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SOUTH  
AUSTRALIA



Government of South Australia

Department for Environment  
and Water

# PATHWAYS TO TIDAL RESTORATION OF THE DRY CREEK SALT FIELD



UNIVERSITY OF ADELAIDE, AUGUST 2019

**Citation:** Mosley LM, Thomas B, Fitzpatrick R, and Quinn J (2019). Pathways to tidal restoration of the Dry Creek salt field. Report to the Department for Environment and Water. The University of Adelaide.

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**ACKNOWLEDGEMENTS**

The funding and support of the Department for Energy and Mining for this project is gratefully acknowledged. The University of Adelaide thanks the Department for Environment and Water (DEW) and Adelaide-Mt Lofty Ranges Natural Resources Management Board (AMLR NRMB) and for providing funding and other support for the tidal restoration trial. In particular, the support and advice of Murray Townsend (DEW), Tony Flaherty (AMLR NRMB), and Kasun Ekanayake and Aleisa Lamana (Birdlife Australia) was much appreciated.

We thank Buckland Dry Creek Pty Ltd for facilitating access to the site and assisting with construction and operation of the tidal trial. In particular the assistance of Allan Mathieson, George Kontogeorgos, Petar Jurkovic is gratefully acknowledged.

The Goyder Institute blue carbon project research team led by Prof. Sabine Dittman is also thanked for providing knowledge to inform this assessment.

**Cover photo:** main aerial overview of tidal creek and pond XB8A connection (credit: Jason Quinn, DEW)

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# EXECUTIVE SUMMARY

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Salts have been produced by evaporating seawater at the Dry Creek salt field (area of approx. 5000 ha) north of Adelaide since the late 1930s. The salt production operation has ceased with portions of the site transitioning to alternative land uses.

One potential management option for the site is to restore tidal connections to transition the land back to a natural salt marsh-mangrove ecosystem. There are, however, large challenges in doing so given the environmental hazards that are present; in particular hypersaline water, precipitated salt, and sulfidic materials. Therefore, the restoration process needs to be carefully managed to ensure impacts on the surrounding environment are minimised, particularly as the site is adjacent to important aquatic ecosystems and marine reserves.

## **Tidal restoration trial**

To trial a tidal restoration strategy at the salt field, tidal gate infrastructure was designed and installed in the levee bank of Pond XB8A (38 ha) within Section 3 of the salt field. The infrastructure consisted of 4 x 1.2 m diameter x 10 m long polyethylene pipes and controllable tidal gates. The system operated off solar power and was able to be controlled remotely. A water quality sensor was installed at the tidal gate with remote data delivery and an automated alert system.

Monitoring of water quality, sediment quality, hydrology and benthic macroinvertebrates was undertaken prior to tidal restoration, and for an approximately 2 year period after tidal restoration commenced on 29 July 2017. Key outcomes of the trial in Pond XB8A were:

- Tidal connection was successfully restored to pond XB8A with regular wetting and drying cycles occurring driven by natural tidal variations.
- Salinity in the pond was rapidly restored to near coastal seawater conditions; salinity in the sediment showed less change.
- pH, dissolved oxygen, dissolved metals, chlorophyll *a* and nutrients are variable but are being maintained at satisfactory levels during tidal exchange.
- No acid sulfate soil risks have eventuated with near neutral soil pH being maintained. Wetting and drying cycles promoted in situ oxidation of the monosulfidic “black ooze” material, transforming it to a normal wetland soil.
- Improved sediment and water quality conditions have enabled recolonisation by benthic invertebrates and native vegetation, with the restored intertidal mudflat habitat being utilised by local and migratory shorebirds.

## **Potential for wider implementation**

There is potential for wider implementation of tidal restoration strategies at the Dry Creek salt field. In particular, in the seaward parts of Section 3 and 4, much of which is government-owned land currently operated under a mining lease with the salt field owner.

There are likely more cost-effective ways to do tidal restoration on a large scale. If ponds could be drained or evaporated before tidal reconnection then this would reduce the initial large volume of hypersaline water present and make construction easier and cheaper. In regard to construction, the current tidal trial, being the first in the salt field, had strict environmental regulations and hence had sophisticated control gates installed. These were not regularly required after the initial period (<2 weeks) of tidal restoration as water quality was satisfactory and tidal cycle dilution processes were effective. Hence in any potential future wider restoration, removal of bund walls and/or simple open culvert/pipe structures are recommended. Risks arising from saline water discharge and acid sulfate soils can be managed as demonstrated in the trial.

As well as achieving restoration of coastal mangrove and saltmarsh ecosystems, tidal reconnection could be planned and implemented in an integrated manner to result in a wide number of other benefits including flood risk mitigation,

recreation and tourism. Incorporating blue carbon sequestration and carbon crediting activities would also be beneficial in any wider tidal restoration at the Salt Field.

