Buckland Dry Creek Pty Ltd

Dry Creek Salt Field PEPR Revision 4 v.1

Appendix 10

ENVIRONMENTAL MONITORING AND RISK MANAGEMENT PLAN

for

A Tidal Restoration Trial at the Dry Creek Salt Field

University of Adelaide

1st November 2016

TABLE OF CONTENTS

1 INTRODUCTION

Salt has been produced at the Dry Creek salt field (4,000 ha) north of Adelaide since 1940. The salt is produced by evaporating seawater pumped into a series of concentrating ponds where water evaporation induces gypsum ($CaSO_4$) and then common salt (halite, NaCl) precipitation. One major issue during closure of the Dry Creek operations is that in some areas gypsum and salt crusts, thick layers of "monosulfidic black ooze" (MBO, comprising iron monosulfides, FeS), and acid sulfate soil materials have formed over some areas, which poses an environmental hazard (Figure 1; Fitzpatrick et al. 2015a,b). The salt production operation is now being scaled back with the transitioning of parts of the site to new land uses.

One option to manage the more seaward government-owned land on the site post-closure of the salt operation is restoration of tidal cycling. The University of Adelaide (UoA) and Department of Environment, Water and Natural Resources (DEWNR) undertook preliminary desktop and laboratory-based research on this option that suggested it could be feasible without creating unacceptable environmental risks. The Scientific and Technical Advisory Group (STAG) for the salt field project requested a proposal to undertake a tidal restoration trial in pond XB8A, which is north of St Kilda.

The project proposes to trial the restoration of tidal cycling to a pond (XB8A) at the Dry Creek salt fields over an approximately 2 year period. This pond is located in Section 3 of the Salt Fields, north of St Kilda (Figure 1).

This monitoring and management plan documents the monitoring activities and potential risk mitigation options to be undertaken during the trial.

2 PROJECT AIMS AND CONCEPTS

The aim of the project is to trial a long-term future management option for a portion of the salt field should no commercial proposal(s) come to fruition. This will be achieved by:

1. Trialling reconnection of a Pond XB8A at the salt field to tidal exchange
2. Reducing the hyper-salinity and monosulfide hazard in Pond XB8A while minimising impacts on adjacent coastal ecosystems, and
3. Improving sediment and water quality conditions to enable recolonisation by benthic invertebrates and native vegetation
4. Restore intertidal mudflat habitat that is utilised my migratory shorebirds

A conceptual model of the project's aims is shown in Figure 2.

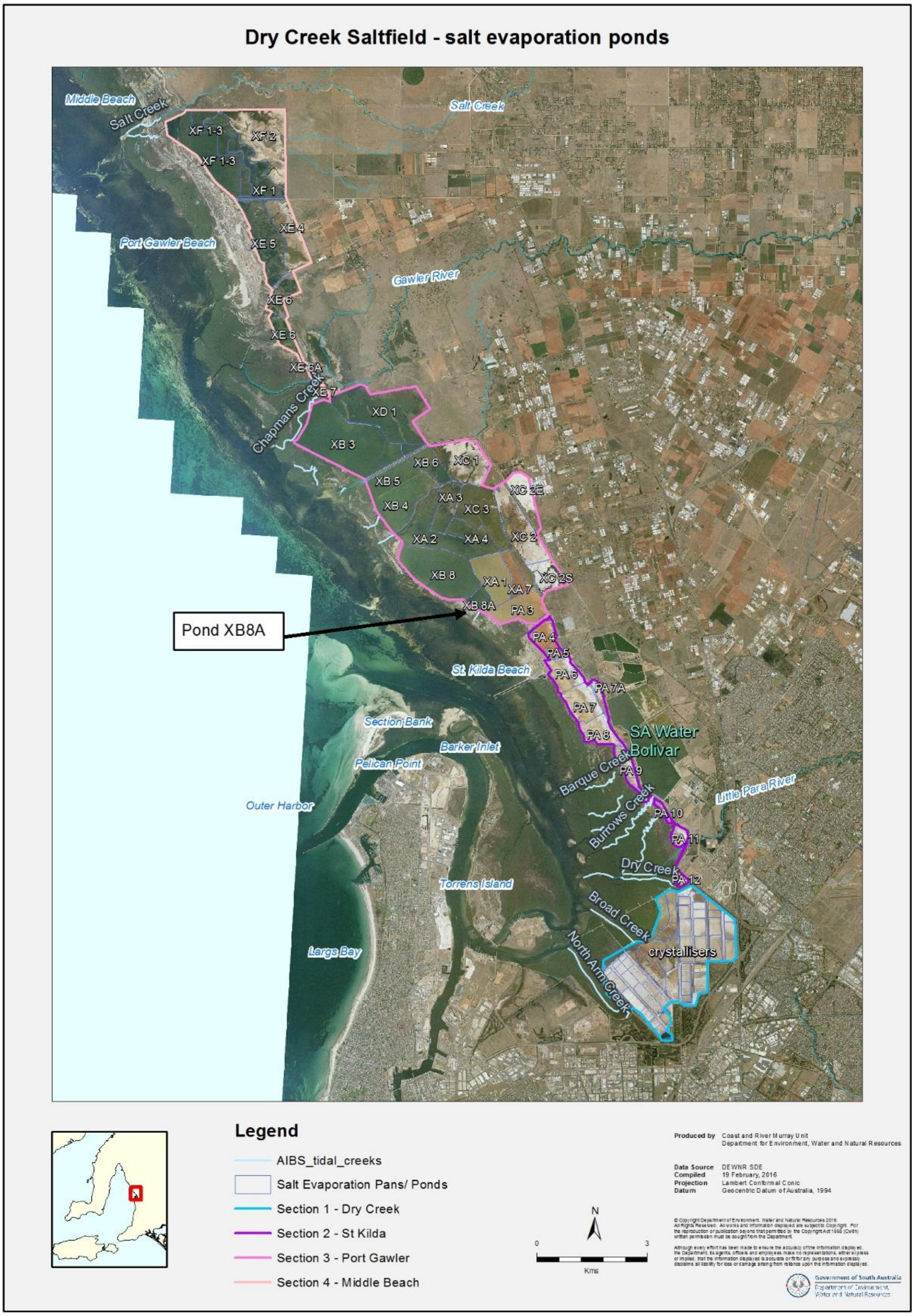


Figure 1. Dry Creek salt field showing location of Pond XB8A where the trial is proposed

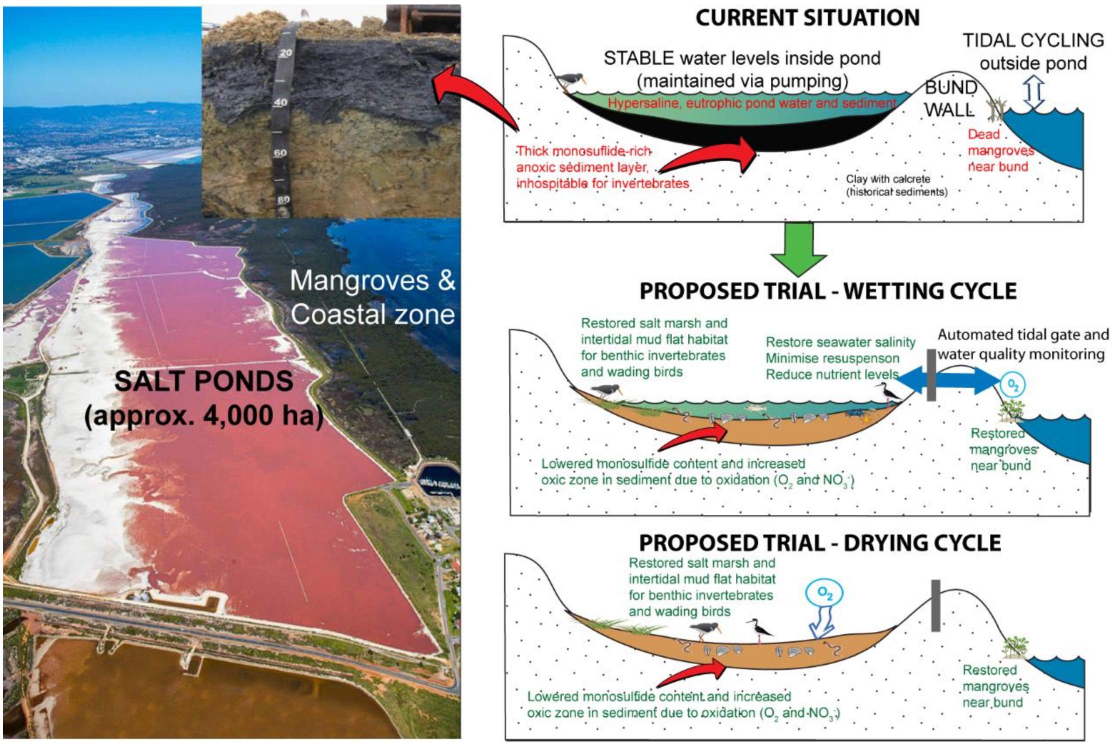


Fig. 2. (left) Overview of the Dry Creek Salt Fields showing a typical subaqueous sediment/acid sulfate soil profile with a thick black layer containing monosulfidic material and (right) conceptual model of project showing hypothesised outcomes of the lower monosulfide concentration and benthic invertebrate and vegetation re-colonisation while minimising external environmental impacts

3 TRIAL ESTABLISHMENT

A trial is being proposed to examine the feasibility of restoring tidal cycling to the salt field to determine both the positive and potential negative aspects of this potential management option.

The positive benefits focus on the reduction of salinity in the water, monosulfide content in the sediment and restoration of intertidal ecology (invertebrates, samphire) and shorebird habitat. Potential risks include discharge of saline water, deoxygenation and sediment transport to the coastal environment.

These factors will be monitored and managed during the course of the trial, as explained in the Monitoring section of this document.

Prior to the trial commencing, a series of approvals and assessments will be required. These include:

- Agreement between DEWNR, University of Adelaide and Buckland Dry Creek Pty Ltd to conduct the trial under the mineral lease
- Approval from DSD to enable Buckland Dry Creek Pty Ltd to undertake an activity not included within their current mining lease and PEPR
- Approval from EPA for minor dredging works required to reconnect the tidal creek to Pond XB8A. Water quality discharges from the pond will also need to comply with the Environment Protection (Water Quality) Policy 2015 and there is a general environmental duty to protect aquatic ecosystems from harm.
- Approval or exemption from PIRSA for conducting an activity that discharges to an Aquatic Reserve
- Support of the Strategic and Technical Advisory Group (STAG) and CE Steering Committee for the trial

Other work that has been, or will be conducted prior to the trial includes the following:

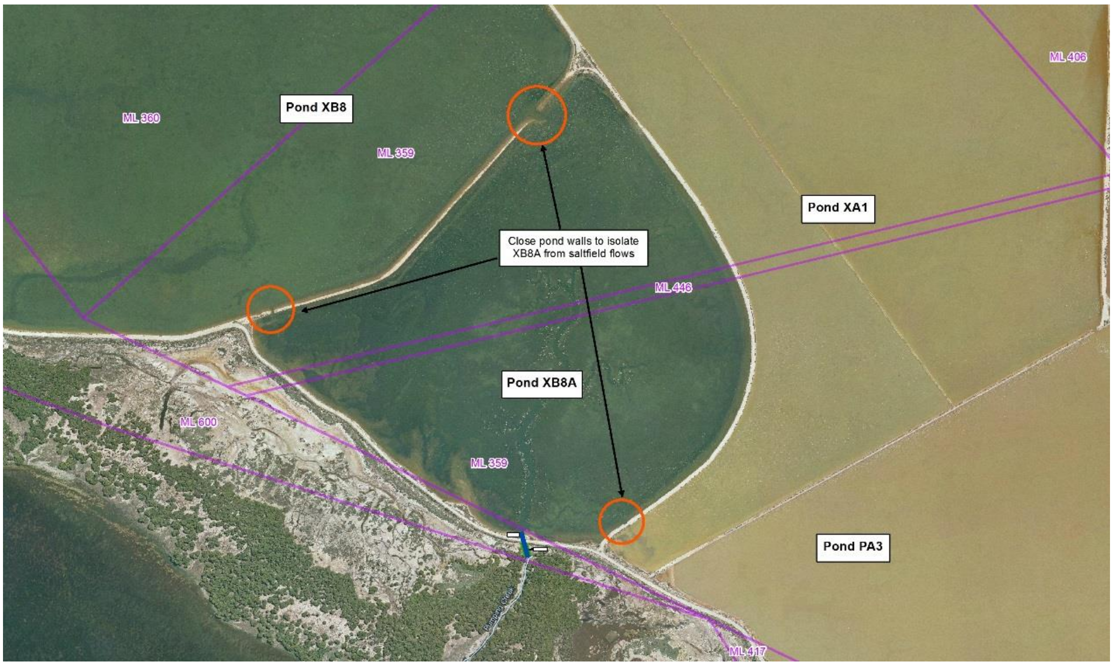
- Assessment of likelihood of resuspension of sediment causing salt impacts and salt dilution processes. This involved laboratory resuspension experiments, sediment shear stress estimation, and hydrodynamic modelling (University of Adelaide 2015). This is discussed further below.
- Survey and hydraulic assessment of Pumping Creek to establish the capacity of the Creek and sizing of tidal gate structures (Tonkins 2015).
- Detailed design and cost estimate for infrastructure and civil works required for tidal exchange
- An Environmental Site Assessment (BESA), to establish a baseline environmental condition of the pond and adjacent tidal creek-mangrove area to ensure that any changes made during the trial to the site characteristics are quantifiable. This will include sediment, water quality, and ecological (benthic invertebrate, vegetation, bird) monitoring. The ESA will also assess a control site in the salt ponds to ensure changes observed can be attributed to the trial and not other factors. A second ESA will be conducted at the end of the trial to determine the impacts that have occurred during the trial.

4 TRIAL METHODOLOGY

1. Isolate Pond XB8A from existing flow path

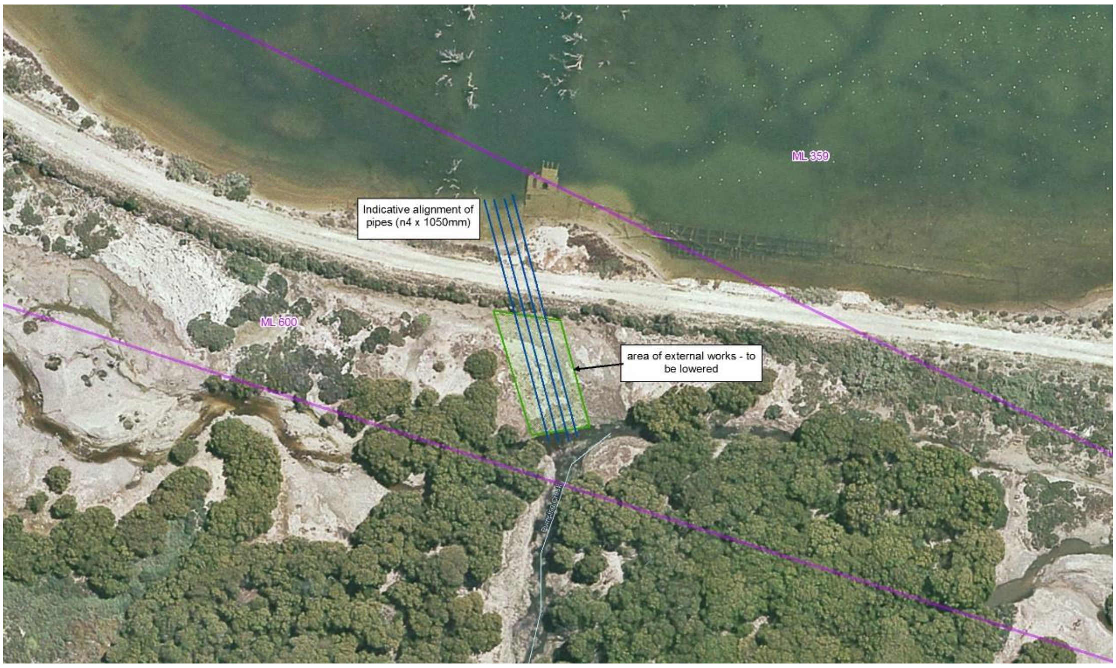
To undertake the trial it will be necessary to isolate Pond XB8A from the existing salt field flow path. This activity will be undertaken in collaboration with Buckland Dry Creek Pty Ltd. Two key activities are required:

a) Close existing XB8A inflows and outflows (see red circles in map below). This will require earthworks, possibly with imported fill or material excavated from site.
b) Provide XB8 with a controllable outflow to XA1. This could require 2 or 3 pipes with gate valves inserted into the common bund between them.



2. **Install tidal gate and monitoring equipment**

Tidal circulation will be restored to Pond XB8A at the Dry Creek salt field by installing controlled tidal gates. Based on a survey of the tidal creek (Pumping Creek) that will be reconnected with Pond XB8A and hydraulic modelling by Tonkin Consulting, four 1 m diameter poly pipes will need to be installed in the existing levee bank. The pipes will need to extend for a length of approximately 10m through the levee bank of the pond.



An example of the type of tidal gate to be installed is shown below (AWMA i-Gate, marine grade aluminium alloy and stainless steel). Some excavation works will be required on the seaward side of the pipes to re-align the end of the tidal creek to its historical alignment into the pond (see green shaded area in map above).

For practical reasons it is desirable that the water level in Pond XB8A is lowered as far as possible prior to installation of the pipes and gates. The current idea (to be refined upon receipt of final design for tidal gate and discussions with Buckland Dry Creek Pty Ltd) is to:

a) Lower the water level in pond XB8A as far as practically possible via outflow to the adjacent Pond (PA3). The degree to which the water level in XB8A can be lowered is practically constrained by both bathymetry (PA3-5 ponds are at higher elevation) and the need to maintain salt field flows that are high enough to ensure salinity is kept within a tolerance range for discharge to the bolivar outfall channel. The time of year that this operation is undertaken will also influence the degree to which this strategy can be employed.
b) Construct a small cofferdam to isolate the section of sea wall where the tidal gate will be installed from Pond XB8A to Pumping Creek
c) Pump out the water from between this cofferdam and the sea wall. This may need to be a continuous pumping operation until the cofferdam can be removed.
d) Install the tidal gate
e) Dredge small channel to reconnect tidal gate from Pumping Creek. A soil survey of this area indicates the dredged material will not require active acid sulfate soil management (see Appendix C, negative net acidity in acid-base accounting data).
f) When the gate systems are in place, commissioned and ready to initiate tidal resotration, remove the coffer dam
g) Initiate commissioning phase of tidal restoration trial as described further below.

To enable full control of tidal cycling, each poly pipe will have an adjustable tidal gate on the end (on pond side of pipe). The gate will be motorized and able to open and close to control water flow as required, including automatic closure in response to water quality triggers (e.g. low dissolved oxygen or pH – see monitoring plan section below).

3. Restore tidal cycling in controlled stages

The restoration of tidal cycling will be undertaken in two stages (Commissioning and Operational):

Stage 1: Commissioning Phase

The commissioning phase of the trial involves the reduction of the current hypersaline salt load in the pond. This will be achieved by:

a. Draining pond XB8A as far as practically possible to the downstream pond (PA3) as described above.

b. Pulsed discharges of pond XB8A water down Pumping Creek

It is proposed that, during the commissioning phase of the trial, pulsed discharges of hypersaline water will occur from Pond XB8A to Pumping Creek. The pulses will be timed to coincide with a high tide and the ebb.

To inform the degree to which this strategy may cause any adverse environmental impacts a preliminary water quality assessment was undertaken in Pumping Creek. The whole creek was hypersaline at low-mid tide of our survey (Figure 4). Some sites at the head of creek had higher salinity than the adjacent salt pond proposed to be used in the trial. This is presumably due to seepage of hypersaline water from the ponds and evaporation in the shallow intertidal areas. When the tide rose, the salinity reduced to near marine salinities (approx. 55,000 µS/cm).

Some initial benthic invertebrate sampling we conducted in the creek at the time of the water quality survey showed no invertebrates present. This is unusual but perhaps understandable given the hypersaline state. Based on the water quality results we believe the pulsed discharge strategy will create insignificant adverse effects on the current hypersaline creek system, with a view to improving the water and sediment quality once tidal exchange is fully operational.

We will monitor the salinity on the incoming to high tide cycle following the pulsed discharge to ensure salinity has returned to background (approximately seawater salinity at head of creek near pond) levels before commencing the next pulse.

