:

- Regular (as needed) removal of floating organic matter such as macroalgae or phytoplankton scum that accumulates upstream of the Vasse surge barrier to reduce the rate of sediment accumulation at the surge barrier.
- Regular maintenance (every 5–10 years) to remove sulfidic black ooze from the immediate area on the upstream side of the Vasse surge barrier to ensure large sediment accumulations do not persist at this location.
- Continued monitoring of water quality, sediment accumulation and community perceptions of odour in the Vasse Estuary exit channel so that management may be adjusted as these aspects change over time.
- Extend the existing water quality monitoring program to include the Estuary View Drive area (when water levels permit) to provide a more robust assessment of this area.
- If, in the future, it is not possible to manage hydrogen sulfide odour from the Estuary View Drive area by keeping sediments inundated, consider removal of sediment from this area in the medium to long term. A winter/spring project using a micro dredge with sediment to be dewatered using geotextile bags is the preferred removal technique under this scenario. The use of this technique to remove the large accumulation of sediment near Estuary View Drive is likely to cost between $300 000 and $600 000, including further testing and approvals, removal, monitoring and disposal.
- Future sediment removal proposals would require further sampling to meet approval requirements in addition to consultation with Indigenous groups and the wider community.

1 Introduction

1.1 Project aims

As for many other estuaries and waterways in Western Australia, there have at times been community requests to remove sediments from the Vasse Estuary exit channel in order to improve water quality. The *Sediments of the Vasse Estuary exit channel* study was undertaken in response to these requests and as a further step to help inform management decisions that address the issue of poor water quality in the Vasse Estuary exit channel.

The study was not designed as an approval mechanism for the large-scale removal of sediment from the exit channel. Rather, it was intended to examine whether it was technically feasible to remove sediments from the channel. If sediment were proposed to be removed from the channel, then further sampling will be required to comply with state and Commonwealth approvals processes related to dredging and disposal of estuarine sediments and management of potential impacts on the Vasse Wonnerup Wetlands Ramsar-listed site.

The specific aims of the study were to:

a) determine the volume and composition of sediment within the Vasse Estuary exit channel by field investigations

b) evaluate the feasibility of a range of options for removal of sediment from portions of the channel

c) evaluate a trial technique under consideration by monitoring a small-scale removal of sediment (<200 m^3) immediately upstream of the Vasse surge barrier by the Water Corporation.

1.2 Why were sediments being investigated?

The Vasse Estuary exit channel has experienced severe water quality problems during summer for many decades. These have included regular toxic phytoplankton blooms, hydrogen sulfide odour, low oxygen conditions and mass fish kills (DOW 2010). The build-up of sulfidic sediment rich in organic matter in the channel upstream of the Vasse surge barrier is believed to be one of the factors contributing to these problems. An ecological character description prepared for the Ramsar site in 2007 recommended that dredging of the lower reaches of the exit channel be investigated to help address noxious gas release from the sediments (Wetland Research and Management 2007).

Estuaries are naturally a highly productive environment where organic matter from macroalgae, phytoplankton and fringing plant material tends to accumulate. The Vasse Estuary receives a large catchment load of nutrients from fertilisers, stock farming and a growing component of urban sources. These nutrients provide fuel for large blooms of macroalgae and phytoplankton, which in turn add to the sediment layer within the estuary as they decompose.

Historically, management priority has been placed on addressing catchment sources of nutrients to the estuary. Over the past few decades, substantial action has occurred to address these large catchment sources, including fertiliser management, dairy effluent upgrades, restoration of rivers, and community awareness programs to reduce nutrient transport to the wetlands. In addition, trials to examine the benefits of allowing more sea water into the channel have been undertaken, and a purpose-built oxygenation plant has been used to oxygenate water in the channel over the summer/autumn period. Developing an understanding of how to manage sediments to improve water quality complements these catchment-based and engineering initiatives. The need to remove sediments from the exit channel or not is likely to depend on the future success of these other techniques at alleviating water quality and odour problems in the channel.

1.3 How can sediments contribute to water quality issues?

As algal blooms within estuaries decompose, most of the oxygen within the sediment and water layer above it is consumed by the microbes that degrade the organic matter. This generates low oxygen conditions, and microbes that do not require oxygen take on the task of degrading the remaining organic material within the sediments. In estuarine and marine sediments, the most important of these microbes are typically sulfate-reducing bacteria, which use sulfate from sea water instead of oxygen and produce toxic gases, such as hydrogen sulfide, that also have an unpleasant odour. The accumulation of sulfidic sediments (referred to in this report as sulfidic black ooze) occurs when dissolved iron and other metals form sulfide minerals with some of the hydrogen sulfide.

Large accumulations of sulfidic black ooze can have a negative impact on water quality, can affect water flows and may also cause problems during dredging and land-based disposal. Under low oxygen conditions, nutrient-enriched sediment can release nutrients back into the water column, contributing to further algal blooms (Diaz 2008, Cloern 2001, Froelich 1979) and has been observed in the Vasse Estuary exit channel (DWER In preparation). The sulfides and organic matter within sulfidic black ooze also rapidly consume oxygen from the water when these sediments are disturbed by wind, flow or during dredging, thereby increasing the risk of fish kills. Furthermore, sulfidic black ooze has the potential to generate sulfuric acid when exposed to oxygen and therefore is a potential acid sulfate soil. This is particularly relevant when considering land-based disposal after dredging. Special management of drainage water and the addition of lime to neutralise the acid may be required.

The Australian government has recently published a guidance document on the management of monosulfidic black ooze accumulations in waterways and wetlands (Sullivan et al. 2018). This document states clearly that the development of techniques for the long-term management and/or removal of these sediments is still in its infancy. These and all other guidance documents relating to acid sulfate soils state that sulfidic sediments should not be disturbed where possible. But there are some qualifiers. In particular, it is clear that management of sulfidic sediments becomes much more difficult as their volumes accumulate. There is general agreement that management should therefore focus on the prevention or the slowing of these accumulations. At the Vasse surge barrier, such an approach could feasibly include regular removal of small accumulations of sulfidic sediment combined with the existing practices of removing floating surface algae/scums and improving water exchange by opening the surge barrier when possible.

2 The Vasse Estuary exit channel

2.1 Location and hydrology

The Vasse Estuary exit channel is located where the estuary narrows and bends to the north-east in the vicinity of Estuary View Drive, and extends for about 1600 m until it concludes at the Vasse surge barrier (Figure 1 and Figure 2). Two long, narrow islands dissect the south-western portion of the channel. The width of the main channel is about 30–40 m but this narrows to 10 m near one of the islands and widens to about 60 m near Estuary View Drive. Downstream of the Vasse surge barrier is Wonnerup Inlet, which also receives water from the Wonnerup Estuary before discharging to Geographe Bay.

The existing surge barrier at the lower end of the channel was constructed in 2004 to replace the previous ageing wooden floodgate originally built in 1908, and subject to various upgrades and repairs during the intervening years. The original floodgates that were built on the exit channels of both the Vasse and the Wonnerup estuaries enabled outflow of water, but not inflow, thereby allowing storage of floodwater and preventing seawater incursion into the estuaries (Lane et al. 1997). These hydrological changes allowed farming of land surrounding the estuary that previously would have been too wet during winter and spring, and too salty during summer and autumn, and also protected Busselton from storm surges (Wetland Research and Management 2007). The existing surge barrier has been designed to enable both inflow and outflow of water and has a special mechanism to enable fish to pass upstream or downstream.

The Vasse Estuary receives surface water flow from the Lower Vasse, Lower Sabina and Abba rivers (Figure 2). Substantial hydrological changes were undertaken in the catchments of the estuary from the early 1900s onwards to provide flood protection for the Busselton townsite and to enable agricultural development. Land clearing, which began in the 1830s, resulted in much greater water yields so from 1900 onwards a network of artificial drains was constructed to alleviate waterlogging of farmland. In 1927 the Vasse Diversion Drain was constructed to reduce flooding of the Busselton township by diverting river flow to the ocean (GHD 2013). Similarly, the Upper Sabina River was diverted into the Sabina Diversion Drain, and then connects into the Vasse Diversion Drain. Today, flow from the upper catchments of both rivers is managed using valves so that 90 per cent of flow from the Upper Vasse and 60 per cent of flow from the Upper Sabina is diverted into Geographe Bay.

Figure 1 *The Vasse Estuary and its exit channel*

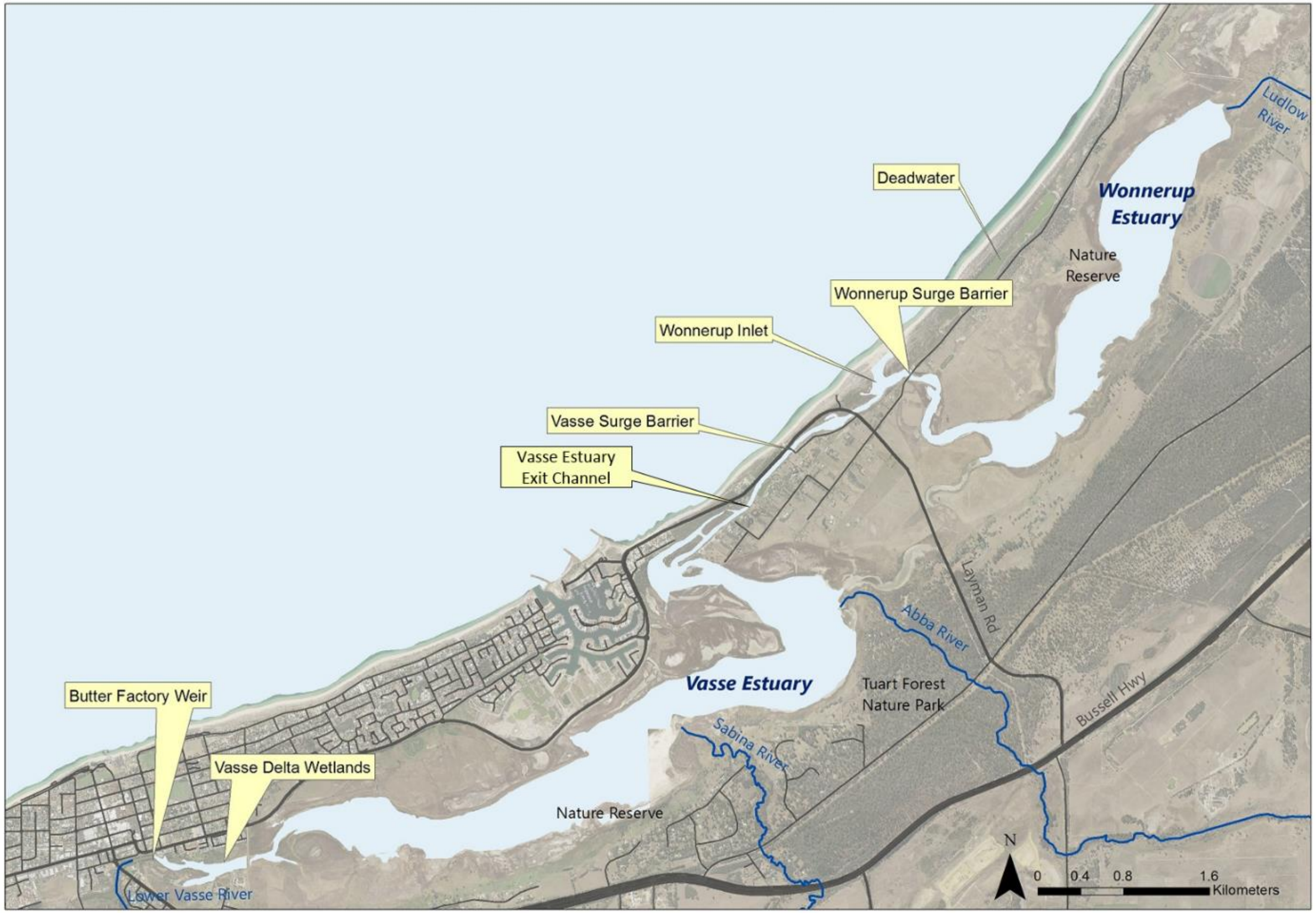


Figure 2 Components of the Vasse Wonnerup Wetlands system

2.2 Water quality issues

The Vasse Estuary exit channel occupies a small area of the Vasse Wonnerup Wetland system but is the location of some of the more severe water quality problems recorded in the system. Table 1 provides a summary of these issues.

Table 1 *Water quality issues in the Vasse Estuary exit channel*

Issue	Example photograph
Most known mass fish kill incidences in the Vasse Wonnerup Wetlands have been described as occurring within or close to the exit channel of the Vasse Estuary. The causes of these fish kills have been identified as low oxygen levels, toxic phytoplankton blooms or a combination of both.	
Floating blooms of macroalgae such as this *Ulva* bloom have a tendency to accumulate at the surge barrier and at the south end of the channel near Estuary View Drive. It is possible that south-westerly summer prevailing winds push floating material in towards the barrier and towards the northern banks. This material eventually sinks to the bottom of the channel and rots, adding organic content to the sediment layer and helping to form sulfidic black ooze. More recent management has involved regular suction and removal of floating material at the surge barrier to minimise the formation of nutrient-rich organic sediments forming via these processes.	
Scum from phytoplankton blooms tends to accumulate within the channel and particularly at the surge barrier. These scums are unsightly and contribute to odour problems as they collapse and decompose. At times, benthic scums (that have formed over the surface of sediments) have also risen to the surface, contributing to severe odour issues. Similar to floating macroalgae, they contribute to the accumulation and formation of sulfidic black ooze.	
Sulfidic black ooze sediments associated with strong hydrogen sulfide odour are present at the start of the exit channel near Estuary View Drive. Residents in this area have expressed concern over odour and poor visual amenity of these sediments for many years. The problem is exacerbated when water levels are very low. The shallow conditions around Estuary View Drive have precluded this site from the regular water quality monitoring program undertaken by DWER.	

2.3 Water quality monitoring

Dissolved oxygen

Monitoring of dissolved oxygen upstream of the Vasse surge barrier has been undertaken regularly in the Vasse Estuary exit channel since the summer of 2014 from two in situ probes that are logged at 15-minute intervals. Regular surface to bottom profiles of dissolved oxygen have also been taken over the past few years along the length of the exit channel in association with two separate seawater and oxygenation trials. This monitoring data has shown that dissolved oxygen levels are generally lower directly upstream of the Vasse surge barrier (Figure 3). The development of low dissolved oxygen water close to the surface near the surge barrier suggests extremely high oxygen demand from the sediments at this location.

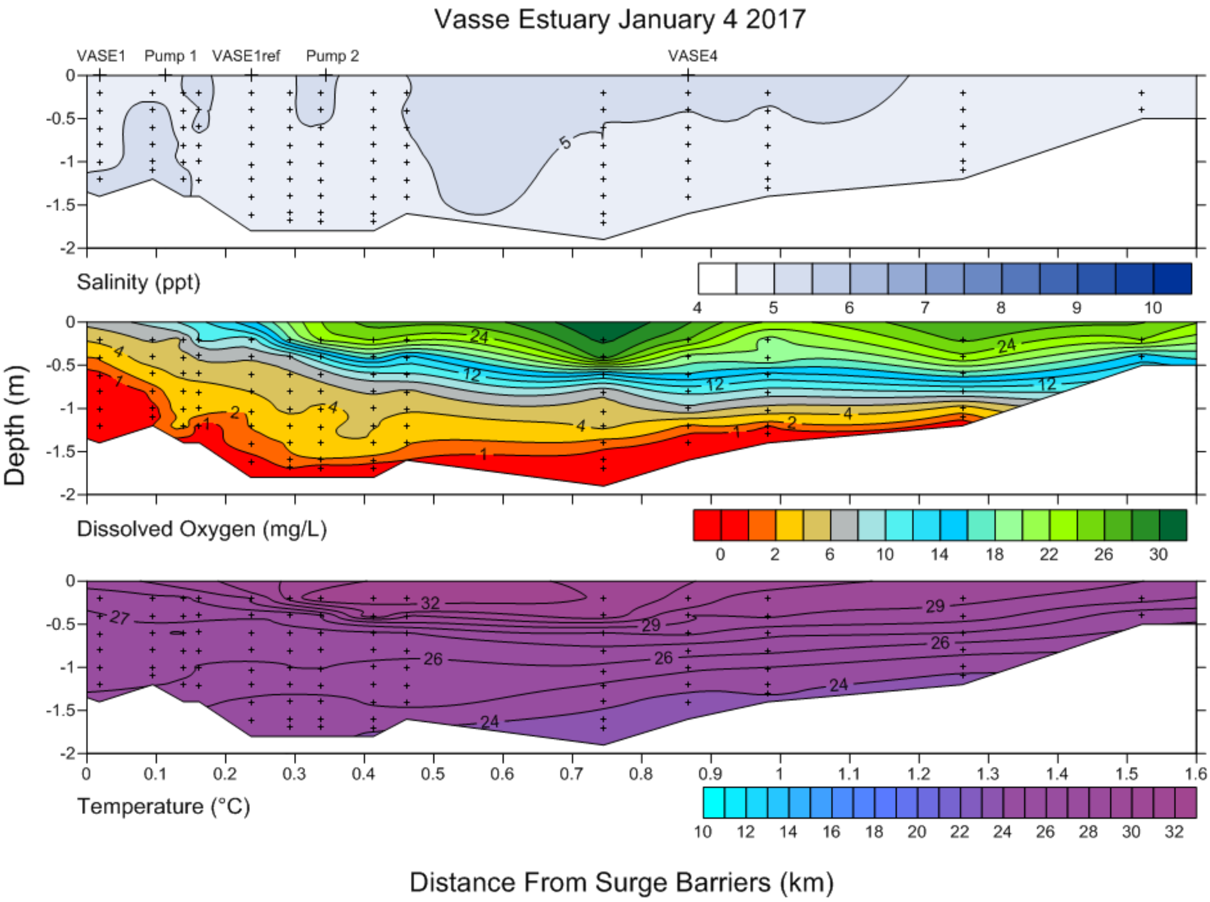


Figure 3 *Example of a profile of dissolved oxygen, temperature and salinity in the Vasse Estuary exit channel between the surge barrier to 1.6 km upstream showing low dissolved oxygen closer to the barrier*

Nutrient concentrations

The organic material that accumulates in sediments contains nutrients. When microbes degrade organic material, the nutrients are released. The nutrients can be stored in sediments over long periods of time in deeper layers after burial. However, in the surface sediment layer, they can be released back into the overlying water. Chemical reactions in the sediment change when no oxygen is present and nutrient release can be enhanced (Sundby 1986). There is evidence of enhanced nutrient release from the sediments in the Vasse channel when oxygen concentrations are low.

Nutrient concentrations in the water of the Vasse exit channel have been monitored regularly by DWER since 2014. Figure 4 shows the concentrations of ammonium and phosphate in surface and bottom waters in addition to phytoplankton cell counts of the Vasse exit channel over summer in 2016/17. Both are forms of nitrogen (ammonium) and phosphorus (phosphate), respectively, which are highly bioavailable and can be taken up immediately by phytoplankton and macroalgae to fuel their growth. The trigger values for south-west estuaries specified in the ANZECC guidelines are 0.04 mg/L for ammonium and 0.005 mg/L for phosphate (ANZECC and ARMCANZ, 2002). The measured nitrogen and phosphorus concentrations regularly exceed ANZECC threshold values significantly, particularly during summer. During winter, the ammonium and phosphate concentrations in the water were less extreme and more consistent than in summer and autumn when there were strong fluctuations with extremely high peak values followed by abrupt declines. These fluctuations were caused by extensive phytoplankton blooms that first consumed large amounts of these nutrients when growing, lowering their concentrations. Once the nutrients were used up, the blooms crashed and decomposed, removing oxygen from the water and releasing ammonium and phosphate from the sediment back into the water and causing the spikes. This in turn fuelled the next phytoplankton bloom.

The initial spike in ammonium and phosphate, which occurred in December after the first significant phytoplankton bloom for the season, was only observed in bottom waters but not in water closer to the surface. This suggests that the first spike in nutrients was released from sediments and then fuelled successive phytoplankton blooms. The first phytoplankton bloom was fuelled by nutrients from winter runoff, but successive blooms used nutrients that largely came from the sediments rather than from external nutrient sources. Throughout the cycling in summer, nutrient concentrations generally remained slightly higher in bottom waters compared to the surface water. This may indicate further nutrient release from sediments but it is also caused by the presence of phytoplankton in the surface water layer, which consumed the nutrients.

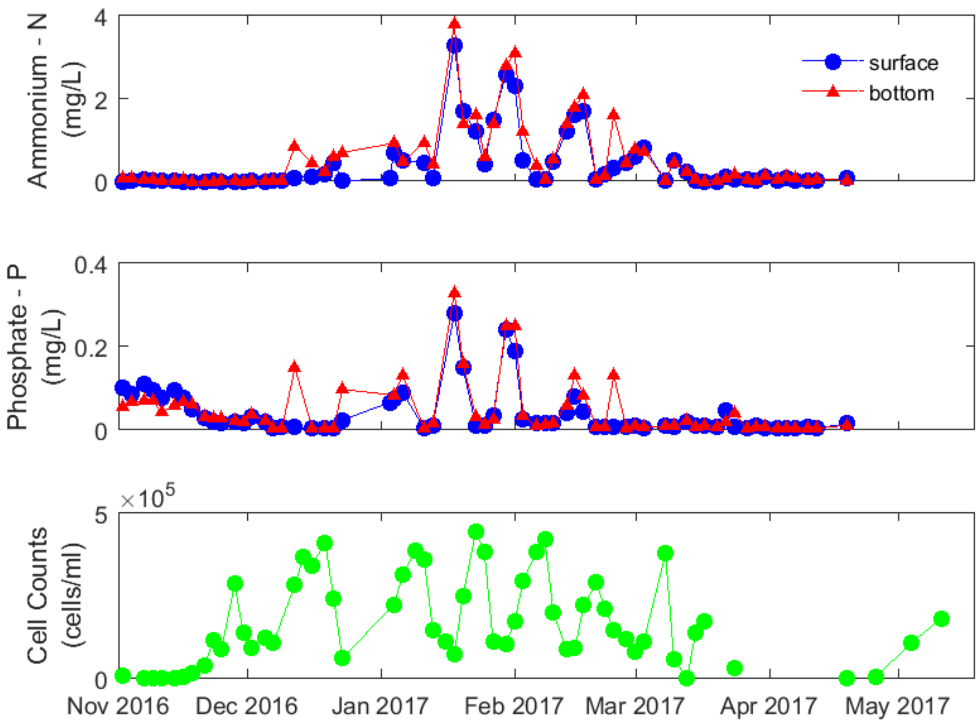


Figure 4 *Concentrations of ammonium and phosphate and cell counts of phytoplankton in the Vasse Estuary exit channel over summer 2016/17 (DWER in prep.)*

2.4 Fauna

The Vasse Estuary exit channel is part of the internationally significant and RAMSAR-listed Vasse Wonnerup Wetlands system. The Vasse Estuary exit channel is an important connection between the Vasse Estuary and Wonnerup Inlet, and Geographe Bay. Both waterbirds and fish use the channel at various times of the year. However, the abundance and diversity of macroinvertebrates and aquatic plants (macrophytes) are very low compared with other parts of the estuary. This is likely to be a result of frequent low oxygen conditions in the channel. Table 2 provides a brief summary of the existing knowledge regarding fauna in the channel.