**Key outcomes and benefits for South Australia that would result from tidal restoration:**

- Restoration of degraded coastal ecosystems
- Enhanced fishery nursery areas
- Provision of new shorebird habitat and realizing the vision of the Adelaide International Bird Sanctuary
- Enhanced recreational opportunities and access to the coast for the public
- Greatly enhanced eco-tourism and associated economic and employment benefits
- Blue carbon sequestration to mitigate climate change and provide funding for site operations via carbon markets
- Opportunity to utilise the coastal wetlands for stormwater and flood management
- Provide buffer against sea level rise and storm surge events
- Reduce current pumping costs and liabilities to BDC while providing opportunities for enhancing development outcomes on private land at the Salt Field.

# 1. INTRODUCTION

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## 1.1 BACKGROUND

Salt has been produced since the 1930s at the Dry Creek Salt Field which occupies approximately 5,500 ha of land, and stretches along 28 km of coastline, north of Adelaide. Seawater is pumped and flowed through a series of ponds, where natural evaporation concentrates the salinity until finally the desired end product (common salt/halite/NaCl) is precipitated. The site is currently classified as a mine, with the land under 46 separate mineral leases, and operated by Buckland Dry Creek Pty Ltd (BDC). As well as privately owned BDC land, substantial areas of the land at the salt field are owned by the South Australian Government. The site is operated under an approved Program for Environment Protection and Rehabilitation (PEPR), a legislative responsibility under the Mining Act.

The salt production operation has ceased at the present time with parts of the site transitioning to alternative land uses. One major issue noted during closure of the Salt Field is that hypersaline and sulfide-rich sediments have also built up over large areas which poses a potential environmental hazard and barrier to remediation of the site. One option to remediate the low-lying seawater areas of the Salt Field is to undertake tidal restoration. As described in detail below a tidal restoration trial was undertaken from 2017–2019 to assess the feasibility and potential benefits/risks of this approach. In particular tidal restoration outcomes needs to ensure that impacts on the surrounding environment are minimised as the site is adjacent to important aquatic ecosystems and marine reserves. There was also a “blue carbon” project conducted during the tidal trial to assess whether there are any opportunities to generate “carbon credits” by this activity.

## 1.2 PROJECT AIMS

The aim of this project was to document the various learnings from the smaller-scale tidal restoration project to be collated and documented to inform any future implementation of wider tidal restoration strategies at the site, including development of a ‘roadmap to implementation’ at the salt field if this strategy proceeds.

The areas to be incorporated in the Guideline include:

- Design and construction process for the tidal restoration trial,
- Key learnings from the design and construction phase,
- Regulatory approvals,
- Operation of the tidal gates,
- Review of the success of monitoring activities and strategies,
- Key observations, photographs, and aerial imagery during the trial (e.g. of sediments, vegetation),
- Assessment and management of acid sulfate soil and other risks,
- Preliminary scoping of strategies for potential future tidal restoration at the Dry Creek salt field; including such as aspects of management of hypersaline water and sequential strategies for draining, areas that can be tidal inundated, and locations of potential reconnection.

## 4. SALT FIELD DESCRIPTION

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### 5.1 SITE LOCATION

The salt field occupies approximately 5,500 hectares of land along 28 km of coastline north of Adelaide from Dry Creek to Middle Beach. It comprises a mix of Crown land and freehold land owned by BDC.

The site is divided up into four sections (see Figure 1):

Section 1 – South of Dry Creek

Section 2 – Dry Creek to St Kilda

Section 3 – St Kilda to Port Gawler

Section 4 – Port Gawler to Middle Beach.

Within each Section there are multiple interconnected ponds (see Figure 1). Seawater is pumped into the Salt Field at Middle Beach and flows between individual ponds and Sections via gravity flow or pumping. The current discharge point is SA Water’s Bolivar Channel near St Kilda, which also involves salinity dilution with the treated wastewater discharges prior to reaching the coastal marine environment.

### 5.2 LAND TENEMENT AND USE – PUBLIC VERSUS PRIVATE OWNERSHIP

The land tenure at the salt field is currently a mix of public and private ownership as highlighted on Figure 2. Forty six mining leases and two private mines provide the mining tenure for the mining operations. The mining operations fall within the Hundreds of Port Adelaide and Port Gawler, and the local government areas of City of Salisbury, City of Port Adelaide Enfield, City of Playford and the District Council of Mallala. The entire site is located within the 2008 gazetted boundaries of the Adelaide and Mt Lofty Ranges Natural Resources Management Board (AMLR NRMB). A detailed list of land tenements is provided in the PEPR (see Table 7.1 in BDC 2017).

Currently most of the site landuse is still as a Salt Field (“Mineral Extraction” landuse) with additional Coastal Conservation land. Section 1 is currently in transition to mixed use urban development. Parts of the Salt Field have been relinquished to now form part of the Northern Connector motorway.

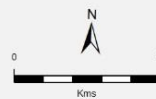


# Dry Creek Saltfield - salt evaporation ponds



## Legend

- Section 1 - Dry Creek
- Section 2 - St Kilda
- Section 3 - Port Gawler
- Section 4 - Middle Beach



Produced by Coastal Management Branch  
Department of Environment, Water and Natural Resources

Data Source DEWNR SDE  
Compiled 23 March 2016  
Projection Lambert Conformal Conic  
Datum Geocentric Datum of Australia, 1994

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Figure 1 Site location map of the salt field showing Section 1-4 and individual ponds. Source Department for Environment and Water



## 5.3 LEGISLATIVE AND REGULATORY CONTEXT

The Dry Creek Salt Field and its operations fall under several pieces of legislation as outlined briefly below.