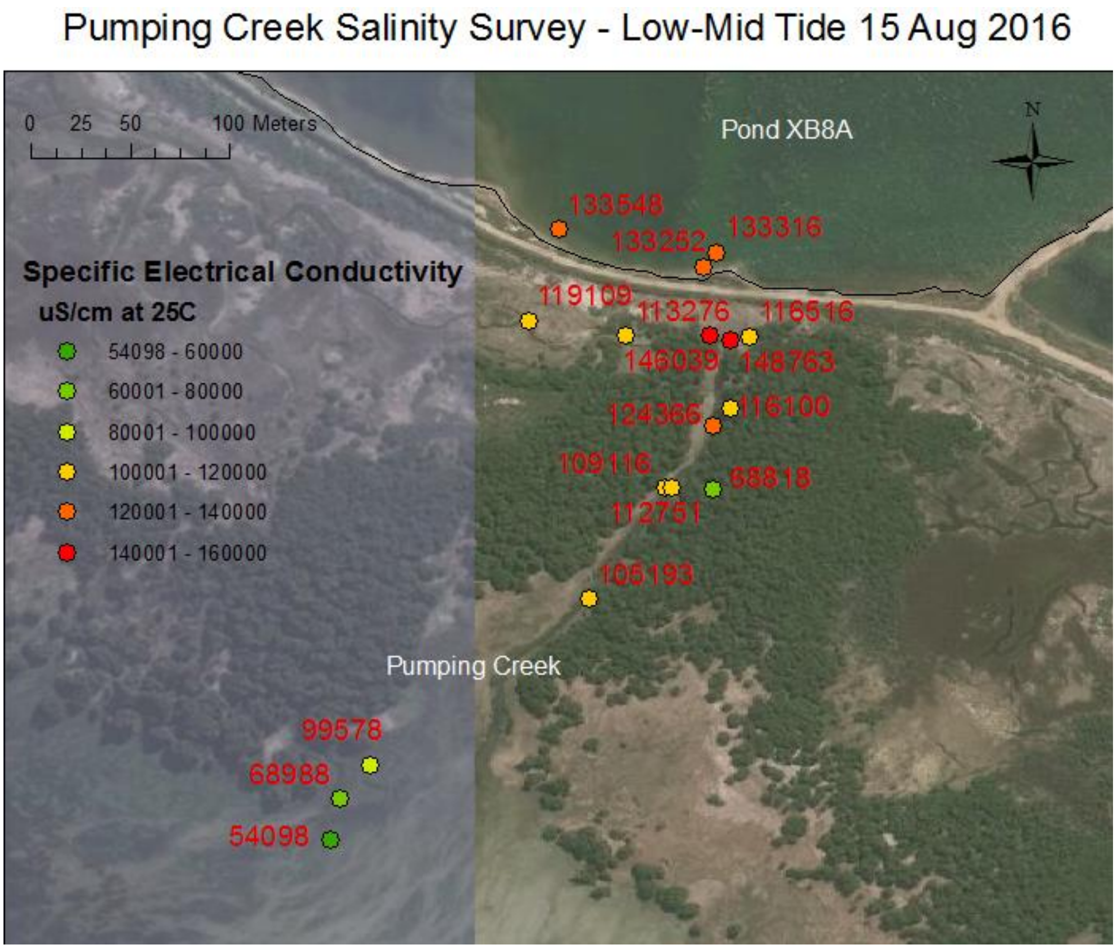


Figure 4: Pumping Creek salinity survey results from 15 August 2016

Stage 2: Operational Phase

Once the hypersaline water load/level is reduced in the pond sufficiently, tidal cycles will be introduced. Discharge will occur in Stages (Table 1). The speed of progression between these stages will be based on water quality in the ponds and outgoing water following tidal introduction and agreement of the Project Steering Committee.

Table 1 – Proposed stages of introducing a tidal cycling regime to pond XB8A

Stage	**Commissioning Phase**
1	Remove Pond XB8A from salt field flow path and drain to downstream pond and pulse discharge to tidal creek (repeat as required until pond drained)
2	**Operational Phase**
	a. Introduce a tidal cycle to pond

	b. Allow a small pulsed discharge immediately after high tide (+2 h) and monitor outflow water quality and mixing c. Increase discharge time up to +6 h from high tide and monitor outflow water quality and mixing d. Introduce full tidal cycles, monitor outflow water quality and mixing against agreed compliance triggers.

The associated monitoring and risk management activities are discussed in Sections 5 and 6 respectively below.

5 MONITORING PLAN

The purpose of the monitoring and research program is to assess the environmental benefits of tidal restoration and also to enable early identification and management of risks to enable action if certain triggers are approached or reached (as described below). The program will involve monitoring a range of water quality, sediment and biological parameters, both within the pond and in the adjacent area, as well as taking advantage of other pre-existing programs. A summary of the monitoring types, methods and frequency is shown in the Table below:

Monitoring Type	Method	Frequency
Water quality at tidal gate	Multi-parameter (salinity, pH, dissolved oxygen, turbidity, temperature) probe at tidal gate	Continuous
Water level, flow rate and direction at tidal gate	Pressure sensors either side of tidal gate, gauging to determine flow	Continuous
Water quality in pond and Pumping Creek	Field and laboratory measurements of various physico-chemical parameters	Before trial and quarterly after commencement and 5 event-based samplings over tidal cycles
Sediment quality in pond and Pumping Creek	Sediment cores and analysis of various physico-chemical parameters	Before trial and quarterly after commencement
Benthic invertebrates in pond and Pumping Creek	Sediment cores and identification to lowest taxonomic level	Before trial and quarterly after commencement
Seagrass extent offshore of Pumping Creek	Remote sensing – analysis of satellite imagery	Before and at end of trial
Terrestrial vegetation	Photo points and quadrats (when recolonisation observed)	To be determined based on observations

The water quality and benthic ecological sampling before the trial commissioning phase will serve to provide a Baseline Environmental Assessment in the pond and Pumping Creek prior to undertaking any discharge from the pond. Two sites in a control pond (XB8) will be monitored for the same parameters and at same frequency as the trial pond (Figure 3).

The general location of monitoring sites in XB8A (and adjacent control pond) are shown in Figure 3. Indicative initial sample sites are shown but will be reviewed and may be altered due to accessibility or other suitability considerations before the trial begins. Water quality, sediment and ecological monitoring will be conducted in the same locations to enable comparison of changes. Two sites will be located in an adjacent pond to serve as a control site.

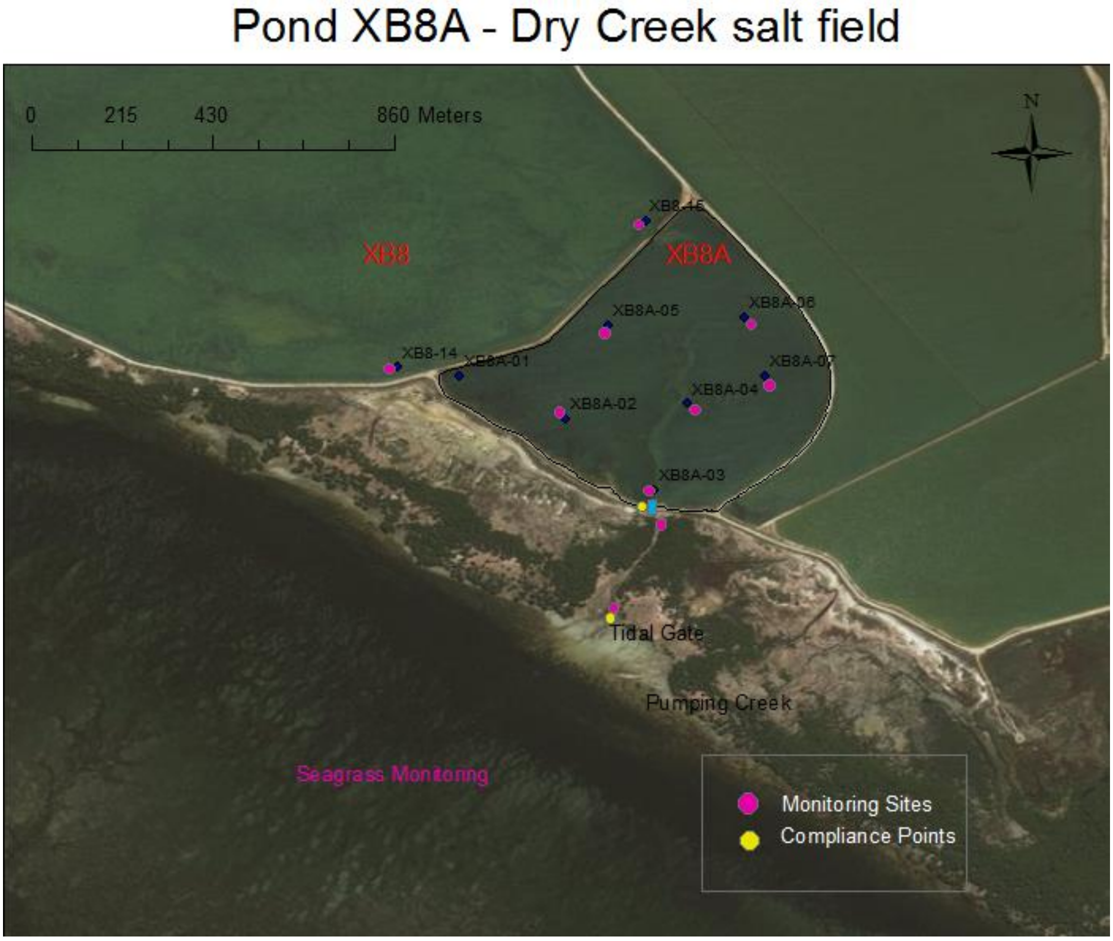


Figure 3: Indicative monitoring locations (purple dots) in trial pond, control pond and tidal creek (Pumping Creek). A continuous water quality and level logging system will be installed at the tidal gate. The compliance points down the tidal creek and at the tidal gates are shown as the yellow dots.

Further details on the monitoring program are provided below.

Continuous monitoring of incoming/outgoing water quality

A multi-parameter (conductivity, temperature, pH, dissolved oxygen, turbidity) sensor (YSI pro-plus TM 6000 series) and data logger will be installed at the tidal gate for continuous (15 minute interval) measurement of incoming and outgoing water quality. Water level sensors will be installed on either side of the gate and gauging of a larger tidal cycle will be undertaken to determine the relationship between water velocity and head differential.

The automated water quality monitoring and tidal gate adjustment system will be telemetered and pre-programmed to immediately close the tidal gate and send an email alert if the outgoing water quality exceeds Level 3 triggers (see Risk Management Plan below).

All tidal gate and water quality monitoring infrastructure will run off solar power and be connected via telemetry to a real time data management and communication system.

An additional continuous salinity logger will be placed further away from the tidal gate down Pumping Creek. This will be the EPA compliance point for regulatory monitoring of salinity discharges to the marine environment.

Pond and Creek Water Quality Grab Sampling

Water samples will be collected quarterly at 10 sites in pond XB8A and adjacent coastal ecosystem and analysed for turbidity, total suspended solids, electrical conductivity, pH, dissolved oxygen, redox potential, alkalinity, total, dissolved and colloidal metals (Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, Zn) and metalloid (As), and sulfate-S.

Tidal event-based sampling for the full suite of water quality parameters will be undertaken at all of the 10 sites on the transect over five large tidal cycles (sampled at three times each cycle, incoming, high, and outgoing tide).

Sediment/soil quality sampling

Sediment and soil samples will be collected to assess chemical and physical properties to 30 cm depth (monosulfide-rich layer). Samples will be taken at 10 sites along a transect from the pond, through the tidal gate and down the tidal creek through the mangrove area to the edge of Barker Inlet. A horizontal transect will also be sampled, as well as the control pond. The exact sample sites will be chosen to cover a range of bed elevations based on assessment of the pond bathymetry.

Three sediment/ASS layers will be sampled at each site (e.g. 0-5 cm, 5-10 cm, 10-30 cm). These layers correspond to the zone that is most likely to be oxidised by restoration of wetting and drying cycles, and where benthic organisms may recolonise. Selected samples may also be taken from deeper layers at some sites pending observations of the extent of the drying front. The following properties will be determined in the sediment samples: electrical conductivity (to assess dilution of hypersalinity from pond sediment and water during trial), redox potential (to quantify development of more oxidising conditions following wetting and drying during tidal action), acid volatile sulfide (AVS, measure of monosulfide content that is hypothesised to decrease with wetting and drying cycles), pyrite (to assess if AVS:pyrite ratio decreases as hypothesised), pH (to assess effects of sulfide oxidation and metal availability), pore water and dilute acid-extractable (1M HCl) metals and metalloids (As, Al, Fe, Mn, Cd, Co, Cu, Ni, Pb, V, Zn - to assess if these metals are released from the sediment into the pore water during monosulfide oxidation).

Changes in iron and sulfur minerals will be examined in selected layers using powder X-ray diffraction (XRD). Sediment samples will also be analysed for organic matter content and nitrogen availability (nitrate, nitrite and ammonium). Redox probes with data loggers will be installed at different depths (e.g. 1, 3, 5, 10, 15, 30 cm) at 2 sites.

Biological monitoring

Benthic invertebrates

Sediment cores (7 cm wide X 10 cm deep using a PVC tube with plug) will be taken from sites spatially distributed about the pond XB8A, Pumping Creek and pond XB8 that is not subject to tidal influence (salt pond control community). We will use methods suitable for high salinity systems, whereby sediments will be transported to the laboratory where they will be washed through a 0.5 mm sieve and all invertebrates collected will be identified and enumerated to a suitable level (i.e. mostly species, genus or family level) under a light microscope.

Birds

Monitoring of shorebird species in pond XB8A will occur as a baseline before the trial, and monthly throughout the trial. The shorebird species abundance and diversity will be assessed along with how shorebirds are utilising (e.g. feeding, roosting) the intertidal habitat created by the trial. Bird monitoring data for the XB8A trial pond will be compared to bird monitoring data collected by Birdlife Australia and Buckland Dry Creek Pty Ltd at other (control) locations in the salt field. The monitoring programme for this trial has been developed in concert with Brett Lane and Associates, whom BDC contract for broader bird monitoring across the entire salt field.

Vegetation

Assessment of aquatic and terrestrial vegetation changes will occur via:

- Assessment of changes in terrestrial vegetation cover and re-establishment of vegetation (e.g. samphire and mangrove) in the pond during the trial.
- Before and after assessment of seagrass cover and density in the nearshore coastal waters adjacent to Pumping Creek via satellite imagery – to be undertaken by DEWNR.

6 RISK MANAGEMENT PLAN

Compliance triggers for the research trial are listed in the table below. The coordinates of the compliance trigger points are:

Creek near outlet to coastal water - 138.515655 -34.730522 Decimal Degrees

Tidal gate - 138.516584 -34.728131 Decimal Degrees

The compliance triggers will apply following the completion of the commissioning phase of the trial and upon introduction of full tidal cycles (Stage 2d in Table 1).The motorised tidal gate to shut down in the event of Level 3 compliance triggers being reached, alerts will be sent on Level 2. Based on ongoing monitoring during the trial the water quality triggers will be reviewed and revised if required in discussion with EPA, DEWNR, DSD and PIRSA.

We have documented the potential and environmental operational risks that will need to be assessed and mitigated if required (see Table below). These risks are low-moderate and if they occur are able to be mitigated through various methods of management and intervention without risks to the external marine environment. The key risks identified are discharge of poor quality water (hypersaline, deoxygenated, high turbidity low pH) to the tidal creek, odour and failure of control mechanisms on the tidal gate.

It should be noted that while the trial has environmental risks that will be managed, <u>we believe it will bring net environmental benefit to the site</u>. Firstly, based on our initial Pumping Creek salinity survey findings we expect that once the trial is in operation the hyper-salinity in the creek will be reduced towards marine water salinity. Hence we expect the trial to relatively quickly deliver an environmental improvement in the creek and adjacent intertidal zone. Also we will create additional intertidal habitat once pond XB8A is reconnected, and expect to improve sediment and water quality in the pond to enable recolonisation of a healthy intertidal ecosystem. Additional variable water level shorebird and samphire habitat will also be created.

Risk communication and administration

A project steering committee will be established with Buckland Dry Creek Ltd, DEWNR, AMLR NRM Board and other stakeholder representatives. The steering committee will meet quarterly or more frequently if required. Project reporting will occur periodically to the STAG as required. The STAG and Buckland Dry Creek Pty Ltd will be given access to real-time water quality and tidal flow information via an internet login as required.

Monitoring reports will be provided to the Steering Committee and Regulators as required. Immediate notification will occur of any exceedance of Level 3 triggers.

Communication protocol with triggers for notification in the event of exceedances and for reporting of monitoring will be included in the PEPR review.

A separate agreement has been formulated between DEWNR, the University of Adelaide and Buckland Dry Creek Pty Ltd relating to responsibility for the potential legal/regulatory/financial liabilities caused by the design, construction and implementation of the trial.

Risk Table and Action Triggers						
Specific Risk	**Ranking**	**Explanation and Mitigation Strategy**	**Action Level 1 and Trigger**	**Action Level 2 and Trigger**	**Action Level 3 and Trigger**	**Assumptions and Considerations**
Risk of hypersaline water being exported from pond	L	This risk is related to hypersaline water being exported from the pond to the tidal creek and adjacent mangrove environment after commissioning phase of trial. Continuous monitoring of salinity will occur at the tidal gate. Full remote control and telemetered systems on the tidal gate will ensure any risks can be immediately managed (ie alert and automatic gate closure if level 3 trigger reached) The mitigation strategy is based on initial lowering of the pond salt load before the trial commences (see above) and replacement/dilution of water in the trial pond and discharge into the	Salinity greater than 45 in water exiting pond. Continue monitoring observations	Salinity greater than 45 at compliance point down Pumping Creek over less than 6 hour rolling average (while discharging from tidal gate) Investigate dilution strategies or varying tidal gate outflow rate	Salinity greater than 45 trigger at compliance point down Pumping Creek over greater than 6 hour rolling average (while discharging from tidal gate) Close off water export and undertake discharge of saline water into the salt field and replace with fresh tidal creek water	It is expected that salinity risks will be low following the commissioning phase of draining to PA3 and hypersaline creek on outgoing tide. The lack of salt or gypsum crystals present in Pond XB8A will greatly assist in this. Regular tidal exchanges will bring pond and Pumping Creek salinities towards coastal seawater values.

		adjacent salt field if required.				
Risk of deoxygenated water being exported from the pond	L	This risk is related to low dissolved oxygen water being exported from the pond to the tidal creek and adjacent intertidal environment. Continuous monitoring of dissolved oxygen will occur at the tidal gate. Full remote control and telemetered systems on the tidal gate will ensure any risks can be immediately managed (ie alert and automatic gate closure if level 3 trigger reached) The mitigation strategy is based on replacement/dilution of water in the trial pond.	Lower dissolved oxygen saturation in outflowing pond water compared to inflowing tidal water Continue monitoring observations	<75% dissolved oxygen saturation in outflowing pond water averaged over diurnal tidal cycle Consider strategies to replace/dilute water in pond	<50% saturation dissolved oxygen saturation in outflowing pond water averaged over diurnal tidal cycle. Replace pond water with fresh tidal creek water. Stop trial until reaerated water is present. Consider alternative management strategies if required to achieve re-aeration	The tidal water exchange and wetting and drying cycles should ensure oxygenation. No ANZECC (2000) dissolved oxygen trigger is available for marine waters in South Australia. Baseline data suggests that the current pond water is saturated (approx. 100%) with oxygen but at low tide the creek has much lower dissolved oxygen (30-50% saturation). Hence 50% saturation has been set as the Level 3 Trigger for outflowing water from the pond (averaged over diurnal tidal cycle). Based on University of Adelaide resuspension experiments, water deoxygenation is considered unlikely (Appendix A). Based on CSIRO data only a small proportion of the pond contains monosulfidic black ooze (Appendix B). If a deoxygenation event occurs and the gate is closed, based on observations from rainfall rewetting of sediment in other ponds at the

						salt fields, we would expect the pond water to re-oxygenate naturally from the atmosphere within a few days.
Risk of low pH water being exported from the pond	L	This risk is related to low pH water being exported from the pond to the tidal creek and adjacent intertidal environment. Continuous monitoring of pH will occur at the tidal gate. Full remote control and telemetered systems on the tidal gate will ensure any risks can be immediately managed (ie alert and automatic gate closure if level 3 trigger reached) The mitigation strategy is based on replacement/dilution of water in the trial pond. Alternative management strategies such as limestone dosing are also available.	pH < 7.5 in water exiting pond AND/OR Localised (<25% pond area) surface sediment (0-30 cm) acidification (pH<4) Continue monitoring observations. Notify project stakeholders.	pH < 7 in water exiting pond AND/OR Moderate (25-50 %) pond area) surface sediment (0-30 cm) acidification (pH<4) Consider strategies to replace/dilute water in pond Undertake additional analyses including acidity, alkalinity and metals.	pH < 6.5 in water exiting pond. AND/OR Major (>50 %) pond area) surface sediment (0-30 cm) acidification (pH<4) Close off water export and investigate other management strategies (e.g. dilution, limestone dosing) and implement following agreement with project steering committee	The inflowing marine water will bring in acid neutralising capacity (alkalinity) each tidal cycle. The ANECC (2000) water quality guideline (pH<6.5) is set as the Action Level 3 trigger. Baseline monitoring shows typical pH values in the range of 7.5 to 8.5 in the tidal creek and pond. Values for Level 1 and 2 triggers have been set below that. Based on University of Adelaide resuspension experiments, water acidification from resuspension and dissolution of monosulfides is unlikely (Appendix A) Based on assessment of CSIRO sediment incubation data, acidification of top layer (0-30 cm) of sediment that would be able to diffuse or advect to surface water is considered unlikely (Appendix B). The deeper (>80 cm below pond bottom) old mangrove soil layers where some acidification was observed after 8 weeks in CSIRO data is likely to remain fully

						saturated during the tidal trial as these layers will be near mean sea level (i.e. around 0 m AHD). Also regular tidal exchange will not allow deep drying of the profile.
Risk of turbidity due to sediment resuspension due to tidal action	M	This risk is related to elevated turbidity water being exported from the pond to the tidal creek and adjacent mangrove environment due to potential for increased water velocity and duration. Continuous monitoring of turbidity will occur at the tidal gate. Full remote control and telemetered systems on the tidal gate will ensure any risks can be immediately managed (ie alert and automatic gate closure if level 3 trigger reached) Management strategies of settling and slowing tidal outflow velocity (partially closing gate) are available.	Pond outflow turbidity above local reference data (tidal creek inflows and adjacent intertidal mudflat/creek water) Increase monitoring observations	Pond outflow turbidity >125 % of local reference data (tidal creek inflows and adjacent intertidal mudflat/creek water) averaged over diurnal tidal cycle Consider reducing inflow and outflow velocities by partially closing tidal gates	Pond outflow turbidity >150 % of local reference data (tidal creek inflows and adjacent intertidal mudflat/creek water) averaged over diurnal tidal cycle Stop outflow. Allow time for sediment settling. Implement strategies for reducing resuspension by slowing inflow and outflow through the tidal gate.	Tidal creeks are a naturally turbid environment. The ANZECC (2000) marine turbidity value of 0.5 to 10 NTU is not appropriate for a tidal creek. Baseline sampling of the tidal creek showed a wide range of turbidities present (10-300 NTU). The salt pond in its current state has lower (<10 NTU) turbidity as particles settle and coagulate due to the high salt. The Level 3 trigger has been set for when pond outflow turbidity is >150% of the tidal creek water averaged over diurnal tidal cycle. Sediment shear stress measurements and hydrodynamic modelling have suggested risk of large scale resuspension is low (see Appendix A). Scour protection near tidal gate outflow is being factored into the final tidal gate design.