Table 2 Summary of information regarding fauna values in Vasse Estuary exit channel

Fauna value	Example photograph
Fish The following fish species have either been recorded within the Vasse Estuary exit channel or within the wider estuary and are likely to use the channel: black bream, mullet, Swan River goby, western minnow and goldfish (introduced). The channel is a passageway between the wider Vasse Estuary and Wonnerup Inlet. Wonnerup Inlet is an important refuge area for black bream (Cottingham 2015). Large numbers of black bream and mullet have died in the exit channel as a result of very low oxygen conditions. The movement of these species between the inlet and the channel is being monitored by Murdoch University. (Photo by Stephen Beatty)	
Birds The channel is used by a variety of ducks (including musk duck, grey teal and Pacific black), hoary headed grebe, Eurasian coot great egret, little egret, pelican, dusky moorhen, spoonbill, cormorant, darter, whistling kite, osprey, sea eagle, nankeen night heron, white-faced heron, wedge-tailed eagle and seagulls (J. Brown (DWER, Busselton) 2018 pers. Comm; K. Williams (DBCA, Bunbury) 2018 pers. comm) In a typical year as water levels recede over summer, the shallow mudflats near Estuary View Drive are also used by shorebirds such as black-winged stilt, red-necked avocet and sharp-tailed sandpiper. Over the past two years, the summer water levels have been higher owing to changes in surge barrier management. The higher water levels have favoured late summer use of this zone by Pacific black duck. Shorebirds were not recorded in this area (K. Williams (DBCA Bunbury) 2018 pers. comm).	
Macroinvertebrates Murdoch University sampled macroinvertebrates in the channel in March 2017 and found it to be depauperate (lacking in numbers) in fauna, and was the only part of the estuary not to contain crustaceans. Only three species were recorded in the channel: two annelids: *Naididae* (formerly known as *Tubificidae)* sp. and *Capitella capitata,* and one mollusc: *Potamopyrgus* sp. (Tweedley and Cottingham 2019). There are numerous mounds of the tube worm *Ficopomatus enigmaticus* in the vicinity of Estuary View Drive (pictured right). These are exposed when water levels recede. It is unclear whether this species is native or exotic although it is known to filter-feed on phytoplankton and favours shallow, nutrient-enriched saline mudflats where water movement is restricted. These tube worms have a free-floating larvae phase and spawn several times a year (Dittman 2009).	

2.5 Past sediment studies

Before the current investigation, there was very little existing information about the quantity and quality of sediment in the exit channel of the Vasse Estuary. Most past sediment studies of the wetlands had either sampled only within the top 10 cm of sediment or had not sampled at all within exit channel. One past survey identified that accumulations of sulfidic black ooze were present within the lower reaches of the Vasse Estuary and at one site within Wonnerup Inlet (Ward et al. 2009).

Previous sampling of the surface sediments in the Vasse and Wonnerup estuaries by Wilson et al. (2008) found nutrients in the sediments of the wetland system considerably exceeded those of other overly enriched (eutrophied) estuaries in south-western WA (such as the Peel Harvey Estuary). The sites with the highest concentration of nutrients in both estuaries were located close to the gates of each lagoon where they bend and narrow.

Smith and Haese (2008) used benthic chamber experiments to assess the importance of sediments in the Vasse and Wonnerup exit channels as a source of nutrients. This study concluded that organic matter production in the Vasse Estuary exit channel appears to be driven by internal nutrient recycling, meaning that sediments are likely to be releasing nutrients back into the water column where they then provide food for further phytoplankton or macroalgae growth. This then adds to the organic matter in the sediment layer as blooms collapse and rot.

2.6 Removal of sediments during replacement of the floodgates in 2004

During 2004, the previous Vasse floodgates were replaced with the current surge barrier. As part of this process, sediment was removed from a 30 m section of the channel upstream and downstream of the existing surge barrier (R McClean pers. comm. 2016) (Figure 5 and Figure 6). This section was separated from the main body of the exit channel and Wonnerup Inlet via the construction of sand bunds to form a cofferdam. The area was then dewatered to a turkey nest dam (i.e. a dam built above natural ground level) that was constructed on leased private property adjoining the channel (Figure 5). Acid sulfate risks were managed by aeration, dosing with soda ash and letting sea water into the dewatering area. Dried and excavated sediment was trucked to the landfill in Busselton. As a result of these works, we can accurately conclude that within 30 m of the surge barrier, organic sediments that lie above the clean sand layer have accumulated over a 13-year period (from 2004 to 2017).

Figure 5 *Turkey nest dam constructed on the foreshore of the Vasse Estuary exit channel used for dewatering of the channel during the construction of the new surge barrier (Photo: R McClean)*

Figure 6 *Vasse surge barrier under construction. Previous sediment accumulation upstream had been removed using an excavator when this section of the channel was dewatered (Photo: R McClean)*

3 Part A: Field investigations

3.1 Methods

Sediment volume

A survey of sediment depth and volume in the Vasse Estuary exit channel was undertaken in November 2016. The estuary perimeter and survey bounds were established using satellite imagery and mapping software. A grid of 10 m wide and 20 m long cells was overlaid over the area to be surveyed. Two technicians were deployed in a twin-hulled craft, one reading the GPS to determine the grid locations; the other using a sediment corer consisting of a given diameter perspex tube with a valve at one end and a depth scale along its length. The corer was used to establish sediment depths by taking core samples at regular grid intervals (Figure 7) throughout the estuary. Georeferenced location data was recorded for each data point using a GPS. A base profile and a sediment profile of the estuary was generated using the GPS input information. These showed sediment depths and distribution along with the depths of the estuary. Total estuary and sediment volumes were then calculated from these data.

Figure 7 *Coloured points indicate the location of sediment cores taken to measure sediment depth. Points are coloured by water depth. White points indicate the sampling location of sediment (three replicate cores taken at each point)*

Sediment characteristics

Sediment core samples were taken at predetermined locations using a Uwitec sediment corer (Figure 8 and Figure 9). Three replicate cores were collected at each site to account for sediment variability and the results of chemical analysis were given as averages of these replicates. The samples were delivered to shore for processing. Before subsampling, each sediment core was photographed and the visible layers of sediments were described and recorded. A water layer within the core barrel prevented air contact with the sediment. Cores were processed as soon as possible after collection, not exceeding 1–2 hours of storage.

Each sediment core was subsampled for chemical analysis, including nutrient and organic carbon content and assessment of the presence of potential acid sulfate soils and acid volatile sulfur (AVS). AVS is the most unstable fraction of inorganic sulfides that is readily oxidised and poses most concern for oxygen depletion and acid generation. The sampling coordinates, list of parameters analysed and rationale for these is presented in Appendix A.

The number of subsamples collected from each core varied according to the depth of the sediment layer above the sandy base of the estuary. Where the sediment layer was less than 50 cm thick, sampling included the top 10 cm and the bottom 10 cm of that organic layer to produce two subsamples from these sites. Where the sediment layer was greater than 50 cm thick, subsampling occurred in three layers: the top and bottom 10 cm as well as a subsample in the midsection of the core.

Given that the sediment samples were suspected of containing high contents of AVS species, they required special preservation and handling techniques to limit their oxidation. These types of sediments are highly reactive and rapidly oxidise (within minutes) at room temperature when exposed to the atmosphere (Sullivan et al. in press). The Uwitec core extruder was used to collect the subsamples using a slicing device at specified depth intervals. The sample volumes required were 70 mL sediment in a tightly packed vial for sulfur parameters plus about 200 g of sediment in a double resealable plastic bag for the remaining analyses. Samples were transferred into the labelled plastic bags while keeping exposure to the air as short as possible. Air was removed and the bags closed while homogenising (mixing) the sample within the bag. The field pH within the sludge was measured using a calibrated pH probe, taking care to keep a seal around the probe by squeezing the plastic bag.

An aliquot of sediment was transferred into a 70 mL vial for sulfur analysis (tightly packed without headspace) and the vial put back into the plastic bag containing the rest of the sediment. The plastic bag was then resealed without any air inside. Immediately after collection, the vials and plastic bags were placed in a cooler containing ice slurry and then transferred to a freezer as soon as possible. Samples were transported to the laboratory frozen on an ice slurry.

Samples for pesticide herbicide and PAHs analyses (site VWSED2 only) were collected from additional cores, and transferred from the core slicer into 250 mL glass jars.

Figure 8 *Contractors collecting a core sample*

Figure 9 *Sediment core from VWSED6*

3.2 Results

Physical characteristics

Depth and volume of sediment

The depth of sediment accumulation along the Vasse Estuary exit channel was found to be highly variable. Zones of deep sediment were concentrated around site VWSED1 (10 m upstream of the floodgates) and at sites VWSED6 and VWSED7 near Estuary View Drive at the opposite end of the channel (Figure 10). The area between VWSED1 and VWSED4 (downstream of the islands) was relatively clear of sediment, with the accumulated layer less than 20 cm deep.

Estimates of sediment volume were made for specific areas of interest (Table 3). About 300 m^3 of black sulfidic ooze was found to have accumulated directly upstream of the Vasse surge barrier at site VWSED1. The deep accumulation near VWSED6 was about 6000 m^3 but consisted of two equal layers with different compositions. The top 30 cm of sediment comprised black sulfidic ooze material and a volume of about 3000 m^3. Below this black layer was red–brown mud, also with a volume of about 3000 m^3.

Table 3 Estimates of sediment volume from surveys of the Vasse Estuary exit channel

Site name	Site description	Estimated volume of sulfidic black ooze layer	Comment
VWSED1	Between surge barrier and 20 m upstream	300 m^3	Uniform composition of black sulfidic ooze to a depth of up to 1 m
VWSED6	Near Estuary View Drive	3000 m^3	Two distinct layers of sediment (total volume of both layers 6000 m^3). Top 30 cm comprised black sulfidic ooze, lower layer 30 cm red–brown mud
VWSED7	West of the northern-most channel island	600 m^3	Two distinct layers of sediment (total volume of both layers 1200 m^3). Top 30 cm comprised black sulfidic ooze, lower 30 cm red–brown mud

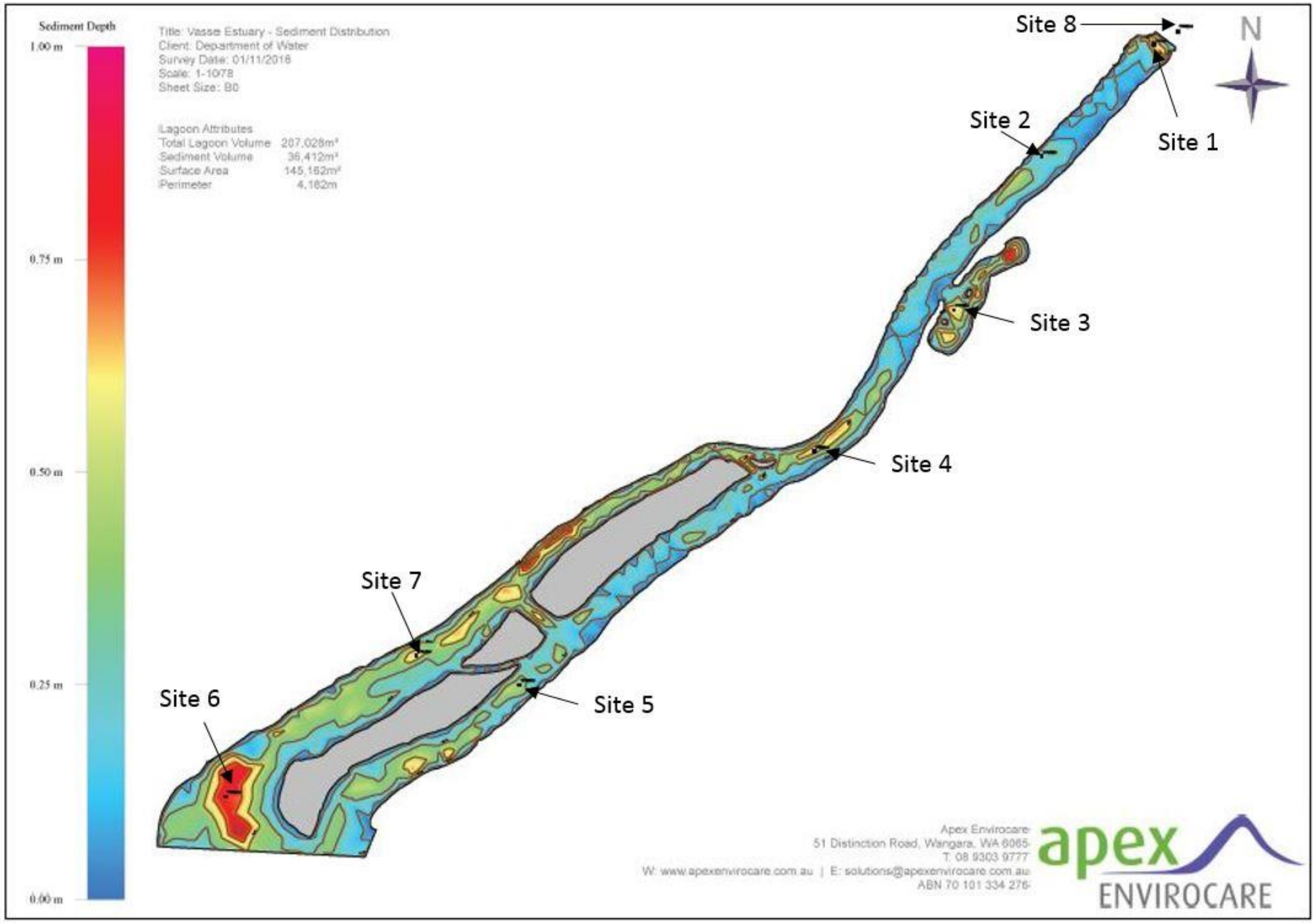


Figure 10 *Sediment depth profile and sampling locations in the Vasse Estuary exit channel. Sites 1 to 8 represent sites VWSED1 to VWSED8*

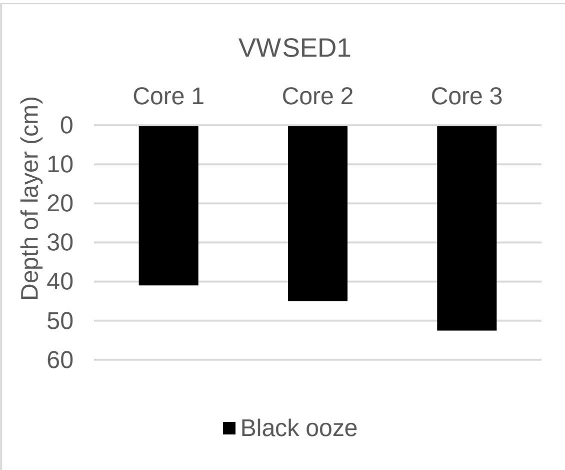
Sediment profiles

The visual profiles of sediment cores were graphed based on recorded observations and photos of each core (Figure 11a to 11h). A layer of black sulfidic ooze occurred at all sites, although the thickness of this layer varied across sites and was less than 20 cm deep at all sites, except VWSED1, VWSED5 and VWSED6, and in one core at VWSED8.

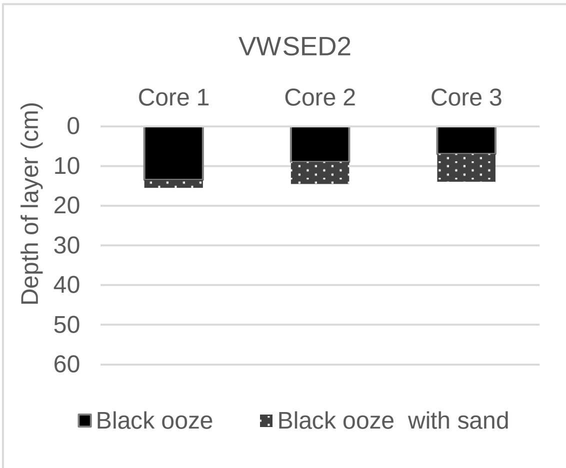
Site VWSED1, just upstream of the surge barrier, was the only site at which deep accumulations of sulfidic black ooze pervaded all the way through the sediment profile. Black sulfidic ooze at this site extended beyond 50 cm deep in the samples taken and was underlain by clean white sand. The composition of this mud was fairly uniform throughout the core profile with no other obvious layers visible.

Although sediment was very deep at sites VWSED6 and VWSED7, the black sulfidic ooze layer was only about 10–30 cm deep at these locations. Below this layer was a reddish-brown clay.

Sites VWSED4, VWSED6 and VWSED7 contained a lot of plant material mixed with the lower sediments. It was difficult to determine whether this was seagrass or other plant matter.

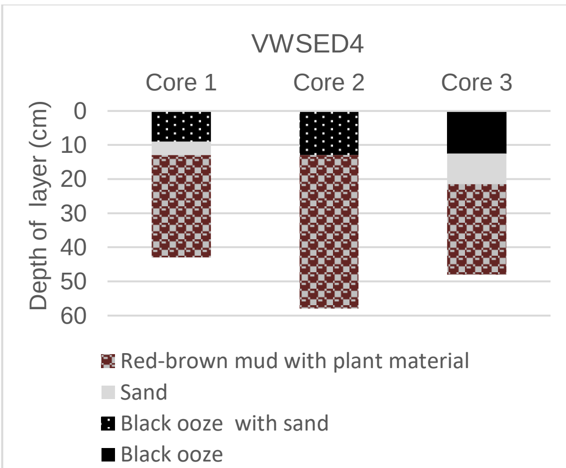


a)

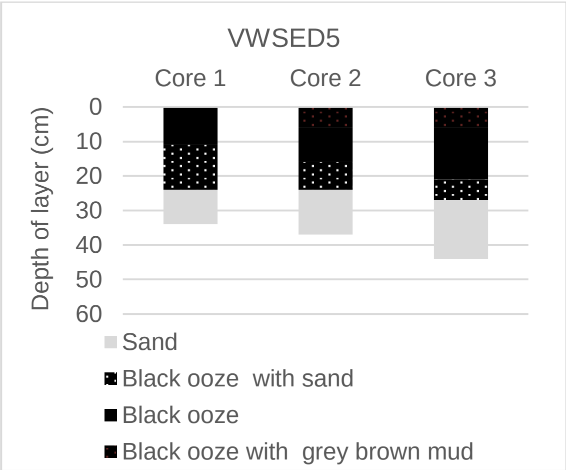


b)

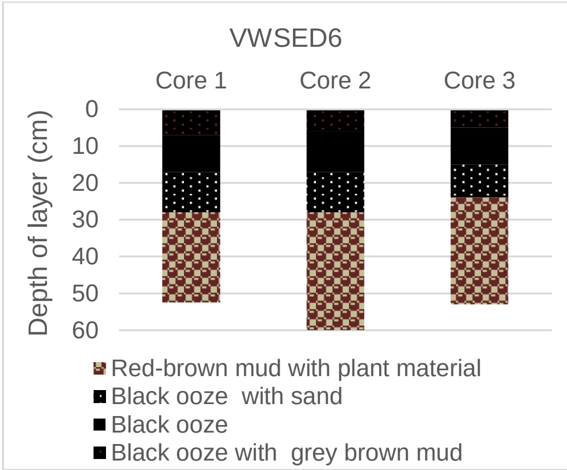
c)



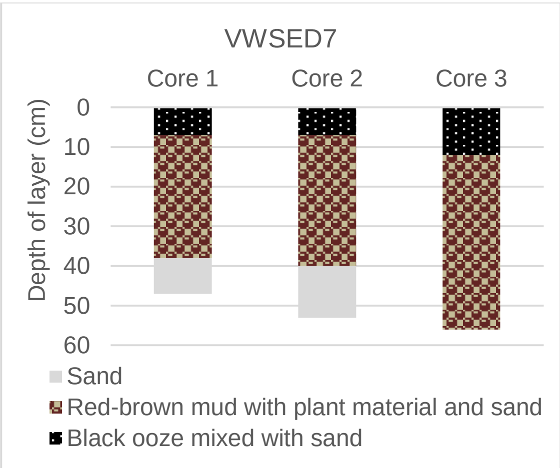
d)



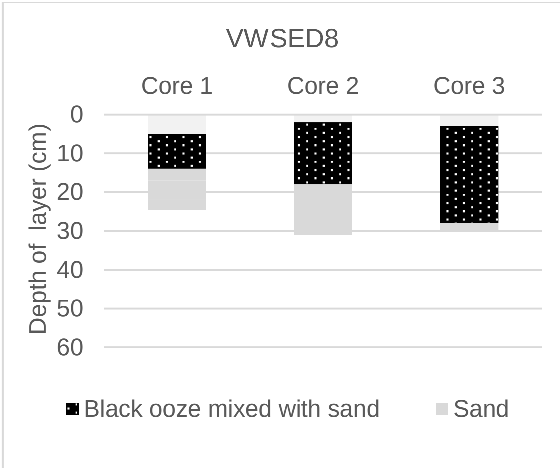
e)



f)



g)



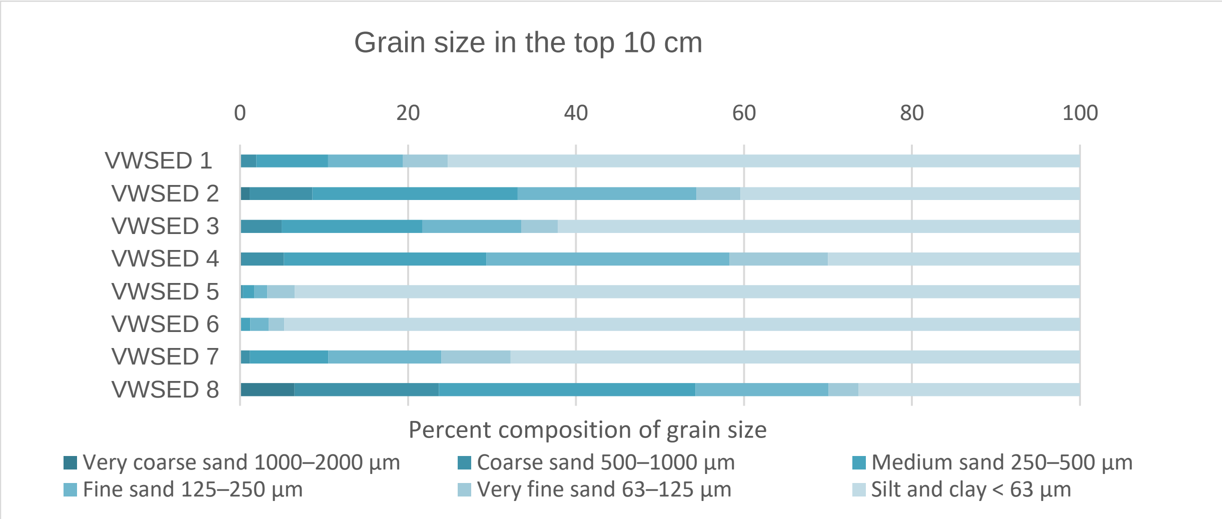
h)

Figure 11a–h *Sediment profiles in the Vasse Estuary exit channel at sites VWSED1 to VWSED8*

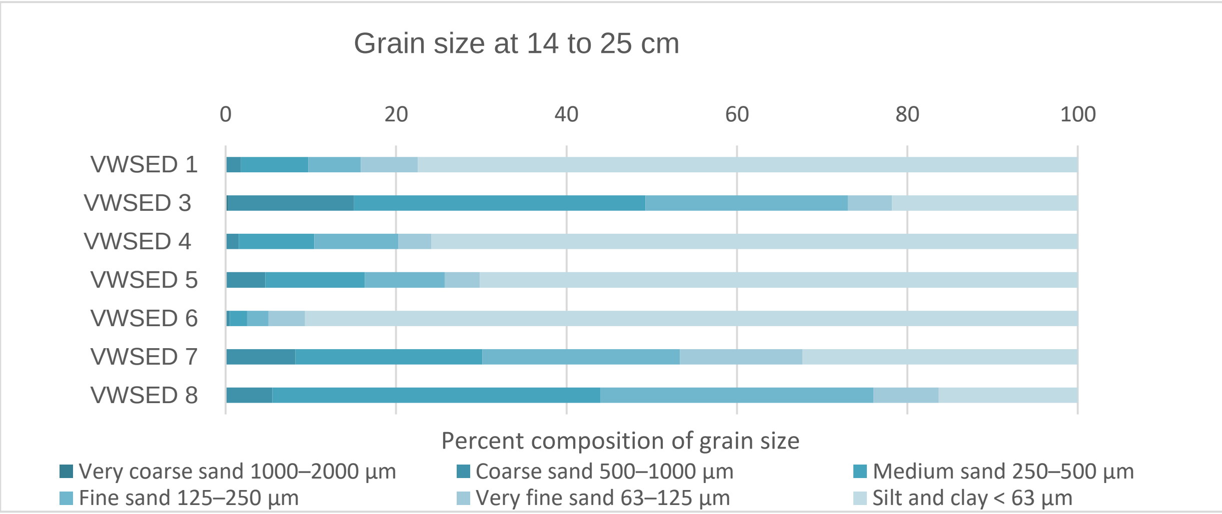
Grain size

The greatest proportion (over 95 per cent) of fine silt and clay in surface sediments were located at sites VWSED5 and VWSED6 near Estuary View Drive followed by VWSED1, which had over 75 per cent silt and clay (Figure 12a-c). The grain size at VWSED1 did not change dramatically with depth; however, all other sites displayed an increase in grain size with depth.