### 4.4.1 Mining Act

The *Mining Act 1971* and *Mining Regulations 2011* provide the framework for the approval and regulation of all mining operations in South Australia and are administered by the Department for Energy and Mining (DEM). The *Mining Act* is the principal legislation for regulating the operations and closure of the Dry Creek Salt Field. The site is currently operating under a Mining Program for Environment Protection and Rehabilitation (MPEPR #2017/001) the requirements for which is established in Part 10 (Sections 70E-H) of the *Mining Act*. The general objectives of a PEPR are to ensure that the holders of mining tenements:

- a) provide adequate information about the mining operations that will be conducted under the tenements; and
- b) ensure that mining operations that have (or potentially have) adverse environmental impacts are properly managed to reduce those impacts as far as reasonably practicable and eliminate, as far as reasonably practicable, risk of significant long term environmental harm; and
- c) ensure that land adversely affected by mining operations is properly rehabilitated.

The Minister for Energy and Mining, must, in acting under Part 10, also have regard to, and seek to further, the objects of the *Natural Resources Management Act 2004*.

A PEPR must set out the environmental outcomes that are expected to occur as a result of the mining operations (including after taking into account any rehabilitation proposed by the holder of the tenement and other steps to manage, limit or remedy any adverse environmental impacts); and the criteria to be adopted to measure those environmental outcomes. Under Section 70F there are also powers to direct rehabilitation of land (including land outside the area of the mining tenement) in accordance with the requirements of a PEPR or to secure compliance with a condition of the mining tenement.

Release of land from mining tenements to enable other types of development can occur via the surrender of mineral tenements or the revocation of a private mine, upon demonstration by the tenement holder that the mine closure outcomes specified in the PEPR have been met. Mineral tenements or private mines can be partially surrendered or revoked as the land is progressively developed for a suitable post-mine land use. The revocation of a private mine occurs through the Warden's Court, and if supported, the Warden will make a recommendation to the Governor that the Private Mine may be revoked. DEM is the lead government agency on the surrender and revocation process.

For more information on PEPR's see the DEM guideline (DSD 2015).

<https://sarigbasis.pir.sa.gov.au/WebtopEw/ws/samref/sarig1/image/DDD/MRGMG8.pdf>

### 4.4.2 Environment Protection Act

The *Environment Protection Act 1993* (EP Act) provides for the protection of the environment and defines the functions and powers of the Environment Protection Authority (EPA). The Act facilitates the adoption and implementation of environment protection measures and regulates activities, products, substances and services that, through pollution or production of waste, may cause environmental harm. The Act also regulates the generation, storage, transportation, treatment and disposal of waste. Additional Environment Protection Policies (EPPs) have been established under the EP Act and ones of relevance to the Salt Field include the air, noise and water quality EPPs.

Schedule 1 of the Environment Protection Act specifies 'Prescribed activities of environmental significance' that require environmental authorisation from the EPA. BDC Corporation holds Licence 40942 for the following prescribed activities on the salt field:

- 1(1) Chemical storage and warehousing facilities
- 1(2)(b) Chemical works: Salt production
- 8(7) Discharge to marine or inland waters.

The EPA has set conditions under the license, which have also been embedded in the PEPR, such as a criteria to discharge water out the Bolivar Channel with a salinity of no more than 45 ppt. The requirement to obtain a dredging license, if such activities are undertaken, is also a requirement of Schedule 1 of the EP Act.

#### 4.4.3 Environment Protection and Biodiversity Conservation Act 1999

The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) is the Australian Government's primary environmental legislation. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places which are defined in the EPBC Act as matters of national environmental significance.

The only matters relevant to the Dry Creek Salt Field are listed threatened species and ecological communities, and listed migratory shorebird species (BDC 2015). Approval is required from the Commonwealth Environment Minister for any actions in this that are likely to have a significant impact on these matters. BDC has submitted a self-assessment for the Holding Pattern and will update this at intervals during the Holding Pattern to account for new information from monitoring and the implementation of the Holding Pattern or closure activities (BDC 2015).

#### 4.4.4 Fisheries Management Act 2007

The *Fisheries Management Act 2007* provides for the conservation and management of the aquatic resources of the State, the management of fisheries and aquatic reserves, the regulation of fishing and the processing of aquatic resources, the protection of aquatic habitats, aquatic mammals and aquatic resources and the control of exotic aquatic organisms and disease in aquatic resources.

Section 77 of the Act prohibits disturbance of water beds, or removal or interference with animals or plants, in an aquatic reserve without authorisation. BDC holds a permit to allow discharge of water from the Bolivar Channel Outfall into the St Kilda – Chapman Creek Aquatic Reserve. The permit is subject to the discharge criteria set by the EPA license.