Risk of elevated temperature in water exiting ponds	L	This risk is related to elevated temperature pond water being exported from the pond to the tidal creek and adjacent mangrove environment. Continuous monitoring of temperature will occur at the tidal gate. Full remote control and telemetered systems on the tidal gate will ensure any risks can be immediately managed (ie alert and automatic gate closure if level 3 trigger reached)	Pond outflow temperature outside (above or below) local reference data temperature (tidal creek inflows and adjacent intertidal mudflat water)	Pond outflow temperature ± 5 % outside local reference data (tidal creek inflows and adjacent intertidal mudflat water) averaged over diurnal tidal cycle	Pond outflow temperature ± 10 % outside local reference data (tidal creek inflows and adjacent intertidal mudflat water) averaged over diurnal tidal cycle	Regular exchange of water over high tide period should maintain water near the tidal creek temperature. Any temporarily impounded water in the trial pond should have a similar temperature compared to ponds on adjacent intertidal mudflats. No ANZECC (2000) temperature trigger is available for marine waters in South Australia. We expect the pond water to be similar temperature to adjacent samphire-mangrove sites but insufficient data is available to confirm this. We have used a ±10% change (averaged over diurnal tidal cycle) as Level 3 trigger. In winter a 10% temperature change would likely equate to 1-2 °C, in summer it would likely equate to 3-4 °C.
Risk of odour being generated from the trial pond	L	This risk is related to odour being generated above the normal background level of odour	Odour is detected above normal background concentrations	Odour becomes offensive to onsite staff.	Odour risk may extend to residents. Action –cease discharge and investigate alternative	Due to the significant distance (>3 km) between the trial site and the nearest residents it is considered very unlikely that any odour

and impacting residents		expected from the lagoon water. The mitigation strategy is based on replacement of water in the trial pond.	by project team. Increase monitoring observations via an odour diary	Action – discharge water into salt fields and replace with fresh tidal water.	odour management strategies (e.g. replacement of XB8A water with fresh tidal water or upstream pond water without discharge). Increase water quality monitoring.	generated will be an issue to residents. Regular wetting and drying cycles in the trial will reduce monosulfide content, hence reducing odour risk.
Risk of failure of tidal gate control structure	L	This risk relates to potential failure of the automated motorised tidal gates. The mitigation strategy is that gates can be closed manually if required (e.g. if a king tide event was imminent or poor water quality required closure)			Gate cannot be closed using automated systems and uncontrolled tidal event occurred. Site visit for investigation and maintenance. As a precaution undertake manual closure of gates depending on water quality and tidal conditions (e.g. if king tide or storm surge predicted).	Notification will be received that there has been a gate failure. An uncontrolled flow event is not likely to cause any major external risks (i.e. pond is isolated)
Impacts from construction – civil works	L	Risk of damaging roads and other infrastructure during construction	Monitoring of construction impacts detects minor issue.	Monitoring of construction impacts detects moderate issue.	Major impact – stop construction until issue is addressed by contactors	Contractors will be contractually required to restore any damage created by civil works.

			Discuss with contractor to rectify.	Formally request that contractor rectify		
Impacts from construction – dredging	L	Risk of turbidity impact to Pumping Creek when dredging silt accumulation seaward of the pond	Monitoring of dredging detects minor turbidity impact on adjacent waters. Stop work and review timing and method.		Monitoring of dredging detects significant turbidity issue in adjacent waters. Stop and review work method and timing.	Dredging will be staged and timed with tides to ensure minimal sediment impact to the creek. Silt curtains will be used by licensed dredging contractor if required.

7 TRIAL CLOSURE

> **The tidal restoration trial in Pond XB8A will be deemed successful if:**
> 1. The concentration of salt and monosulfides in the surface sediment layers of pond XB8A decreases significantly
> 2. The water exported from the ponds has acceptable quality (within EPA guidelines)
> 3. Benthic invertebrate and terrestrial vegetation abundance and diversity is increased
> 4. Resident and migratory shorebirds utilise the intertidal mudflat habitat created by the trial

Success for the trial pond does not imply that wider application of tidal restoration strategy within the saltfield would produce desirable and necessary (under State and Commonwealth legislation and policies) conservation outcomes, in particular waterbird and shorebird habitat. Further assessment and evidence would be required of (a) technical feasibility (i.e. ability to successfully deliver tidal restoration to different ponds), and (b) whether the current proportional mix of areas of different water depths and salinities afforded by the saltfield (and used in different measure by waterbirds and shorebirds of different species) may or may not be provided by tidal restoration, and (c) other plans for utilisation of the site. However the XB8A trial will contribute important information into the process of assessing the potential benefits of wider implementation of tidal restoration.

The project will develop a tidal restoration trial operations manual detailing all the management-related learnings of the trial and ongoing operational procedures.

Following completion of the research trial the gate may be maintained in a fully operational state pending agreement with Buckland Dry Creek Pty Ltd and other key stakeholders. Operational costs and responsibilities for this will be discussed and agreed prior to the trial completion. Undertaking the trial will not prevent the pond being reinstated as a brine pond should a salt field commence operation on this part of the site. The gates can be decommissioned at the end of the trial if desirable.

8 REFERENCES

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APPENDIX A PRE-TRIAL REPORT – UNIVERSITY OF ADELAIDE (see separate pdf attachment)

THE UNIVERSITY of ADELAIDE

Acid Sulfate Soils Centre

Research to inform a tidal cycling trial at the Dry Creek salt ponds

Luke M. Mosley, Petra Marschner and Rob W. Fitzpatrick

Acid Sulfate Soils Centre Report: ASSC_xxx - Confidential
15th June, 2015

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Cover image

Photograph of pond PA12 showing a gypsum and halite crust with areas of exposed monosulfidic material.

Contents

List of Figures

List of Tables

Acknowledgments

We would like to kindly acknowledge the support provided by DEWNR, in particular Murray Townsend and Jason Quinn. The advice, assistance and LIDAR data provided by Nick Withers (Ridley Corporation) is also appreciated.

EXECUTIVE SUMMARY

The University of Adelaide (UoA) has undertaken preliminary research to inform a potential tidal cycling trial at the Dry Creek salt ponds for the Department of Environment, Water and Natural Resources (DEWNR). Tidal reconnection to government-owned land at Dry Creek is one option among several being considered as the existing salt operation is decommissioned.

Methods:

A combination of field sampling, chemical and physical characterisation, critical sediment shear stress (for resuspension) measurement, resuspension experiments to examine water quality outcomes with different sediment amounts and timeframes, and hydrodynamic modelling (Delft-3D-flow) was used to assess water quality risks/benefits of tidal cycling. Five sites from two ponds (PA12 and XB8A) were sampled and had various experiments performed, and one pond (PA12) was used in the modelling.

Key findings:

- The critical shear stress was between 0.8-1.5 Nm^{-2} for sites XB8A-1, XB8A-2, and PA12-1, but was much higher at PA12-1 and PA12-3 (between 2.4-4.3 Nm^{-2}). The critical shear stresses, particularly for pond PA12, are likely influenced by the thick organic biofilms and gypsum “gravel” in the sediment.
- We found that even if resuspension of pond PA12 and XB8A sediments did occur in high concentrations (up to 10 g/L) this would not pose significant water quality risks. Some minor reductions in dissolved oxygen and pH, and increases in dissolved metals were observed but pH and metal concentrations remained within ANZECC (2000) guidelines for protection of aquatic ecosystems. The AVS and metal content of the sediment was not high which is consistent with these findings.
- Pond PA12 bathymetry was analysed and showed that only higher tides would inundate the area. A Delft-3D model scenario using the existing inlet channel structure showed that only limited inundation (0-30 cm water depth) would occur under most tidal conditions. Hence the pond would resemble an intertidal mudflat with substantial periods with no standing surface water. The initial salinity set in the model (60 g/L) was shown to dilute quite rapidly to seawater salinities. However it should be noted that halite and gypsum dissolution is not accounted for in the modelling.
- The sediment/bed shear stresses in the model were mostly less than the critical shear stresses measured by the CSM. This indicates major resuspension of MBOs is unlikely. There is some uncertainty as to whether the critical shear stress will reduce over time however, as the gypsum crust and crystals dissolve. A localised region of higher shear stress is occasionally present during high tidal velocities in the outflow area from the inlet channel.

Recommendations:

The results demonstrate that proceeding with a field trial of controlled (via adjustable/motorised gate) tidal cycling could be worthwhile as water quality risks were small based on this preliminary laboratory-based research.

1. INTRODUCTION

1.1 Background

Abandoned salt ponds have the potential to become highly valued coastal wetlands, however it is important to minimise the threat to surrounding coastal areas during restoration. The Dry Creek salt fields (4,000 ha) are located on the coast, 12 km NW of Adelaide, South Australia (Figure 1-1). The ponds extend about 35 km from Dry Creek (Section 1) to St Kilda (Section 2) to Port Gawler (Section 3) to Middle Beach (Section 4).Salt has been produced at this site since the late 1930's by evaporating seawater pumped into a series of concentrating ponds to the point where common salt (NaCl or halite) precipitates. The less soluble salts, iron oxide and calcite, followed by gypsum, are precipitated out during passage and evaporation of seawater through the chain of ponds. The current salt production operation is now being ceased with the goal to close and rehabilitate the site and/or transfer salt production to another company or the ponds to other uses.

Due to the stable water levels and organic and sulfate-rich conditions in the salt ponds, high concentrations of iron monosulfides (FeS, also known as monosulfidic black ooze, MBO) have built up (Figure 1-1). FeS is a nanocrystalline material that forms in the sediment as a result of sulfate reduction. After cessation of operations or a change in water regime, these monosulfide-rich sediments pose a threat to the environment, because if resuspended, they can rapidly deoxygenate water and release metals (Simpson et al., 1998; Bush et al., 2004). Sediment/monosulfide resuspension occurs when the critical sediment shear stress, exerted by moving water, is exceeded. If tidal reconnection occurs at the Dry Creek site it is important to understand whether large amounts of monosulfides will be resuspended and how best to control these risks.

1.2 Aims and scope of work

The aim of this report is to undertake a preliminary research to inform a potential trial of restoring tidal cycling into a pond at the Dry Creek salt fields. A combination of field sampling, resuspension experiments, and hydrodynamic modelling is used

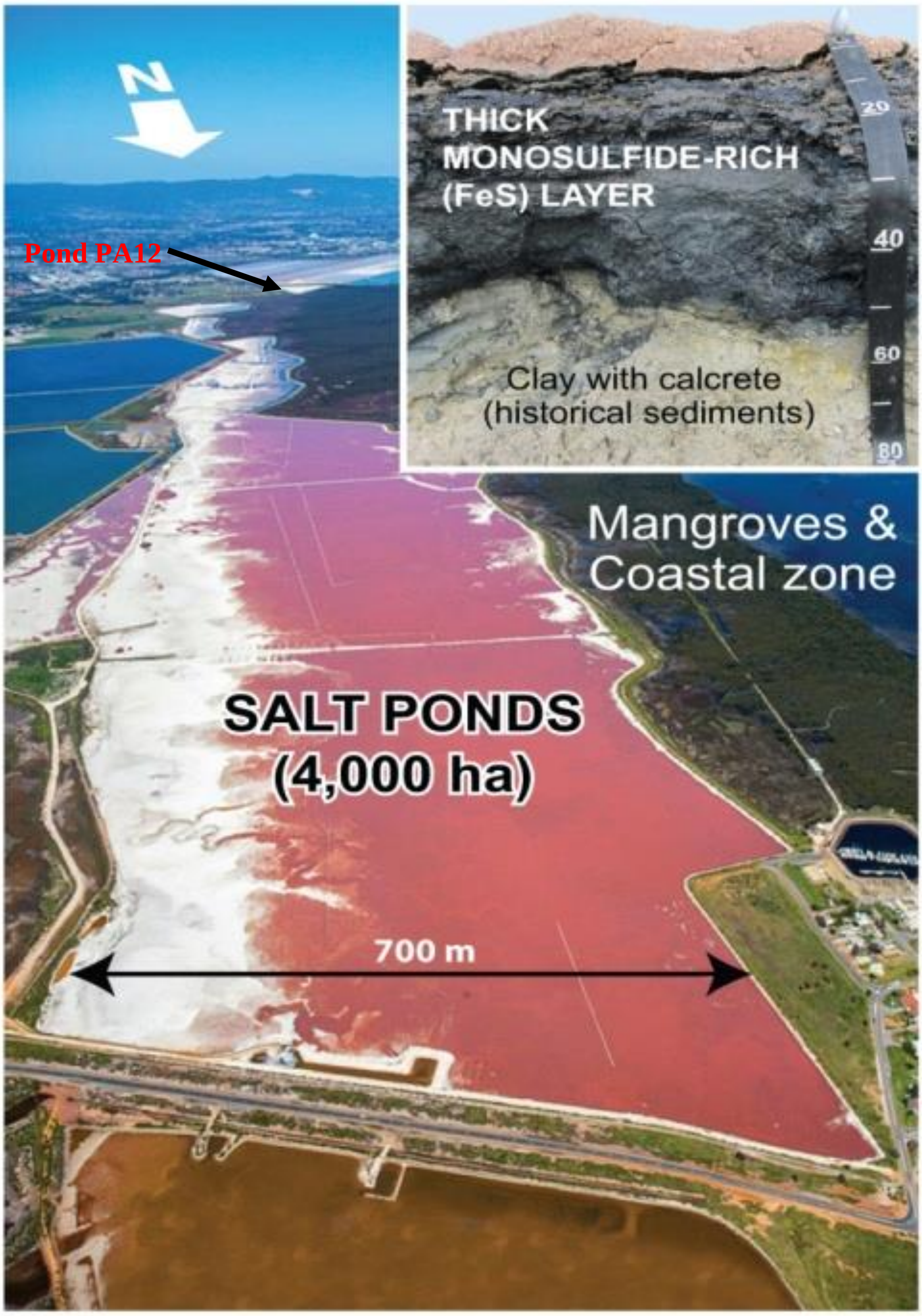


Figure 1-1: Aerial photograph of the series-flow salt field at the Dry Creek Salt fields showing: (i) a portion of the impounded salt ponds extending south from the road connecting St Kilda, which is located on the coast adjacent to mangrove swamps, (ii) the series of salt concentrating ponds with gypsum crusts near St Kilda, to the final concentrators and crystallisers at Dry Creek (southernmost ponds) where common salt (Halite) precipitates and (iii) a soil profile (inset) near St Kilda showing a pink coloured gypsum layer underlying a thick black gypseous layer with high concentrations of iron monosulfides, pyrite and carbonate (shell grits) termed “monosulfidic material” or monosulfidic black ooze (MBO), and (iv) Pond PA12 one of the two ponds sampled in this study.

2. METHODS

2.1 Sediment sampling

Sediment samples were collected from two ponds (PA12 and XB8A) at Dry Creek that may be used in a tidal inundation trial fields (Figure 1-1; Appendix 1) on 19th March 2015. Photographs of pond PA12 are shown in Figure 2-1 and Figure 2-2. Pond PA12 was drained so the three samples were collected by shovel following removal of the layers of the salt (halite, NaCl) and gypsum above the monosulfidic material (Table 2-1).

Figure 2-1: Photographs of pond PA12 showing: a) view of pond from north to south with culvert in background (*top left hand side*) and b) view of pond from south to north east with culvert on foreground of pond PA12 (*top right hand side*) and c) view from south to north of mangrove swamps, tidal creek and likely inlet point in bund wall (*bottom left hand side*)

Figure 2-2: Photographs of pond PA12 showing: a) sampling site No DPA12c-01, which is from the previous sampling sites (DPA12a-01 & DPA12b-01) by Fitzpatrick *et al.* 2015 (left hand side) and b) sampling site No DPA12c-02

Figure 2-3: Photograph of pond PA12 showing soil from sampling site No DPA12c-03

The following two samples of monosulfidic material were taken in pond XB8A, which is located in Section 3 of the salt fields and is currently inundated. The top layer (approx. 0–10 cm) of the submerged MBOs in this pond was sampled using a grab sampler. All samples were immediately placed in double ziplock bags with no air gap and transported to the Waite laboratories on ice for analysis.

Table 2-1 Soil profile locality, profile codes and GIS coordinates (WGS 84 datum, zone 54 south). Two ponds were targeted during this investigation on 19th March, 2015

Pond	Sample ID	Soil sample No	Site Landscape Position	Sample type (near surface)	Easting	Northing
PA12	PA12-1	DPA12c-01	Figure 3 (a)	[1]Subaqueous	0278449	6147220
	PA12-2	DPA12c-02	Figure 3 (b)	[1]Subaqueous	0278465	6147219
	PA12-3	DPA12c-03	Figure 4	[1]Subaqueous	0278494	6147255
XB8A	XB8A-1	DXB8Ac-01	Inundated pond	Subaqueous	0272643	6154294
	XB8A-2	DXB8Ac-02	Inundated pond	Subaqueous	0272723	6154295

[1]Below halite and gypsum crusts; [2] Below ponded water

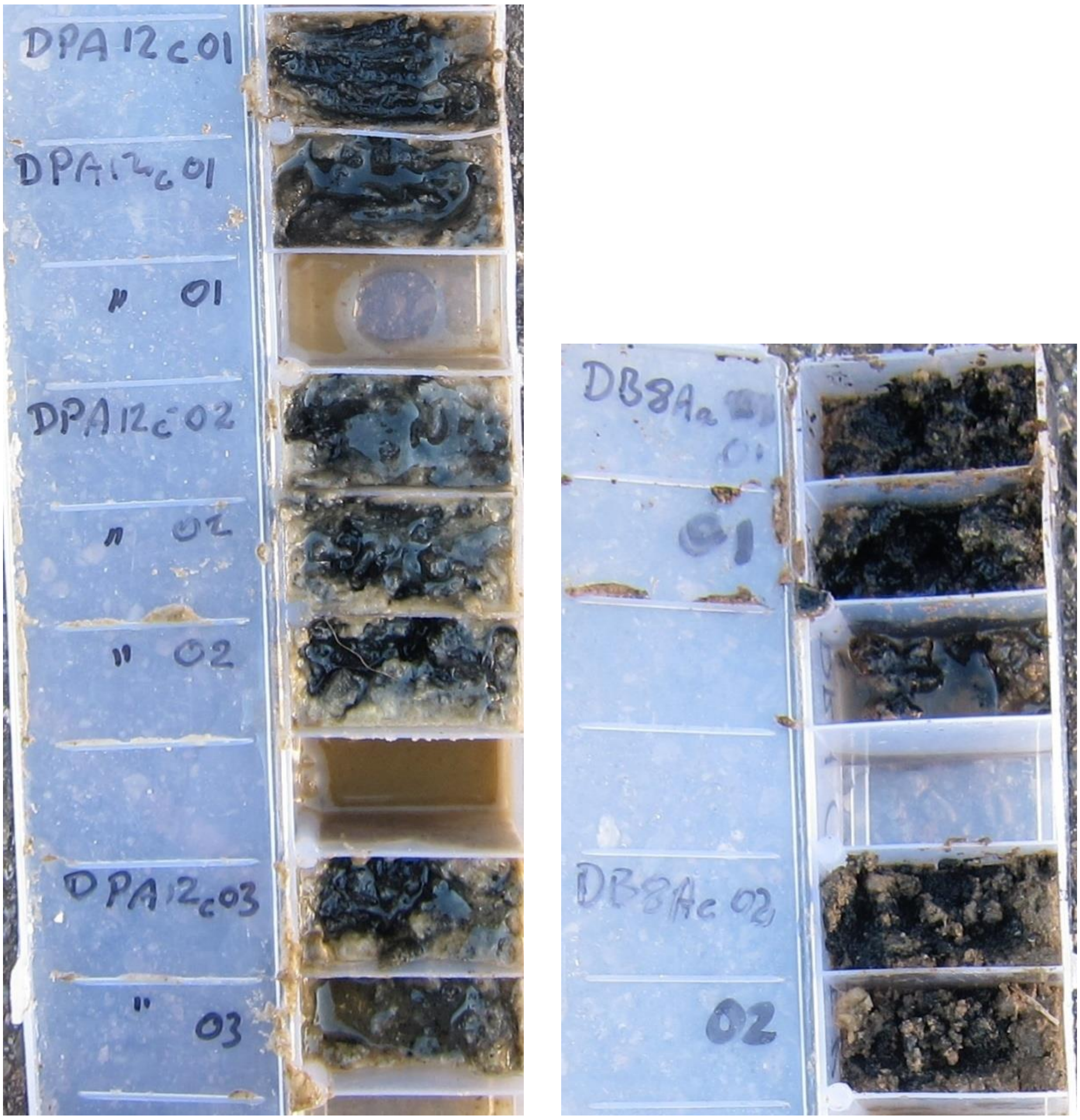


Figure 2-4: Photograph of chip tray with samples of monosulfidic material from pond PA12 (sample numbers: DPA12c-01, 02, 03) and pond XB8A (sample numbers: DXB8Ac-01 and 02)

2.2 Sediment cohesive strength measurements

Resuspension occurs when the critical sediment shear stress, exerted by moving water, is exceeded. The critical shear stress for pond PA12 and XB8A sediments was estimated using a Cohesive Strength Meter (CSM, Partrac Pty Ltd, U.K.). The CSM employs a jet of pressurised water to determine the critical shear stress and erosion rate of the sediment/MBOs (Tolhurst et al. 1999). By sequentially increasing the force of the jet, the point of erosion is initiated and can be determined by the associated reduction in light transmission across a test chamber as sediment is resuspended. The CSM transmission was also calibrated to a suspended solids concentration for each sample. For this, various amounts of sediment were weighed out to make a range of suspended solids concentrations in deionised water and then the transmission of these solutions measured by the CSM.