Sediment located downstream of the surge barrier in Wonnerup Inlet (VWSED8) contained only 26 per cent silt and clay and the greatest proportion of coarse and very coarse sand. These results are consistent with sediment profiles recorded from the collected cores as presented in Figure 11a to 11h.



a)



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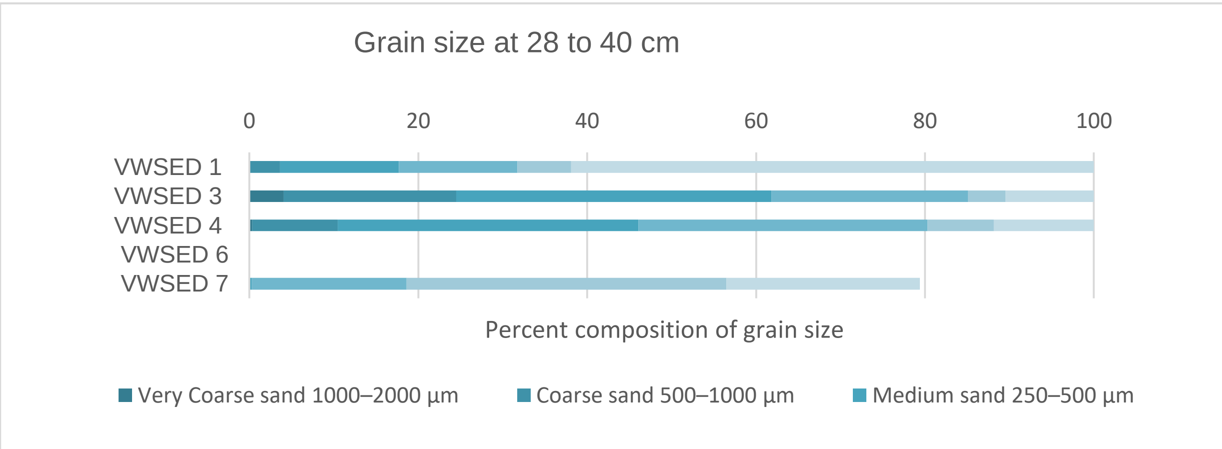


c)

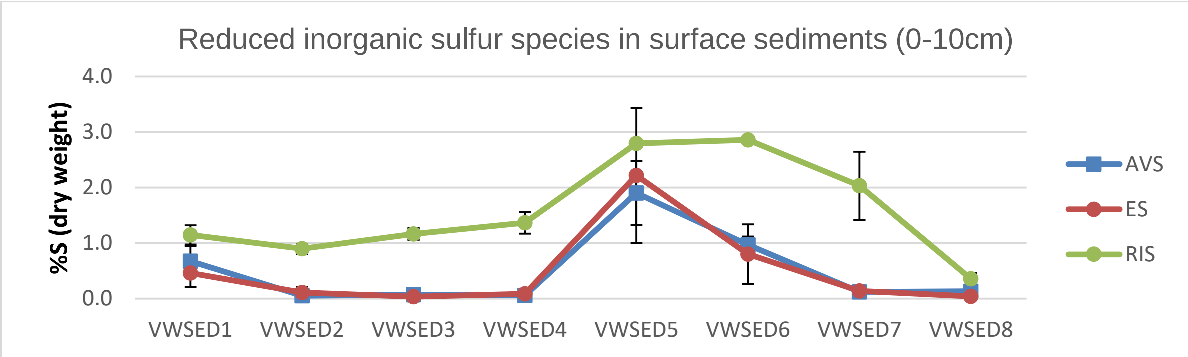
Figure 12a–c *Grain size in sediments of the Vasse Estuary exit channel in a) the top 10 cm; b) 14–25 cm; and c) 28–40 cm (core 1 samples only)*

Chemical characteristics

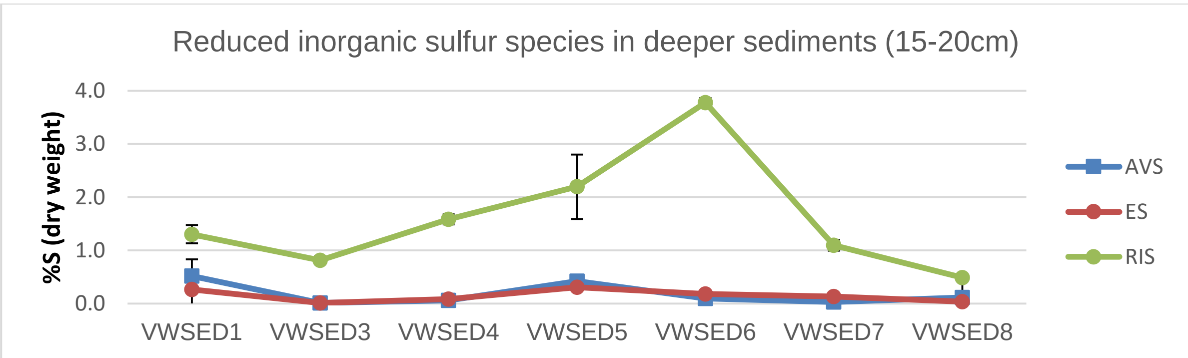
Acid generating potential and liming rates

Analysis of total reduced inorganic sulfur (RIS) demonstrated that all sediments upstream of the Vasse surge barrier contained significant amounts of sulfides and elemental sulfur and therefore have acid-forming potential when exposed to air (Figure 13).

AVS stands for acid volatile sulfur, which represents the most reactive sulfide fraction of particular concern and is associated with rapid deoxygenation and acidification. ES stands for elemental sulfur and is an oxidation product of AVS. RIS is the total of AVS, ES and other more stable sulfide minerals such as pyrite. All RIS has the potential to oxidise and generate acidity when exposed to air.



13a)



13b)

Figure 13a & 13b *Reduced inorganic sulfur species in sediments of the Vasse Estuary exit channel at a) the surface and b) at 15–20 cm deep. Error bars represent standard deviations from three replicate cores*

In surface sediments, both AVS and ES were elevated at VWSED5 and VWSED6 compared to all other sites and were also slightly elevated at VWSED1. The presence of elemental sulfur suggests some fluctuation in oxygenated versus no-oxygen conditions within the sediments. ES also has the potential to cause deoxygenation and acidification. Its concentration was in the same range as AVS. Patterns in ES concentration throughout the channel and with sediment depths were also similar to AVS.

Despite the high AVS results, in all except two cases the sediments also had a high inherent acid neutralising (buffering) capacity. With the exception of site VWSED5 (next to the channel islands) and some samples at site VWSED6 (near Estuary View Drive), the buffering capacity of the sediments will offset the amount of acid that could be generated when exposed to air. This results in negative liming rates calculated for these sites (Figure 14).

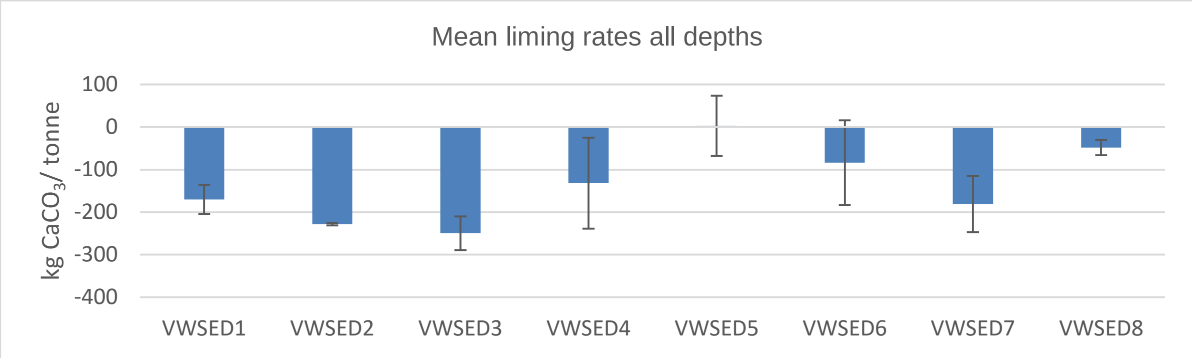


Figure 14 *Mean liming rates (all depths combined) in sediments of the Vasse Estuary exit channel*

Nutrients and organic carbon

Total organic carbon (TOC) concentrations ranged between 5 and 15 per cent at most sites. Some extremely high TOC values in the range of 20–25 per cent were measured at site VWSED4 in deeper sediment layers where large amounts of non-degraded plant material were identified. However, due to the low reactivity of this material, the high values are no major concern in these particular sediment layers.

TOC, total phosphorus (TP) and total nitrogen (TN) concentrations in sediments followed similar patterns to the AVS content and were generally elevated at sites VWSED1 (Vasse surge barrier), VWSED5 (next to the channel islands) and VWSED6 (Estuary View Drive) compared to all other sites (Figure 15, Figure 16 and Figure 17). The site with the lowest percentage of all three parameters was VWSED8 located downstream of the Vasse surge barrier in Wonnerup Inlet.

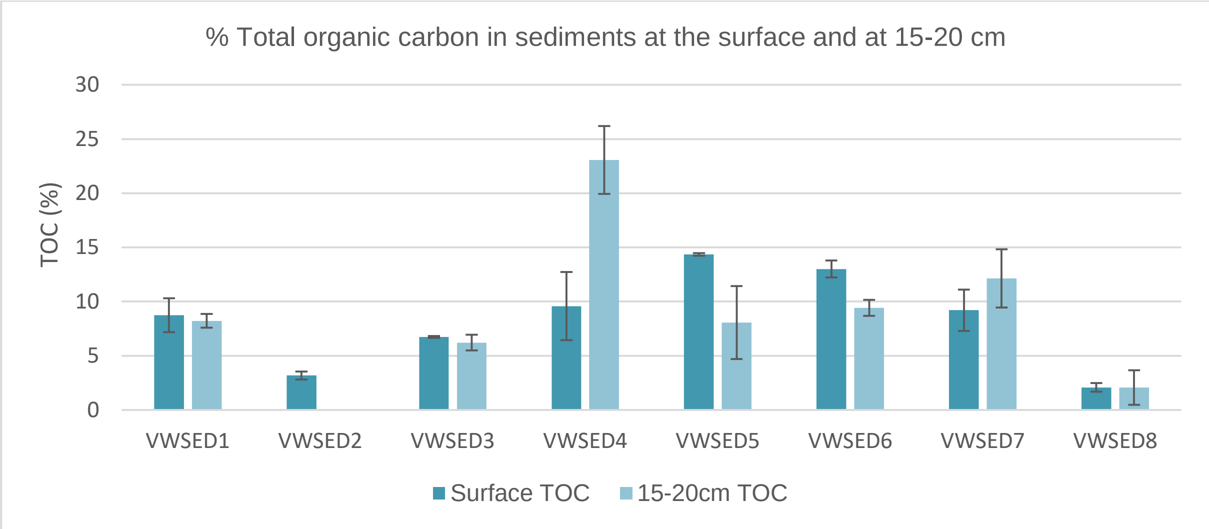


Figure 15 *Total organic carbon in sediments at the surface and at 15–20 cm. Error bars represent standard deviation of triplicate measurements. Sediment depth at VWSED2 was less than 15 cm*

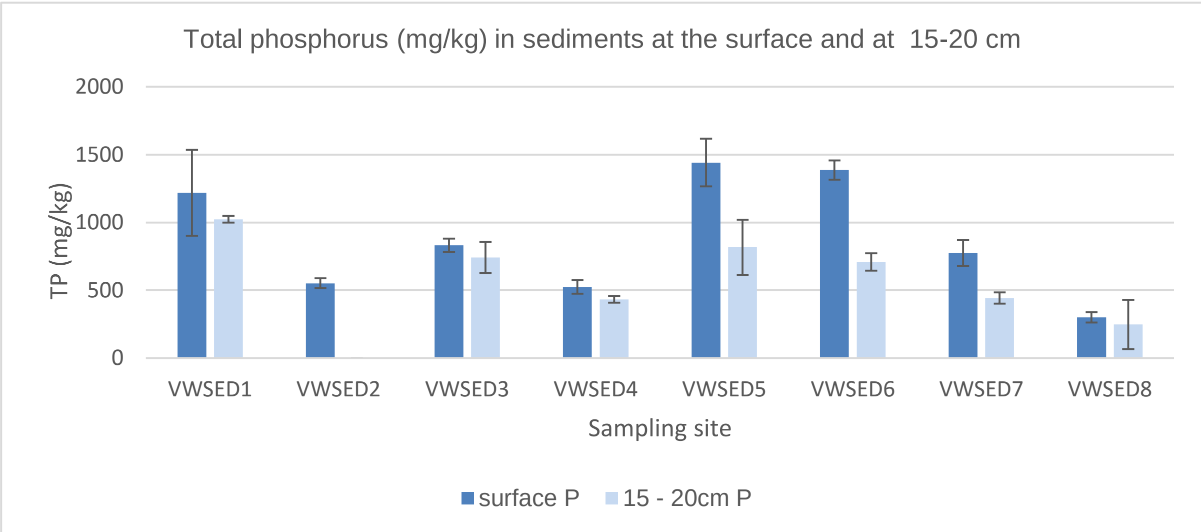


Figure 16 *Total phosphorus in sediments at the surface and at 15–20 cm. Error bars represent standard deviation of triplicate measurements. Sediment depth at VWSED2 was less than 15 cm*

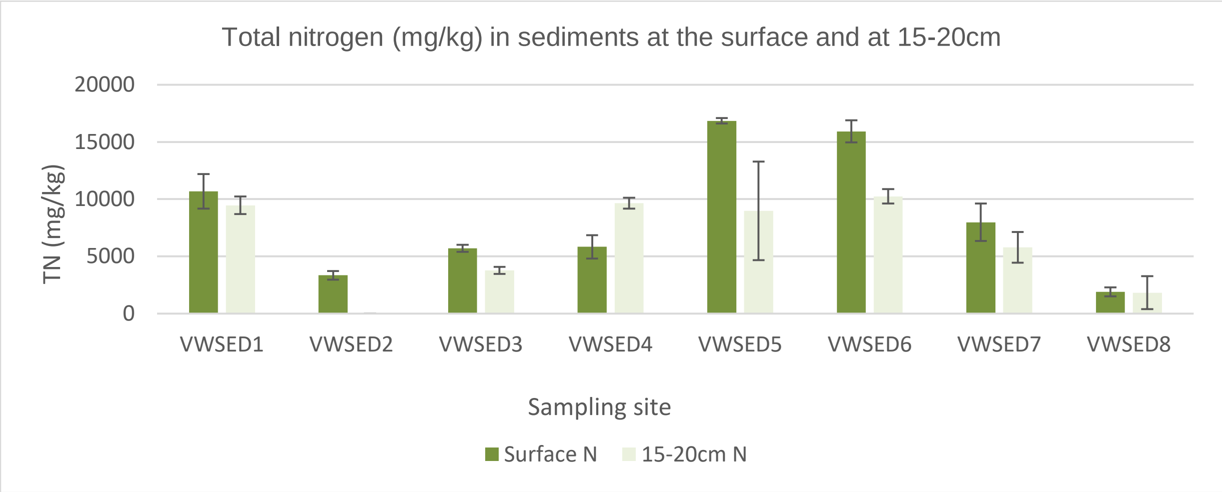


Figure 17 *Total nitrogen in sediments at the surface and at 15–20cm. Error bars represent standard deviation of triplicate measurements. Sediment depth at VWSED2 was less than 15 cm*

Metals, pesticide, polyaromatic hydrocarbons contamination

Result from the metals, polyaromatic hydrocarbons and pesticide analysis did not raise any contamination issues, noting that polyaromatic hydrocarbons and pesticides were only tested from samples collected at Site VWSED2 (Appendix E) due to budget constraints. This site was selected as it is relatively close to the surge barrier but was far enough away to be considered as representative of the wider channel area.

Metal concentrations were all below the ANZECC 'ISQG-low' guideline levels (where such guidelines have been developed). There are no guidelines for manganese, selenium, iron and aluminium. Pesticides were all below detection limits while hydrocarbons were below detection limits in all cases except four samples. These returned very low concentrations of phenanthrene, fluroanthene and pyrene (all under 0.05 mg/kg). All samples taken complied with guidelines set for disposal of solid waste to a Class 3 landfill facility (Department of Water and Environmental Regulation 2018).

3.3 Implications of sediment characteristics

Acid sulfate soils

The AVS content in most organic-rich sediments throughout the Vasse Estuary exit channel was high enough (≥ 0.01 per cent) to classify the sediments as monosulfidic black ooze (MBO), according to the Australian acid sulfate soil management guidelines (Sullivan et al. 2012). However, in this report it was chosen not to use this term because the actual composition of AVS has not been analysed. AVS includes different sulfide species and, although monosulfides typically represent a large fraction of this group, other unstable species such as dissolved sulfides may also be present in significant amounts (Rickard 2005). Nevertheless, the high AVS content suggests that sediments within the exit channel are, at times, likely to adversely impact water quality within the channel. This finding lends weight to consider the strategic removal of isolated large accumulations for the purposes of improving water quality, but this option is not without risk.

AVS is the sulfide fraction that poses most concern as it is unstable and readily oxidises, potentially leading to rapid deoxygenation of the water or acid formation when dredged or disturbed otherwise. A high AVS content may also be associated with high amounts of hydrogen sulfide and other noxious gases causing foul odour, chiefly when water levels are low. Removing sulfidic black ooze, particularly with a high AVS content, is usually considered risky, since acidification may occur if there is not enough acid neutralising capacity in the sediment. This process may also lead to leaching of metals, potentially causing water contamination (Simpson 2018). In addition, deoxygenation, nutrient release, and odour formation are all potential impacts that would require management, particularly for sensitive environments.

Although sediments in the Vasse Estuary exit channel all have a high potential to form acid when exposed to oxygen, in all but two cases the high natural buffering capacity of the sediment means that the calculated liming rates were negative. Despite this finding, precautionary liming would still be recommended if sediments were planned to be removed in a way that would expose them to air.

There were significant variations in AVS content throughout the channel, and at some sites additional caution is warranted when considering disturbance of sediments. It was highest in surface sediments (0–10 cm depth) at sites VWSED5 (next to the channel islands) and at VWSED6 near Estuary View Drive (see Figure 13a). Both sites are also associated with the most noticeable sulfide odour. AVS was also elevated at VWSED1 just upstream of the surge barrier. AVS concentrations declined with depth at most sites because it is being converted to more stable sulfide species over time and the lower RIS measurements at depth at sites VW5 to VW7 may indicate that less sulfate reduction-forming sulfides were present in the past (see Figure 13b).

To put these measurements in perspective, the AVS and reduced inorganic sulfur concentrations in surface sediments from VWSED5 (Table 4) were substantially higher compared to previously reported concentrations in sediments from the Peel Harvey Estuary, which is another WA estuary with known MBO accumulations (Choppala 2017, Kraal 2013, Morgan 2012). Ward (2010) previously reported high AVS values of up to 1.02 per cent from the Vasse Estuary exit channel in sediments from a nearby location.

Table 4 *Comparison of AVS, TOC and nutrients in the Vasse Wonnerup, Peel and Swan Canning estuaries*

Reference	Peel Harvey	Swan Canning	Leschenault	Vasse Wonnerup
Reported AVS ranges (S%)				
Morgan et al. 2012	0.05–0.95			
Choppala et al. 2017	< 0.39			
Kraal 2013	< 1			
Kilminster 2010	0.05–0.55		0.01–0.17	
Ward et al. 2010				0.19–1.02
This study				0.007–2.3
Reported RIS ranges (S%)				
Morgan et al. 2012				
Choppala et al. 2017	< 0.9			
Kraal 2013	< 2.8			
Kilminster 2010	0.95–1.70	0.03–1.17	0.6–1.07	
Ward et al. 2010				1.34–2.08
This study				0.29–3.8
Reported TOC ranges (%)				
Morgan et al. 2012	0.7–8.2			
Choppala 2017	< 2.9			
Kraal 2013	< 8			
Kilminster 2010	1.7–7.4	0.2–19.7	2.4–4.9,	
This study				*2.9–14.5

Reported nutrient ranges (mg/kg)				
Kilminster 2010		TN 140-5880, TP 74-1640	TN 3360-5420, TP 270-370	
This study				TN 230-1680 TP 351-1623

*Some deeper core sections had a TOC of up to 25.4 per cent from undecomposed plant material but this did not represent the general sediment TOC

TOC concentrations ranged between 5 and 15 per cent at most sites and at these levels may pose a significant deoxygenation risk. Organic carbon also fuels sulfate-reducing bacteria, leading to the build-up of sulfidic sediments. Elevated phosphorus in sediments is of concern where low oxygen events can occur such as in the vicinity of the surge barrier. Low oxygen conditions can lead to the release of dissolved phosphorus from sediments into the water column thereby exacerbating poor water quality conditions by providing additional fuel for algal growth.

Organic carbon and nutrient contents in the Vasse exit channel were generally in a similar range to previously published sediment reports from the Swan Canning Estuary and slightly higher compared to reports from the Peel Harvey and Leschenault estuaries (Table 4) (Choppala 2017, Kraal 2013, Morgan 2012,Kilminster 2010).

Fine grain size

Sediments within the exit channel were all characterised by very fine grain size. This is particularly evident near Estuary View Drive where over 95 per cent of sediment in the top 10 cm is comprised of silt and clay (< 63 µm). This very fine grain size is considered a significant constraint for a range of potential sediment removal techniques. Removal of fine silt and clay is likely to involve additional management to separate water from the sediment and to manage sediment plumes resulting from disturbance. Very fine sediment layers are also typically associated with decomposed organic matter (e.g. algae), which may form sulfidic sediments under suitable condition. Ensuring that water can be separated from sediment as part of removal is very important to reduce the cost of transport and improve logistics associated with the disposal of dredge spoil. Some sediment techniques are completely unsuitable for removal of fine grain sediment, while others would require large areas of space to do so.

Low contamination

The low concentration of metals, pesticides and polyaromatic hydrocarbons allows the sediments to be disposed of within a Class 3 municipal waste facility or wastewater treatment plant or to be evaluated for reuse (e.g. as a soil conditioner). If disposal to a Class 2 facility is proposed, then further leachate testing will be required on fresh sediment samples. The Vidler Road waste facility is currently transitioning from a Class 2 to a Class 3 waste facility.

Pattern and volume of sulfidic black ooze accumulation

The pattern of sediment accumulation within distinct and isolated zones greatly improves the logistics associated with removal. Zones can be addressed separately as distinct projects to maximise the potential benefits of removal while reducing cost and isolating zones of the channel with sediment curtains to minimise disturbance.