#### 4.4.5 Other relevant pieces of legislation

Other South Australian legislation relevant to current and potential future activities at the Dry Creek Salt Field includes, but is not limited to, the following Acts (and associated Regulations):

- *Native Vegetation Act 1991*
- *Natural Resources Management Act 2004*
- *Adelaide Dolphin Sanctuary Act 2005*
- *Coast Protection Act 1972*
- *Development Act 1993*
- *Heritage Places Act 1993*
- *Aboriginal Heritage Act 1988*
- *National Parks and Wildlife Act 1972*
- *Carbon Credits (Carbon Farming Initiative) Act 2011*

## 5.4 CURRENT OPERATIONS UNDER PEPR

The Salt Field is currently operating under procedures outlined in the PEPR, with activities being undertaken having the purposes of:

- stopping salt production and implementing residual salt processing operations in Section 1
- implementing a Holding Pattern for Sections 2 to 4:
  - sustaining water quality within inundated ponds (using a combination of managed entrainment and licensed pumped discharge)
  - providing opportunities to investigate, in a managed environment, the opportunities and constraints on pond drainage and drying.
- providing time (i.e. with acceptable and manageable levels of environmental risk) for the investigations and design needed to develop the mine completion PEPR.

## 5.5 CURRENT ENVIRONMENTAL VALUES WITHIN SALT FIELD

The Dry Creek Salt Fields provide an area of significant habitat value for migratory and resident shorebirds and is listed in the Directory of Important Wetlands in Australia (Environment Australia 2001). This value is recognised by key stakeholder organisations (e.g. DEW, AMLR NRM Board, Birdlife Australia), bird watchers and ecologists. In total, 62 EPBC Act listed migratory bird species have been recorded in the area or are considered likely to occur (BDC 2015). This includes 32 listed Migratory shorebirds. Birds are most abundant in Ponds XE1-3. Significant seasonal fluctuations occur in shorebird numbers with counts from 1978 to present ranging from 2112 birds to 58,124. This is primarily due to changes in wider, regional habitat such as water levels at Lake Eyre as well as population trends generally among shorebird species within the East Asia-Australian Flyway (BDC 2015). The Australian Fairy Tern, an EPBC Act species listed as “threatened”, has been recorded 20 times on the salt fields between 1999 and 2011. There are also other reptile, mammal and feral species recorded within the salt field (see BDC 2015).

There are also important native vegetation habitats in and adjacent to the Salt Field including mangrove, intertidal and supratidal salt marsh, and lignum shrub land. Twenty-three terrestrial flora species with conservation interest occur, or have the potential to occur within, or near the salt field (BDC 2015). Seven species are listed under the EPBC Act and 22 are on the National Parks and Wildlife Act (NPW Act). No EPBC Act listed flora species have been recorded on the salt field.

There are fish populations in the Salt Field that are derived from species found in Barker Inlet whose eggs and larvae are transported in via the seawater pumps (BDC 2015).

Although access to the Salt Field itself is currently restricted via locked gates and security systems, there are community/environmental values such as birdwatching and fishing that occur on the margins, or via agreed access arrangements (e.g. bird watching groups).

## 5.6 ADJACENT CONSERVATION RESERVES AND IMPORTANT ECOSYSTEMS

There are important conservation reserves adjacent to the Salt Field that must be protected from any adverse environmental impacts. These include the:

- *Adelaide Dolphin Sanctuary* which encompasses the Port Adelaide River, entire Barker Inlet, and coastal waters up to adjacent Port Gawler. Hence this sanctuary is adjacent to the western margin of the entire salt field.

- *St Kilda – Chapman Creek Aquatic Reserve* protects important fish nursery grounds and breeding habitats in this region which is adjacent to Section 3 and 4 of the Salt Field.
- *Adelaide International Bird Sanctuary* which encompasses 60km of coastline north of Adelaide, from Barker Inlet to Port Parham. This sanctuary includes sites adjacent to the Salt Field and may in the future include parts of the Salt Field. The sanctuary's primary focus is on protecting significant migratory shorebirds, while creating other benefits such as ecotourism and related employment.

## 6 ENVIRONMENTAL HAZARDS

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The main environmental hazards of relevance to the current project involving tidal restoration are described below.

### 6.1 HYPERSALINE WATER AND PRECIPITATES

While salt production is the primary goal of an operating Salt Field, the dissolved and solid salt poses a potential hazard to aquatic and terrestrial ecosystems, including during tidal restoration. Through the salt production process, 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. At the Salt Field this in general means gypsum tends to precipitate by Section 3 (St Kilda) and halite in Section 4.

This sequence of salt precipitation process due evaporation is managed to produce the desired end salt product. The process is well understood and based on fundamental chemical principles of salt mineral solubility and when this will occur relative to salinity concentration via evaporation. The transition of the site means this general gradient of salt precipitation is more complex. This is because the drying of ponds promotes production of a wider range of minerals as salinity increases within an individual pond as it dries.

Under the PEPR holding pattern, hypersaline water (salinity from 40-150) is still present in many ponds of Sections 2-4. This poses a potential environmental hazard requiring management during tidal restoration as outlined below.

In addition, thick salt (gypsum and halite) crusts have built up in many areas of the salt field as a result of previous salt production processes or drying of ponds as the site is transitioned (see Figure 3). If conditions change to be conducive for mineral dissolution (e.g. following salinity dilution due to heavy rainfall or during tidal restoration), then the solid salt phases will begin to dissolve but this may occur slowly and stop once equilibrium of the water with the solid phase is reached again. Hence salt crusts may pose a long term management challenge and other management options may be beneficial than just dilution with lower salinity water (e.g. scraping off gypsum and spreading on agricultural land).