2.3 Sediment resuspension experiments

Resuspension experiments were carried out using the monosulfidic material collected in ponds PA12 and XB8A to estimate water quality. Two resuspension experiments were conducted. In the first experiment the kinetics of monosulfide oxidation/dissolution were studied by using one sediment:water concentration (10 g/L XB8A-2 sample) and shaking/suspending for 0,1, 3, 6, 12, 24, and 48 hours. At each time period pH and dissolved oxygen were measured in the suspension using a calibrated meter (TPS model) and then the solution filtered through 0.45 um filters, acidified with ultrapure nitric acid (HNO_3) to a concentration of 2% volume/volume, and analysed for dissolved metals ((Fe, Al, As, Cd, Cu, Mn, Ni, Zn) using ICP-MS. Total metal concentrations were also assessed by acidifying the unfiltered solution to the same nitric acid concentration. Three replicates of each sediment:water solution were analysed.

In the second experiment, the suspended sediment concentration was varied (0.5, 1, 5, 10 g/L) and the resuspension experiment conducted over 24 hours. In the first experiment, oxidation of monosulfides did not further increase after 24 h.. The solutions were analysed as described above for pH, dissolved oxygen, and dissolved and total metals.

2.4 Physico-chemical analysis of the sediments

A hydrometer analysis method was used to determine the percentage sand, silt and clay using the method of Gee and Bauder (1986). Acid volatile sulfide (AVS) concentration was measured using the methods of Simpson (2001). Total organic carbon (TOC) was analysed by the Walkely-Black method. Total sediment extractable metals were analysed by ICP-MS of a 1:3 Nitric/HCl acid digest (APHA method 3125 ICPMS).

2.5 Hydrodynamic modelling

Tidal cycling in pond PA12 was simulated using the 3-dimensional model Delft-3D Flow. Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing (Delft 2014). Key reasons why this model was chosen was its ability to handle wetting and drying cycles and that it is also used in the coastal zone modelling of the salt fields. A model grid was established for pond PA12 using the available LIDAR data (Figure 2-5). A tidal boundary was created in the model at the edge of the existing (currently blocked) inlet channel/open culvert. Hourly tidal data was obtained from the Bureau of Meteorology for the Outer Harbor gauge. As the LIDAR data was in metres Australian Height Datum (m AHD) the tidal data was corrected to this datum by subtracting 1.45 m (i.e. zero on the Outer Harbor tide datum equates to -1.45 m AHD).. Five observation points (Obs 1-5) were placed in the model (Figure 2-5). These are points that the model outputs detailed time series information on key parameters such as water depth, salinity and sediment shear stress. Full domain/pond spatial output was also acquired at hourly intervals.

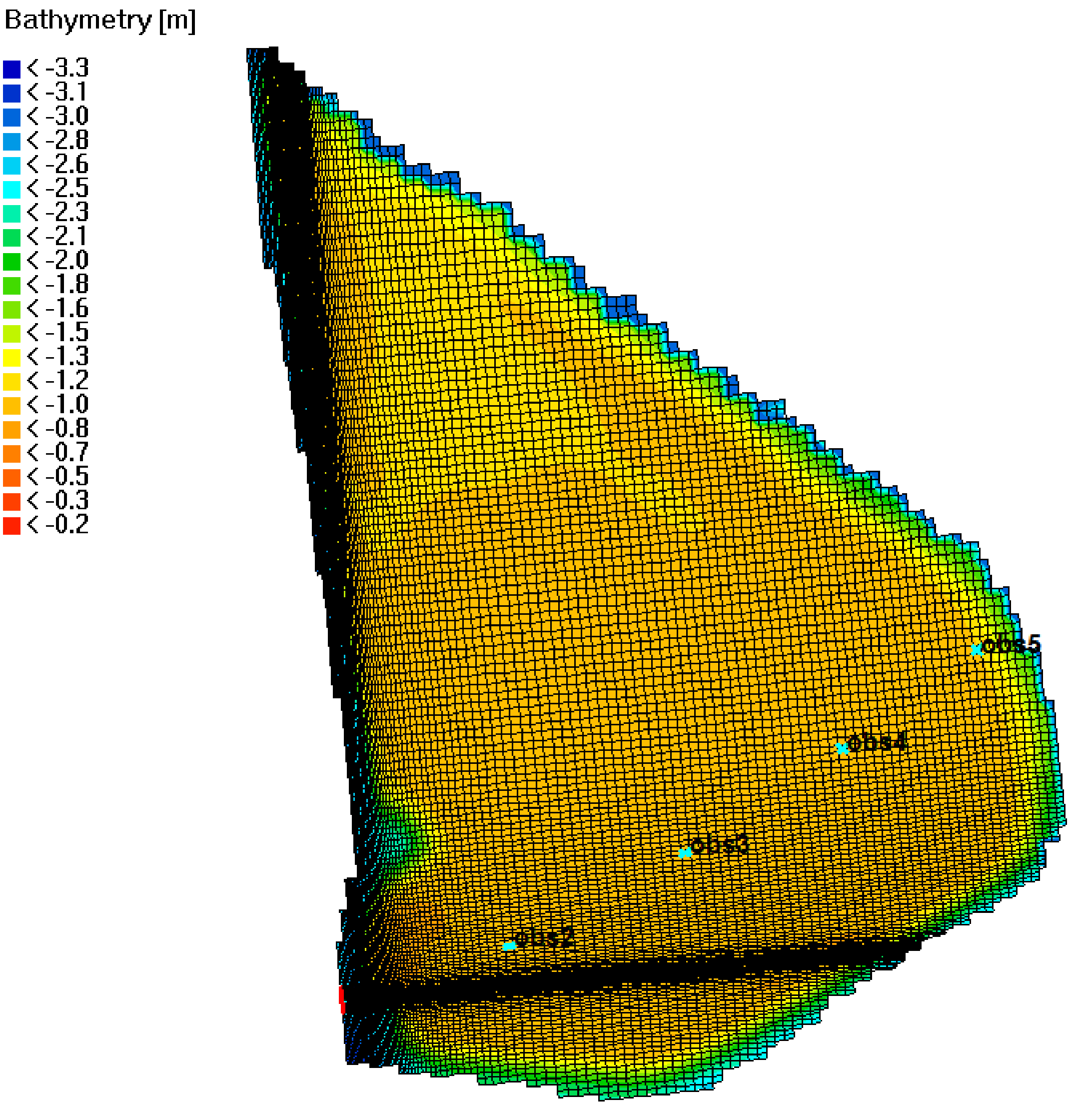


Figure 2-5: Model bathymetry, grid cells, and observation nodes for pond PA12. The bathymetry is displayed in negative m AHD as per the DELFT 3D model requirements. The tidal boundary is configured on the outer edge of the inlet channel (red line) on the left hand side of the domain. This is where Observation Node 1 (Obs1) is located also (not visible on figure).

The cumulative frequency distribution for the bathymetry of pond PA12 is shown in Figure 2-6. About 90% (probability of 0.9) of the bathymetry of the pond lies between 0.9 to 1.5 m AHD.

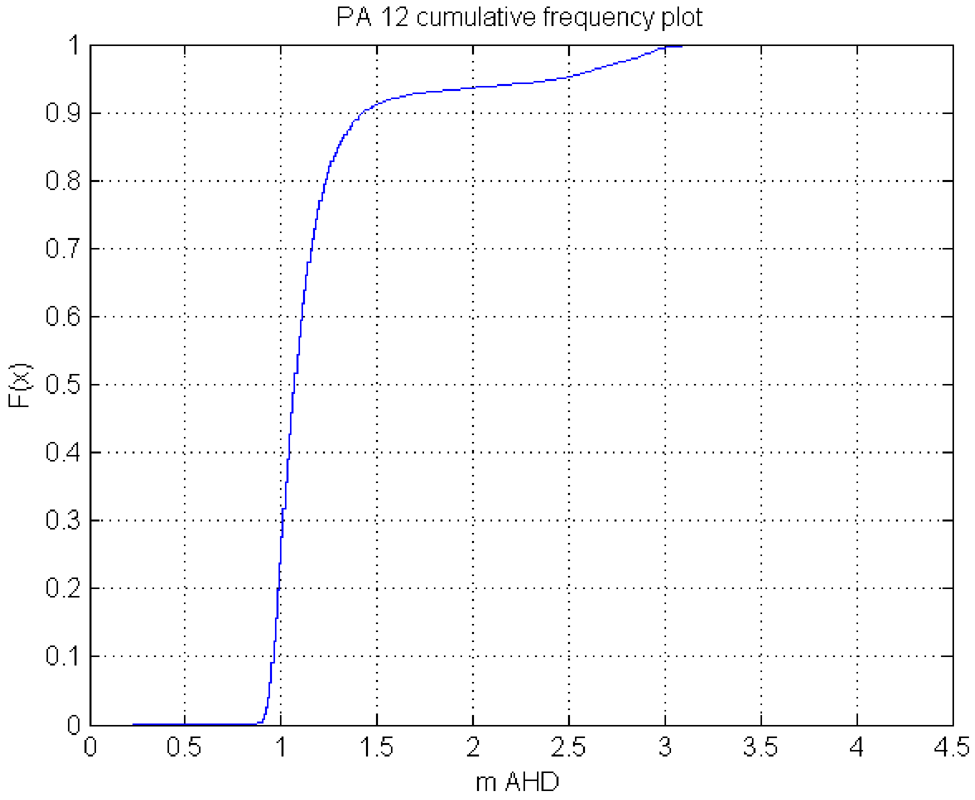


Figure 2-6: Cumulative frequency distribution f(x) of pond PA12 bathymetry

The Outer Harbor tidal range is shown in Figure 2-7. It can be seen that, ignoring possible limitations in water transfer (dealt with in the modelling described above), after converting the tidal data to m AHD, pond PA12 is only likely to be inundated on higher tides and there will be periods where no tidal inundation occurs.

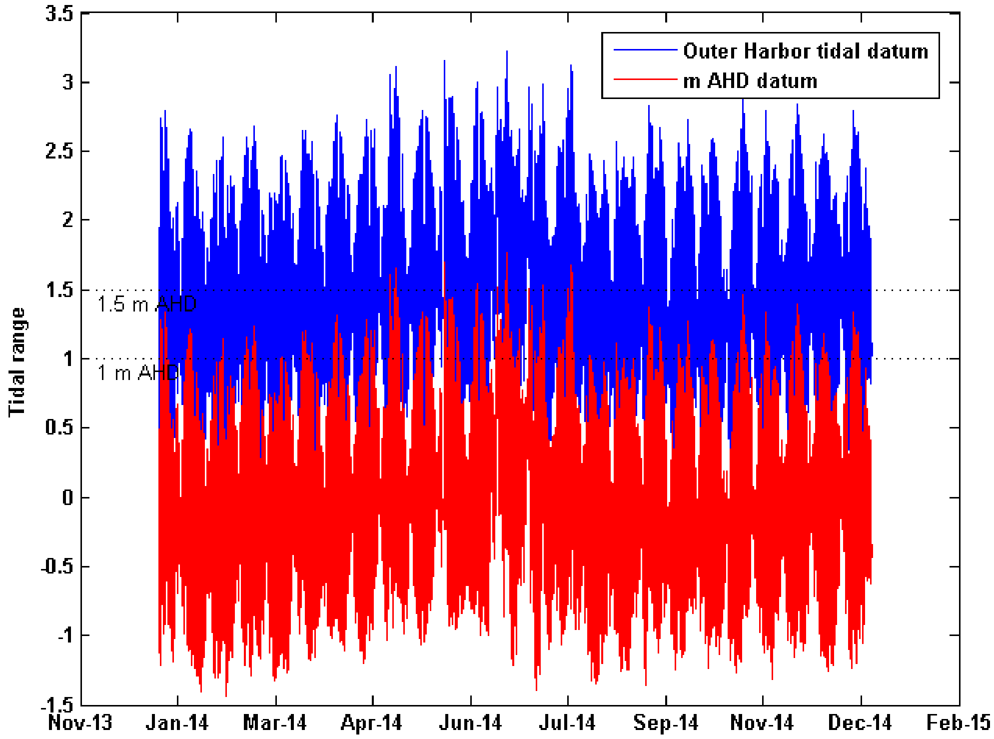


Figure 2-7: Tidal data from 1 Jan 2014 to 1 Jan 2015 for the Outer Harbor tidal guage. The data is displayed relevant to the Outer Harbor tidal datum and to m AHD (minus 1.45 m off tidal datum).

3. RESULTS

3.1 Sediment properties

The chemical and physical properties of the sediments are shown in Table 3-1. The sediments have a high organic carbon content, in particular the XB8A sites (3-4% TOC). The monosulfidic material in the sediment, as estimated by the AVS concentration, was low-moderate compared to AVS in the 35 sediments analysed by Simpson (2001). The metal concentrations are relatively low and do not exceed sediment quality guidelines (see Table 3-1). The samples show a very complex grain size distribution ranging from gravel to clay. The "gravel" consists of salt (gypsum/halite) crystals in the sediments.

Table 3-1: Total organic carbon (TOC), acid volatile sulfide (AVS), metals, moisture, and grain size (in <2mm sediment fraction) in pond XB8A and PA12 samples. The data are compared to the interim sediment quality guideline values (low-high trigger values) from Simpson et al. (2005).

Parameter	XB8A-1	XB8A-2	PA12-1	PA12-2	PA12-3	Guideline
TOC (% C)	4.57	3.22	1.81	0.97	0.91	*n/a*
AVS (mg/kg)	577	285	273	64	64	*n/a*
Metals						
Silver (mg/kg)	0.05	0.04	0.03	<0.1	<0.1	*1-3.7*
Arsenic (mg/kg)	5.6	1.6	1.4	<0.5	<0.5	*20-70*
Lead (mg/kg)	3.7	11.8	8.1	0.4	0.7	*50-220*
Cadmium (mg/kg)	0.1	0.1	0.1	<0.1	<0.1	*1.5-10*
Chromium (mg/kg)	9.7	10.2	14.9	1.1	0.9	*80-370*
Copper (mg/kg)	9	29	7	2	2	*65-270*
Manganese (mg/kg)	39	35	30	3	4	*n/a*
Nickel (mg/kg)	4.2	4.4	5.1	<0.5	<0.5	*21-52*
Selenium (mg/kg)	1.1	0.7	0.7	<0.5	<0.5	*n/a*
Zinc (mg/kg)	18	41	23	4	4	*200-410*
Mercury (mg/kg)	<0.1	<0.1	<0.1	<0.1	<0.1	*0.15-1*
Iron (mg/kg)	6400	6600	11200	500	500	*n/a*
Aluminium (mg/kg)	5600	6700	8400	500	500	*n/a*
Moisture	66%	49%	37%	34%	34%	
Particle size						
Gravel >2mm	16.4%	11.0%	2.1%	27.0%	34.4%	*n/a*
Sand >50µm	19.9%	44.2%	40.1%	42.1%	45.2%	*n/a*
Silt 2-50µm	29.1%	27.3%	32.8%	14.5%	16.7%	*n/a*
Clay <2µm	51.1%	28.5%	27.0%	43.4%	38.1%	*n/a*

3.2 Sediment shear stress

The critical shear stress measured by the CSM instrument is shown in Figure 3-1 together with the corresponding Total Suspended Solids (TSS) concentration. The critical shear stress is quite similar for XB8A-1, XB8A-2, and PA12-1 between 0.8-1.5 Nm^{-2} for sites. This is considered moderate (e.g. very coarse sand has a critical shear stress of 0.47 – 1.3 Nm^{-2}, Berenbrock and and Tranmer 2008). The critical shear stress for sites PA12-1 and PA12-3 was much higher, between 2.4-4.3 Nm^{-2}. This is similar to that found for fine gravel (Berenbrock and and Tranmer 2008). These findings are generally consistent with the complex grain size distribution. The thick organic biofilms (particularly in PA12-1 and PA12-3) also likely increase the critical shear stress. The corresponding TSS values when resuspension commences (90% transmission) are approximately 0.5-1 g/L.

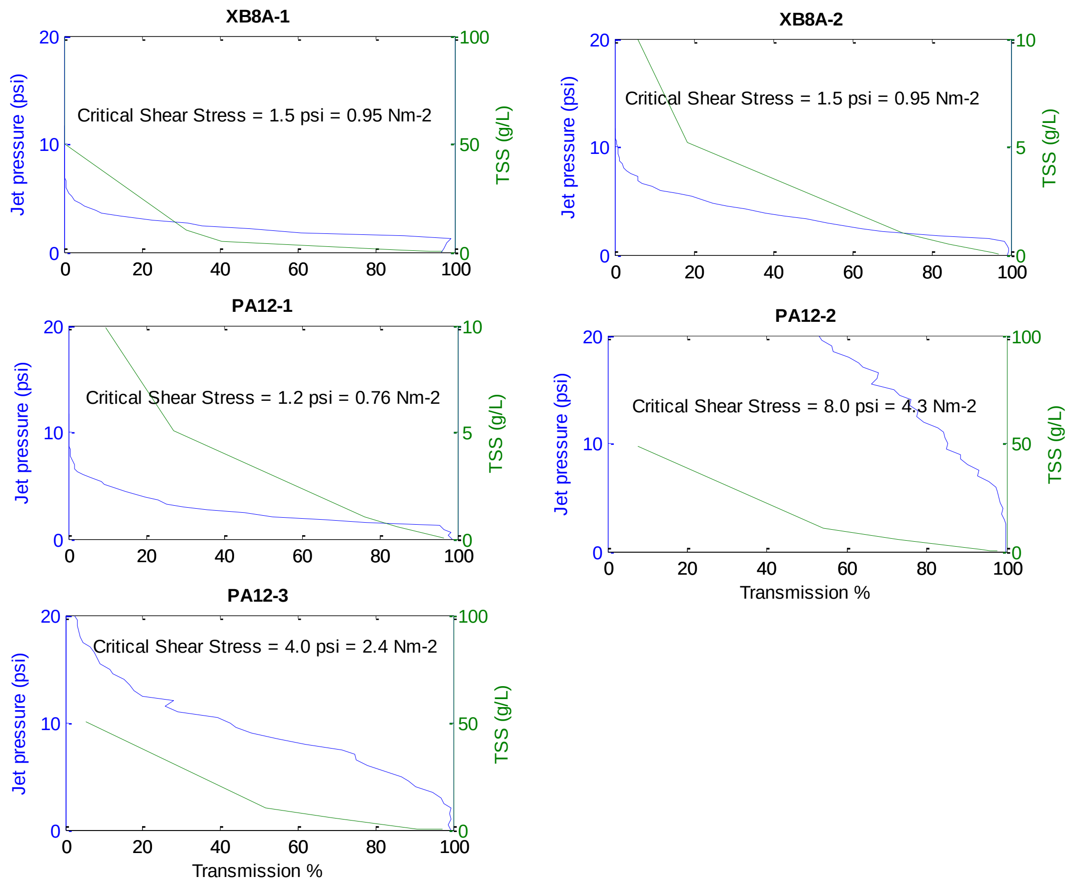


Figure 3-1: Light transmission versus CSM jet pressure for the XB8A and PA12 pond sediments and the corresponding total suspended solids (TSS) concentration.