3.4 Priority locations for sediment removal

Two keys areas of sediment accumulation located at opposite ends of the Vasse exit channel (Figure 8) were identified as potentially problematic from a water quality and amenity perspective. These were the areas immediately upstream of the Vasse surge barrier and a larger area at the south-west corner of the channel, near Estuary View Drive. Both locations comprise a deep layer of sulfidic black ooze. Large accumulations of black ooze sediments can emit noxious hydrogen sulfide gas, accelerate nutrient cycling and cause deoxygenation and acidification (Sullivan et al. 2018). At each of these locations, there has been a history of complaints from adjoining residents regarding hydrogen sulfide odour.

The Vasse surge barrier

The potential removal of organic-rich sediment immediately upstream of the Vasse surge barrier in the vicinity of VWSED1 was identified as the main management priority. This location has long been associated with poor water quality, especially low dissolved oxygen and phytoplankton blooms. Most known mass fish kill events in Vasse Wonnerup Wetlands have occurred close to the Vasse surge barrier. Removal of sediment from this location was believed to have the potential to reduce the frequency and severity of low dissolved oxygen events.

Sediment located upstream of the Vasse surge barrier was small in volume (300 m^3), concentrated in a relatively small area (95 m perimeter) and was easily accessible. These three characteristics considerably improved the practicalities associated with removal. In addition, there were no issues associated with contamination from metals and, although sediments had acid sulfate potential, there was also a high natural buffering capacity present, meaning the risks of disturbing these sediments were manageable.

This zone of sediment was removed by the Water Corporation in May 2017 following notification of the above field results. The removal process and monitoring data associated with removal is outlined in section 6 (Part C) of this report. Future sediment removal may be required from this location in the medium to long term if sediment from decaying organic matter continues to accumulate in front of the surge barrier.

Estuary View Drive

The second area located at the south-west end of the channel near Estuary View Drive contains a much larger volume of sediment, and the benefits of removal are much less clear compared to sediments at the surge barrier. Even if only the top 30 cm of sediment were to be removed, the total volume of that sediment (> 3000 m^3) would still be over 10 times the volume as that in front of the surge barrier. An extensive layer of sulfidic black ooze about 30 cm deep occurs across a wide area of the initial bend in the exit channel. This larger volume of sulfidic sediment may pose a deoxygenation risk when disturbed during removal, noting that natural processes, such as wind, may also give rise to disturbance of sulfidic sediments and subsequent deoxygenation events.

The sulfidic black ooze layer occurs over a deeper layer of fine-grained low AVS sediments of equivalent thickness. This layer is unlikely to be influencing odour or water quality due to the lower AVS values. There is, however, potential for the surface black layer to contribute to hydrogen sulfide odour when water levels are low. It is not clear whether sediments at Estuary View Drive have contributed to low oxygen levels in the water column. The very shallow water at this location normally precludes monitoring since access to the area is difficult from a boat during summer. The potential for a continuous dissolved oxygen logger to be deployed in this area could be investigated although use of a logger may also be limited by the shallow depth.

Residents along and near Estuary View Drive have in the past complained about odour from this area, particularly when water levels are low leading to sediments being partially exposed. Recent management of the Vasse surge barrier (during the summer of 2017/18) has maintained water levels at 0.0 m AHD, 0.1 m higher than in previous years and is currently being evaluated for a longer term approach. If deemed acceptable, then sediment removal may not be required from this location in the short term.

The presence of a large bloom of *Cladophora* macroalgae in the main body of the estuary was an additional source of odour in 2018 when these algae began to rot during early autumn. Floating macroalgae tends to accumulate in the bend of the estuary where water is about to enter the exit channel near Estuary View Drive. This pattern of accumulation may be a factor of restricted water flow as water enters the channel and/or the influence of prevailing south-westerly summer/autumn winds. The accumulation and subsequent rotting of macroalgae and other floating plant material in this corner of the estuary is one of the reasons why black sulfidic sediment has accumulated there, yet removal of sediment will not prevent this from occurring again and so will not completely solve the odour problem. In addition, sediment odour issues may still occur as most of the sediments in the channel have at least 10 cm of sulfidic sediment close to the surface that may contribute to odour under particular water column conditions (e.g. overturning of a previously stratified water column). Dredging is therefore unlikely to entirely resolve the odour issue.

4 Part B: Sediment removal feasibility

4.1 Characteristics of the Vasse Estuary exit channel that influence the feasibility of removing sediment

Characteristics of the Vasse Estuary exit channel that require specific consideration when evaluating the feasibility of sediment removal were as follows:

- Physical space: The exit channel is a relatively shallow waterbody with a narrow foreshore located between private property and Layman Road, with Geographe Bay located to the north (and west of Layman Road). There are few unvegetated areas along the foreshore that are wide enough to enable room for dewatering of sediment. A small area exists along the Floodgate Road verge and a grassed area at James Richardson Park on Estuary View Drive also provides some space. Some adjoining residents have indicated they would be supportive of the use of private land for this purpose where low-impact techniques were proposed, such as the use of geotextile bags outlined in Appendix C. There are limitations to how far sediment can be pumped easily; therefore, appropriate foreshore zones need to be relatively close to the area of proposed sediment removal works.
- Fish kill mitigation requirements: Summer algal blooms are a regular feature of the exit channel and these blooms frequently result in very low oxygen conditions in the water column. When oxygen is already low, then the risk of adverse effects (such as fish kills) from sediment removal works is heightened. The sulfidic characteristics of the sediments within the channel area can lead to reduced lower dissolved oxygen levels if they are disturbed. All sediment removal techniques will involve some form of localised disturbance to sediments during removal operations. Avoiding the summer period is the lowest risk option but this poses a major constraint to sediment removal techniques that depend on having low surface or groundwater conditions present at the time of removal.
- Ecological sensitivity and Ramsar obligations: Although the exit channel is arguably one of the most degraded parts of the estuary, it is part of the Ramsar-listed area and management approaches need to give due consideration to the importance of preventing damage to waterbird habitat and minimising disturbance to waterbirds. Earthworks on foreshore areas that involve destruction of fringing vegetation such as samphire, rushes and sedges would need to be avoided. Consideration also needs to be given to maintaining important feeding habitat. Monthly waterbird monitoring by the Department of Biodiversity, Conservation and Attractions indicates that the shallow sediments near Estuary View Drive are sometimes used by shorebirds such as avocets and back-winged stilts, although it is not clear how significant these mudflats are as a feeding habitat in comparison to the wider estuary. Timing of sediment removal works would also need to give due consideration to minimising disturbance of waterbirds. This is more pertinent at the south end of the channel near Estuary View Drive where the sediment accumulation is closer to the main body of the estuary and where a wider range of bird species may need to be considered.

- Wonnerup Inlet – refuge for bream: Wonnerup Inlet has been identified as an important refuge area for black bream (Cottingham 2015). The populations of black bream are still recovering from a very large (> 30 000) mass kill in 2014. Sediment removal techniques that involve moving sediment into Geographe Bay via Wonnerup Inlet would need to ensure that sediment is not inadvertently deposited in the inlet. A deterioration in water quality within Wonnerup Inlet is highly undesirable given the importance of the refuge habitat that the inlet provides.
- Geographe Bay – Ngari Capes Marine Park: The Vasse Wonnerup Wetlands system drains into Geographe Bay, which is included within the Ngari Capes Marine Park. Any proposal that involves transporting dredge spoil into the marine park is likely to require a detailed assessment of the risk to nearshore seagrass meadows. Actual risks to seagrass are likely to vary with the quantity of sediment being deposited and the time of year works are undertaken.
- Estuary neighbours: The Vasse Estuary exit channel is bordered by private property on both sides of the channel. Although adjoining neighbours may be supportive of attempts to address water quality and odour problems in the estuary, they may also be unsupportive of techniques that result in excess noise, infrastructure, traffic disruption and odour during the works.
- Separation of the exit channel from the wider Vasse Estuary: The Vasse Estuary exit channel is morphologically separated from the main body of the Vasse Estuary aside from its connection via a narrow opening, which itself is divided by island formations. The elongated and narrow shape of the channel greatly improves the ability to use management measures such as silt curtains to limit disturbances associated with sediment removal to within the immediate works area. At the southern end of the channel, this separation is not as distinct where sediments have accumulated near Estuary View Drive since this zone of accumulation exists where the estuary starts to widen out.
- Ability to manipulate water flow via surge barrier: Although the surge barrier has been implicated in the accumulation of sulfidic sediments in the exit channel, they can be used as a tool to contain the area of potential disturbance or silt transport during any future sediment removal works. They can be kept closed to prevent sediment in suspension from entering Wonnerup Inlet if needed, or opened (when the sand bar is open) to allow inflow of seawater or to allow passage of disturbed water out of the channel and into Geographe Bay.

4.2 Summary of options evaluated

Seven techniques were evaluated for their potential to remove sediment from the Vasse Estuary exit channel. These potential removal options examined criteria that included environmental risk, potential impacts on neighbours, technically feasibility and cost effectiveness. The following seven removal options were considered:

1. Dredge to geotextile bags
2. Drainage and excavation

3. Dredge to sand dam
4. Dredge to drying ponds
5. Mechanically suspend and flush to the ocean via Wonnerup Inlet
6. Dredge directly to Geographe Bay
7. Suction pump to tankers and transport to the wastewater treatment plant

If removal of sediments is proposed, the option ‘dredge to geotextile bags’ was found to be the preferred method of removal with this option having the least impact on neighbours, the best ability to manage environmental risks and was most technically feasible. A summary of the assessment is presented in Table 5 and further details about each technique are detailed in Appendix C.

Following receipt of initial field results in April 2017, the Water Corporation committed $100 000 to remove sediment accumulated immediately upstream of the Vasse surge barrier and completed these works in May–June 2017. The technique used was a suction pump mounted on a floating pontoon and is described in section 6 (Part C) of this report.

Table 5 *Feasibility assessment of potential options for removal of sediment from the Vasse Estuary exit channel*

Technique	Description	Environmental risk	Impact on neighbours	Technical feasibility	Comments
Dredge to geotextile bags	A small dredge pumps sediment slurry to geotextile bags that are used to dewater sediments	Low Winter removal reduces risk	Low (odour managed by bags)	Good Sufficient space on foreshore is available	Preferred option Environmental risks are manageable for small projects, low impact on neighbours and few technical constraints
Drainage and excavation	Sections of the channel are separated with sand bunds and dewatered to a constructed dam. Sediment is then removed with earthmoving equipment	Moderate Summer removal only, fish movement is restricted	High odour, noise and visual impact	Constrained due to limited space for dewatering dams Summer removal only (requires low groundwater)	Not recommended High neighbour impact; limited space for dewatering dams
Dredge to sand dam	A small dredge pumps sediment slurry into a bunded area of clean sand. Sand and sediment are mixed together to enable removal and transport	High (difficult to control leachate return to inlet)	Moderate to high (odour and noise)	Poor due to insufficient space	Not recommended Insufficient space
Dredge to drying ponds	A small dredge pumps sediment to specially constructed drying ponds	High (summer removal required for drying, physical disturbance)	High odour and visual impact	Poor Limited space for drying ponds	Not recommended Insufficient space

Technique	Description	Environmental risk	Impact on neighbours	Technical feasibility	Comments
Mechanically suspend and flush to the ocean via Wonnerup Inlet	Earthmoving equipment is used to disturb sediment to enable high flow events to transport it to the ocean	High (sediment may simply shift to Wonnerup Inlet, disturbance of banks)	Moderate (noise)	Poor Channel is too wide for long-reach excavator; flow rates are low and do not create adequate shear stress to suspend sediments	Not recommended Technically constrained; environmentally risky
Dredge directly to Geographe Bay	A small dredge pumps sediment slurry directly into Geographe Bay during winter via a pipe laid across Layman Road. The pipe would need to be floated out to sea far enough to dissipate the slurry	High (potential for beach fouling, smothering of seagrass)	High (traffic disruption)	Poor Technical issues with floating the pipe in winter swell during exposed conditions	Not recommended. Not cost-effective; environmentally risky; unlikely to be supported by community
Suction pump to tankers and transport to WWTP	A suction pump mounted on a floating pontoon is used to pump sediment slurry directly into tankers for transport to the waste water treatment plant	Manageable Winter removal reduces risk	Low (sediment contained in tankers; no air exposure)	Moderate Low rate of sediment removal	Trial conducted Not cost-effective for larger scale than trial

5 Part C: Case study – removal of sediment from the Vasse surge barrier using a sump pump

Description

Arising from a review of the sediment survey (presented in Part A), the Water Corporation committed $100 000 in May 2017 to remove the zone of sulfidic black ooze directly upstream of the surge barrier. Works were undertaken in June 2017 and monitoring of the technique used enabled this case study to be presented.

A suction pump was mounted on floating pontoon and a sediment curtain was erected on the upstream side of the works area (Figure 18). The slurry of sediment and water suctioned from the channel was then transferred into trucks for transport to the licensed sludge drying beds at the Water Corporation's Busselton WWTP (Figure 19). The slurry was added to other sewerage sludge at the treatment plant where subsequent drying, mixing and disposal of the waste took place as part of the Water Corporation's standard operations (Figure 20 and Figure 21).

Figure 18 *A floating pontoon and sediment curtain used during sediment removal works*

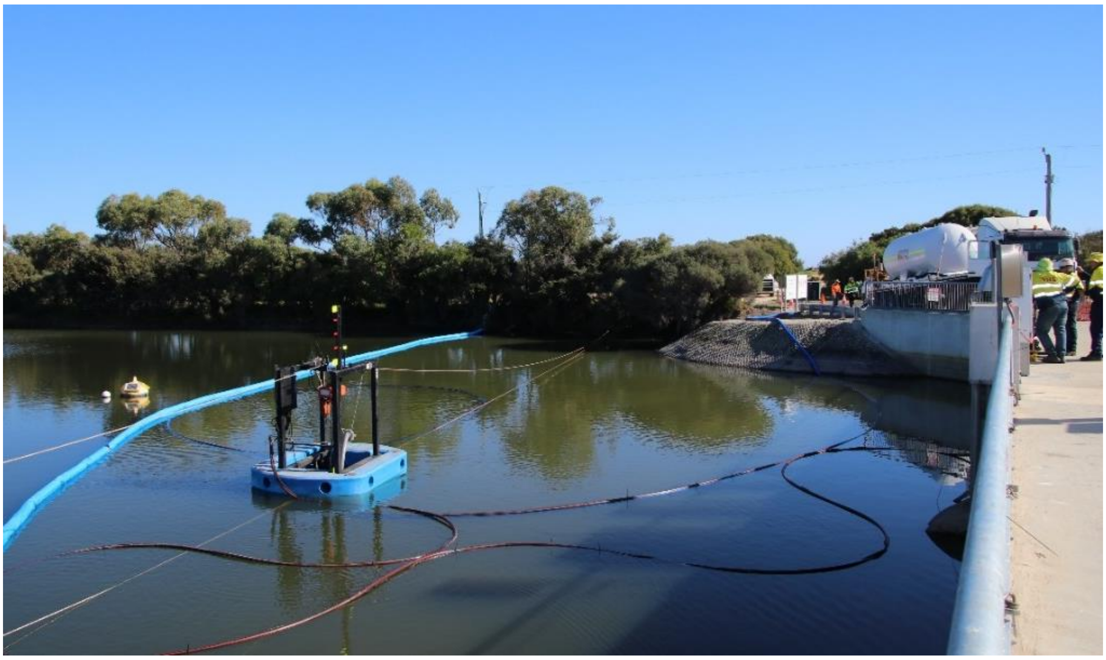


Figure 19 *Sediment being pumped directly to waiting tankers for transport away from site*

Figure 20 *Tankers at the wastewater treatment plant transfer sediment slurry into drying ponds*

Figure 21 *Sediment in the ponds will be incorporated with sewage sludge for drying and disposal*

Practical feasibility

This method proved to be a low-impact approach and no adverse environmental effects were identified during the monitoring program. However, a low efficiency of removal was achieved with the use of the sump pump, with about one-third of the original target sediment volume removed from this section of the channel. A large amount of water was transported with the sediment. The Water Corporation reported that transport of sediment away in tankers was achieved with about 11 per cent solids in the tankers with the balance being water, making this a relatively expensive option given the total quantity of sediment removed. The Water Corporation completed their own pre- and post-sediment surveys, as the opening of the prop gates in April–May 2017 had moved some sediment from the location of the original survey. They estimated that 119 m^3 of sludge was removed from an estimated original volume of 216 m^3.

There were no problems associated with receiving the sediment at the WWTP; however, in some cases, transfer of sediment out of the trucks was difficult since heavier sediment particles tended to settle at the bottom of the tanks.

For future sediment removal, it is possible that a higher ratio of sediment-to-water removal may be possible through the use of a small dredge compared to a suction pump. However, this technique is likely to result in a higher degree of turbidity and possibly lower oxygen levels in the channel during the works.

Sediment removal works were undertaken over a period of three weeks and were managed by the Water Corporation. The methods used removed logistics associated with drying sediment onsite, such as odour management, treatment of nutrient-enriched return water and finding space required for construction of drying ponds.

Environmental risk management

DWER continued regular monitoring of water quality close to the works area and within other areas of the exit channel during that time. Monitoring of dissolved oxygen, pH, turbidity and filterable reactive phosphorus was undertaken weekly during the sediment removal works and up to 2–3 times a week during the summer period. This monitoring demonstrated that there were no measurable water quality impacts of the sediment removal works immediately upstream of the works area (Figure 22 to Figure 27). Dissolved oxygen levels remained at an acceptable concentration for aquatic life throughout the works period and at levels that are typical for the channel at that time of year. There were no indications of acidification within the channel with pH also remaining at neutral levels throughout the removal period. Similarly, dissolved phosphorus and turbidity remained very low throughout, demonstrating that the extent of disturbed sediment was localised around the immediate zone of the pump.

Cost implications

Since truck movements comprised the greatest component of the project cost, this resulted in a high cost ratio compared to the volume of sediment removed (about \$840/m^3). However, treatment of sediment with lime was not required since the material was transported and disposed of in slurry form.

Community acceptance

The works completed resulted in positive media coverage and positive comments from members of the community. There were no complaints about odour or noise.

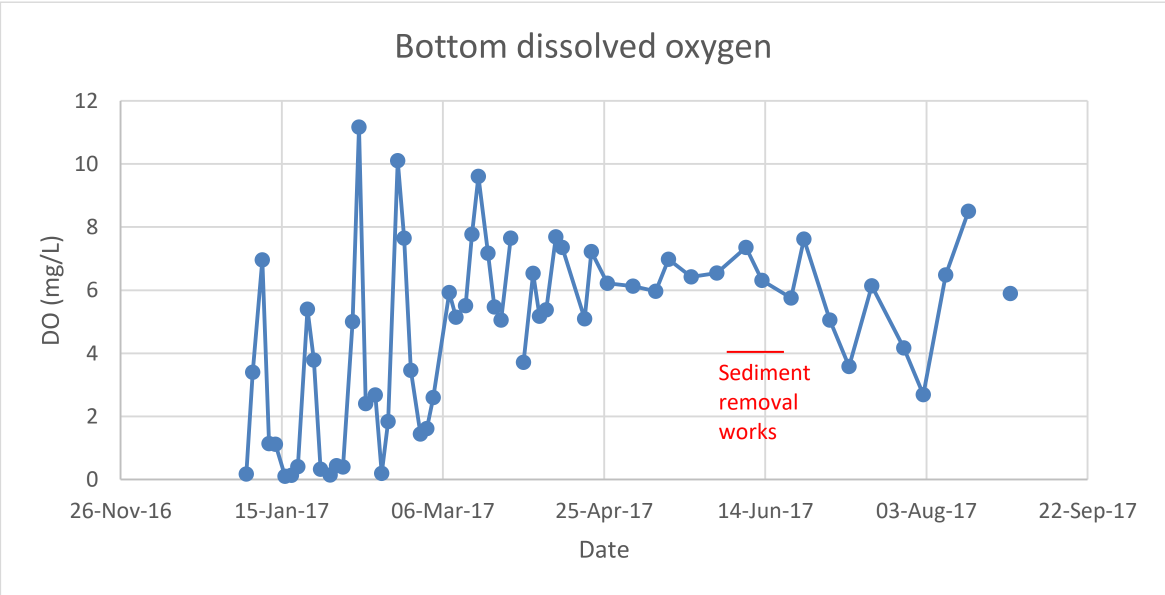


***Figure 22** Dissolved oxygen in the bottom waters immediately upstream of the silt curtain during sediment removal works and at other times of the year*

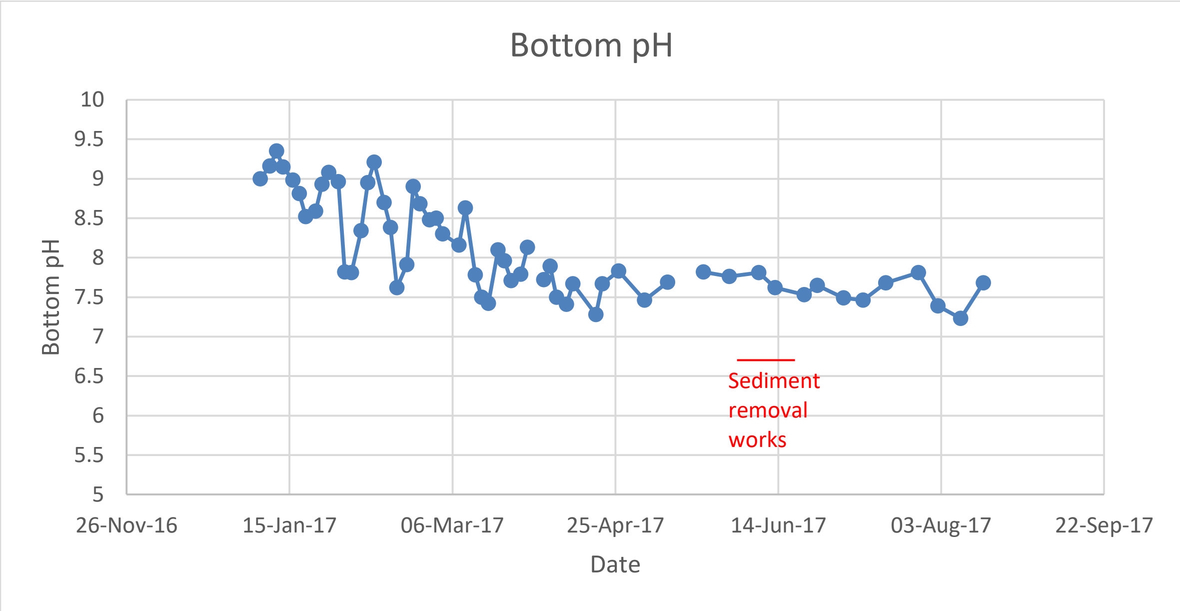


Figure 23 *pH in the bottom waters immediately upstream of the silt curtain during sediment removal works and at other times of the year*