Figure 3 Photographs of pond PA12 showing salt crystals and crusts (gypsum and halite). This right hand picture also shows monosulfidic material present underneath the crusts.

## 6.2 ACID SULFATE SOILS

'Acid sulfate soils' (ASS) is the name given to those soils or sediments in which sulfuric acid may be produced, is being produced, or has been produced in amounts that have a lasting effect on main soil characteristics. These soils contain sulfide minerals (principally iron sulfides) or are affected by geochemical or biochemical transformations of sulfide minerals. In coastal regions such as the Salt Field site, iron sulfides are typically formed during contemporary or historical sea-level inundation when seawater or brackish waters containing dissolved sulfate covers organic-rich environments such as swamps, mangroves, salt marshes or tea-tree.

Under oxygen-depleted conditions, iron present within soils or sediments combines with sulfur from sulfate to form iron sulfides, in particular pyrite ( $\text{FeS}_2$ ). When these sulfides are disturbed and exposed to air, oxidation occurs and sulfuric acid is produced. These soils may either contain acidity or have the potential to form acid in amounts that either drain into waterways or react with carbonates and clay minerals in soils or sediments to liberate dissolved aluminium, iron, manganese, heavy metals such as copper and arsenic, and other metal ions. If sufficient quantities of acid or dissolved metals are mobilised, this can be extremely toxic to plants and animals in coastal environments.

Acid sulfate soils may be acidic (i.e. contain sulfuric material,  $\text{pH} < 4$ ) or may have the potential to generate sulfuric acid when exposed to oxygen because of the presence of sulfide minerals, principally pyrite (i.e. they contain hypersulfidic or hyposulfidic materials). The following nomenclature and definitions used for acid sulfate soil materials are defined in the second edition of Australian Soil Classification (Isbell and NCST 2016):

- **Hypersulfidic material:** sulfidic material that had a field pH of 4 or more and the pH dropped by at least 0.5 units to less than 4 when incubated at field capacity for at least 8 weeks
- **Hyposulfidic material:** sulfidic soil material that had a field pH of 4 or more and the pH dropped by at least 0.5 units to not less than 4 when incubated at field capacity for at least 8 weeks
- **Sulfuric material:** soil material that has a  $\text{pH} < 4$  (1:1 by weight in water, or in a minimum of water to permit measurement) when measured as a result of the oxidation of sulfidic materials and evidence of sulfidic material, such as underlying sulfidic material and/or the presence of yellow masses of jarosite along old root channels and faces of peds
- **Monosulfidic material:** soil material containing  $\geq 0.01\%$  acid volatile sulfide. Monosulfidic materials pose water deoxygenation risks when they are resuspended.

When acid sulfate soils with hypersulfidic material dry, oxidation of pyrite may cause strong acidification ( $\text{pH} < 4$ ) and form sulfuric material. Resaturation of acid sulfate soils with sulfuric material can lead to reformation of pyrite and

pH increase (but this may take months to years) due to activity of sulfate-reducing bacteria, which also require available organic carbon.

The formation of sulfidic (hypo-, hyper-, mono-) materials in the Salt Field is likely promoted by:

- Maintaining ponded conditions which keeps soils in a subaqueous/submerged state which promotes sulfate reduction reactions to form acid sulfate soil materials
- the closed and highly depositional environment of the ponds which promotes accumulation of organic material within the system
- high sulfate concentrations (from saline water)
- low iron and carbonate concentrations (precipitated early in the salt production process); and;
- low re-suspension (due to very slow seawater inflow / throughflow velocities and more sheltered nature of the bunded ponds).

A series of acid sulfate soil investigations have been undertaken across the Salt Field commissioned by BDC as part of their PEPR development. A summary of this is provided in BDC (2015) based on studies by Fitzpatrick et al. (2015, 2016) and Baker and Fairbrother (2016).

### Section 1

Section 1 has received limited acid sulfate soils assessment as hazards were assessed as likely to be minimal due to the engineered (e.g. filled) and oxidizing/drying environment (crystallizer ponds) in this section of the Salt Field which is believed to have limited buildup of acid sulfate soil materials (BDC 2015). Nevertheless this likely only applies to surface soil layers and deeper layers below the current water table may contain hypersulfidic materials.

### Section 2

Sampling was undertaken at sites for ponds PA3 to PA12 and the adjacent drains, over a 3 month period from December 2013 to March / April 2014 (which included extensive reflooding and drying events). Ponds PA3 to PA12 in Section 2 are mostly covered by a gypsum crust of varying thickness (see Figure 3). In some locations, there are low-lying areas where water has remained or the soil is mostly saturated. To the east, there is a sequence of shallow drains adjacent to ponds PA3 to PA12 and situated below ponds PA3 and PA11. The ponds are bounded on the west by the coastal mangrove swamps and samphire. The Section 3 ponds are located to the north.