3.3 Water quality effects of resuspension - kinetics

The dissolved oxygen and pH during the 0-48 resuspension experiment is shown in Figure 3-2. The dissolved oxygen decreased in the first 6 hours of the experiment and then increases again. The reduction in dissolved oxygen is minor, about 0.5 mg/L. There is no South Australian ANZECC (2000) marine water guideline for dissolved oxygen but levels observed (4.5-5 mg/L) are not expected to cause any negative ecological effects on a tidal mudflat. A slight reduction in pH also occurs, but only 0.4 pH units to about pH 8.2. Levels remain well within guidelines for protection of aquatic ecosystems (pH 6.5-9.0, ANZECC 2000).

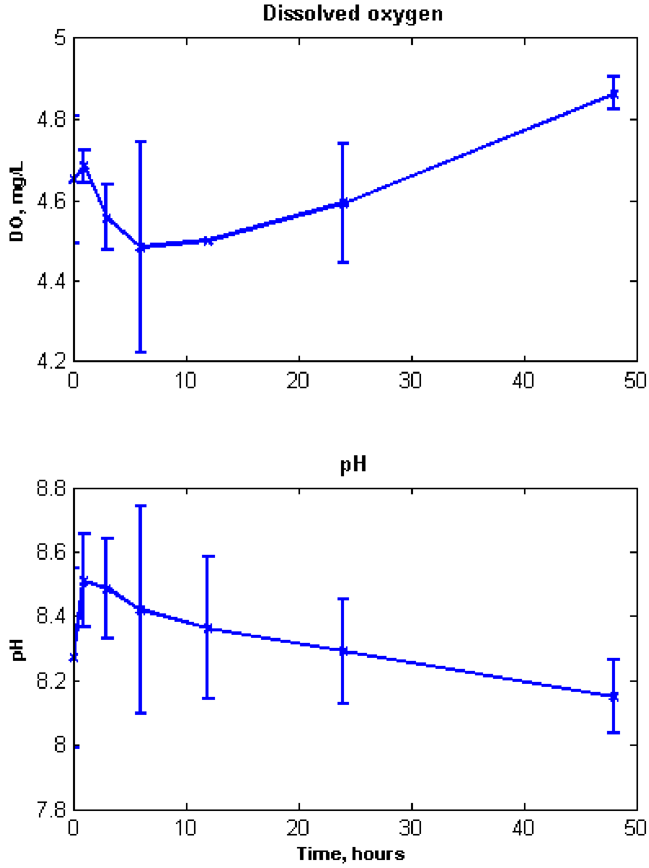


Figure 3-2: Dissolved oxygen and pH during resuspension of sediment XB8A-2 at a concentration of 10 g/L (wet weight basis) over 48 hours.

The dissolved metals concentrations after resuspension of sample XB8A-2 are shown in Figure 3-3. Dissolved Fe, Ni and Co were released in the first 6 h of resuspension and then the concentration stabilised. Dissolved Mn and Zn were also released over the initial time period but their concentration decreased after 6h. Dissolved Al, Cu and As showed no consistent change in concentration during the experiment.

The “total” (2% HNO_3 extractable) metal concentrations were much greater than the dissolved concentrations but did not show any discernible trends over time (Figure 3-4).

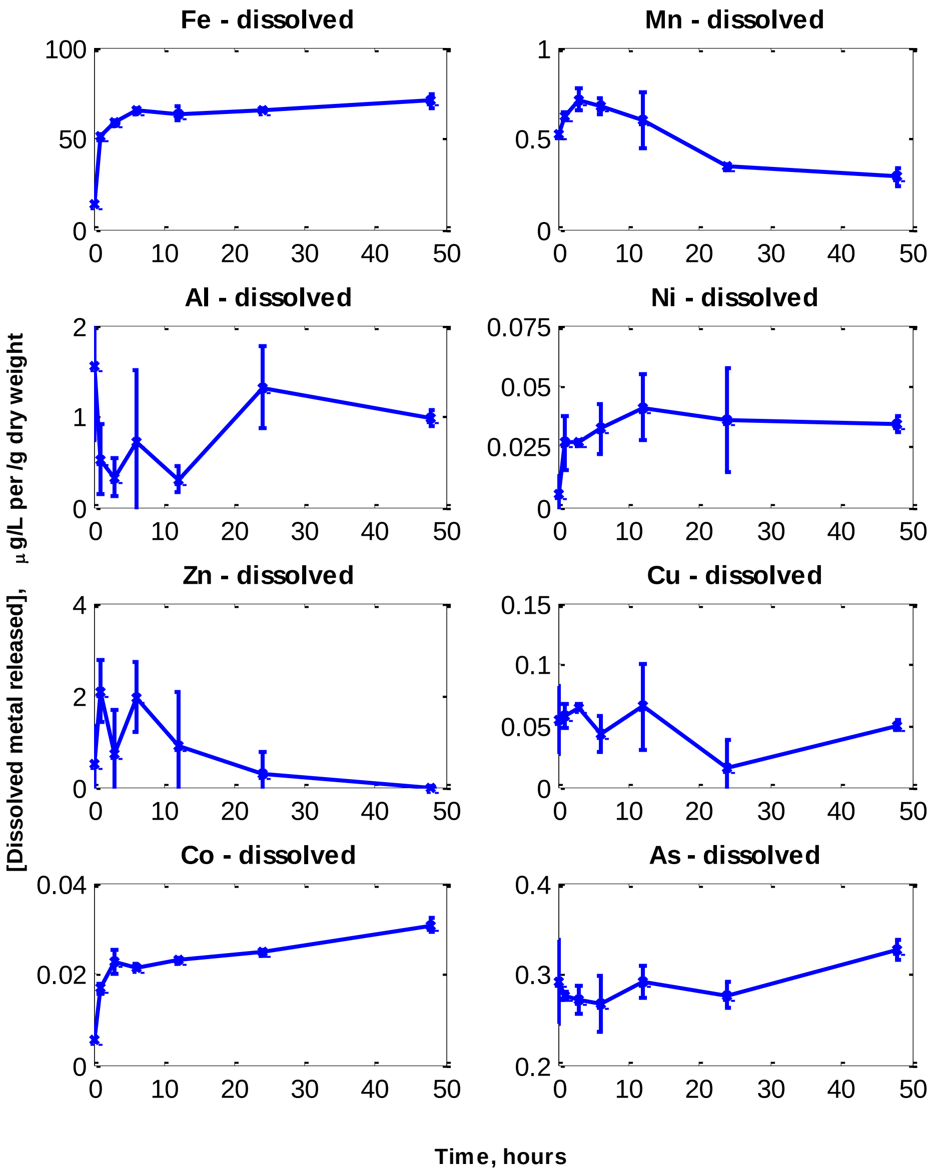


Figure 3-3: Dissolved (<0.4 µm filtered) metals during resuspension of sediment XB8A-2 at a concentration of 10 g/L (wet weight basis) over 48 hours.

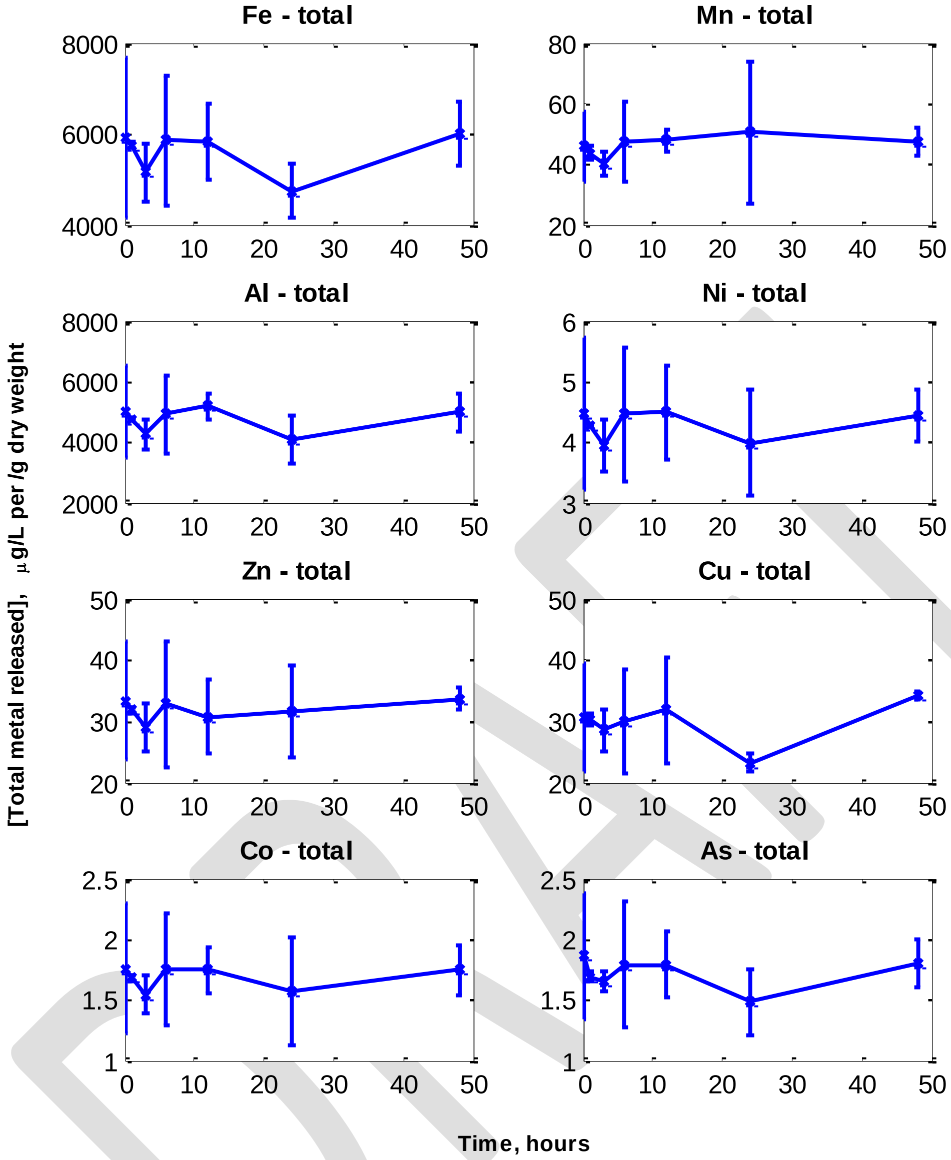


Figure 3-4: Total metals during resuspension of sediment XB8A-2 at a concentration of 10 g/L (wet weight basis) over 48 hours.

3.4 Water quality effects of resuspension – amount of sediment

The dissolved oxygen and pH during experiments with different sediment amounts is shown in Figure 3-2. The effects of sediment concentration on dissolved and pH is relatively minor.

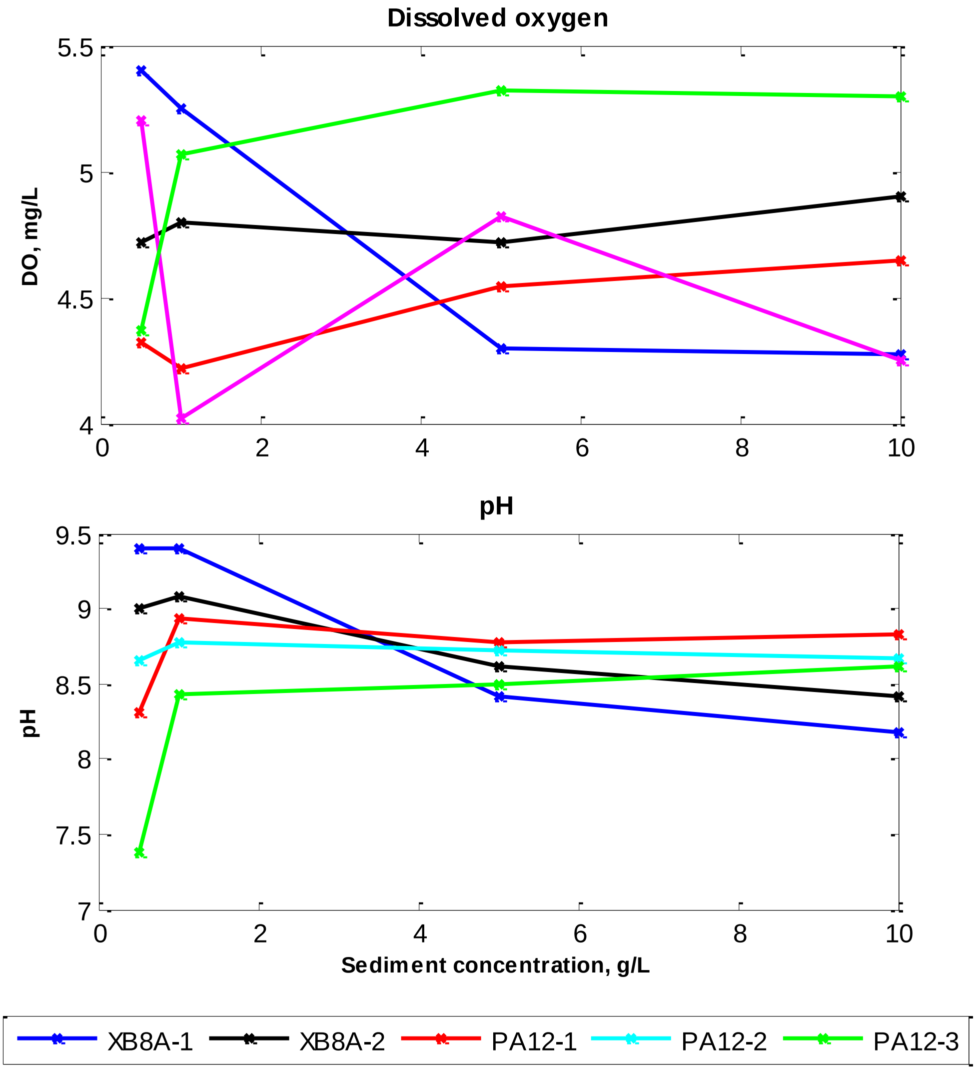


Figure 3-5: Dissolved oxygen and pH during resuspension of varying amount of sediment over 24 hours.

The dissolved metals (Fe, Mn, Al, As) with different sediment amounts is shown in Figure 3-2. There was significant variability between the samples/sediments. For Fe and As, higher sediment concentration resulted in higher dissolved metal release. Mn also showed this pattern for most samples (except PA12-2). Al was variable with three samples (XB8A-1, PA12-2, PA12-3) showing an increase with increased sediment concentration but in other samples showing little change (XB8A-2) or decreasing (PA12-1). Even at the highest suspended sediment concentration (10 g/L) the concentrations of none of the metals exceeded guidelines for protection of aquatic ecosystems (i.e. from ANZECC 2000; Al < 55 µg/L when pH>6.5, Fe has no guideline/non-toxic, Mn <1900 µg/L, As <13 µg/L, guidelines for 95% protection of aquatic ecosystems, freshwater guidelines used where marine guidelines are not available). Cu, Co, and Ni (not shown) concentrations were also below guidelines (<1 µg/L).

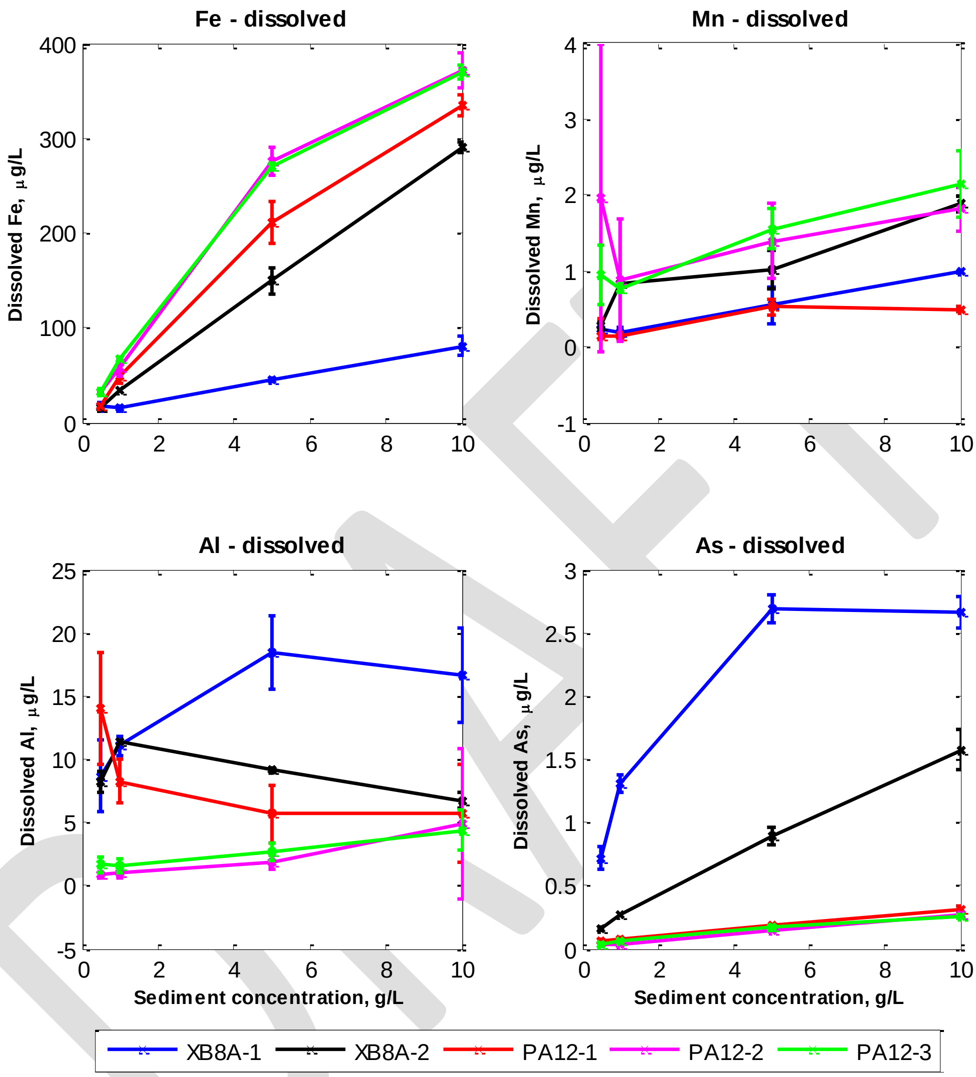


Figure 3-6: Dissolved metals (Fe, Mn, Al, As) during resuspension of varying amount of sediment over 24 hours.

3.5 Modelling

The modelled water level in Pond PA12 over several tidal cycles is shown in Figure 3-7. The tidal level is represented in m AHD by the Obs1 (blue) line. We modelled decreasing tidal height from a "high" high tide (1.7m AHD or 3.15m on tidal datum) to a "low" high tide (0.7m AHD or 2.15m on tidal datum). In all cases the tide is attenuated significantly through the inlet channel. During the larger tidal cycles (beginning to middle of time series) the pond has a water depth of 10-20 cm but during the smaller tidal cycles (towards end of time series) the pond largely remains dry.

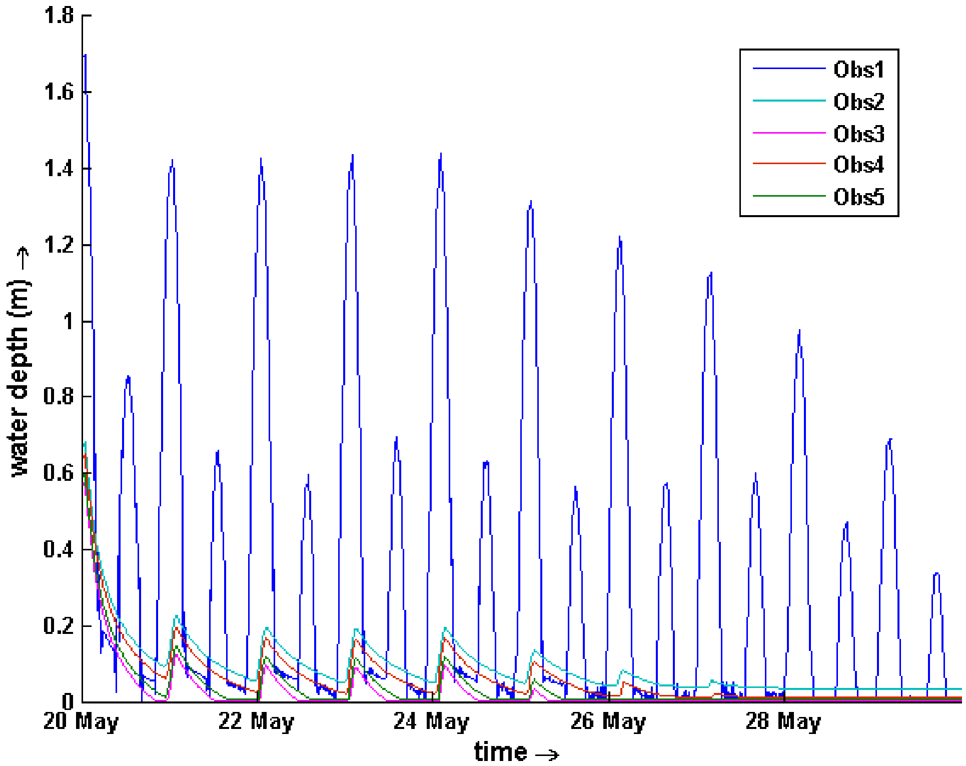


Figure 3-7: Modelled water level at each of the five observation nodes in pond PA12 over several tidal cycles.