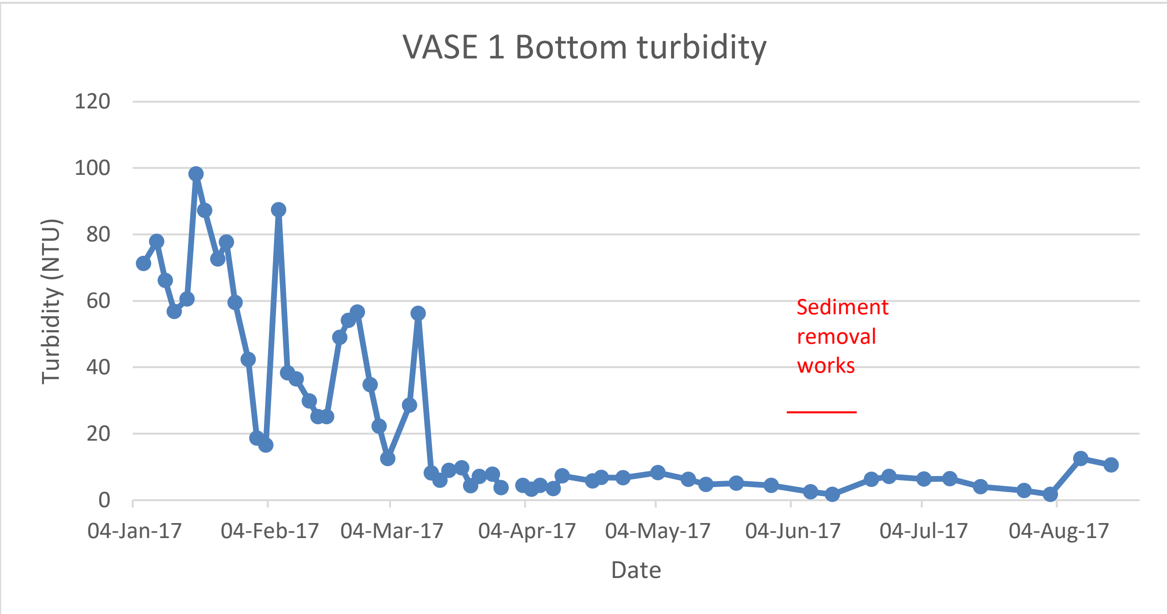


Figure 24 *Turbidity in the bottom waters immediately upstream of the silt curtain during sediment removal works and at other times of the year*

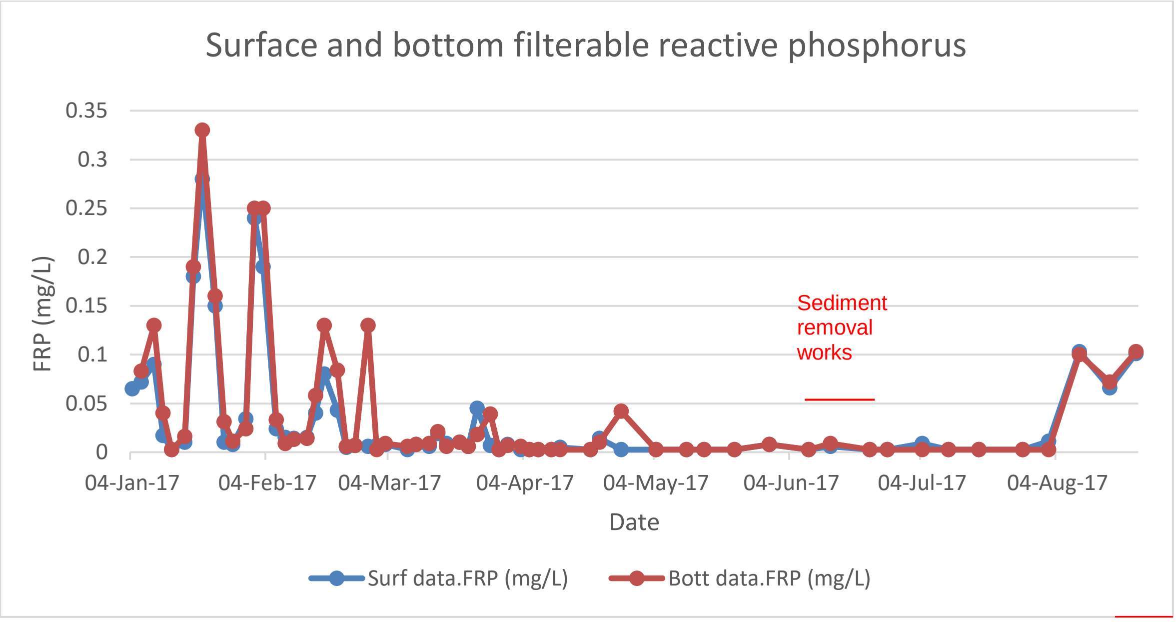


Figure 25 Filterable reactive phosphorus (dissolved inorganic P) in the surface and bottom waters immediately upstream of the silt curtain during sediment removal works and at other times of the year

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7 Appendices

Appendix A Coordinates of field sampling and parameters for analysis

Table A1 *Coordinates of sediment sampling locations in the Vasse Estuary exit channel*

Site name	Northing	Easting	Site location description
VWSED1	6278894	352862	Vasse Estuary exit channel approx. 10 m upstream of Vasse surge barrier
VWSED2	6278744	352714	Vasse Estuary exit channel approx. 230 m upstream of Vasse surge barrier
VWSED3	6278536	352595	Vasse Estuary exit channel within the kidney-shaped depression leading to the side of the channel
VWSED4	6278328	352399	Vasse Estuary exit channel downstream of island
VWSED5	6278063	352020	Vasse Estuary exit channel south side of island
VWSED6	6277858	351618	Vasse Estuary near western end of Estuary View Drive
VWSED7	6278031	351857	Vasse near eastern end of Estuary View Drive foreshore
VWSED8	6278922	352883	Wonnerup Inlet approx. 10 m downstream of Vasse surge barrier

Table A2 *Proposed parameters for chemical and physical analysis of sediment cores*

Parameter	Why analyse
Reduced inorganic sulfur (measured as chromium reducible sulfur CRS)	• Reduced inorganic sulfur (RIS) includes all acid volatile sulfur (AVS) components, elemental sulfur (ES) and the more stable sulfide minerals such as pyrite • All RIS species have the potential to generate sulfuric acid when exposed to air and to deoxygenate water when disturbed • Needed to estimate deoxygenation potential and to calculate the acid-forming potential when exposed to air • Needed to calculate liming rates for land disposal of dredged sediments
AVS (acid volatile sulfur)	• Consists largely of monosulfide minerals and dissolved sulfides • Sulfur fraction that is most unstable and easily oxidised • High risk for rapid acid formation • Rapid deoxygenation of the water when disturbed • AVS-rich sediments likely to produce noxious odours • AVS typically transformed in sediments to more stable sulfide minerals such as pyrite over time • AVS content often used to classify sediments as monosulfidic black ooze (MBOs)
ES (elemental sulfur)	• Intermediate oxidation product of AVS • Will generate acidity and consume oxygen if further oxidised upon disturbance/dredging • Required to form more stable pyrite from monosulfide minerals
Acid neutralising capacity of the sediment	• Inherent capacity of the sediment to neutralise acid • Influenced by carbonate and seawater content in sediments • Used together with the acid-forming potential (calculated from RIS concentrations and sediment pH) to determine whether the sediment would

	generate net acidity upon dredging or if the generated acidity would be offset by the neutralising capacity • Needed to calculate liming rates for land disposal of dredged sediments
pH	• Measures ‘actual acidity’ • Needed to calculate the net acidity and amount of lime needed for neutralisation • Indicates whether sulfide oxidation and sediment acidification has already occurred
Particle size analysis	• Required to better characterise the type of sediment and assess how easily it is transported and disturbed
Total metals/metalloids (Fe, Al, As, Cd, Cr, Cu, Mn, Ni, Zn, Pb, Hg, Se, Ag)	• These are toxic contaminants that may potentially be released from sediments upon oxidation by disturbance or dredging • Relevant for land-based and marine sediment disposal • Additional analyses such as SEM (scanning electron microscope) would be required to further characterise metal speciation if ANZECC guideline criteria for total metals were exceeded
Total organic carbon (TOC)	• To determine how much organic material is contained in the sediments (and would potentially be removed upon dredging) • Breakdown of organic matter contributes to deoxygenation. Disturbance of organic matter-rich sediments therefore often negatively influences water quality • Organic matter fuels sulfate-reducing bacteria when there is no oxygen available and this leads to the formation of sulfidic sediments • Organic material accumulates in sediments under low oxygen conditions or high sedimentation rates • High organic loads are one cause and a prerequisite for sulfidic sediment accumulation
Total nitrogen (TN) and total phosphorus (TP)	• Estimates the amount of nutrients that could be released from sediments under low oxygen conditions if not dredged • Estimates the influence of sediments on water quality at different locations within the channel

Appendix B Field investigation data

Sediment metal content from the Vasse Estuary exit channel

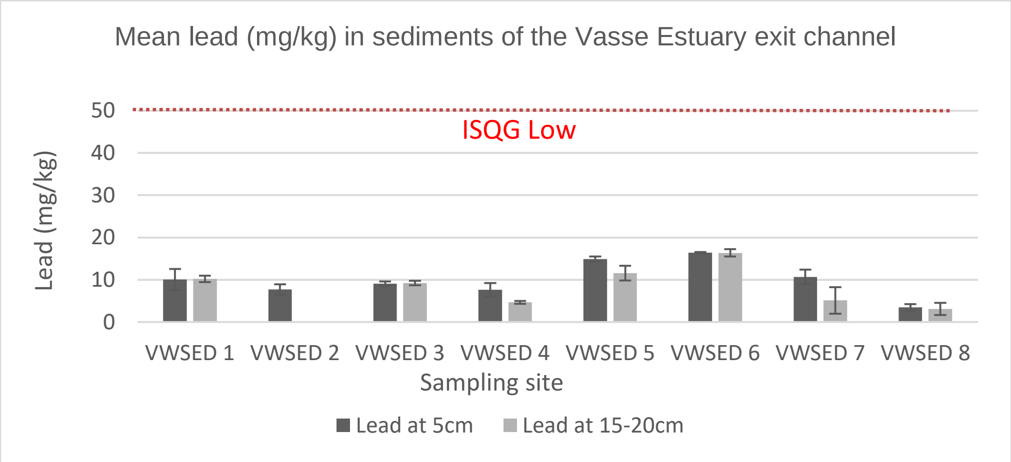


Figure B1 Mean lead in sediments at 5 cm and at 15–20 cm

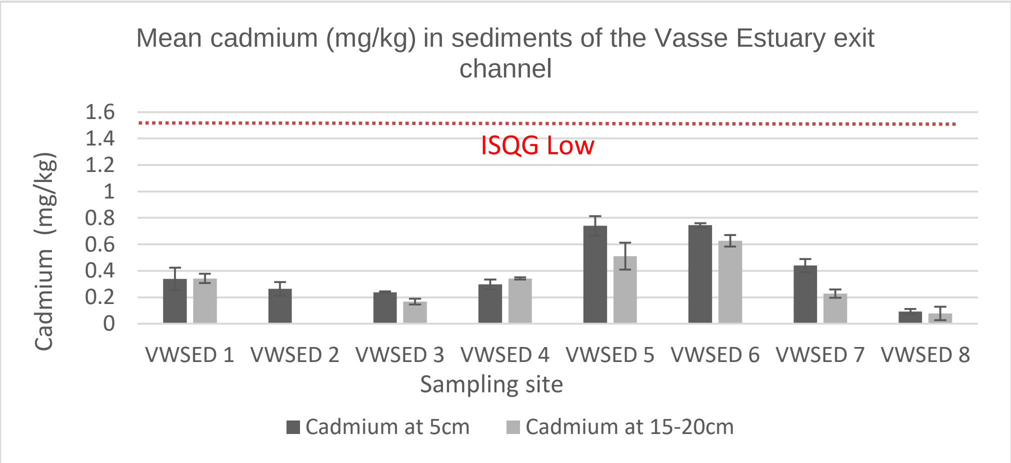


Figure B2 Mean cadmium in sediments at 5 cm and at 15–20 cm

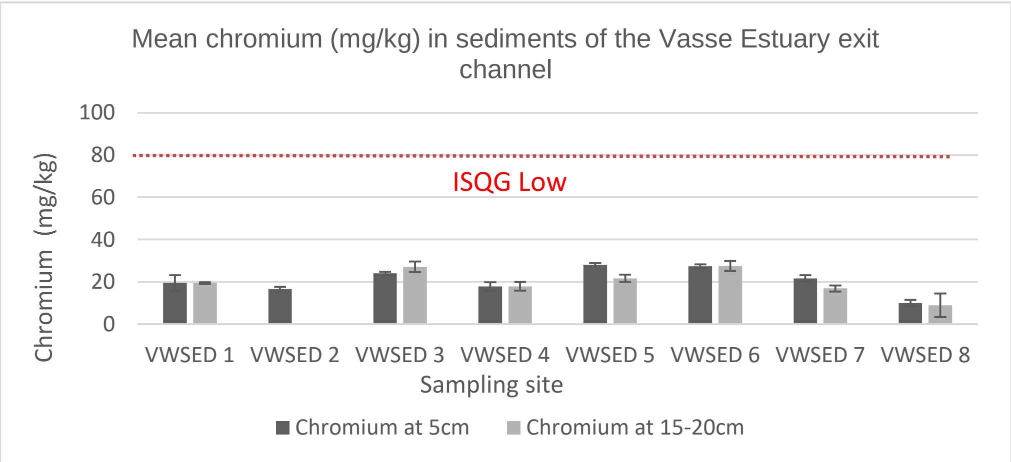


Figure B3 Mean chromium in sediments at 5 cm and at 15–20cm

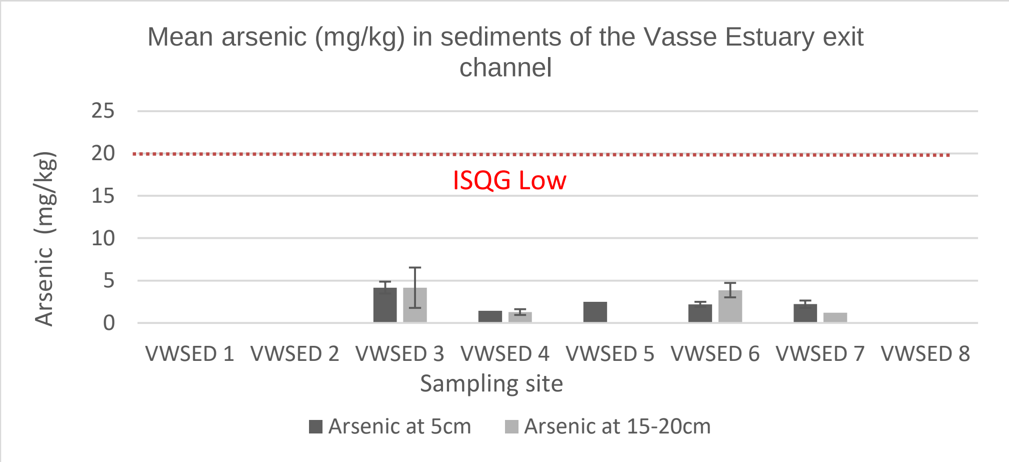


Figure B4 Mean arsenic in sediments at 5 cm and at 15–20cm

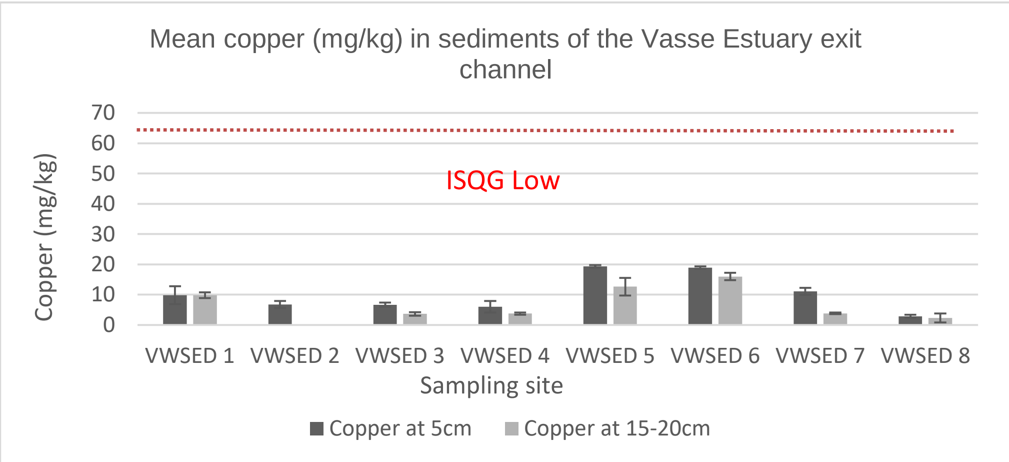


Figure B5 Mean copper in sediments at 5 cm and at 15–20cm

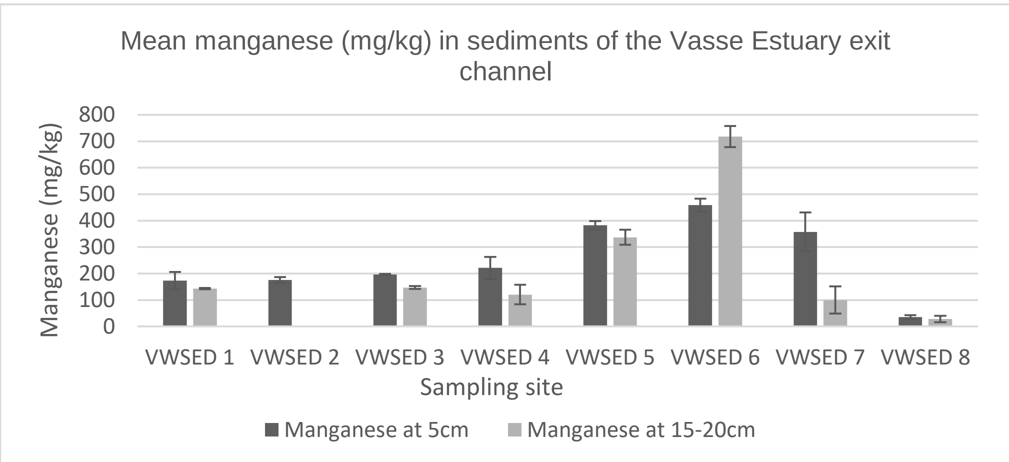
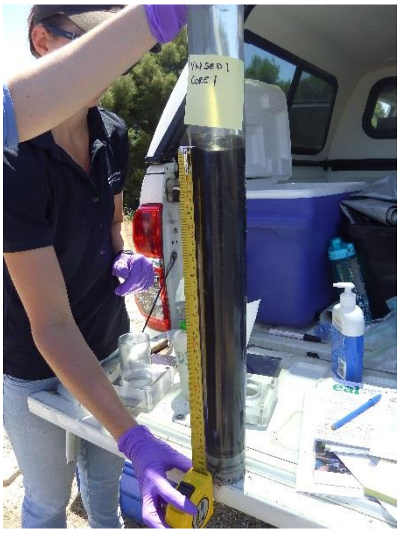


Figure B6 Mean manganese in sediments at 5 cm and at 15–20 cm

Sediment core photos


VWSED1 core 1


VWSED1 core 2


VWSED1 core 3


VWSED2 core 1

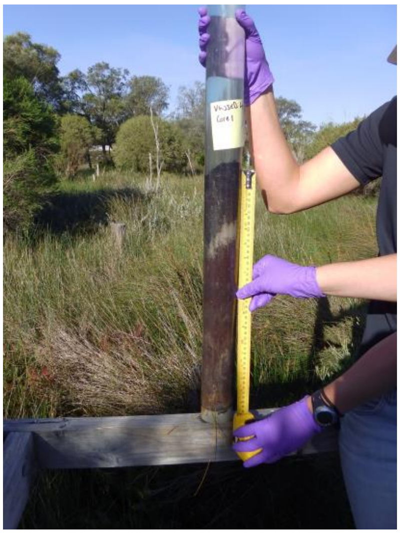

VWSED2 core 2


VWSED2 core 3


VWSED3 core 1


VWSED3 core 2


VWSED3 core 3


VWSED4 core 1

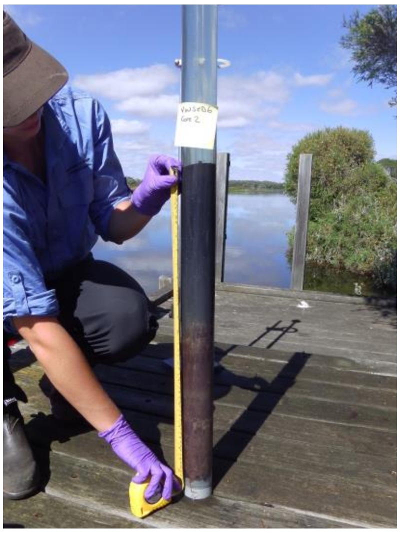

VWSED4 core 2


VWSED4 core 3


VWSED5 core 2


VWSED5 core 3


VWSED6 core 1


VWSED6 core 2


VWSED6 core 3

VWSED7 core 1

VWSED7 core 2

VWSED7 core 3

VWSED8 core 1

VWSED8 core 2

VWSED8 core 3

Plant material at base of VWSED7 cores

Sandy base beneath cores of overlying black ooze

Appendix C Sediment removal options

Micro-dredge with geotextile bags

Description

This option involves the use of a micro-dredge to pump sediment slurry into geotextile bags laid along the shore. The aim would be to trap sediment within the bags while allowing water to drain through and return to the channel. This option was the only sediment removal technique that was found to be a feasible, cost-effective and low environmental impact approach that responded to all of the localised constraints described above.

A number of companies in Western Australia operate small dredges that have been designed for transportation between sites for the purposes of desludging sedimentation ponds, tailings dams and contained waterways. Many of these micro-dredges are capable of being placed in a 20-foot container or on a standard flatbed truck. The transportability and small size of these dredges enables sediment removal to be undertaken within relatively shallow waterways without the need for dewatering. Such technology is regularly used in the mining industry to desludge tailing ponds but has also been used to remove sediment from stormwater detention basins.

These small dredges operate with a cutter head that ‘bites’ into the sediment profile and pushes out a channel in front of the dredge from which sediment is pumped. There is potential for a plume of suspended sediment particles within the water column; therefore, management of these impacts using silt curtains would be required. There may be some limitation in the use of small dredges in very shallow waterways (under 1 m deep) but these limitations would vary across individual equipment designs as some are able to cut a channel in front of them as they work.

The use of geotextile bags involves sediment slurry being pumped into the bags under pressure to force the sediments to dewater through the membranes of the bag and enable a larger volume of slurry to be pumped through the bags. The bags are fully sealed with a hole in the top surrounded by a fabric sleeve. A flocculating agent is added during an ‘in-line’ process to flocculate the sediment, thereby assisting the dewatering process. The effective flocculation of sediment within the bags is the key to ensuring that water and sediment separate effectively, thus allowing the bags to dry out sufficiently to enable sediment to be removed from the drying site. Failure to achieve effective flocculation of sediment particles is likely to result in bags filling quickly and failing to dry out sufficiently within a reasonable time.

Return water from the dewatering process is highly likely to be enriched in dissolved nutrients (Molloy 2006). Bags would need to remain in place for an unknown period of time (up to a few months) until the sediment inside was sufficiently dry for it to be transferred into trucks for transport. Disposal could occur either to a waste facility or be reused and incorporated into soil amendment or composting products.

A key advantage of this option is that sediment slurry can be pumped into the geotextile bags without the need for exposure to air, minimising risks of oxidisation of sediments with acid sulfate potential (during the sediment removal phase); reducing nuisance odour during the drying process; and minimising earthworks required to achieve drying and removal of sediment. Sediments with acid-forming potential will require treatment prior to disposal as they may still oxidise and become acidic inside the bags as they dry out if not treated appropriately (Molloy 2006). In-line liming is not recommended since the addition of lime can alter the pH of the slurry and therefore inhibit the chemical flocculation of sediment particles.

The use of geotextile bags is only suitable for the removal of relatively small volumes of sediment. The removal of large volumes of sediment requires the use of many bags and a larger space to lay them during drying. Aspects such as available space for drying of bags and budget for purchase of bags will vary with each project.