The soil classification indicated at the time of the field survey in March / April is summarized below from Fitzpatrick et al. (2015, see Appendix 4):

- Ponds PA3 to PA12 - hypersulfidic and hyposulfidic subaqueous sandy/shell grit soils with monosulfidic material; hyposulfidic and hypersulfidic hydrosol loams over clays with monosulfidic material
- Pond PA7a - hyposulfidic subaqueous hydrosol loams over clays with monosulfidic material; hyposulfidic hydrosol loams over clays with monosulfidic material (wet)
- Drains - hyposulfidic subaqueous hydrosol loams over clays with monosulfidic material; sulfuric and hyposulfidic hydrosol loams over clays with salt efflorescences.

The acidification hazard was assessed as medium for the western segments and low for the eastern segments of ponds PA3 to PA12. A representative hydro-toposequence model is shown in Figure 4 below:



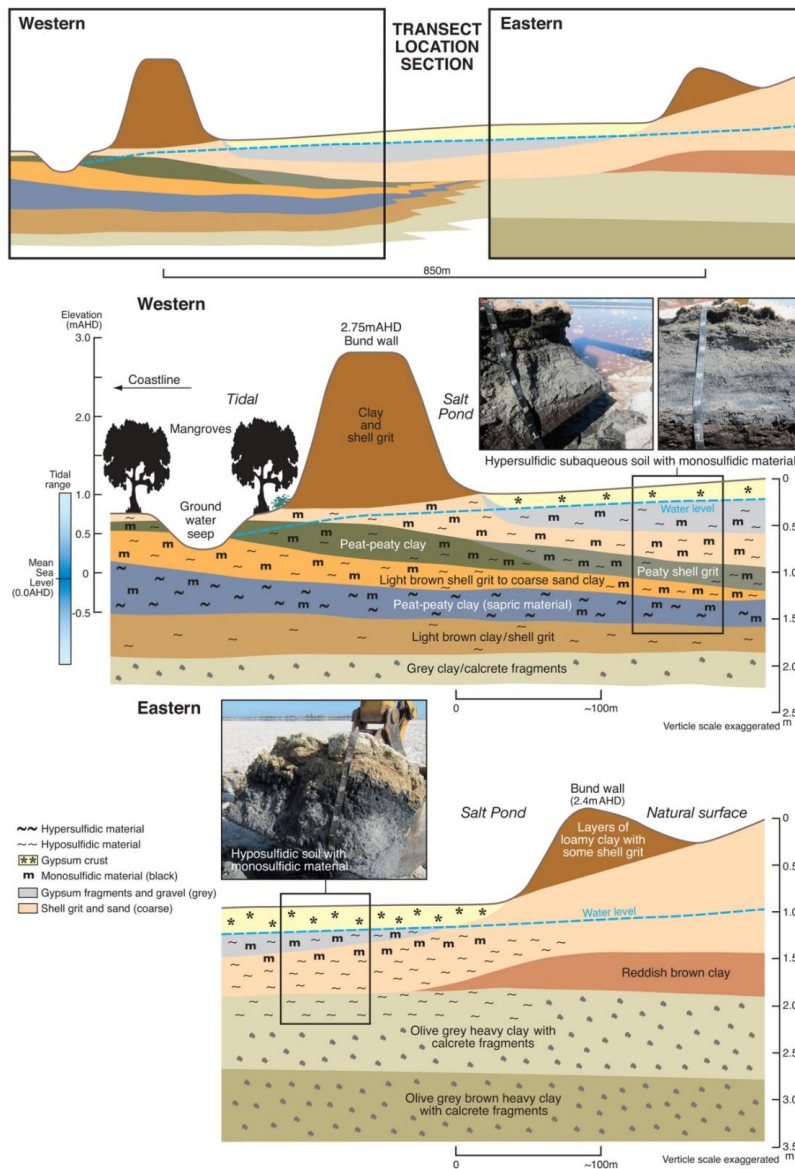


Figure 4 Representative soil-regolith hydro-toposequence model linking the mangrove swamp, adjacent bund wall, ponded western salt pond segment with subaqueous soils and the dry eastern salt ponds by showing the spatial distribution of: (i) water levels from West to East (horizontal scale less exaggerated), (ii) topography, including salt ponds, bund walls, tidal creek in mangrove swamp and AHD levels, (iii) vegetation (mangroves and samphire), (iv) major acid sulfate soil materials: monosulfidic, hypersulfidic and hyposulfidic (vertical scale exaggerated) and (v) soil horizons (gypsum crusts / fragments comprising Gypsic horizons; halite crusts comprising Salic horizons) and sediment layers based on colour and texture (light brown clay / shell grit). (From Fitzpatrick et al. 2015)

### Sections 3 and 4

The Section 3 ponds generally do not have thick gypsum crusts but are permanently ponded with saline water and contain subaqueous acid sulfate soils. Baker and Fairbrother (2016) also surveyed acid sulfate soils across Section 3 and 4 using sub-bottom profiling techniques (coverage of 300 linear km within ponds) coupled with acid sulfate soil incubations from profiles taken from 194 locations. Monosulfidic material was present at 67 of the 194 sites surveyed, a total of 56 ground truthing sites comprised soil/sediment horizons that, following 16 weeks of incubation, acidified to a pH of less than 5.5, and soil/sediment material from 28 of these sites acidified to a pH of less than 4 and were classified as hypersulfidic (see Figure 5).