The varying water levels across PA12 during the first large tidal cycle in Figure 3-7 is shown in Figure 3-8. It can be seen there is some spatial variability in wetting and drying across the pond due to minor changes in bathymetry and the pond remains largely dry between the 12-18 plots.

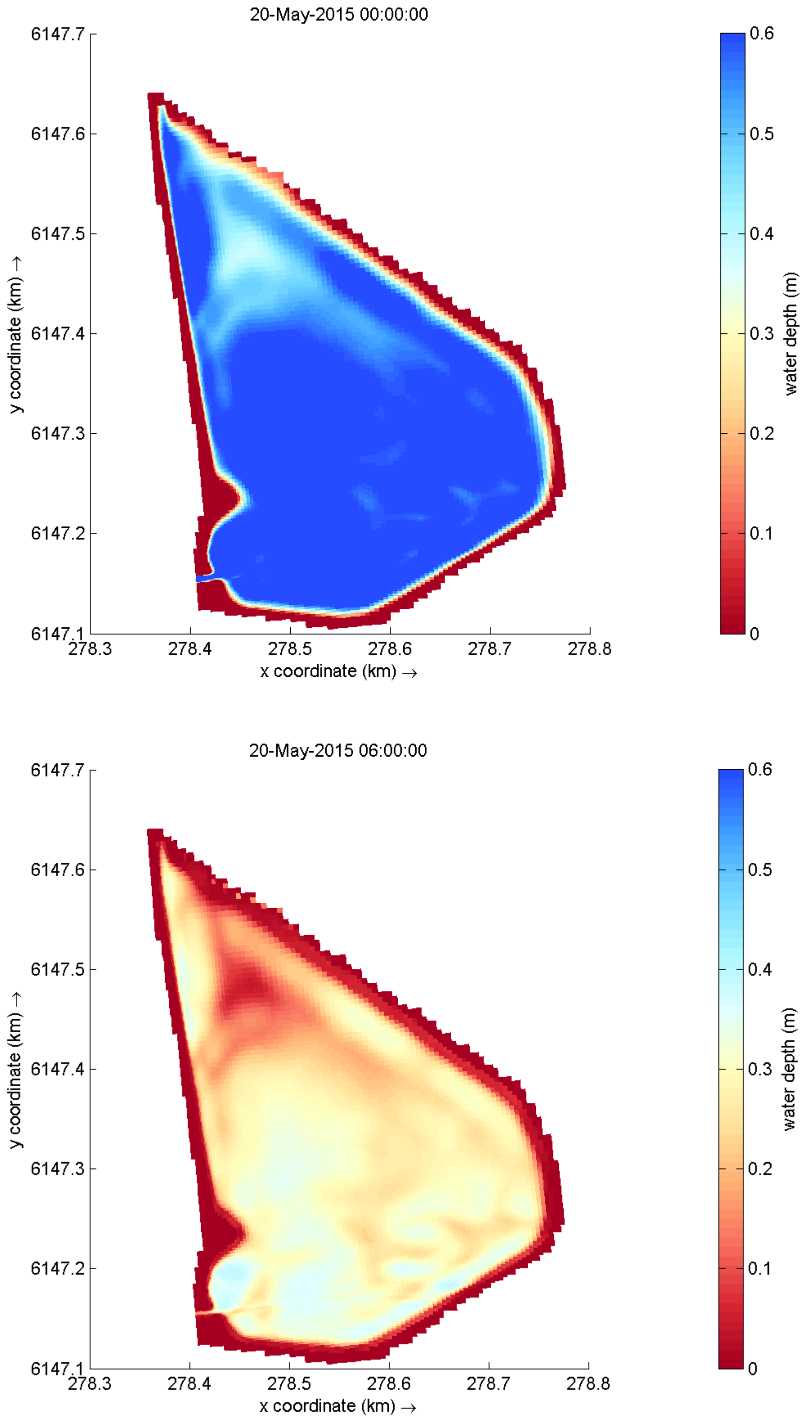
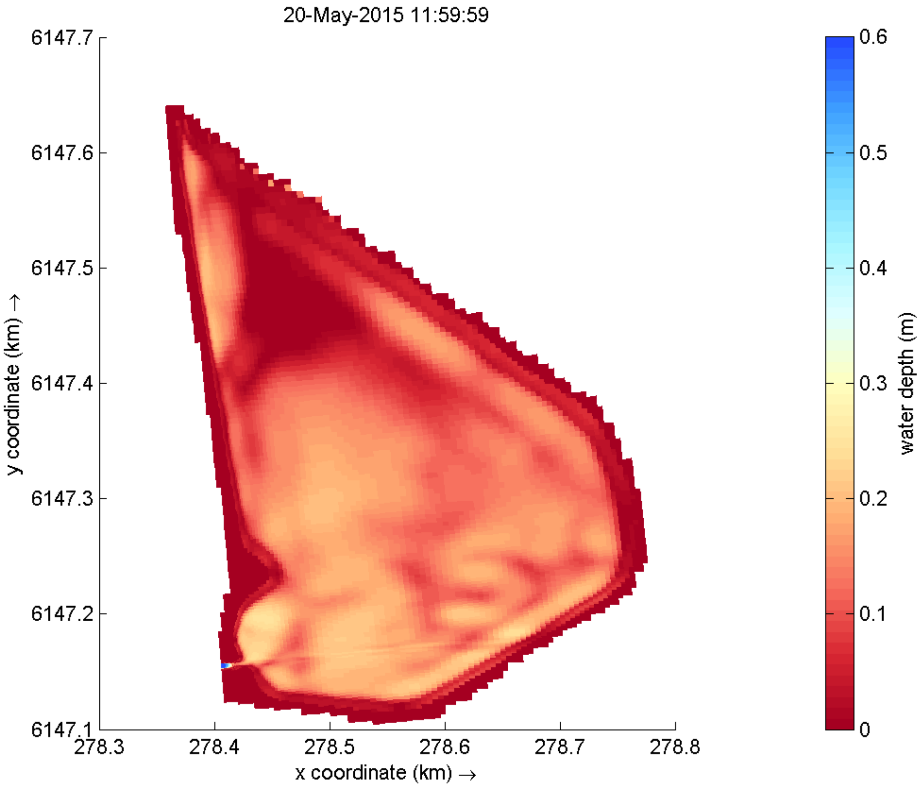
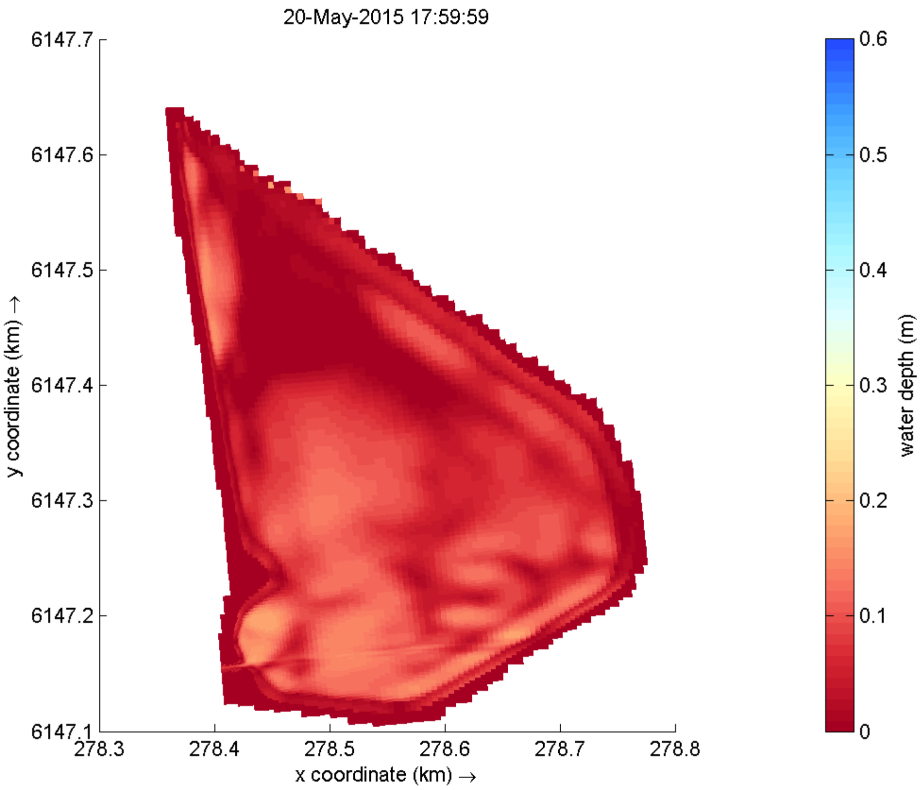


Figure 3-8: Modelled water level in pond PA12 over a tidal cycle Results are displayed for (top) 0h (bottom) 6h and on the following page (top) 12h and (bottom) 18h after start of the large first tidal cycle shown in Figure 3-7.


20-May-2015 11:59:59
y coordinate (km) →
6147.7
6147.6
6147.5
6147.4
6147.3
6147.2
6147.1
278.3
278.4
278.5
278.6
278.7
278.8
x coordinate (km) →
water depth (m)
0.6
0.5
0.4
0.3
0.2
0.1
0


20-May-2015 17:59:59
y coordinate (km) →
6147.7
6147.6
6147.5
6147.4
6147.3
6147.2
6147.1
278.3
278.4
278.5
278.6
278.7
278.8
x coordinate (km) →
water depth (m)
0.6
0.5
0.4
0.3
0.2
0.1
0

The salinity during the modelled tidal cycles is shown in Figure 3-9. The salinity is quite dynamic in response to pond inflow and outflow but dilution to near seawater salinity (approx. 35 ppt) occurs within a few days (4-5 tidal cycles).

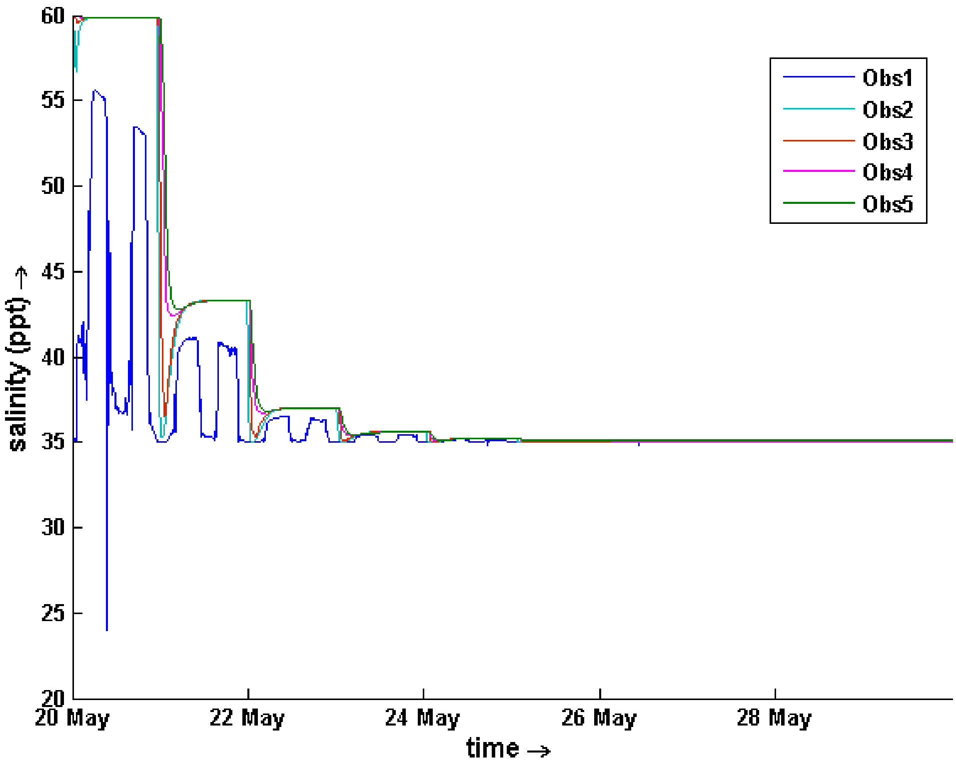


Figure 3-9: Modelled salinity in pond PA12 over several tidal cycles.

The maximum bed shear stress estimated by the model at the observation nodes in the pond (Obs 2-5) is shown in Figure 3-10. The results show that sediment shear stresses are predicted to remain less than 0.4 Nm^{-2}. Examination of the spatial outputs suggests there is a localised area near the inlet channel that may experience higher shear stresses during maximum tidal velocity.

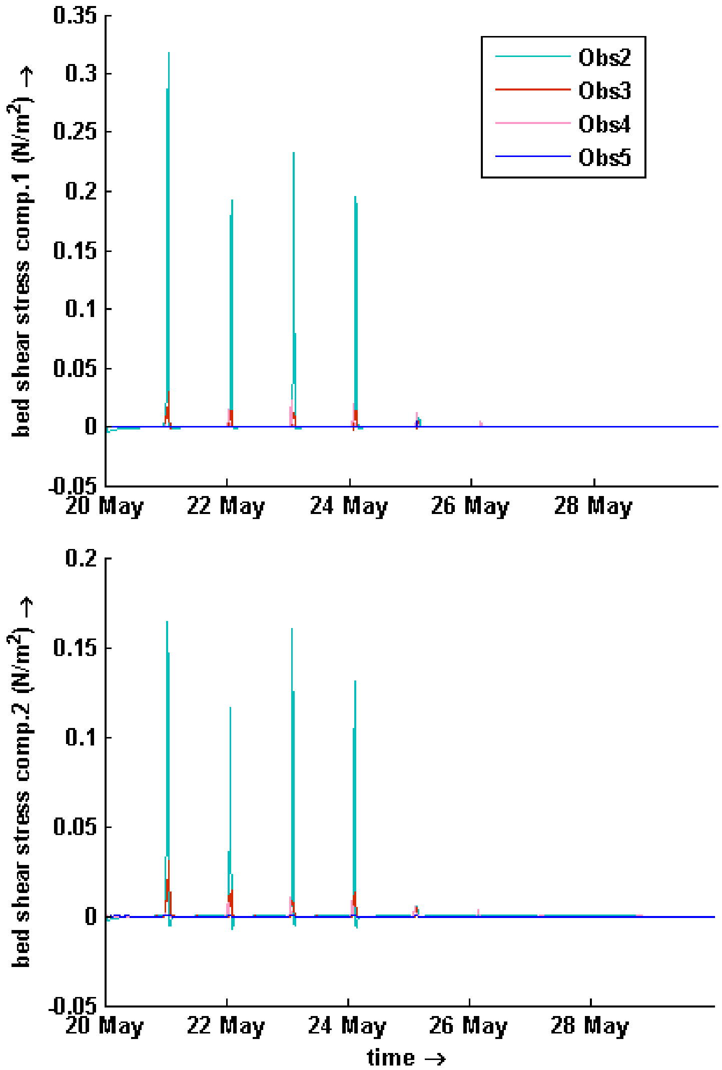


Figure 3-10: Modelled maximum sediment bed shear stress at Observation Nodes 2-5. The top plot (Component 1) is for the x-direction and bottom plot (Component 2) for the y-direction.

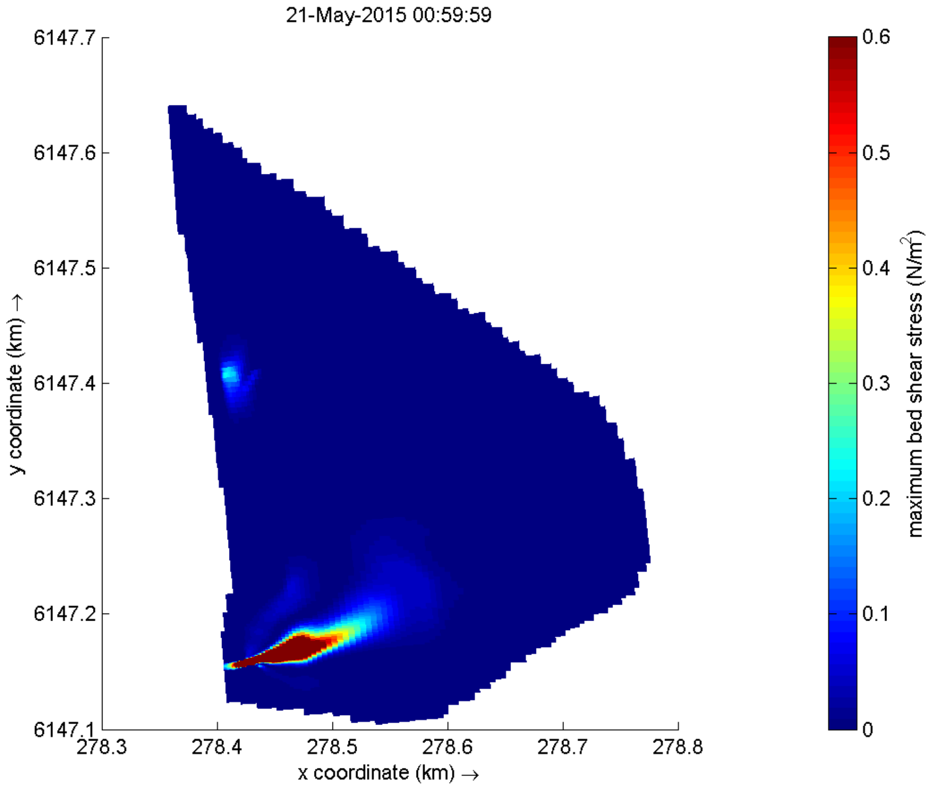


Figure 3-11: Spatial variability in modelled maximum sediment bed shear stress in PA12.

4. DISCUSSION

4.1 Integration of experiments and modelling

The critical shear stress measured by the CSM was between 0.8-1.5 Nm^{-2} for sites XB8A-1, XB8A-2, and PA12-1, but was much higher at PA12-1 and PA12-3 (between 2.4-4.3 Nm^{-2}). These high critical shear stresses in pond PA12, are likely due to the thick organic biofilms and gypsum “gravel” in the sediment. The critical shear stress light transmission correlated to a Total Suspended Solids concentration of about 0.5-1 g/L.

We found resuspension of up to 10 g/L in ponds PA12 and XB8A sediments would not pose significant water quality risks. In our kinetic experiment most monosulfide oxidised/dissolved within 6 h. Some minor reductions in dissolved oxygen and pH, and increases in dissolved metals were observed but pH and metals concentrations remained within ANZECC (2000) guidelines for protection of aquatic ecosystems. The AVS and metal content of the sediment was not high which is consistent with these findings. This is likely due to the main source of metals to the ponds being from the relatively clean seawater input water, with no significant external anthropogenic sources of metals. Also dissolved metals would likely be removed earlier in the chain of ponds due to solid Fe oxide and carbonate precipitation and settling.

Pond PA12 bathymetry was used in the modelling and showed that only the higher tides would inundate the entire pond. With the existing inlet channel structure only limited inundation (0-30 cm water depth) would occur under most tidal conditions. Hence the pond would resemble an intertidal mudflat with substantial periods without standing surface water. The initial salinity set in the model (60 g/L) diluted quite rapidly to seawater salinities. However it should be noted that halite and gypsum dissolution is not accounted for in the modelling so salinities during a field trial may be quite different to model predictions. An approximately 5-10 cm thick gypsum crust at PA12 covers the sediments and is included in the LIDAR bathymetry. After dissolution of the crust the inundated area/water depth is likely to increase.

The sediment/bed shear stresses in the model were mostly less than the critical shear stresses measured by the CSM. This indicates that major resuspension of MBOs is unlikely. There is some uncertainty as to whether the critical shear stress will reduce over time however, as the gypsum crust and crystals dissolve. A localised region of higher shear stress is present during high tidal velocities in the outflow area from the inlet channel. Some scour protection may be warranted in this area if a field trial proceeds.

4.2 Potential field trial

The results demonstrate that proceeding with a field trial of controlled (via adjustable/motorised gate) tidal cycling could be worthwhile. No large scale water quality risks were identified in this preliminary research. One major additional consideration for any field trial will be to monitor the outflowing water and extent and severity of any saline plume. LIDAR data was not available from Ridley for the adjacent tidal creek and mangrove area but if bathymetry can be obtained inclusion of this region in future modelling would be worthwhile. At Dry Creek it is particularly important to prevent impacts on surrounding mangrove and other coastal ecosystems if tidal reconnection to the salt ponds occurs.