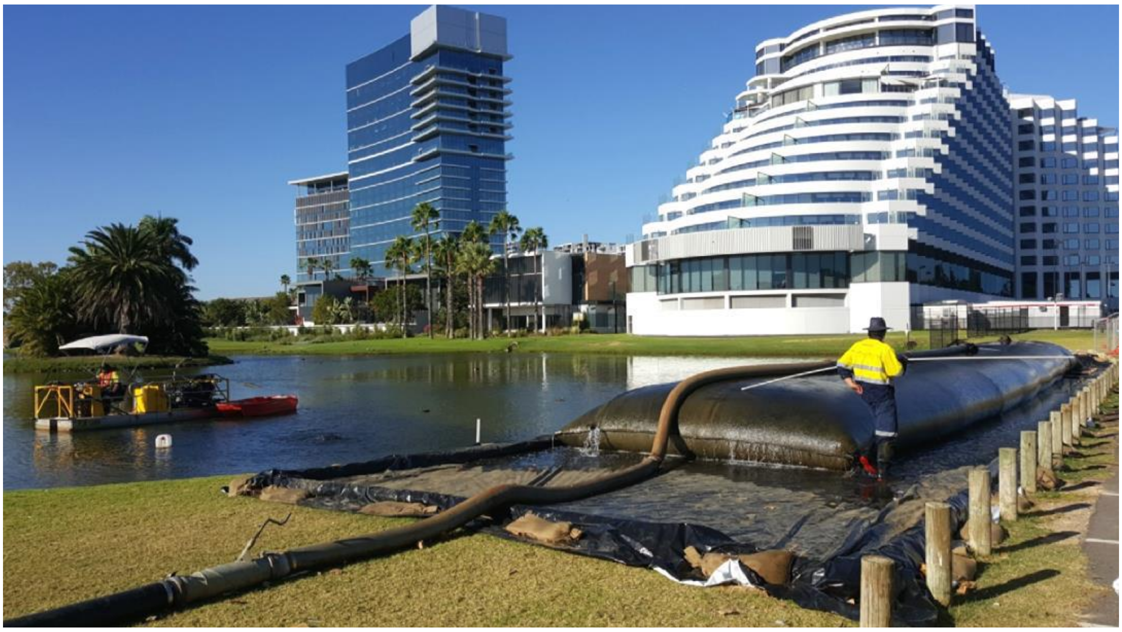


Figure C1 *Example of a micro-dredge pumping sediment to geotextile bags at Burswood (Source: Apex Envirocare)*

Practical feasibility

This method has a high practical feasibility when undertaking removal of distinct zones of sediment. Geotextile bags can be laid out on grassed foreshore reserve areas, road reserve or potentially leased private land for the period of works and drying. Care must be taken to ensure that the correct flocculating agent is used or the bags may not dewater effectively. It is therefore imperative that operators that are experienced in this technique are selected for implementation.

The micro-dredge still requires reasonable access and water depth to launch. However, a small crane can be used for this purpose if water is to be reduced and if works are undertaken during winter when water in the estuary is cooler, less salty, and there are fewer shorebirds using the estuary. The micro-dredge can be launched in one location, then towed to its desired operating location.

Because the geotextile bags essentially use a chemical process for dewatering, the whole sediment removal process could be undertaken during winter when water levels are higher, salinity is low (and therefore optimal for flocculation) and the environmental risks associated with this type of disturbance are lower.

There is available space to lay geotextile bags for the removal of the Estuary View Drive accumulation at James Richardson Park (the public grassed foreshore area along Estuary View Drive). Should this technique be considered for future sediment removal at the Vasse surge barrier, the best location to lay geotextile bags would be grassed areas on private property that adjoin the surge barrier. If this were not possible, a small-scale project may be possible using long, narrow bags laid along the road verge of Floodgate Road.

Environmental risk management

The use of geotextile bags to dewater sediments provides a higher degree of control in managing environmental risk. The use of bags greatly reduces the degree of disturbance required to achieve dewatering of sediment and, where cleared or grassed areas of foreshore can be accessed, there should be minimal physical disturbance to the banks of the estuary.

Return water (water that flows from the bags back into the estuary) is highly likely to be enriched with dissolved nutrients and this carries a risk of fuelling an algal bloom if works are carried out when water temperatures are warm. This risk can be minimised if works are undertaken during winter when water in the estuary is cooler, less salty and the conditions are unsuitable for algal blooms. Low salinity is desirable to enable effective flocculation of sediments in the geotextile bags. During summer, water in the estuary is usually hypersaline, which would pose an added technical constraint. Since the process of flocculation within the geotextile bags is a chemical separation process rather than a physical drying process (requiring heat), a winter removal scenario is feasible.

Liming of the dewatered sediment is recommended as a precaution to account for potential error in laboratory methods used to calculate net buffering capacity. Additional sampling would also be required to meet approval processes.

Cost implications

A ‘ballpark’ quote of $250 000 was provided by an experienced contractor to remove 3000 m^3 of sulfidic black ooze near Estuary View Drive using geotextile bags laid along James Richardson Park. This figure excluded the cost of earthworks to create a sand pad beneath geotextile bags, monitoring, and disposal of sediment spoil to the municipal waste facility. With these factors added, it is expected that the total cost of this project would be about from $300 000 to $600 000, giving a ratio of about $100–166 per cubic metre of sediment to be removed.

Community acceptance

This technique was considered to present the greatest opportunity to efficiently remove sediments while minimising potential adverse effect, such as odour, for adjoining residents.

An informal meeting of adjoining residents was hosted by the DWER in March 2018 to provide an outline of recent estuary management and to gauge community responses to the concept of sediment removal using geotextile bags laid along James Richardson Park at

Estuary View Drive. There were 22 attendees and, of these, nine completed a survey form. Seven of the nine survey respondents stated that they would support the use of geotextile bags on the foreshore of James Richardson Park to dewater sediments if dredging was ever proposed in the future. Of the remaining two, one skipped this question and one indicated that they would only support sediment removal 'if it would actually fix the problem'.

Community acceptance of this technique is likely to be higher than other sediment removal options, since there is a greater degree of control possible to mitigate potential environmental impacts and odour from the dewatering of sediments removed from the estuary.

Drainage and excavation

Description

Drainage and excavation of sediments would involve construction of either one or two sand bunds, depending on the location of sediment removal (e.g. Figure C2). This technique was used at both the Vasse and Wonnerup surge barriers when these structures were replaced in 2004. A dry works area was required to carry out these works, and accumulated sediment was removed from these areas at the same time.

Figure C2 *A sand bund and silt curtain in place downstream of the Wonnerup surge barrier during drainage and excavation works undertaken during replacement of the structure*

Practical feasibility

If sediment were to be removed near the surge barrier, then one bund would be required on the upstream side of the surge barrier followed by dewatering of the small section of channel that lies between the bund and the surge barrier. In 2004, when the Vasse surge barrier was replaced, the turkey nest dam was constructed on private land adjacent to the surge barrier. This land was leased from the owner. A similar arrangement would need to be negotiated for future projects of this kind.

In other locations, two bunds would be required with dewatering to occur between them. Water would need to be pumped to a dam to be constructed nearby to enable treatment and solids separation before flowing back into the channel. Once dewatered, the remaining wet sediment could be excavated from the channel into the dam where it would then be allowed to dry out. Dry material could then be transported away from the site in trucks.

This method is practically feasible at the surge barrier location where the channel is narrow and defined but would be extremely difficult to implement in wider parts of the channel, such as the area near Estuary View Drive.

Environmental risk management

This technique would need to be undertaken during the summer months as the watertable would be too high to enable dewatering at other times of the year. This is considered a major limitation. During the period of works, it would not be possible to allow the passage of fish through the works area at a time of year when the risk of fish kills is high. The usual logistics (allowing fish to move in and out of the surge barrier) that is used to reduce the risk of fish kills would not be available during the period of sediment removal works. The added bank disturbance associated with the use of earthmoving equipment and construction of dewatering ponds also adds to the overall environmental disturbance associated with this option.

Cost implications

Dewatering will be required and this may add to the regulatory approvals process, depending on the size of the area of works. Dewatering from large sections of the channel is likely to be expensive and may trigger a more formal approvals process, since a large project may have potential to adversely impact Ramsar values.

Community acceptance

Odour generated when dewatered sediments are exposed to air may be a nuisance to neighbours close to the works area.

Dredge to sand dam

Description

This technique would involve the use of a micro-dredge with sediment being pumped to an elongated above-ground sand dam on the banks of the estuary. The dam would be constructed so that water would flow into sections that were separated by sand bunds. Sediment slurry would be allowed to filter through sections of sand before flowing back into the estuary channel. Once dredging had ceased, the sand and sediment slurry would be mixed together until it was of a consistency that could be excavated into trucks for transport away from the site. In this way, the sand would effectively be used as a sponge to soak up excess water, thereby enabling transport.

Practical feasibility

The main limitation for this technique is lack of space. This technique is also only suitable for relatively small volumes of sediment as larger volumes would require very large sand dams, a large space, and high transport costs associated with trucking sand to and from the site. This technique would also need to be undertaken in dry conditions since heavy rainfall could disrupt the process and wash part of the sand dam back into the estuary.

Environmental risk management

Control over the rate and quality of leachate return to the estuary would be difficult with this method. If undertaken in summer (to ensure dry conditions), there is a risk that nutrient-laden leachate could exacerbate poor water quality in the channel.

Cost implications

This option is likely to be relatively low cost for small-scale projects, although transport costs of carting the sediment/sand mix away from the site would be higher than simply carting dried sediment on its own, given the much larger volumes required.

Community implications

Odour generated when dewatered sediments are exposed to air may be a nuisance to neighbours close to the works area.

Dredge to drying ponds

Description

This technique would involve the use of a micro-dredge with sediment being pumped to a series of drying ponds constructed on the estuary foreshore. Sediment slurry would be allowed to dry out in the ponds; therefore, these works would need to be undertaken in late spring or early summer. Once drying had occurred, the sediment could be excavated from the pond(s) and trucked away for disposal. Sediment pond construction would require a turkey nest design (i.e. constructed above natural ground level) since groundwater levels are naturally high at this location. This technique was previously trialled in the Lower Vasse River in 2001 (Figure C3).

Figure C3 *A small dredge working in the Lower Vasse River circa 2001*

Figure C4 *Dredge spoil being removed from drying ponds adjacent to the Lower Vasse River circa 2002*

Practical feasibility

A major limitation of this option is the need for sufficient space to construct drying ponds and the need to undertake the project at a time of year when the risk of fish kills is high and water quality within the channel is already poor. At Estuary View Drive, the only likely location that is close enough to be practical is the foreshore area between the exit channel and Estuary View Drive (James Richardson Park). The level of disturbance, noise and odour associated with this concept is unlikely to be acceptable to local residents along Estuary View Drive. At other locations along the channel, the only option would be to lease adjoining private land for the period of works since most of the adjoining public foreshore is vegetated with fringing vegetation or samphire.

Note that while some dredging companies also use ‘cyclone technology’ to separate solids from water, the grain size of the sediment in the Vasse Estuary exit channel is considered far too fine for this technique.

Environmental risk management

This technique would need to be undertaken during the summer months to ensure that drying of sediment within the ponds could occur. This is considered a major limitation as the risks of a fish kill due to low oxygen levels in the water (resulting from disturbance of sulfidic black ooze) is much greater in summer when the water levels in the channel are low and oxygen levels are typically already depleted. The added bank disturbance associated with the use of earthmoving equipment and construction of drying ponds also adds to the overall environmental disturbance associated with this option.

Cost implications

Large volume drying ponds are likely to be expensive to build and may rapidly fill with water. Waiting for return water to separate from sediments and flow back into the estuary may also result in the dredge being stopped and started, which can increase operating times and overall cost.

Community acceptance

Odour generated when dewatered sediments are exposed to air as well as visual disturbance from the constructed ponds may be a nuisance to neighbours close to the works area.

Dredge directly to Geographe Bay

Description

This option would involve the use of a micro-dredge with sediment being pumped directly into Geographe Bay during winter via a pipeline laid across Layman Road. In some respects, the technique may have a similar effect as if the estuary were flushed by tides and winter flow. Sediment would bypass the Wonnerup Inlet and enter directly into Geographe Bay, thereby avoiding the risk of sediment accumulating in the inlet rather than being flushed to the sea.

Following extreme high rainfall events, large loads of sediment are at times exported into Geographe Bay via drains, rivers and estuaries of the catchment (Figure C5). These events generally occur in winter when seagrass meadows are dormant and residence time of water in the bay is relatively small.

Figure C5 *Plume of sediment transported into Geographe Bay, July 2016*

Practical feasibility

The practicalities of dredging even a small volume of sediment directly to Geographe Bay may prove to be very difficult and expensive. There are also significant challenges associated with undertaking this project in winter when swells may complicate the process of enabling temporary pipes to pass sediment slurry far enough out to sea to enable sufficient dispersal.

Environmental risk management

Although seagrass meadows in Geographe Bay are dormant in winter, and therefore less susceptible to the impacts of low light conditions or sediment particles settling on shoots, there are still potential risks associated with this option even if undertaken during winter. Sediment transported via rivers and streams is likely to be small in particle size in order for it to have been able to pass through to the ocean without settling out within a channel. These small particles are more likely to remain in suspension once they reach the ocean. Sediment transported via means of a dredge may contain larger particle sizes that may settle closer to shore; however, it would be important to ensure that sediment does not form a smothering bank over seagrass meadows that could persist into the summer months.

There are uncertainties about short-term aesthetic impacts such as staining of the beach and, in practice, the degree to which sediment would be flushed from shore would be highly dependent on the weather conditions at the time of dredging. And the risks of smothering seagrass are increased as the size of the sediment removal project increases. The ability to ensure that sediment could be dispersed rapidly is highly dependent on local weather conditions at the time of operations. The residence time of water within Geographe Bay varies according to the prevailing wind conditions. The average flushing time has been estimated at three to five days for easterly, southerly and south-westerly winds (Fahrner & Pattiaratchi 1995). Under these conditions, the direction of water transport is predominantly away from the coast. Conversely, longer flushing times of up to 14 days occur in south-easterly and north-westerly winds (Fahrner & Pattiaratchi 1995). North-westerly winds also result in water movement being predominantly towards the coast, rather than away, which may result in sediment being washed up onto beaches rather than dispersed.

Given Geographe Bay is now formally part of the Ngari Capes Marine Park, this option will also require a higher level of assessment and approval than the three preceding dredge spoil disposal options, including modelling of potential plume transport. The marine park status does not automatically preclude this disposal option; however, under the marine park management plan, permission to undertake this activity from the Department of Primary Industries and Regional Development would need to be sought.

Cost implications

Traffic management required for the passage of the pipe across Layman Road may negate the cost savings of this option compared to other disposal methods.

Community acceptance

If the quantity of sediment to be removed is small, and if works were undertaken during favourable wind conditions during winter (when seagrass is dormant), this option is unlikely to have a detrimental impact on Geographe Bay. However, the community perception of dredging directly to Geographe Bay may be very negative.

Mechanically suspend and flush to Geographe Bay

Description

This option would involve mechanical disturbance of sediment within the channel during winter at a time when water flow was expected to be high. The surge barrier would be opened to enable suspended sediment to flow out to Wonnerup Inlet, with the aim of flushing it to the ocean.

Practical feasibility

It is unclear how sediment would be physically re-suspended under this scenario. A long-reach excavator would be required, although it still may not have sufficient reach and space to work. A work pad for an excavator would need to be constructed along both shorelines to enable a reach of about 18 m from each side and there is likely to be an associated loss of fringing vegetation to achieve this.

Mobilisation of sediment would have to occur at a very specific time period to allow flushing to occur (e.g. just before the surge barrier was opened). Estuary modelling has shown that there is very low shear on the surface sediments even during high flow events through the estuary. This is a feature of the very flat landscape of the catchment as a whole and the shape of the estuary. The flow is unlikely to be sufficient to move sediment very far.

Environmental risk management

Sediment slurry with zero or very low oxygen would then need to pass through Wonnerup Inlet, although it may deposit within the inlet rather than being flushed to the sea. Wonnerup Inlet is an important refuge site for black bream, particularly young fry, and is also a valued resource for recreational fishers (Cottingham et al. 2015). This option has potential to cause kills of fish and molluscs in Wonnerup Inlet during and immediately after dredging and is likely to require a higher level of investigation, including modelling of potential plume transport.

Cost implications

If practically feasible, this option would represent a low-cost option; however, it is likely that money spent may not result in an appreciable quality of sediment being removed from the channel.

Community acceptance

This option would create some noise associated with earthmoving equipment, although overall the impact to neighbouring households is likely to be low. Some members of the community may view this option as reflecting natural scouring processes, noting that suspended sediment is deposited into Geographe Bay every year from rivers and drains across the catchment. However, Wonnerup Inlet is a highly valued section of the estuary, particularly among recreational fishers. If detrimental impact occurred within Wonnerup Inlet, this would cause considerable community concern.

Appendix D Approvals and guidelines for sediment removal proposals

Local government approvals

Disposal or reuse of sediment

Where disposal of sediment to a landfill facility is proposed, quality criteria identified in the *Landfill waste classification and waste definitions 1996* (as amended April 2018) (Department of Water and Environmental Regulation 2018) must be met. Criteria differ for the various classes of landfill facilities and in some cases leachate testing of sediment samples is required before a final determination is made.

Dewatering of sediment on a local government reserve

Approval from the City of Busselton will be required should dewatering of sediments be proposed on a reserve managed by the City. This would apply to proposals to use geotextile bags on James Richardson Park at Estuary View Drive for the dewatering of sediments removed from the adjoining channel area.

Western Australian approvals

Environmental Protection Authority referral

Proposals to remove sediment from Ramsar wetlands and/or that expose acid sulfate soil may require referral to the Environmental Protection Authority (EPA) under section 38 of the *Environmental Protection Act 1986.* Following referral, the EPA may require an environmental impact assessment to be undertaken.

Acid sulfate soils

Dredging operations in Western Australian waterways require an assessment of acid sulfate soils (ASS) to be completed. Assessment of ASS should follow the principles identified in *Identification and investigation of acid sulfate soils and acidic landscapes* (DER 2015). Activities that have the potential to disturb ASS, either directly or by affecting the elevation of the watertable, need to be managed appropriately to avoid environmental harm. An acid sulfate soil management plan (ASSMP) should be prepared and implemented, following advice provided in *Treatment and management of soils and water in acid sulfate soil landscapes* (DER 2015). If ASS are not managed appropriately, environmental harm may be caused, as defined in the EP Act. Any works in areas containing ASS should be governed by the guiding principle that the disturbance of ASS should be avoided wherever possible.

Aboriginal heritage

Aboriginal sites are protected under the *Aboriginal Heritage Act 1972* (WpoA) and should not be disturbed without consent from the Western Australian Department of Planning, Lands and Heritage. The entire Vasse Wonnerup system is of cultural and historical significance to the Wardandi people with registered sites of archaeological and spiritual significance throughout the area. In addition to the legal and statutory requirements to ensure that registered sites are not disturbed, proposals to remove sediment should not be implemented without consultation with the South West Aboriginal Land and Sea Council.

The Ngari Capes Marine Park

The nearby shoreline and waters of Geographe Bay to which the Vasse Wonnerup wetland system drains forms part of the Ngari Capes Marine Park. The waters that lie parallel with the Vasse Estuary exit channel are located within the 'general use' zone of this marine park. All development proposals within the proposed marine park are subject to the environmental impact assessment requirements of the Environmental Protection Act. Development proposals include minor works, such as the installation of moorings or navigation markers, and would also include proposals to dispose of dredge spoil into Geographe Bay. The level of assessment applied would depend on the scale of the project and its potential to impact on the ecological and social values of the marine park (DEC 2013).

Commonwealth approvals and guidelines

The EPBC Act

The *Environment Protection and Biodiversity Conservation Act 1999* established a legislative framework that allows the Australian government to manage environmental protection of matters of national environmental significance through an assessment and approvals process. As a Ramsar-listed wetland, the Vasse Wonnerup Wetlands are recognised as a matter of national environmental significance and an action that may have a significant impact on the ecological character of that wetlands must be referred to the Minister and undergo an environmental assessment and approval process (Department of Environment, 2013).

Removal of sediment that is small in scale, isolated in location, and for which potential impacts can be easily managed are unlikely to trigger the Act since the impacts of these activities are unlikely to have a significant impact on the ecological character of the wetland. Larger sediment removal proposals that involve significant earthworks covering a large area of the wetland, large-scale dewatering, disturbance within sensitive parts of the estuary, risks to aquatic life or significant disturbance to waterbirds are likely to trigger a referral requirement with associated physical assessment and documentation.

National acid sulfate soils guidelines

The Australian government has also recently published guidelines for the dredging of ASS sediments and associated dredge spoil management (Simpson 2018) as well as a guidance document on the management of monosulfidic black ooze accumulations in waterways and wetlands (Sullivan et al. 2018). These documents are useful references although Commonwealth approvals are not required unless the proposed activity triggers the Act.

Appendix E Raw data from field investigations

Raw metals and nutrients

RESULTS OF SOIL ANALYSIS

71 samples supplied by Department of Water-WA on 14th November, 2016 - Lab. Job No. F4739 (re-issued with typographic correction of Arsenic units of measurement 25/09/2018)

Analysis requested by Svenja Tulipani. **Your Project: Vasse Sediments**

(Atrium Level 5, 168 St Georges Tce PERTH WA 6842)

	Method	Sample 1 VWSED 1_ Core 1 0-10 cm	Sample 2 VWSED 1_ Core 1 15-25 cm	Sample 3 VWSED 1_ Core 1 30-40 cm	Sample 4 VWSED 1_ Core 2 0-10 cm	Sample 5 VWSED 1_ Core 2 15-25 cm	Sample 6 VWSED 1_ Core 2 30-40 cm	Sample 7 VWSED 1_ Core 3 0-10 cm	Sample 8 VWSED 1_ Core 3 15-25 cm	Sample 9 VWSED 1_ Core 3 30-40 cm	Sample 10 VWSED 2_ Core 1 0-10 cm	Sample 11 VWSED 2_ Core 2 0-10 cm
	Job No.	F4739/1	F4739/2	F4739/3	F4739/4	F4739/5	F4739/6	F4739/7	F4739/8	F4739/9	F4739/10	F4739/11
METALS												
Silver (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Arsenic (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Lead (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	10.5	9.8	8.2	12.4	11.1	6.8	7.4	9.7	8.6	7.2	9.1
Cadmium (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	0.4	0.3	0.3	0.4	0.4	0.2	0.3	0.3	0.3	0.2	0.3
Chromium (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	20.1	19.5	20.4	22.8	19.8	14.7	15.6	19.1	18.0	16.3	17.8
Copper (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	9.8	9.8	6.9	12.8	10.8	5.4	6.8	8.9	7.8	6.2	8.1
Manganese (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	175.4	140.2	103.9	204.7	143.6	87.1	139.9	145.9	123.6	166.1	187.8
Nickel (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	7.9	7.9	8.1	11.0	8.8	4.7	5.9	7.2	6.9	5.3	7.2
Selenium (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	0.9	0.9	0.5	0.9	1.1	0.6	1.0	0.5	0.4	0.5	0.6
Zinc (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	38.5	37.5	25.6	50.1	38.5	20.2	30.9	33.1	29.1	22.4	29.5
Mercury (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	0.05	0.04	0.03	0.05	0.06	0.01	0.02	0.04	0.04	0.03	0.04
Iron (%)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	1.892	1.747	1.262	2.469	1.877	1.021	1.365	1.711	1.473	1.205	1.578
Aluminium (%)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	0.961	0.885	0.700	1.363	0.990	0.554	0.608	0.877	0.762	0.596	0.831
Phosphorus (mg/kg)	1:3 Nitric/HCl digest - APHA 3125 ICPMS	1,184	996	613	1,551	1,029	502	921	1,046	710	518	591

Notes:

1: ECEC = Effective Cation Exchange Capacity = sum of the exchangeable Mg, Ca, Na, K, H and Al

2: Exchangeable bases determined using standard Ammonium Acetate extract (Method 15D3) with no pretreatment for soluble salts. When Conductivity ≥0.25 dS/m soluble salts are removed (Method 15E2).