In Section 4, sampling was also undertaken by Fitzpatrick et al. at sites for ponds XF2 and XE4 between November 2013 and June 2014 following extensive reflooding (from extremely high rainfall events) and drying events. Pond XF2 is situated on the north-eastern side of the saltfield and is bounded to the north by native samphire and salt bush, in the east by farmland and on the western and southern side mostly by pond XF1. Pond XE4 is located below ponds XF1 and XF2 on the north eastern side of salt field and is bounded to the north by ponds XF1 and XF2, in the east by farmland and on the western side mostly by pond XE3.

At the time of the November survey, the ponds were generally dry with some wetter areas, mostly due to seepage from the adjacent ponds. The soil classification at the time of the field survey (June 2014) is summarised as follows (see Fitzpatrick et al 2014; Appendix 3):

- Pond XF2 and XE4 - In general, soil profiles in XF2 comprise sulfuric, hypersulfidic and hyposulfidic clayey soils with high (mostly) to low acidification hazard ratings (see Figure 12-9 below). Profiles in XE4 comprises mostly hyposulfidic and minor hypersulfidic clayey soils with low acidification hazard ratings.
- Pond XF1 - During investigations in January 2015 Pond XF1 was permanently ponded with saline water and sampling identified mostly hyposulfidic materials (hyposulfidic subaqueous clay soils) with only one sample containing sulfuric material (sulfuric subaqueous clay soil). Most of the profiles sampled encountered thick (0-30 cm) black, organic-rich monosulfidic black ooze materials, which occurred in thicker amounts (>30cm) on the western boundary due to seepage into the drainage trench and also from the adjacent pond. The final soil survey campaign was conducted in February 2016 (summer), 13 months after the commencement of draining of pond XF1, identified a wide range of acid sulfate soil subtypes and associated features as shown in the maps (Figure B10 and 11). As expected, the Hypersulfidic hydrosol clay soils with organic-rich monosulfidic material identified in winter and spring in the low lying south west corner of the pond were transformed to Sulfuric hydrosol clay soils with organic-rich monosulfidic material (see map unit Su2 in Figures B10 and B11). The reason for this is that the lowering of the water table level to 50cm causing more extensive and deeper cracking of the surface organic layer to permit more air (oxygen) to permeate the hypersulfidic material at depth and oxidise pyrite to form sulfuric acid and jarosite.