Discussions were held on site with Ridley operators on the practicality of undertaking a tidal inundation trial in ponds PA12 and XB8A. The consensus was that pond PA12 would be easier for this purpose as it is currently isolated from other operations at the site (unlike XB8A, which is on the present salt field holding pattern flow path) and there is existing infrastructure, which could be more easily used to install a tidal gate (see Figure 2-1 culvert in foreground of pond PA12 photo). However one Ridley consultant, feels that XB8A may be a better option so further discussion may be needed (Nick Withers, pers. comm.). The existing PA12 open culvert infrastructure would likely substantially reduce costs of tidal gate installation in a trial. A potential disadvantage of pond PA12 is the thick crust of gypsum ($CaSO_4$) interspersed with halite (common salt, NaCl) covering the site (Figure 2-2). Due to the limited amount of halite (only precipitated as gypsum pond dried not when pond PA12 was in salt production chain), it will dissolve quickly exposing some of the underlying monosulfidic material (MBOs). The gypsum crust may also break-up relatively quickly but will take longer to fully dissolve. Pond PA12 is broadly representative of other gypsum ponds in Section 2 however so a trial could provide valuable information how to remediate sites where gypsum and monosulfidic layers are present.

A key aim of any field trial will be to restore healthier (less saline, more oxic) sediment conditions in the pond. Reconnecting of the ponds to tidal cycling will promote more oxic sediment conditions through regular flushing with oxygen–rich fresh seawater during higher tides and exposure to the atmosphere during lower tides. Following tidal connection, we expect the accumulated monosulfide will be oxidised *in situ* and precipitate as more stable forms (e.g. FeIII oxides and sulfate in oxic zone or pyrite in anoxic zone). This will minimize export of the monosulfides and dissolved metals into the surrounding mangroves by the outgoing tide (although our experiments for the two ponds did not suggest these risks may be large). Further, creating more aerobic conditions in the eutrophic pond sediment will promote organic nitrogen (in organic matter/biofilms) mineralisation, leading to formation of nitrate. Nitrate can serve as additional electron acceptor during oxidation of monosulfides. The expected outcome is that tidal cycling trial will significantly reduce the overall sediment hazard in the pond. Assessing the responses of benthic ecosystems and migratory birds to the expected improvements that will occur in sediment and water quality following tidal reconnection will be critical considerations.

The potential benefits of wider implementation of tidal reconnection at the site could be more fully considered after a field trial is undertaken. There are potential cost savings for the government compared to current high-volume and energy intensive pumping operations. There will be a new capital cost of installing culverts/tidal gates however.

5. RECCOMMENDATIONS

It is recommended that:

- A controlled field trial is conducted in one pond as described in the pending DEWNR-UoA ARC linkage grant. Discussions with Ridley Corporation will need to take place as to pond selection and any legal issues.
- Advice from a hydraulic engineer is obtained for optimising the tidal gate design. It may be required to survey the culvert/tidal creek area to inform optimum design and modelling.
- Given the variability in sediment properties within individual ponds, more intensive sampling and analysis (particularly for AVS) of the identified pond is undertaken.
- If pond PA12 is used in a trial further research into the gypsum dissolution following tidal reconnection is necessary.

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APPENDIX B CSIRO incubation and mapping data

CSIRO were contracted to verify on site, previously acquired sub-bottom profile data for the salt field (Baker and Fairbrother, 2016a). Occurrence and thickness of MBO was recorded and ASS incubation experiments on all samples collected. Below are the sample locations in pond XB8A and the sediment core for sample 1, the only site of the seven where MBO was observed.

Pond XB8A. CSIRO Sub-bottom profile ground-truthing sample sites (n=7). Red pin denotes MBO observed at the sample site (site 1).


Sediment core pond XB8A, site 1. MBO material in the top 10cm of the core and a sample of MBO from the site (above the core).

CSIRO also undertook some incubation (to simulate oxidation/drying of sulfides) of the samples (Baker and Fairbrother 2016b in preparation) and the table below shows soil pH from 0, 8 and 16 weeks of incubation. The yellow shaded cells went to pH<5.5 and the red cells to pH<4. Only two deep (>80 cm below pond bottom) old mangrove sediment layers were classified as hypersulfidic (pH<4) after 16 weeks incubation. *Note: Regular tidal cycles will not allow as longer duration or as deeper drying of the profile so oxidation and acidification of the old mangrove layers is considered very unlikely in the trial as discussed in the risk management table in main body of report*.

Profile Layer	Upper depth (cm)	Lower depth (cm)	Main texture	Incubation pH (0 weeks)	Incubation pH (8 weeks)	Incubation pH (16 weeks)	ASS classification
XB8a-01.1	0	15	mbo	7.29	7.07	6.8	Hyposulfidic
XB8a-01.2	15	25	clay	7.39	7.16	6.65	Hyposulfidic
XB8a-01.3	25	45	clay	7.57	7.54	7.22	Hyposulfidic
XB8a-01.4	45	100	mangrove layer	7.67	6.49	5.57	Hyposulfidic
XB8a-01.5	100	115	shell layer	7.2	7	6.82	Hyposulfidic
XB8a-02.1	0	15	clay	7.67	7.13	6.81	Hyposulfidic
XB8a-02.2	15	30	clay	7.45	7.24	6.86	Hyposulfidic
XB8a-02.3	30	60	mangrove layer	7.31	6.81	6.49	Hyposulfidic
XB8a-02.4	60	90	mangrove layer	7.3	5.13	4.13	Hyposulfidic
XB8a-02.5	90	100	clay	7.02	7.1	6.79	Hyposulfidic
XB8a-03.1	0	15	clay	7.58	7.16	6.97	Hyposulfidic
XB8a-03.2	15	70	clay	7.73	7.18	7.08	Hyposulfidic
XB8a-03.3	70	85	clay	7.59	7.2	7.07	Hyposulfidic
XB8a-03.4	85	130	clay	7.58	4.69	3	**Hypersulfidic**
XB8a-04.1	0	30	clay	7.62	6.96	6.76	Hyposulfidic
XB8a-04.2	30	50	clay	7.45	7.16	6.98	Hyposulfidic
XB8a-04.3	50	70	clay	7.33	7	6.73	Hyposulfidic
XB8a-04.4	70	85	clay	7.45	6.03	4.7	Hyposulfidic
XB8a-04.5	85	135	mangrove layer	7.4	4.3	2.81	**Hypersulfidic**
XB8a-05.1	0	7	gypsum	7.63	6.89	6.67	Hyposulfidic
XB8a-05.2	7	30	clay	7.71	6.06	5.1	Hyposulfidic
XB8a-05.3	30	60	mangrove layer	7.47	5.59	4.8	Hyposulfidic
XB8a-05.4	60	90	clay	7.14	6.8	6.76	Hyposulfidic

XB8a-06.1	0	25	mangrove layer	7.19	6.99	7.04	Hyposulfidic
XB8a-06.2	25	30	clay	7.26	6.95	7.02	Hyposulfidic
XB8a-06.3	30	50	mangrove layer	7.16	7.03	7.01	Hyposulfidic
XB8a-06.4	50	90	clay	7.42	7.13	7.17	Hyposulfidic
XB8a-06.5	90	100	clay	7.79	7.37	7.38	Hyposulfidic
XB8a-07.1	0	15	clay	7.37	7.03	7.2	Hyposulfidic
XB8a-07.2	15	30	clay	7.36	6.98	6.57	Hyposulfidic
XB8a-07.3	30	60	mangrove layer	7.27	6.04	5.07	Hyposulfidic
XB8a-07.4	60	80	clay	7	6.87	6.81	Hyposulfidic

APPENDIX C - Acid-base accounting data for minor dredging works to restore tidal creek to proposed gate

RESULTS OF ACID SULFATE SOIL ANALYSIS

5 samples supplied by University of Adelaide on 1st June, 2016 - Lab. Job No. F0775

Analysis requested by Luke Mosley. **Your Project: LMRIA SARMS**

(Faculty of Sciences Waite Campus PMB 1 GLEN OSMOND SA 5064)

required if pH_{KCl} > 6.5

Sample Site	EAL lab code	TEXTURE (note 7)	MOISTURE CONTENT (% moisture of total wet weight)	(g moisture / g of oven dry soil)	TITRATABLE ACTUAL ACIDITY (TAA) pH_{KCl}	(To pH 6.5) (mole H^+/tonne)	REDUCED INORGANIC SULFUR (% chromium reducible S) (%Scr)	(mole H^+/tonne)	ACID NEUTRALISING CAPACITY (ANC_{BT}) (% $CaCO_3$)	(mole H^+/tonne)	NET ACIDITY Chromium Suite mole H^+/tonne (based on %Scrs)	LIME CALCULATION Chromium Suite kg $CaCO_3$/tonne DW (includes 1.5 safety Factor when liming rate is $^+$ve)
Method Info.		**	**		*(ACTUAL ACIDITY-Method 23)*		*(POTENTIAL ACIDITY-Method 22B)*		*(NEUTRALISING CAPACITY)*		*** & note 5*	*** & note 4 and 6*
L-XB8Aa-1.1	*F0775/1*	Fine	76.3	3.22	8.74	0	0.367	229	21.3	4252	-2606	-130
L-XB8Aa-1.2	*F0775/2*	Fine	73.7	2.81	8.84	0	0.355	221	24.9	4979	-3098	-155
L-XB8Aa-1.3	*F0775/3*	Fine	76.1	3.19	8.92	0	0.512	319	21.4	4282	-2535	-127
L-XB8Aa-1.4	*F0775/4*	Fine	77.7	3.49	8.95	0	0.707	441	19.4	3882	-2147	-107
L-XB8Aa-1.5	*F0775/5*	Fine	75.4	3.07	8.96	0	0.742	463	23.4	4683	-2659	-133

NOTE:

(NOTE: negative Net Acidity indicate excess acid neutralising capacity)

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 - Meth

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 - **ABA Equation**: **Net Acidity = Potential Sulfidic Acidity (ie. Scrs 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

NATA WORLD RECOGNISED ACCREDITATION
Accreditation No. 14960.
Accredited for compliance with ISO/IEC 17025.

(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

Impact Events

Environmental Aspect	Trial Phase	Event ID	Potential Impact Event	Source	Source Description	Pathway	Pathway Description	Receptor(s)	Receptor Description	Linkage Confirmed	Evidence of the Linkage/Non-Linkage
Flora & Fauna	Drainage of XB8A to PA3 and Pumping Creek to facilitate civil works.	F1 XB8A F1	**Impacts on numbers / diversity of protected birds from habitat change.** Drainage of pond XB8A leading to temporary change of water level and drained areas of the pond.	Changes in the depth of water in ponds	Drainage of pond XB8A	Surface Water	Water Level	Shorebirds and water birds	32 listed migratory species recorded or considered likely to occur.	Yes	Previous studies have shown the relationship between water levels and usage by shorebirds and water birds.
	Dredging of material seaward of seawall to reconnect Pumping Creek to XB8A	XB8A F2	**Impacts on marine water quality and biodiversity from dredging** (eg: DO, acidity, metal contaminants, turbidity)	Disturbance of sediment impacting marine water quality	Excavation of material	Surface Water	Mobilisation of contaminants from dredge site to adjacent marine environment	Marine flora and fauna	External marine life in Gulf St Vincent	Yes	Known impact from activity
	Civil works to install tidal gate infrastructure and isolate pond XB8A from flow path	XB8A F3	**Short term disturbance of roosting/feeding birds during construction phase**	Noise and proximity to machinery and people	Civil works (excavation to install tidal gate); closure of bunds to isolate pond and redirect flow path	Whole of pond	Noise and activity localised to construction area disturbs birds in close proximity	Shorebirds and water birds	32 listed migratory species recorded or considered likely to occur.	Yes	Previous studies have shown the relationship between disturbance and shorebird behaviour
	Dilution and flushing with tidal water to remove excess salt	XB8A F4	**Impacts on numbers / diversity of protected birds from habitat change.** Drainage and filling of pond XB8A leading to cycles of changes in water level and presence of drained areas of the pond.	Changes in the depth of water in ponds	Filling and drainage of pond XB8A	Surface Water	Water Level	Shorebirds and water birds	32 listed migratory species recorded or considered likely to occur.	Yes	Previous studies have shown the relationship between water levels and usage by shorebirds and water birds.
	Tidal cycling	XB8A F5	**Impacts on numbers / diversity of protected birds from habitat change.** Drainage and filling of pond XB8A leading to cycles of changes in water level and presence of drained areas of the pond. Water level significantly lower than Holding Pattern water level.	Changes in the depth of water in ponds	Filling and drainage of pond XB8A	Surface Water	Water Level	Shorebirds and water birds	32 listed migratory species recorded or considered likely to occur.	Yes	Previous studies have shown the relationship between water levels and usage by shorebirds and water birds.
	Tidal cycling	XB8A F6	**Predation of migratory shorebirds**. Land produced by draining and then wetting and drying XB8A will provide easier access for predators and feral animals. Feral animals will be attracted by the bird life and by other fauna that colonise the drained pond.	Changes in the depth of water in ponds	Drainage	Drained areas	Creation of drained and shallow areas of the pond	Shorebirds and water birds	32 listed migratory species recorded or considered likely to occur.	Yes	Likely impact from activity
	Tidal cycling	XB8A F7	**Increase in exotic and invasive plants and weeds.** Eventually, without adequate control, weeds could spread over drained areas impacting on flora and fauna habitat. Conditions will tend to favour salt tolerant plants.	Drainage and filling of pond	Changes to the water / groundwater regime within the pond, and associated changes to soil substrate conditions	Whole of pond	Creation of drained areas of ground	Biodiversity	Reduced potential for establishment of native plant communities.	Yes	Weed invasion a known impact when water cover removed and salinity decreased
	Tidal cycling	XB8A F8	**Increase in exotic and invasive fauna.** Exotic animal species can occupy habitat niches to the exclusion of native species. They may also graze or trample flora to excess, and the physical aspects of some exotic species (e.g. sharp hoofs) may be damaging to emerging plants.	Changes in the depth of water in ponds	Filling and drainage of pond XB8A	Whole of pond	Creation of drained areas of ground	Emerging saltmarsh and benthic infauna. Disturbance of Shorebirds and water birds	Feeding and roosting habitat for migratory shorebirds and food.	Yes	Lowering the pond water level and drying areas of the pond will allow greater access across parts of the pond by fauna.
	Tidal cycling	XB8A F9	**Impact on food sources for migratory and resident birds** from a change in water quality (eg: changing salinity, increase in BOD, nutrients, algae). Reduction of availability of benthic organisms, fish and bottom dwelling species for food.	Decline in the quality of water in the pond if tidal exchange inadequate	Poor quality of residual water if the tidal exchange is inadequate.	Surface Water	Reduction in water quality (eg: changing salinity, increase in BOD, nutrients, algae)	EPBC Act listed marine or migratory bird species recorded at the site	The birds rely on benthic organisms, fish and bottom dwelling species for food.	Yes	Water quality known to influence abundance, availability and diversity of bird prey
	Tidal Cycling	XB8A F10	**Impacts on marine water quality and biodiversity from discharge** (eg: salinity, DO, acidity, metal contaminants, turbidity, nutrients)	Discharges into the marine environment of water from the pond	Discharge of water from pond to Pumping Creek and marine waters	Water	Cycling of tidal water through gated pipes at the discharge location	Marine flora and fauna	External marine life in Gulf St Vincent	Yes	
Surface Water	Drainage of XB8A to PA3 and Pumping Creek to facilitate civil works.	XB8A SW1	**Poor quality of residual water in the drained pond**	Changes to water level in the pond	Drainage of pond XB8A	Whole of pond	Reduction of water in the pond	Environmental uses	Environmental uses of the pond	Yes	
	Dredging of material seaward of seawall to reconnect Pumping Creek to XB8A	XB8A SW2	**Impacts on marine water quality and biodiversity from dredging** (eg: DO, acidity, metal contaminants, turbidity)	Disturbance of sediment impacting water quality	Excavation of material	Water	Mobilisation of contaminants from dredge site to adjacent marine environment	External users of marine environment	External users of the marine environment	Yes	
	Civil works to install tidal gate infrastructure and isolate pond XB8A from flow path	XB8A SW3	**Impacts on pond water quality and biodiversity from construction** (eg: DO, acidity, metal contaminants, turbidity)	Disturbance of sediment impacting water quality	Excavation of material	Water	Mobilisation of contaminants from excavation of the seawall to elsewhere within the pond. Filling of gaps to isolate pond causes turbidity.	Environmental uses	Environmental uses of the pond	Yes	
	Tidal Cycling	XB8A SW4	**Impacts from midges and mosquitoes** etc. as a result of water quality in the pond if left un-drained or not flushed via tidal exchange sufficiently	Deterioration of water quality in the ponds, if left un-drained or not flushed	Deterioration of quality of residual water in draining / drained pond and its topographic depressions, trenches, creek resulting in breeding of midges and mosquitoes etc	Air	Pest insects increase	Humans	Residents and occupants / workers at and outside the site	Yes	
	Tidal cycling	XB8A SW5	**Algal blooms in the water if left un-drained or not flushed via tidal exchange sufficiently**	Deterioration of water quality in the pond, if left un-drained or not flushed	Deterioration of water quality in the pond, if left un-drained or not flushed, with the right temperature conditions, the water quality could deteriorate (low oxygen, increase in salinity, availability of nutrients and organic carbon) and lead to algal blooms in the water	Whole of pond	Reduction in water in the ponds and/or inadequate tidal exchange	Environmental uses	Environmental uses of the pond	Yes	
	Tidal cycling	XB8A SW6	**Short term increases in salinity of tidal waters localised to the vicinity of the discharge point**	Discharges into the marine environment of water from the site	Discharges into the marine environment of water from the pond containing salt at concentrations higher than background seawater, and if present, other chemicals at concentrations higher than background sea water.	Water	Cycling of tidal water through gated pipes at the discharge location	External users of marine environment	Environmental uses of water in the parts of Gulf St Vincent adjacent to the site. Flora and fauna in the marine environment	Yes	
	Whole of trial	XB8A SW7	**Prevention of formation of healthy terrestrial flora and fauna habitats as a result of poor water quality in the pond**	Changes to water levels and/or quality in the pond	Deterioration of water quality in the pond, if left un-drained or not flushed	Surface water	Pollutants enter surface water within the pond.	Environmental uses. Biodiversity	Environmental uses of the pond	Yes	
Ground Water	Whole of trial	XB8A GW1	**Groundwater seepage impacting groundwater dependent ecosystems and/or adjacent marine environment**	Changes to water levels in ponds	Contamination, salinity, acid sulphate conditions impair the quality of infiltration to groundwater at the site	Groundwater	Seepage / Leaching of water to the groundwater and/or adjacent marine environment	Environmental uses Biodiversity	Environmental uses of surface water within the site. Environmental uses of water in the parts of Gulf St Vincent adjacent to the site. Flora and fauna in the marine environment	Yes	
Air Quality	Drainage of XB8A to PA3 and Pumping Creek to facilitate civil works.	XB8A A1	**Dusts from exposed ground surfaces affecting the amenity of people**	Exposed ground surface	Surfaces exposed from draining of pond	Air/wind	Hot, windy conditions creating and transporting dusts from exposed ground surfaces	Humans	Adjoining residents / businesses	Yes	
	Civil works to install tidal gate infrastructure and isolate pond XB8A from flow path	XB8A A2	**Dusts from excavation and transportation activities during tidal gate construction and pond isolation**	Earthworks and soil transportation	Earthworks will disturb soil and trucking of soil material may result in dust mobilisation	Air/wind	Windy conditions creating and transporting dusts from site of earthworks and whilst transporting	Humans	Adjoining residents / businesses	Yes	
	Tidal cycling	XB8A A3	**Dusts from exposed ground surfaces affecting the amenity of people, if left un-drained or not flushed via tidal exchange sufficiently**	Exposed ground surface	Surfaces exposed from draining of pond	Air/wind	Hot, windy conditions creating and transporting dusts from exposed ground surfaces	Humans	Adjoining residents / businesses	Yes	
		XB8A A4	**Dust from ASS affecting health of adjoining human or ecological receptors**	Exposed acid sulfate soil	Surfaces exposed from draining of pond	Air/wind	Hot, windy conditions creating and transporting dusts from exposed ground surfaces	Humans and ecological receptors	Adjoining residents / businesses. Adjacent environment.	Yes	
		XB8A A5	**Odour from exposed acid sulphate soils affecting the amenity of adjoining receptors**	Exposed acid sulfate soil	Surfaces exposed from draining of pond	Air/wind	Light wind conditions transporting odours from exposed acid sulfate soil surfaces	Humans	Adjoining residents	Yes	
		XB8A A6	**Odour from algal blooms affecting the medium-term amenity of adjoining receptors**	Deterioration of water quality in the pond, if left un-drained or not flushed	Deterioration of water quality in the pond, if left un-drained or not flushed, with the right temperature conditions, the water quality could deteriorate (low oxygen, increase in salinity, availability of nutrients and organic carbon) and lead to algal blooms in the water	Air/wind	Light wind conditions transporting odours from affected areas of the pond	Humans	Adjoining residents	Yes	