3. ppm = mg/Kg dried sample

4. Exchangeable sodium percentage (ESP) is calculated as sodium ($cmol^+/Kg$) divided by ECEC

5. All results as dry weight DW - samples were dried at 40°C for 24-48hrs prior to crushing and analysis.

6. Aluminium detection limit is 0.05 $cmol^+/Kg$; Hydrogen detection limit is 0.1 $cmol^+/Kg$.
However for calculation purposes a value of 0 is used.

7. For conductivity 1 dS/m = 1 mS/cm = 1000 µS/cm

8. 1 $cmol^+/Kg$ = 1 meq/100g

9. Methods from Rayment and Lyons, Soil Chemical Methods - Australasia

10. Conversion of cmol+/Kg to mg/Kg multiply cmol+/Kg by:
230 for Sodium; 391 for Potassium; 200 for Calcium; 122 for Magnesium; 90 for Aluminium

11. Metals analysed by ICP-MS (Inductively Coupled Plasma - Mass Spectrometry) or ICP-OES (Inductively Coupled Plasma - Optical Emission Spectrometry)

checked: ....

Sample 12	Sample 19	Sample 20	Sample 21	Sample 22	Sample 23	Sample 24	Sample 25	Sample 26	Sample 27	Sample 28	Sample 29	Sample 30	Sample 31	Sample 32	Sample 33	Sample 34
VWSED 2_ Core 3 0-10 cm	VWSED 3_ Core 1 0-10 cm	VWSED 3_ Core 1 15-25 cm	VWSED 3_ Core 1 28-38 cm	VWSED 3_ Core 2 0-10 cm	VWSED 3_ Core 2 15-25 cm	VWSED 3_ Core 2 28-38 cm	VWSED 3_ Core 3 0-10 cm	VWSED 3_ Core 3 15-25 cm	VWSED 3_ Core 3 28-38 cm	VWSED 4_ Core 1 0-10 cm	VWSED 4_ Core 1 15-25 cm	VWSED 4_ Core 1 30-40 cm	VWSED 4_ Core 2 0-10 cm	VWSED 4_ Core 2 15-25 cm	VWSED 4_ Core 2 30-40 cm	VWSED 4_ Core 3 0-10 cm
F4739/12	*F4739/19*	*F4739/20*	*F4739/21*	*F4739/22*	*F4739/23*	*F4739/24*	*F4739/25*	*F4739/26*	*F4739/27*	*F4739/28*	*F4739/29*	*F4739/30*	*F4739/31*	*F4739/32*	*F4739/33*	*F4739/34*
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
<1.0	3.8	6.0	3.2	3.7	4.3	2.9	5.0	5.4	5.2	<1.0	1.0	<1.0	<1.0	<1.0	<1.0	1.4
6.8	9.2	9.5	7.1	8.5	8.6	7.2	9.6	9.6	8.2	6.0	4.6	3.7	9.1	5.1	3.7	7.9
0.2	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
15.8	24.3	29.8	21.2	23.1	26.7	21.0	24.6	24.9	22.6	15.6	17.1	17.6	19.2	20.3	14.0	18.7
6.0	7.4	4.2	2.4	6.5	3.5	2.8	6.1	3.2	3.0	4.3	3.7	3.3	8.1	4.2	3.1	5.8
175.0	199.0	153.0	148.7	197.5	142.4	138.3	194.6	146.4	124.4	184.5	101.9	58.2	213.0	162.9	79.1	266.9
5.4	6.8	7.9	4.9	6.6	6.4	5.0	6.7	5.8	5.7	6.6	9.7	8.2	7.7	10.5	9.6	8.1
0.9	0.5	1.3	0.5	0.6	0.7	0.6	0.9	0.7	0.8	0.8	1.1	0.9	0.6	1.3	1.2	0.5
22.3	21.2	11.4	8.8	18.7	10.5	9.2	18.9	9.7	8.0	13.8	10.2	7.5	26.4	10.0	8.7	18.4
0.03	0.03	0.01	0.01	0.01	0.00	0.01	0.02	0.01	0.01	0.04	0.04	0.03	0.04	0.02	0.02	0.02
1.191	1.522	1.111	0.781	1.359	0.964	0.762	1.327	0.900	0.849	1.165	1.313	0.889	1.693	1.432	1.067	1.585
0.634	0.652	0.390	0.274	0.561	0.395	0.286	0.534	0.329	0.317	0.476	0.385	0.357	0.835	0.359	0.277	0.585
546	859	871	469	775	709	526	862	645	620	470	452	472	568	442	377	534

Sample 35	Sample 36	Sample 37	Sample 38	Sample 39	Sample 40	Sample 41	Sample 42	Sample 43	Sample 44	Sample 45	Sample 46	Sample 47	Sample 48	Sample 49	Sample 50	Sample 51
VWSED 4_ Core 3 15-25 cm	VWSED 4_ Core 3 30-40 cm	VWSED 5_ Core 1 0-10 cm	VWSED 5_ Core 1 10-20 cm	VWSED 5_ Core 2 0-10 cm	VWSED 5_ Core 2 10-20 cm	VWSED 5_ Core 3 0-10 cm	VWSED 5_ Core 3 10-20 cm	VWSED 6_ Core 1 0-10 cm	VWSED 6_ Core 1 10-20 cm	VWSED 6_ Core 1 20-30 cm	VWSED 6_ Core 1 30-40 cm	VWSED 6_ Core 2 0-10 cm	VWSED 6_ Core 2 10-20 cm	VWSED 6_ Core 2 20-30 cm	VWSED 6_ Core 2 30-40 cm	VWSED 6_ Core 3 0-10 cm
F4739/35	*F4739/36*	*F4739/37*	*F4739/38*	*F4739/39*	*F4739/40*	*F4739/41*	*F4739/42*	*F4739/43*	*F4739/44*	*F4739/45*	*F4739/46*	*F4739/47*	*F4739/48*	*F4739/49*	*F4739/50*	*F4739/51*
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
1.6	<1.0	<1.0	<1.0	<1.0	<1.0	2.5	<1.0	<1.0	3.1	2.4	<1.0	2.4	5.4	1.7	<1.0	2.0
4.5	2.2	15.4	9.9	14.2	13.4	15.1	11.4	16.3	16.0	8.6	1.7	16.4	17.4	9.1	1.5	16.6
0.3	0.1	0.8	0.4	0.7	0.6	0.7	0.5	0.7	0.6	0.4	0.2	0.8	0.7	0.4	0.2	0.8
16.4	11.4	28.2	19.9	28.9	23.4	27.4	21.7	27.3	30.1	19.1	12.5	28.4	25.2	20.2	10.9	26.4
3.4	1.2	19.7	9.5	19.4	15.2	18.8	13.2	18.7	17.3	7.3	2.5	19.4	15.0	7.3	2.2	18.6
96.2	53.0	368.3	312.6	399.0	330.2	379.6	368.3	480.0	732.1	390.0	52.4	464.5	672.1	398.3	58.3	432.4
9.9	3.2	16.4	8.9	16.9	13.2	16.5	11.7	17.3	17.4	10.1	7.5	18.7	15.8	11.1	7.1	16.4
0.9	0.6	1.0	0.6	0.8	0.6	0.9	0.9	1.2	1.1	1.2	1.5	1.3	1.1	1.0	1.3	1.3
8.3	3.7	85.1	39.9	83.5	61.5	87.1	55.5	68.7	62.5	19.8	4.0	70.0	55.1	20.2	4.4	68.0
0.04	0.01	0.08	0.03	0.09	0.09	0.10	0.07	0.08	0.09	0.05	0.00	0.09	0.10	0.05	0.00	0.08
1.194	0.350	4.901	2.416	4.997	3.487	4.782	3.435	4.406	4.715	2.453	0.594	4.528	4.130	2.675	0.566	4.086
0.365	0.134	2.607	1.222	2.370	1.815	2.451	1.612	2.343	2.024	1.082	0.214	2.477	2.425	1.137	0.187	2.268
405	362	1,272	608	1,428	1,014	1,623	830	1,388	781	443	390	1,457	666	409	355	1,314

Sample 52	Sample 53	Sample 54	Sample 55	Sample 56	Sample 57	Sample 58	Sample 59	Sample 60	Sample 61	Sample 62	Sample 63	Sample 64	Sample 65	Sample 66	Sample 67	Sample 68
VWSED 6_ Core 3 10-20 cm	VWSED 6_ Core 3 20-30 cm	VWSED 6_ Core 3 30-40 cm	VWSED 7_ Core 1 0-10 cm	VWSED 7_ Core 1 10-20 cm	VWSED 7_ Core 1 30-40 cm	VWSED 7_ Core 2 0-10 cm	VWSED 7_ Core 2 10-20 cm	VWSED 7_ Core 2 30-40 cm	VWSED 7_ Core 3 0-10 cm	VWSED 7_ Core 3 10-20 cm	VWSED 7_ Core 3 30-40 cm	VWSED 8_ Core 1 0-10 cm	VWSED 8_ Core 1 14-24 cm	VWSED 8_ Core 2 0-10 cm	VWSED 8_ Core 2 10-20 cm	VWSED 8_ Core 2 20-30 cm
F4739/52	*F4739/53*	*F4739/54*	*F4739/55*	*F4739/56*	*F4739/57*	*F4739/58*	*F4739/59*	*F4739/60*	*F4739/61*	*F4739/62*	*F4739/63*	*F4739/66*	*F4739/67*	*F4739/68*	*F4739/69*	*F4739/70*
<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
3.1	3.2	1.0	2.5	1.2	1.2	<1.0	<1.0	1.8	1.9	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
15.8	5.9	1.4	11.5	8.7	1.3	8.7	2.9	1.7	11.9	3.8	1.1	4.4	2.5	3.2	2.1	2.3
0.6	0.3	0.2	0.5	0.2	0.4	0.4	0.3	0.3	0.5	0.2	0.2	0.1	0.1	0.1	0.0	0.0
27.3	16.4	11.5	23.2	16.8	10.5	20.1	18.4	13.0	21.7	15.5	9.9	10.5	7.9	8.4	3.9	5.4
15.6	4.4	2.5	11.5	3.8	2.5	9.7	3.6	2.9	12.0	4.1	1.5	3.4	1.7	2.7	1.3	1.2
748.2	256.9	38.0	399.4	97.0	20.9	273.3	50.3	24.5	400.4	153.2	22.1	42.3	25.2	35.7	18.8	16.2
16.1	9.0	6.7	12.3	7.9	10.5	10.8	9.0	9.9	13.0	7.0	4.9	4.0	3.8	3.1	1.2	2.5
0.9	1.6	1.5	1.4	1.5	1.8	1.1	1.9	1.7	1.6	1.1	1.4	0.7	0.2	0.1	0.2	0.2
55.7	12.4	2.7	34.4	6.7	2.5	28.5	5.3	2.8	37.4	8.8	1.4	11.8	5.9	9.1	4.2	4.2
0.08	0.04	0.01	0.07	0.04	0.01	0.03	0.04	0.00	0.07	0.04	0.01	0.01	0.01	0.02	0.00	0.00
4.318	1.738	0.491	2.916	1.061	0.467	2.187	1.040	0.594	2.847	1.122	0.289	0.704	0.302	0.507	0.251	0.212
2.074	0.750	0.206	1.431	0.468	0.129	1.097	0.458	0.195	1.479	0.479	0.135	0.406	0.170	0.264	0.132	0.111
677	426	406	672	435	351	858	488	396	797	406	360	318	175	256	121	116

Sample 69	Sample 70	Sample 71
VWSED 8_ Core 3 0-10 cm	VWSED 8_ Core 3 10-20 cm	VWSED 8_ Core 3 20-30 cm
F4739/71	*F4739/72*	*F4739/73*
<0.1	<0.1	<0.1
<1.0	<1.0	<1.0
2.9	4.8	3.4
0.1	0.1	0.1
11.2	14.9	8.5
2.6	4.0	2.6
29.4	42.1	35.2
3.0	6.7	2.8
0.3	0.4	0.5
8.1	13.5	8.7
0.02	0.02	0.02
0.436	0.759	0.509
0.235	0.429	0.274
326	377	269

checked: ....

Raw pesticide and hydrocarbon screen

PAGE 1 OF 1

RESULTS OF SOIL ANALYSIS

71 samples supplied by Department of Water-WA on 14th November, 2016 - Lab. Job No. F4739
Analysis requested by Svenja Tulipani. **Your Project: Vasse Sediments**
(Atrium Level 5, 168 St Georges Tce PERTH WA 6842)

ANALYTE	METHOD REFERENCE	Sample 13 VWSED 2_ Core 4 0-10 cm	Sample 14 VWSED 2_ Core 4 10-15 cm	Sample 15 VWSED 2_ Core 5 0-5 cm	Sample 16 VWSED 2_ Core 5 5-8.3 cm	Sample 17 VWSED 2_ Core 6 0-10 cm	Sample 18 VWSED 2_ Core 6 10-15 cm
	Job No.	*F4739/13*	*F4739/14*	*F4739/15*	*F4739/16*	*F4739/17*	*F4739/18*
PESTICIDE ANALYSIS SCREEN							
DDT+DDE+DDD (mg/Kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Aldrin + Dieldrin (mg/kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Chlordane (mg/kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Endosulfan (mg/kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Endrin (mg/kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Heptachlor (mg/kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
HCB (mg/kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Methoxychlor (mg/kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Other Organochlorine Pesticides (mg/Kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Chlorpyrifos (mg/kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Other Organophosphate Pesticides (mg/Kg)	*c*	<0.02	<0.01	<0.02	<0.01	<0.02	<0.01
Polyaromatic Hydrocarbons (PAH)							
Naphthalene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acenaphthylene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Acenaphthene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluorene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phenanthrene (mg/Kg)	*c*	0.04	<0.01	<0.01	<0.01	<0.01	0.01
Anthracene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Fluoranthene (mg/Kg)	*c*	0.04	<0.01	<0.01	<0.01	<0.01	0.03
Pyrene (mg/Kg)	*c*	0.04	<0.01	<0.01	<0.01	<0.01	0.02
Benzo(a)anthracene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chrysene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(b)&(k)flouranthene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(a)pyrene (BaP TEQ) (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Indeno(1,2,3-c,d)pyrene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Dibenzo(a,h) anthracene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo(g,h,i)perylene (mg/Kg)	*c*	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sum of reported PAHs (mg/Kg)	*c*	0.12	Not detected	Not detected	Not detected	Not detected	0.06
Acid Herbicides (mg/Kg) (See notes below for screening list)	*c*	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5

METHODS REFERENCE
a. [1-3]Nitric/HCl digest - APHA 3125 ICPMS
b. [1-3]Nitric/HCl digest - APHA 3120 ICPOES
c. Analysis sub-contracted - Envirolab report no. 157799

NOTES
1a. HIL A - Residential with garden/accessible soil (home grown produce <10% fruit and vegetable intake (no poultry), also includes childcare centres, preschools and primary schools.
1b. HIL B - Residential with minimal opportunities for soil access; includes dwellings with fully and permanently paved yard space such as high-rise buildings and apartments.
1c. HIL C - Public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths. This does not include undeveloped public open space.
1d. HIL D - Commercial/industrial, includes premises such as shops, offices, factories and industrial sites.
(REFERENCE: Health Investigation Guidelines from NEPM (National Environmental Protection, Assessment of Site Contamination, Measure), 2013; Schedule B1).
2. Environmental Soil Quality Guidelines, Page 40, ANZECC, 1992.

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Additional NOTES
DW = Dry Weight. na = no guidelines available

Organochlorine pesticide (OC's) screen: (HCB, alpha-BHC, gamma-BHC, Heptachlor, delta-BHC, Aldrin, Heptachlor Epoxide, gamma-Chlordane, alpha-chlordane, Endosulfan 1, pp-DDE, Dieldrin, Endrin, pp-DDD, Endosulfan 2, pp-DDT, Endrin Aldehyde, Endosulfan Sulphate, Methoxychlor)

Organophosphorus pesticide (OP's) screen: (Azinphos-methyl (Guthion), Bromophos-ethyl, Chlorpyriphos, Chlorpyriphos-methyl, Diazinon, Dichlorvos, Dimethoate, Ethion, Fenitrothion, Malathion, Parathion, Ronnel)

Acid Herbicides Screen: (Azinphos-methyl (Guthion), Bromophos-ethyl, Chlorpyriphos, Chlorpyriphos-methyl, Diazinon, Dichlorvos, Dimethoate, Ethion, Fenitrothion, Malathion, Parathion, Ronnel)

Environmental Analysis Laboratory, Southern Cross University,
Tel. 02 6620 3678, website: scu.edu.au/eal

Raw grain size

GRAIN SIZE ANALYSIS (laser particle size techniques)

71 soil samples supplied by Department of Water - WA on the 14th November, 2016 - Lab Job No. F4739.
Analysis requested by Svenja Tulipani. **Your Project: Vasse sediments.**
(Atrium Level 5, 168 St Georges Tce, Perth WA 6842)

		USDA and ISSS Sand/Silt/Clay Classification					Wentworth (1922) Grain Size Classification					
SAMPLE ID	Lab Code	SAND > 50 µm USDA (< 2 mm fraction)	SAND > 20 µm ISSS (< 2 mm fraction)	SILT 2–50 µm USDA (< 2 mm fraction)	SILT 2–20 µm ISSS (< 2 mm fraction)	CLAY < 2 µm (< 2 mm fraction)	Very Coarse Sand 1000–2000 µm (< 2 mm fraction)	Coarse Sand 500–1000 µm (< 2 mm fraction)	Medium Sand 250–500 µm (< 2 mm fraction)	Fine Sand 125–250 µm (< 2 mm fraction)	Very Fine Sand 63–125 µm (< 2 mm fraction)	Silt and Clay < 63 µm (< 2 mm fraction)
VWSED 1_ Core 1 0-10 cm	F4739/1	26.7	42.6	70.5	54.6	2.8	0.0	1.9	8.6	8.9	5.4	75.3
VWSED 1_ Core 1 15-25 cm	F4739/2	28.7	61.4	68.6	36.0	2.6	0.0	1.8	7.9	6.2	6.7	77.5
VWSED 1_ Core 1 30-40 cm	F4739/3	40.1	57.1	58.2	41.2	1.7	0.0	3.6	14.0	14.0	6.4	61.9
VWSED 1_ Core 2 0-10 cm	F4739/4	22.8	44.1	75.6	54.3	1.6	0.0	1.6	7.2	6.5	5.0	79.7
VWSED 1_ Core 2 15-25 cm	F4739/5	34.0	51.0	60.9	43.9	5.1	0.0	2.2	9.4	10.2	8.9	69.3
VWSED 1_ Core 2 30-40 cm	F4739/6	52.7	67.0	46.5	32.2	0.8	0.2	7.6	22.1	16.4	4.8	48.9
VWSED 1_ Core 3 0-10 cm	F4739/7	36.9	45.5	57.4	48.8	5.8	0.0	5.1	17.2	11.1	2.5	64.1
VWSED 1_ Core 3 15-25 cm	F4739/8	30.9	57.9	66.5	39.6	2.6	0.2	3.4	11.4	8.9	3.8	72.3
VWSED 1_ Core 3 30-40 cm	F4739/9	28.5	41.3	66.7	53.9	4.8	0.0	2.6	9.5	9.3	5.2	73.4
VWSED 2_ Core 1 0-10 cm	F4739/10	60.7	68.5	31.4	23.6	8.0	1.1	7.5	24.4	21.3	5.2	40.4
VWSED 2_ Core 2 0-10 cm	F4739/11	44.9	58.5	52.8	39.2	2.4	0.0	3.1	18.9	17.5	4.2	56.3
VWSED 2_ Core 3 0-10 cm	F4739/12	64.7	74.4	34.6	24.8	0.8	0.0	5.7	27.7	24.9	5.3	36.4
VWSED 3_ Core 1 0-10 cm	F4739/19	39.9	58.0	57.2	39.0	3.0	0.0	5.0	16.8	11.8	4.4	62.2
VWSED 3_ Core 1 15-25 cm	F4739/20	79.2	87.1	19.7	11.8	1.1	0.4	14.7	34.2	23.7	5.2	21.8
VWSED 3_ Core 1 28-38 cm	F4739/21	90.2	94.6	9.8	5.4	0.0	4.0	20.4	37.4	23.3	4.5	10.4
VWSED 3_ Core 2 0-10 cm	F4739/22	44.2	61.2	52.3	35.3	3.5	0.0	5.5	16.0	12.9	7.1	58.5
VWSED 3_ Core 2 15-25 cm	F4739/23	Insufficient sample after organic and acid digestion										
VWSED 3_ Core 2 28-38 cm	F4739/24	84.1	89.3	15.1	9.9	0.7	0.3	18.3	37.9	22.9	4.2	16.5
VWSED 3_ Core 3 0-10 cm	F4739/25	36.6	55.2	60.9	42.3	2.5	0.0	5.1	16.0	10.5	3.3	65.1
VWSED 3_ Core 3 15-25 cm	F4739/26	75.3	84.3	23.4	14.4	1.3	3.4	15.2	30.0	19.8	5.5	26.1
VWSED 3_ Core 3 28-38 cm	F4739/27	90.6	94.4	8.7	4.8	0.7	2.7	22.4	39.3	21.7	3.9	10.0
VWSED 4_ Core 1 0-10 cm	F4739/28	72.5	83.6	25.8	14.7	1.7	0.2	5.0	24.1	28.9	11.7	30.0
VWSED 4_ Core 1 15-25 cm	F4739/29	25.5	36.4	59.0	48.1	15.5	0.0	1.5	8.9	9.8	3.9	75.9
VWSED 4_ Core 1 30-40 cm	F4739/30	88.8	94.1	10.5	5.2	0.7	0.3	10.2	35.6	34.3	7.8	11.9
VWSED 4_ Core 2 0-10 cm	F4739/31	42.8	58.9	55.8	39.7	1.4	0.0	3.8	14.6	14.0	7.9	59.7
VWSED 4_ Core 2 15-25 cm	F4739/32	79.5	88.8	19.8	10.6	0.7	0.1	8.6	30.5	29.3	9.3	22.2
VWSED 4_ Core 2 30-40 cm	F4739/33	80.2	88.6	17.7	9.2	2.1	3.2	7.9	23.8	31.9	12.0	21.3
VWSED 4_ Core 3 0-10 cm	F4739/34	83.0	90.4	16.0	8.6	1.0	0.2	9.3	34.7	30.5	7.1	18.2
VWSED 4_ Core 3 15-25 cm	F4739/35	60.8	70.7	32.5	22.6	6.7	0.0	2.0	21.3	28.0	8.4	40.4
VWSED 4_ Core 3 30-40 cm	F4739/36	92.1	95.3	7.9	4.7	0.0	1.6	6.3	33.2	41.2	9.6	8.1
VWSED 5_ Core 1 0-10 cm	F4739/37	8.5	22.8	79.9	65.6	11.6	0.0	0.3	1.4	1.6	3.3	93.5
VWSED 5_ Core 1 10-20 cm	F4739/38	31.1	41.0	65.4	55.5	3.5	0.1	4.5	11.7	9.4	4.1	70.2
VWSED 5_ Core 2 0-10 cm	F4739/39	7.7	18.9	81.8	70.6	10.4	0.0	0.5	1.2	1.5	2.9	93.9
VWSED 5_ Core 2 10-20 cm	F4739/40	19.1	37.2	74.3	56.2	6.6	0.8	1.2	2.9	4.0	6.9	84.3
VWSED 5_ Core 3 0-10 cm	F4739/41	6.7	17.6	85.7	74.8	7.6	0.0	0.1	0.9	1.4	2.8	94.9
VWSED 5_ Core 3 10-20 cm	F4739/42	24.1	38.2	72.4	58.2	3.6	0.2	2.2	5.8	6.9	6.5	78.5
VWSED 6_ Core 1 0-10 cm	F4739/43	6.3	19.7	83.3	69.9	10.5	0.0	0.0	1.2	2.2	1.8	94.7
VWSED 6_ Core 1 10-20 cm	F4739/44	11.4	25.7	83.8	69.6	4.8	0.0	0.5	2.0	2.5	4.3	90.7

checked: ....
Graham Lancaster
Laboratory Manager

GRAIN SIZE ANALYSIS (laser particle size techniques)

71 soil samples supplied by Department of Water - WA on the 14th November, 2016 - Lab Job No. F4739.
Analysis requested by Svenja Tulipani. **Your Project: Vasse sediments.**
(Atrium Level 5, 168 St Georges Tce, Perth WA 6842)

		USDA and ISSS Sand/Silt/Clay Classification					Wentworth (1922) Grain Size Classification					
SAMPLE ID	Lab Code	SAND > 50 µm USDA (< 2 mm fraction)	SAND > 20 µm ISSS (< 2 mm fraction)	SILT 2–50 µm USDA (< 2 mm fraction)	SILT 2–20 µm ISSS (< 2 mm fraction)	CLAY < 2 µm (< 2 mm fraction)	Very Coarse Sand 1000–2000 µm (< 2 mm fraction)	Coarse Sand 500–1000 µm (< 2 mm fraction)	Medium Sand 250–500 µm (< 2 mm fraction)	Fine Sand 125–250 µm (< 2 mm fraction)	Very Fine Sand 63–125 µm (< 2 mm fraction)	Silt and Clay < 63 µm (< 2 mm fraction)
VWSED 6_ Core 1 20-30 cm	F4739/45	31.6	49.0	64.6	47.1	3.8	0.0	1.2	5.6	10.5	10.8	72.0
VWSED 6_ Core 1 30-40 cm	F4739/46	64.7	82.3	33.8	16.2	1.5	0.8	6.4	16.1	21.1	15.9	39.6
VWSED 6_ Core 2 0-10 cm	F4739/47	6.8	16.2	86.1	76.7	7.1	0.0	0.4	1.3	1.4	2.4	94.5
VWSED 6_ Core 2 10-20 cm	F4739/48	9.6	22.2	86.3	73.7	4.1	0.0	0.6	2.2	2.1	3.1	92.0
VWSED 6_ Core 2 20-30 cm	F4739/49	31.9	52.4	62.9	42.4	5.1	0.1	1.9	5.1	9.2	11.5	72.3
VWSED 6_ Core 2 30-40 cm	F4739/50	Insufficient sample after organic and acid digestion										
VWSED 6_ Core 3 0-10 cm	F4739/51	6.7	15.7	86.7	77.6	6.7	0.0	0.1	1.1	1.6	2.5	94.6
VWSED 6_ Core 3 10-20 cm	F4739/52	13.4	26.5	81.9	68.8	4.7	0.0	0.4	3.2	3.9	3.9	88.5
VWSED 6_ Core 3 20-30 cm	F4739/53	38.6	57.8	57.8	38.6	3.6	0.0	1.6	6.3	12.5	13.8	65.7
VWSED 6_ Core 3 30-40 cm	F4739/54	73.5	87.3	25.7	12.0	0.7	2.1	10.2	20.9	22.4	14.3	30.0
VWSED 7_ Core 1 0-10 cm	F4739/55	34.4	47.5	58.5	45.5	7.0	0.0	1.2	9.4	13.5	8.2	67.8
VWSED 7_ Core 1 10-20 cm	F4739/56	71.4	84.2	26.4	13.6	2.2	0.1	8.1	21.9	23.2	14.4	32.3
VWSED 7_ Core 1 30-40 cm	F4739/57	Insufficient sample after organic and acid digestion										
VWSED 7_ Core 2 0-10 cm	F4739/58	34.5	46.4	58.9	47.0	6.6	0.0	3.5	11.6	11.4	6.2	67.3
VWSED 7_ Core 2 10-20 cm	F4739/59	55.6	68.4	41.0	28.2	3.3	0.3	5.3	14.5	20.7	12.2	47.0
VWSED 7_ Core 2 30-40 cm	F4739/60	63.0	82.3	35.9	16.6	1.1	0.7	3.6	13.1	23.0	17.8	41.8
VWSED 7_ Core 3 0-10 cm	F4739/61	32.4	49.2	63.7	46.8	4.0	0.0	2.3	9.2	10.9	7.4	70.2
VWSED 7_ Core 3 10-20 cm	F4739/62	69.8	83.8	28.2	14.2	2.0	1.3	5.4	18.1	24.5	16.5	34.2
VWSED 7_ Core 3 30-40 cm	F4739/63	89.2	94.6	9.4	4.1	1.4	1.9	5.4	27.9	39.4	13.3	12.1
VWSED 8_ Core 1 0-10 cm	F4739/64	75.0	84.1	24.2	15.1	0.8	6.5	17.2	30.5	15.9	3.5	26.4
VWSED 8_ Core 1 14-24 cm	F4739/65	85.5	92.5	13.9	6.9	0.7	0.0	5.5	38.5	32.0	7.7	16.3
VWSED 8_ Core 2 0-10 cm	F4739/66	84.7	91.2	13.9	7.4	1.4	0.0	9.7	44.0	27.0	2.9	16.4
VWSED 8_ Core 2 10-20 cm	F4739/67	91.6	95.6	8.4	4.4	0.0	0.0	6.7	52.2	31.3	0.8	8.8
VWSED 8_ Core 2 20-30 cm	F4739/68	91.8	97.4	8.2	2.6	0.0	0.0	3.0	39.5	39.2	8.7	9.6
VWSED 8_ Core 3 0-10 cm	F4739/69	77.5	84.4	21.1	14.2	1.4	3.9	22.2	36.1	13.0	1.3	23.4
VWSED 8_ Core 3 10-20 cm	F4739/70	69.0	79.5	29.5	19.0	1.5	0.9	11.3	31.3	19.6	4.3	32.6
VWSED 8_ Core 3 20-30 cm	F4739/71	75.5	86.9	23.3	11.8	1.3	2.3	12.4	26.7	21.8	9.6	27.2

Note:
1: Laser Particle Size using a Mastersizer Hydro 2000MU analyser.
Laser Method: Hydrogen peroxide digestion of organic matter, then acid digestion of shell prior to analysis. Sample dispersed in calgon.
Homogenisation using an IKA RW20 digital overhead stirrer in a bafffled beaker.
Sample aliquot pipetted into measurement beaker of calgon dispersant.
HydroMU 16.00 µm ultrasound applied in 10 sec bursts until dispersion stabilised.
2: Average results reported of at least 3 measurements.

checked: ....
Graham Lancaster
Laboratory Manager

Raw acid sulfate analysis

RESULTS OF ACID SULFATE SOIL ANALYSIS

71 samples supplied by Department of Water-WA on 14th November, 2016 – Lab. Job No. F4739
Analysis requested by Svenja Tulipani. **Your Project: Vasse Sediments**
(Hale Level 1, 168 St Georges Tce PERTH WA 6842)

required if pH_{KCl} > 6.5

Sample Site	EAL lab code	TEXTURE (note 7)	MOISTURE CONTENT 85°C (% moisture of total wet weight)	MOISTURE CONTENT 85°C (g moisture / g of oven dry soil)	ACID VOLATILE SULFUR (AVS) (% Sav WW) (note 3)	ACID VOLATILE SULFUR (AVS) (% Sav DW) (note 3)	ELEMENTAL SULFUR (ES) (% Se WW) (note 3)	ELEMENTAL SULFUR (ES) (% Se DW) (note 3)	REDUCED INORGANIC SULFUR (% chromium reducible S DW) (%Scr DW)	REDUCED INORGANIC SULFUR (mole H^+/tonne)	TOTAL ORGANIC CARBON %C (note 3)	TOTAL NITROGEN %N (note 3)	ACID NEUTRALISING CAPACITY (ANC_{BT}) (% $CaCO_3$)	ACID NEUTRALISING CAPACITY (ANC_{BT}) (mole H^+/tonne)	NET ACIDITY Chromium Suite mole H^+/tonne (based on %Scr)	LIME CALCULATION Chromium Suite kg $CaCO_3$/tonne DW (includes 1.5 safety factor when liming rate is +ve)
Method info.		**	**						(POTENTIAL ACIDITY Method 22B)		(Acid- LECO TruMAC)	(LECO TruMAC)	(NEUTRALISING CAPACITY)		** & note 5	** & note 4 and 6
VWSED 1_Core 1 0-10 cm	F4739/1	Medium	73.3	2.75	0.106	0.398	0.051	0.191	0.953	594	7.29	0.91	35.92	7,177	-4,190	-210
VWSED 1_Core 1 15-25 cm	F4739/2	Medium	80.6	4.15	0.093	0.479	0.049	0.253	1.265	789	7.95	0.95	29.81	5,956	-3,182	-159
VWSED 1_Core 1 30-40 cm	F4739/3	Medium	63.6	1.75	0.056	0.154	0.031	0.085	1.041	649	4.88	0.52	32.91	6,575	-3,734	-187
VWSED 1_Core 2 0-10 cm	F4739/4	Medium	84.1	5.29	0.109	0.685	0.078	0.490	1.189	742	8.57	1.07	34.47	6,887	-3,850	-192
VWSED 1_Core 2 15-25 cm	F4739/5	Medium	82.3	4.65	0.115	0.649	0.074	0.418	1.490	929	8.94	1.02	27.34	5,463	-2,712	-136
VWSED 1_Core 2 30-40 cm	F4739/6	Medium	55.3	1.23	0.036	0.080	0.015	0.034	0.809	505	3.74	0.41	33.16	6,625	-3,912	-196
VWSED 1_Core 3 0-10 cm	F4739/7	Medium	88.6	7.77	0.107	0.938	0.080	0.702	1.295	808	10.40	1.22	29.82	5,958	-3,164	-158
VWSED 1_Core 3 15-25 cm	F4739/8	Medium	70.1	2.34	0.125	0.417	0.033	0.110	1.149	717	7.78	0.87	34.09	6,811	-3,824	-191
VWSED 1_Core 3 30-40 cm	F4739/9	Medium	79.6	3.91	0.062	0.304	0.047	0.231	1.819	1,135	9.30	0.97	23.91	4,777	-2,050	-103
VWSED 2_Core 1 0-10 cm	F4739/10	Medium	68.1	2.14	0.020	0.063	0.019	0.060	0.875	546	3.07	0.33	38.63	7,718	-4,600	-230
VWSED 2_Core 2 0-10 cm	F4739/11	Medium	61.0	1.57	0.024	0.062	0.017	0.044	0.992	619	3.59	0.37	38.40	7,672	-4,496	-225
VWSED 2_Core 3 0-10 cm	F4739/12	Medium	54.1	1.18	0.012	0.026	0.100	0.218	0.820	511	2.89	0.30	38.37	7,666	-4,599	-230
VWSED 3_Core 1 0-10 cm	F4739/19	Medium	65.5	1.90	0.021	0.061	0.012	0.035	1.048	654	6.67	0.61	36.12	7,217	-4,158	-208
VWSED 3_Core 1 15-25 cm	F4739/20	Fine	55.3	1.24	0.003	0.007	0.006	0.013	0.895	558	7.02	0.41	47.62	9,514	-5,785	-289
VWSED 3_Core 1 28-38 cm	F4739/21	Fine	43.1	0.76	0.007	0.012	0.004	0.007	0.611	381	4.34	0.26	36.93	7,379	-4,538	-227
VWSED 3_Core 2 0-10 cm	F4739/22	Medium	65.1	1.86	0.021	0.060	0.011	0.031	1.253	781	6.71	0.55	36.68	7,329	-4,104	-205
VWSED 3_Core 2 15-25 cm	F4739/23	Fine	52.7	1.11	0.007	0.015	0.005	0.011	0.750	468	6.01	0.37	47.11	9,413	-5,807	-290
VWSED 3_Core 2 28-38 cm	F4739/24	Fine	46.0	0.85	0.003	0.006	0.001	0.002	0.292	182	4.96	0.27	44.69	8,929	-5,771	-289
VWSED 3_Core 3 0-10 cm	F4739/25	Medium	72.6	2.64	0.020	0.073	0.008	0.029	1.192	743	6.85	0.55	37.47	7,487	-4,248	-212
VWSED 3_Core 3 15-25 cm	F4739/26	Fine	52.4	1.10	0.006	0.013	0.000	0.000	0.797	497	5.62	0.35	47.85	9,560	-5,877	-294
VWSED 3_Core 3 28-38 cm	F4739/27	Fine	46.2	0.86	0.007	0.013	0.004	0.007	0.692	432	5.38	0.29	38.16	7,624	-4,651	-233
VWSED 4_Core 1 0-10 cm	F4739/28	Medium	81.7	4.46	0.006	0.033	0.011	0.060	1.300	811	11.40	0.60	34.66	6,925	-3,806	-190
VWSED 4_Core 1 15-25 cm	F4739/29	Medium	86.5	6.41	0.009	0.067	0.003	0.022	1.697	1,058	24.30	1.00	11.87	2,372	-523	-26
VWSED 4_Core 1 30-40 cm	F4739/30	Medium	80.5	4.12	0.010	0.051	0.004	0.020	0.964	601	14.50	0.64	36.37	7,267	-4,243	-212
VWSED 4_Core 2 0-10 cm	F4739/31	Medium	73.0	2.70	0.023	0.086	0.021	0.078	1.207	753	5.95	0.47	31.49	6,292	-3,442	-172
VWSED 4_Core 2 15-25 cm	F4739/32	Medium	84.8	5.57	0.008	0.053	0.017	0.112	1.531	955	19.50	0.91	18.92	3,780	-1,565	-78
VWSED 4_Core 2 30-40 cm	F4739/33	Medium	87.0	6.69	0.013	0.100	0.004	0.031	1.418	884	25.80	0.96	7.71	1,540	-143	-7
VWSED 4_Core 3 0-10 cm	F4739/34	Medium	79.5	3.89	0.010	0.049	0.022	0.108	1.583	987	11.40	0.68	24.75	4,945	-2,309	-115
VWSED 4_Core 3 15-25 cm	F4739/35	Medium	86.8	6.57	0.007	0.053	0.014	0.106	1.526	952	25.40	0.98	13.86	2,769	-894	-45
VWSED 4_Core 3 30-40 cm	F4739/36	Medium	60.2	1.51	0.003	0.008	0.001	0.003	0.388	242	5.76	0.23	52.56	10,501	-6,759	-338
VWSED 5_Core 1 0-10 cm	F4739/37	Medium	88.3	7.56	0.253	2.165	0.313	2.679	2.847	1,776	14.30	1.67	6.52	1,303	907	68
VWSED 5_Core 1 10-20 cm	F4739/38	Medium	65.7	1.92	0.053	0.155	0.027	0.079	1.510	942	4.79	0.49	23.77	4,749	-2,224	-111
VWSED 5_Core 2 0-10 cm	F4739/39	Medium	88.4	7.63	0.267	2.305	0.364	3.142	2.735	1,706	14.30	1.68	7.97	1,592	644	48
VWSED 5_Core 2 10-20 cm	F4739/40	Medium	83.3	4.98	0.129	0.771	0.104	0.622	2.649	1,652	11.50	1.35	13.31	2,659	-121	-6
VWSED 5_Core 3 0-10 cm	F4739/41	Medium	79.7	3.93	0.252	1.242	0.170	0.838	2.805	1,749	14.50	1.71	6.95	1,389	824	62
VWSED 5_Core 3 10-20 cm	F4739/42	Medium	79.2	3.80	0.071	0.341	0.045	0.216	2.429	1,515	7.91	0.85	17.94	3,584	-875	-44
VWSED 6_Core 1 0-10 cm	F4739/43	Medium	85.8	6.03	0.161	1.132	0.029	0.200	2.863	1,786	12.10	1.48	19.31	3,858	-786	-39
VWSED 6_Core 1 10-20 cm	F4739/44	Medium	71.1	2.46	0.017	0.059	0.042	0.145	3.846	2,399	8.58	1.10	14.45	2,887	474	36
VWSED 6_Core 1 20-30 cm	F4739/45	Medium	76.1	3.18	0.014	0.058	0.040	0.167	2.594	1,618	10.60	0.66	30.61	6,116	-2,459	-123
VWSED 6_Core 1 30-40 cm	F4739/46	Medium	80.3	4.08	0.012	0.061	0.016	0.081	0.873	544	17.10	0.67	35.23	7,039	-4,148	-207
VWSED 6_Core 2 0-10 cm	F4739/47	Medium	85.8	6.03	0.133	0.935	0.176	1.238	2.908	1,814	13.50	1.67	15.40	3,077	-238	-12
VWSED 6_Core 2 10-20 cm	F4739/48	Medium	79.4	3.86	0.022	0.107	0.033	0.160	3.679	2,295	9.84	1.00	14.86	2,969	315	24
VWSED 6_Core 2 20-30 cm	F4739/49	Medium	72.8	2.68	0.013	0.048	0.026	0.096	2.800	1,746	9.76	0.71	29.38	5,870	-2,167	-108
VWSED 6_Core 2 30-40 cm	F4739/50	Medium	79.3	3.84	0.013	0.063	0.015	0.073	0.803	501	17.10	0.62	34.32	6,857	-4,071	-204
VWSED 6_Core 3 0-10 cm	F4739/51	Medium	84.3	5.38	0.132	0.843	0.151	0.964	2.807	1,751	13.40	1.63	14.89	2,975	-233	-12
VWSED 6_Core 3 10-20 cm	F4739/52	Medium	80.0	4.00	0.024	0.120	0.046	0.230	3.807	2,374	9.84	0.98	14.94	2,985	384	29
VWSED 6_Core 3 20-30 cm	F4739/53	Medium	75.0	3.00	0.010	0.040	0.029	0.116	1.916	1,195	10.60	0.60	33.96	6,785	-3,328	-166
VWSED 6_Core 3 30-40 cm	F4739/54	Medium	77.9	3.53	0.010	0.045	0.011	0.050	0.729	455	15.10	0.56	36.71	7,335	-4,435	-222
VWSED 7_Core 1 0-10 cm	F4739/55	Medium	75.1	3.02	0.022	0.088	0.023	0.093	2.098	1,309	8.02	0.69	29.45	5,884	-2,614	-131
VWSED 7_Core 1 10-20 cm	F4739/56	Medium	81.0	4.26	0.005	0.026	0.024	0.126	1.188	741	12.20	0.58	34.80	6,953	-3,894	-195
VWSED 7_Core 1 30-40 cm	F4739/57	Medium	85.1	5.70	0.005	0.034	0.005	0.034	0.763	476	24.20	0.83	25.81	5,157	-2,962	-148
VWSED 7_Core 2 0-10 cm	F4739/58	Medium	74.2	2.88	0.029	0.112	0.019	0.074	1.388	866	8.19	0.72	33.58	6,709	-3,607	-180
VWSED 7_Core 2 10-20 cm	F4739/59	Medium	83.2	4.94	0.005	0.030	0.029	0.172	1.115	695	14.80	0.71	35.16	7,025	-3,988	-199
VWSED 7_Core 2 30-40 cm	F4739/60	Medium	84.5	5.44	0.005	0.032	0.006	0.039	0.722	450	22.30	0.83	28.57	5,708	-3,355	-168
VWSED 7_Core 3 0-10 cm	F4739/61	Medium	82.1	4.60	0.029	0.162	0.043	0.241	2.610	1,628	11.40	0.99	23.84	4,763	-1,548	-77
VWSED 7_Core 3 10-20 cm	F4739/62	Medium	76.2	3.21	0.007	0.029	0.024	0.101	0.985	614	9.44	0.45	35.48	7,089	-4,112	-206
VWSED 7_Core 3 30-40 cm	F4739/63	Medium	73.8	2.82	0.004	0.015	0.002	0.008	0.410	256	9.90	0.39	50.06	10,002	-6,412	-321
VWSED 8_Core 1 0-10 cm	F4739/64	Medium	48.1	0.93	0.112	0.216	0.034	0.065	0.443	276	2.45	0.23	11.91	2,380	-1,310	-66
VWSED 8_Core 1 14-24 cm	F4739/65	Medium	35.0	0.54	0.036	0.055	0.011	0.017	0.235	147	1.43	0.11	7.58	1,514	-863	-43
VWSED 8_Core 2 0-10 cm	F4739/66	Medium	41.4	0.71	0.070	0.119	0.025	0.043	0.387	241	2.12	0.19	10.46	2,090	-1,152	-58
VWSED 8_Core 2 10-20 cm	F4739/67	Medium	28.0	0.39	0.039	0.054	0.009	0.013	0.176	110	0.95	0.08	4.54	907	-495	-25
VWSED 8_Core 2 20-30 cm	F4739/68	Medium	29.1	0.41	0.027	0.038	0.007	0.010	0.165	103	0.95	0.07	4.65	929	-516	-26
VWSED 8_Core 3 0-10 cm	F4739/69	Medium	38.6	0.63	0.038	0.062	0.007	0.011	0.240	150	1.66	0.15	11.35	2,268	-1,362	-68
VWSED 8_Core 3 10-20 cm	F4739/70	Medium	49.9	1.00	0.083	0.166	0.028	0.056	0.798	498	3.21	0.28	9.09	1,816	-713	-36
VWSED 8_Core 3 20-30 cm	F4739/71	Medium	38.2	0.62	0.064	0.104	0.014	0.023	0.367	229	1.89	0.17	11.24	2,246	-1,268	-63

NOTE: negative Net Acidity indicate excess acid neutralising

NOTE:
1 - All analysis is Dry Weight (DW) - samples dried and ground immediately upon arrival (unless supplied dried and ground)
2 - Samples analysed by SPOCAS method 23 (ie Suspension Peroxide Oxidation Combined Acidity & sulfate) and 'Chromium Reducible Sulfur' technique (Scr - Method 22B)
3 - Methods from Ahern, CR, McElnea AE, Sullivan LA (2004). ***Acid Sulfate Soils Laboratory Methods Guidelines.*** QLD DNRME.
4 - Bulk Density is required for liming rate calculations per soil volume. Lab. Bulk Density is no longer applicable - field bulk density rings can be used and dried/ weighed in the laboratory.
5 - **ASA Equation: Net Acidity = Potential Sulfidic Acidity (ie. Scr or Sox) + Actual Acidity + Retained Acidity - measured ANC/FF (with FF currently defaulted to 1.5)**
6 - The neutralising requirement, lime calculation, includes a 1.5 safety margin for acid neutralisation (an increased safety factor may be required in some cases)
7 - For Texture: coarse = sands to loamy sands; medium = sandy loams to light clays; fine = medium to heavy clays and silty clays
8 - .. denotes not requested or required. '0' is used for ANC and Snag calcs if TAA pH < 6.5 or > 4.5
9 - SCREENING, CRS, TAA and ANC are NATA accredited but other SPOCAS segments are currently not NATA accredited
10- Results at or below detection limits are replaced with '0' for calculation purposes.
11 - Projects that disturb >1000 tonnes of soil, the ≥0.03% S classification guideline would apply (refer to acid sulfate management guidelines).
12 - Results refer to samples as received at the laboratory. This report is not to be reproduced except in full.
13 ** denotes these test procedure or calculation are as yet not NATA accredited but quality control data is available

(Classification of potential acid sulfate material if: coarse Scr≥0.03%S or 19mole H^+/t; medium Scr≥0.06%S or 37mole H^+/t; fine Scr≥0.1%S or 62mole H^+/t) – as per QUASSIT Guidelines

NATA

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