Environmental Aspect	Trial Phase	Event ID	Potential Impact Event	Source	Source Description	Pathway	Pathway Description	Receptor(s)	Receptor Description	Linkage Confirmed	Evidence of the Linkage/Non-Linkage
Soil Quality (contamination, salinity and acid sulfate)	Whole of trial	XB8A SQ1	**Impacts on ecological systems, surface water quality or groundwater quality outside of the site from exposure to salt and/or low pH.**	Salt / ASS impacted sediment in the pond	Exposure to salt / acidity	Drainage / groundwater	Direct exposure via drainage or groundwater leakage, or from sediment mobilised and drained offsite	Environmental and human uses of land outside the site	Environmental receptors adjacent the pond	Yes	Monitoring of Pumping Creek and samphire area adjacent to pond has shown salinity impacts that likely arise from groundwater seepage from salt ponds.
	Whole of trial	XB8A SQ2	**Prevention of formation of healthy terrestrial flora and fauna habitats as a result of acid formation in sub-soil.**	1(a) Actual Acid Sulphate Soils (disturbed)	Anywhere where PASS has been disturbed	Groundwater / surface water	Acidity forms and enters shallow groundwater and the surface water within the pond.	Environmental uses of the pond	Groundwater under pond or surface water outside of pond	No	Buffering of acidity available from saline water and from carbonate content of clays, sands and calcarenite layers / lenses. No large scale or offsite impacts observed following draining of ponds in other locations.
				1(b) Potential ASS (disturbed)	Below 1.5m AHD, above 1m AHD						
				2 Potential ASS (mangrove)	Below 1m AHD						
				3 Potential ASS (tidal stream)	Below 1.5 m AHD						
				4 Potential ASS (intertidal)	Below 1.5m AHD, above 1m AHD						
				5 Potential ASS (supratidal)	Below 2.5m AHD, above 1.5m AHD						
				6 Sand	Above 1.5m AHD						
				7 Calcarenite	Above 1.5m AHD						
				8 Marine Soils	Below 1m AHD						
				9 Other Soils	In topographic depressions at any elevation within ponds						
Noise	Civil works to install tidal gate infrastructure and isolate pond XB8A from holding pattern flow path	XB8A N1	**Noise from machinery used affecting adjoining residents**	Machinery and vehicles	Vehicle and machinery movement at trial site	Air		Humans	Adjoining residents	Yes	
Noise	Civil works to install tidal gate infrastructure and isolate pond XB8A from flow path	XB8A N2	**Noise from machinery used affecting fauna**	Machinery and vehicles	Vehicle and machinery movement at trial site	Air		Fauna	Fauna in proximity	Yes	

Risk Assessment

Environmental Aspect	Event ID	Potential Impact Event	Description of Impact / Expected Impact	Significance of Impact	Applicable Regulatory Standard	Control strategies	Uncertainties	Likelihood of greater impact than expected	Possible level of impact (Consequence)	Risk Rating	Outcome Required (Y/N)	Outcome
Flora & Fauna	XB8A F1	**Impacts on numbers / diversity of protected birds from habitat change.** Drainage of pond XB8A leading to temporary change of water level and drained areas of the pond.	Change to current water level in pond XB8A affects numbers / diversity of protected birds.	Negligible	Yes - EPBC Act: Significant Impact Guidelines 1.1 Significant impact guidelines for 36 migratory shorebird species	Short term event prior to commencement of tidal cycling.	Uncertainties regarding the extent to which drainage of XB8A will provide shorebird habitat.	Unlikely	Low	Negligible	N	
	XB8A F2	**Impacts on marine water quality and biodiversity from dredging** (eg: DO, acidity, metal contaminants, turbidity)	None to a short duration episodic impact to marine fauna in the adjacent creek and gulf waters.	Low	Under EPA Act general environmental duty to protect aquatic ecosystems from harm	Dredging will be staged and timed with tides to ensure minimal sediment impact to the creek. Silt curtains will be used by licensed dredging contractor if required.	Some uncertainty regarding mobilisation of turbidity and export of DO, low pH and salinity.	Unlikely	Low	Negligible	N	
	XB8A F3	**Short term disturbance of roosting/feeding birds during construction phase**	Short term disturbance of roosting and feeding birds in XB8A and adjacent areas during construction.	Negligible	None	Minimise construction period.	Duration of works due to weather or unforeseen circumstances.	Unlikely	Negligible	Negligible	N	
	XB8A F4, F5	**Impacts on numbers / diversity of protected birds from habitat change.** Drainage and filling of pond XB8A leading to cycles of changes in water level and presence of drained areas of the pond.	Controlled tidal wetting and drying creates additional areas of mudflat and shallow water for shorebird feeding and roosting. Expect an increase in shorebird use of the pond.	Negligible	Yes - EPBC Act: Significant Impact Guidelines 1.1 Significant impact guidelines for 36 migratory shorebird species	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface.	Uncertainties regarding the extent to which tidal cycling in XB8A will provide shorebird habitat.	Unlikely	Negligible	Negligible	N	
	XB8A F6	**Predation of migratory shorebirds**. Land produced by draining and then wetting and drying XB8A will provide easier access for predators and feral animals. Feral animals will be attracted by the bird life and by other fauna that colonise the drained pond.	Birds using the pond will be at no greater risk then in similar areas nearby.	Negligible	Yes - EPBC Act: Significant Impact Guidelines 1.1 Significant impact guidelines for 36 migratory shorebird species	Ensure regular wetting and drying via tidal inundation to provide complexity and variable habitat.	Uncertainty relates to cumulative impacts on shorebirds and waterbirds from changes to water levels, water quality and drying of ponds across the entire salt field.	Likely	Low	Low	N	
	XB8A F7	**Increase in exotic and invasive plants and weeds.** Eventually, without adequate control, weeds could spread over drained areas impacting on flora and fauna habitat. Conditions will tend to favour salt tolerant plants.	No significant spread of pest plants	Negligible	None	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface and control of pest plants.	Uncertainty relates to cumulative impacts on shorebirds and waterbirds from changes to water levels, water quality and drying of ponds across the entire salt field.	Probable	Low	Low	N	
	XB8A F8	**Increase in exotic and invasive fauna.** Exotic animal species can occupy habitat niches to the exclusion of native species. They may also graze or trample flora to excess, and the physical aspects of some exotic species (e.g. sharp hoofs) may be damaging to emerging plants.	No significant increase in pest animals	Negligible	None	Ensure regular wetting and drying via tidal inundation to provide complexity, resilience.	Uncertainty relates to cumulative impacts on shorebirds and waterbirds from changes to water levels, water quality and drying of ponds across the entire salt field.	Probable	Low	Low	N	
	XB8A F9	**Impact on food sources for migratory and resident birds** from change in water quality (eg: changing salinity, increase in BOD, nutrients, algae). Reduction of availability of benthic organisms, fish and bottom dwelling species for food.	An increase is expected in benthic productivity and the availability of prey for shorebirds. Lowering the water level in the pond, which is presently too high for many bird species, will also increase the available habitat.	Negligible	None	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface to reduce soil salinity and oxidise sediments.	Uncertainty relates to cumulative impacts on shorebirds and waterbirds from changes to water levels, water quality and drying of ponds across the entire salt field.	Rare	Negligible	Negligible	N	
	XB8A F10	**Impacts on marine water quality and biodiversity from discharge** (eg: salinity, DO, acidity, metal contaminants, turbidity, nutrients)	Short duration / episodic impact may occur. Possibility of cumulative impact from discharge of tidal cycling volumes.	Low	Under EPA Act general environmental duty to protect aquatic ecosystems from harm	Continuous monitoring of water quality will occur at the tidal gate. Full remote control and telemetered systems on the tidal gate will ensure any risks can be immediately managed (ie alert and automatic gate closure if triggers reached). Cumulative impacts monitored through data collection and analysis.	Uncertainty relates to the response of Pumping Creek and the adjacent intertidal areas to the new tidal cycling regime and altered salinity (lower). Also possible turbidity, DO and low pH in discharge.	Likely	Low	Low	N	No adverse impacts on the environmental values of marine waters due to water discharge expected as creek is currently hypersaline so short term hypersaline discharge during commissioning phase of trial (draining of existing pond water) will not create significant additional impact and the salinity in pond after commissioning is expected to represent marine values
Surface Water	XB8A SW1	**Poor quality of residual water in the drained pond**	Minor short term episodic impacts may occur	Low	None	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface to reduce soil salinity and oxidise sediments. Retain water over multiple high tides to achieve inundation as required. Water imported from XB8 if necessary to wet pond surface.	Some uncertainty about seasonal variation in tide heights and area of the pond that can be inundated on tide cycles.	Likely	Low	Low	N	
	XB8A SW2	**Impacts on marine water quality and biodiversity from dredging** (eg: DO, acidity, metal contaminants, turbidity)	None to a short duration episodic impact	Low	Environment Protection (Water Quality) Policy 2015	Timing of works specified for low tides to minimise turbidity mobilisation downstream. Monitoring of turbidity whilst dredging operation occurs. Work stopped if turbidity above agreed trigger and measures implemented to rectify – review timing and use of a silt curtain.	Duration of works and timing with regard to prevailing weather and tides.	Likely	Low	Low	N	

Environmental Aspect	Event ID	Potential Impact Event	Description of Impact / Expected Impact	Significance of Impact	Applicable Regulatory Standard	Control strategies	Uncertainties	Likelihood of greater impact than expected	Possible level of impact (Consequence)	Risk Rating	Outcome Required (Y/N)	Outcome
	XB8A SW3	**Impacts on pond water quality and biodiversity from construction** (eg: DO, acidity, metal contaminants, turbidity)	Short duration / episodic impact may occur	Negligible	None	Use of earth bund to isolate construction works from rest of pond.		Probable	Low	Low	N	
	XB8A SW4	**Impacts from midges and mosquitoes** etc. as a result of water quality in the pond if left un-drained or not flushed via tidal exchange sufficiently	Tidal cycling is expected to ensure wetting and drying and flushing of pond	Low	None	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface.	Lack of detailed bathymetry of pond means there is some uncertainty as to extent of tidal flushing across pond surface	Probable	Low	Low	N	
	XB8A SW5	**Algal blooms in the water if left un-drained or not flushed via tidal exchange sufficiently**	Tidal cycling is expected to ensure wetting and drying and flushing of pond	Low	None	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface. Water imported from XB8 if necessary to wet pond surface.	Lack of detailed bathymetry of pond means there is some uncertainty as to extent of tidal flushing of pond surface area	Probable	Low	Low	N	
	XB8A SW6	**Short term increases in salinity of tidal waters localised to the vicinity of the discharge point**	No adverse impact beyond mixing zone	Low	Environment Protection (Water Quality) Policy 2015	DEWNR / UoA ensure compliance with agreed discharge criteria via monitoring and controlled discharge.	Tidal flushing methodology has not been tested elsewhere.	Unlikely	Low	Negligible	N	
	XB8A SW7	**Prevention of formation of healthy terrestrial flora and fauna habitats as a result of poor water quality in the pond**	No adverse impact expected	Negligible	None	Ensure regular wetting and drying via tidal inundation to provide complexity, resilience.	Active monitoring of pond to ensure any adverse change is managed.	Unlikely	Low	Negligible	N	
Ground Water	XB8A GW1	**Groundwater seepage impacting groundwater dependent ecosystems and/or adjacent marine environment**	No adverse impact expected	Negligible	None	Baseline monitoring in place. Continuous monitoring and controlled wetting and drying to remove salinity and reduce ASS hazard.	Lack of information on seepage from pond to groundwater and adjacent intertidal area	Unlikely	Low	Negligible	N	
Air Quality	XB8A A1	**Dusts from exposed ground surfaces affecting the amenity of people**	No adverse impact expected	Negligible	National Environment Protection (Ambient Air Quality) Measure	Pond will not be fully dried and there will only be a short time period before tidal flushing begins.	Length of time to complete civil works	Unlikely	Low	Negligible	N	
	XB8A A2	**Dusts from excavation and transportation activities during tidal gate construction and pond isolation affecting amenity of people**	No measurable impact expected	Negligible	National Environment Protection (Ambient Air Quality) Measure	Works halted in windy conditions	Timing or works with weather conditions	Unlikely	Negligible	Negligible	N	
	XB8A A3	**Dusts from exposed ground surfaces affecting the amenity of people, if left un-drained or not flushed via tidal exchange sufficiently**	No measurable impact expected	Negligible	National Environment Protection (Ambient Air Quality) Measure	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface. Water imported from XB8 if necessary to wet pond surface.	Some uncertainty about seasonal variation in tide heights and area of the pond that can be inundated on tide cycles.	Unlikely	Negligible	Negligible	N	
	XB8A A4	**Dust from ASS affecting health of adjoining human or ecological receptors**	No measurable impact expected	Negligible	National Environment Protection (Ambient Air Quality) Measure	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface. Water imported from XB8 if necessary to wet pond surface.	Some uncertainty about seasonal variation in tide heights and area of the pond that can be inundated on tide cycles.	Unlikely	Negligible	Negligible	N	
	XB8A A5	**Odour from exposed acid sulphate soils affecting the amenity of adjoining receptors**	No measurable impact expected Short term episodic impact possible	Low	National Environment Protection (Ambient Air Quality) Measure	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface. Water imported from XB8 if necessary to wet pond surface. Odour Monitoring Plan for the broader site applicable.	Some uncertainty about seasonal variation in weather, tide heights and area of the pond that can be inundated on tide cycles.	Unlikely	Moderate	Low	N	No adverse public health or amenity impacts predicted due to odour. Regular wetting and drying will reduce odour risk over time also compared to a mostly dry then flood scenario that has previously caused odour issues.
	XB8A A6	**Odour from algal blooms affecting the medium-term amenity of adjoining receptors**	No measurable impact expected Short term episodic impact possible	Low	National Environment Protection (Ambient Air Quality) Measure	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface. Water imported from XB8 if necessary to wet pond surface. Odour Monitoring Plan for the broader site applicable.	Some uncertainty about seasonal variation in weather, tide heights and area of the pond that can be inundated on tide cycles.	Unlikely	Moderate	Low	N	No adverse public health or amenity impacts predicted due to odour. Regular wetting and drying will reduce odour risk over time also compared to a mostly dry then flood scenario that has previously
Soil Quality (contamination, salinity and acid sulfate)	XB8A SQ1	**Impacts on ecological systems, surface water quality or groundwater quality outside of the site from exposure to salt and/or low pH.**	No measurable impact expected	Negligible	Environment Protection (Water Quality) Policy 2015	Continuous monitoring and controlled inundation and release of tidal waters to remove salinity and reduce acidity hazard.	Lack of complete mapping coverage of pond sediment for ASS and salinity.	Unlikely	Negligible	Negligible	N	
	XB8A SQ2	**Prevention of formation of healthy terrestrial flora and fauna habitats as a result of acid formation in sub-soil.**	No measurable impact expected	Negligible	None	Regular exchange of tidal water in sufficient volumes to achieve wetting and drying of pond surface. Water imported from XB8 if necessary to wet pond surface.	Some uncertainty about seasonal variation in tide heights and area of the pond that can be inundated on tide cycles.	Unlikely	Negligible	Negligible	N	
Noise	XB8A N1	**Noise from machinery used affecting adjoining residents**	Within regulatory limits and generally within background levels	Negligible	Environment Protection (Noise) Policy 2007	All equipment, including that used by contractors, is required to comply with relevant noise control policies and guidelines issued by the EPA.	Duration of works requiring machinery	Probable	Negligible	Negligible	N	
	XB8A N2	**Noise from machinery used affecting fauna**	Minimal short term disturbance	Negligible	None	All equipment, including that used by contractors, is required to comply with relevant noise control policies and guidelines issued by the EPA.	Duration of works requiring machinery	Probable	Negligible	Negligible	N	

Area	Component	Consequence Descriptors				
		Negligible	**Low**	**Moderate**	**High**	**Severe**
Environment	Ecosystem function (terrestrial, aquatic, marine)	Alterations to ecosystem interactions in the localised area not detectable. No conservation or remedial measures necessary	Minor alterations to ecosystem interactions in the localised area are detectable. No conservation or remedial measures necessary.	Moderate alterations to ecosystem interactions in the localised area are detectable Effective conservation or remedial measures necessary for a period of 1 to 5 years	Major alterations to ecosystem interactions in the localised area are detectable. Effective conservation or remedial measures necessary for a period of 5 to 10 years	Major alterations to ecosystem interactions in the localised area are detectable and may not be reversible. Effective conservation or remedial measures, if feasible, necessary for a period of at least 10 years
	Flora and fauna communities and species	Loss in numbers of individuals not apparent and no reduction in localised population viability. No conservation or remedial measures necessary	Minor loss in numbers of individuals apparent but no reduction in localised or regional population viability. No conservation or remedial measures necessary.	Moderate loss in numbers of individuals and apparent and minor reduction in localised or regional population viability. Effective conservation or remedial measures necessary for a period of 1 to 5 years	Major loss in numbers of individuals and apparent and major reduction in localised or regional population viability. Effective conservation or remedial measures necessary for a period of 5 to 10 years	Extreme loss in numbers of individuals apparent and impact on localised or regional population viability may not be recoverable. Effective conservation or remedial measures, if feasible, necessary for a period of at least 10 years
	Surface water and ground water quality Air quality Soil quality (contamination, salinity and acid sulfate)	Concentrations of chemicals of interest and aesthetic properties within natural variability, impacts unlikely to be detectable. No preventive or remedial measures necessary	Minor excursions of concentrations of chemicals of interest and aesthetic properties outside natural variability may be detectable in a localised or regional area but are short term in nature and require no or minimal preventive or remedial measures that can be completed in < 1 year	Moderate excursions of concentrations of chemicals of interest and aesthetic properties outside natural variability are detectable in a localised or regional area and are medium term in nature and require moderate preventive or remedial measures that can be completed in 1 to 5 years.	Major excursions of concentrations of chemicals of interest and aesthetic properties outside natural variability are detectable in a localised or regional area and are long term in nature and require extensive preventive or remedial measures that have to be sustained for 5 to 10 years.	Extreme excursions of concentrations of chemicals of interest and aesthetic properties outside natural variability are detectable in a localised or regional area and are long term in nature and require extensive, complex and permanent (> 10 years) preventive or remedial measures

Area	Component	Consequence Descriptors				
		Negligible	**Low**	**Moderate**	**High**	**Severe**
Engineering	Weather and climate change impacts on engineered systems and structures	Temporary and localised impacts, no or minimal preventive measures or repair / restoration required to sustain functional performance	Short term impacts within localised or regional area, limited preventive measures or repair / restoration required to sustain functional performance	Medium term impacts within localised or regional area, moderate preventive measures or repair / restoration required to sustain functional performance	Long term impacts within localised or regional area, extensive preventive measures or repair / restoration required to sustain functional performance	Catastrophic impacts within localised or regional area, preventive or repair / restoration neither feasible nor practicable
	Geotechnical function (total and differential settlements of structures, stability, bearing capacity)					
Social	Physical amenity (e.g., air, noise, water, visual)	Temporary or no-detectable impacts on amenity. No preventive or remedial measures needed to restore / improve amenity	Short term and minor impacts on amenity. Minor preventive or remedial measures needed for < 1 year to restore / improve amenity	Short term impacts. Limited measures required over a short time period to restore attitudes	Long term and major impacts on amenity. Major preventive or remedial measures needed for 5 to 10 years to restore / improve amenity	Permanent and extreme impacts on amenity. extensive and complex scope and permanent (> 10 years) needed to restore / improve amenity
	Land use amenity (residential, recreational, commercial / industrial, educational, conservation)					
	Stakeholder attitudes	No measurable impact	Short term (days to weeks) limited scale impacts. Limited measures required over a short time period (days to weeks) to restore attitudes	Medium term (weeks to a month) moderate impacts. Extensive measures required over a longer time (weeks to a month) period to restore attitudes	Longer term (months) significant impacts. More extensive measures required over a longer time (months) period to restore attitudes	Permanent or very long term impacts. Very extensive measures required over an extended period to restore attitudes, if attitudes are at all recoverable
	Heritage sites (Aboriginal, historical, maritime)	No measurable impact	Detectable impact only on sites of low significance and without significant impact on heritage values	Detectable impact only on sites of low to moderate significance and with minor and partial impact on heritage values	Detectable impact on sites of moderate to high significance and with major an partial impact on heritage values	Detectable impact on sites of high significance and with complete loss of heritage values

		Consequence					Likelihood Description
		Negligible	Low	Moderate	High	Severe	
Likelihood	Almost certain	Negligible	Low	High	Severe	Severe	It is very probable that the risk event could occur in any year
	Likely	Negligible	Low	Moderate	High	Severe	It is more probable than not that the risk event could occur in any year
	Probable	Negligible	Low	Moderate	High	High	It is equally probable that the risk event could or could not occur in any year
	Unlikely	Negligible	Negligible	Low	Moderate	High	It is less probable than not that the risk event could occur in any year
	Rare	Negligible	Negligible	Negligible	Low	Low	It is improbable that the risk event could occur in any year. The risk event is only theoretically possible, or would require exceptional circumstances to occur.