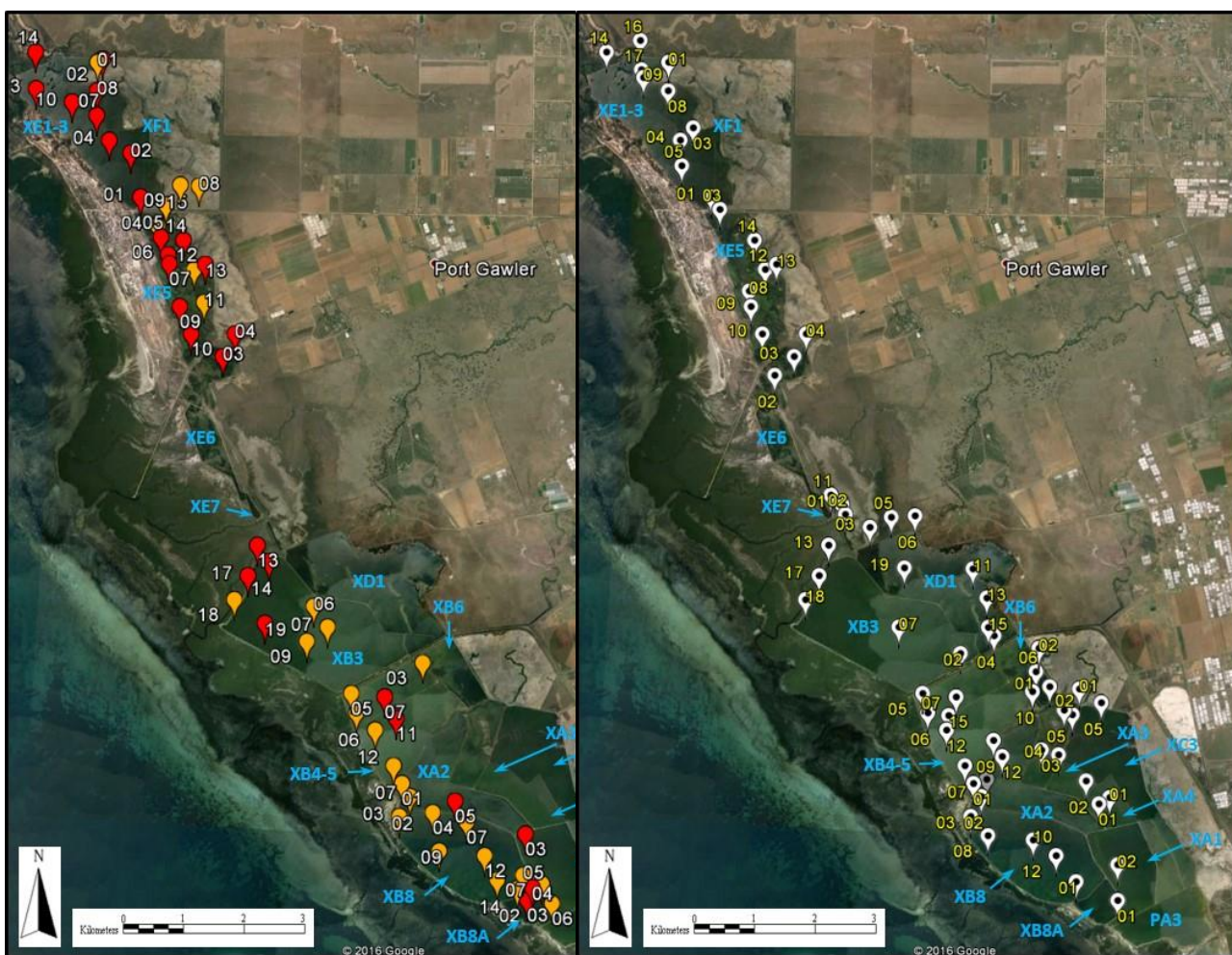


Figure 5 Spatial distribution of sites that comprised soil/sediment horizons that, (left) following 16 weeks of incubation, acidified to a pH of less than 5.5 (orange). 28 of these (red) comprised soil/sediment horizon that acidified to a pH of less than 4 and were classified as hypersulfidic, and (right) monosulfidic materials (67 out of 194 sites sampled).

### 6.3 DUST AND ODOUR

There is potential for nuisance dust emissions from dry ponds and salt stockpiles. However for the most part there have not been persistent dust issues noted at the site during the transition to more dried ponds. Under the PEPR, there are defined assessment and management procedures in place to mitigate any dust risks (BDC 2015). Dust mobilisation can be reduced by keeping sediments moist (e.g. wetting and drying cycles as in the tidal trial), promotion or maintenance of salt crusts, or revegetation to stabilise soils.

There is also potential for odour from acid sulfate soils due to the presence of reduced sulfur species, some of which are volatile ( $H_2S$ ,  $SO_2$ ). Only minor and temporary odour issues have been noted during the site transition. One odour event occurred when a large 100 mm rainfall event and pooled over recently drained sediment with a high organic matter and sulfide load, with the water turning anoxic and reduced sulfur species being generated and mobilised. Maintaining drainage on dried areas can help prevent these risks and over time it is likely that odour risks reduce due to natural oxidation processes.

Where monosulfidic material is present there is a higher odour hazard, but overall this hazard has been assessed as low-moderate for the Salt Field (Fitzpatrick et al. 2015; 2016). This is consistent also with the results of the XB8A tidal trial which has not resulted in any odour issues following drying and rewetting of monosulfidic material.

## 7 TIDAL RESTORATION TRIAL IN POND XB8A

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This section documents the process, results and learnings of a tidal restoration trial in Pond XB8A at the Salt Field. A diagram outlining the process is shown in Figure 6 and discussed in more detail below.

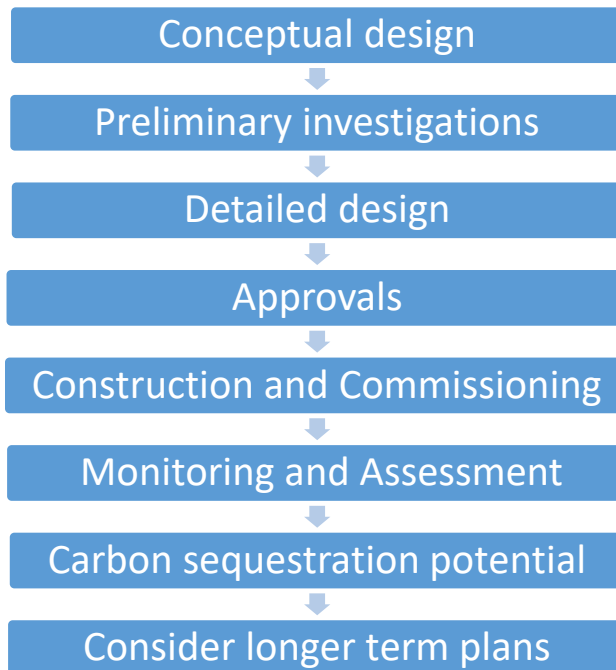


Figure 6 Steps in establishing and operating the tidal restoration trial in Pond XB8A

### 7.1 CONCEPTUAL DESIGN

A tidal restoration trial was conceived as a potential long-term future management option for a portion of the salt field. The objectives of the trial were to:

1. Trialing reconnection of a pond (XB8A) at the salt field to tidal exchange
2. Reducing the hyper-salinity and monosulfide hazard in the pond 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 by migratory shorebirds

A conceptual model of the project's aims is shown in Figure 7. It was predicted that restoration of tidal action will improve sediment and water quality, specifically by promoting less saline and anoxic-sulfidic sediment conditions. This will enable recolonisation by salt marsh, mangrove and benthic invertebrates, eventually providing additional habitat complexity and food sources for fish and wading birds.

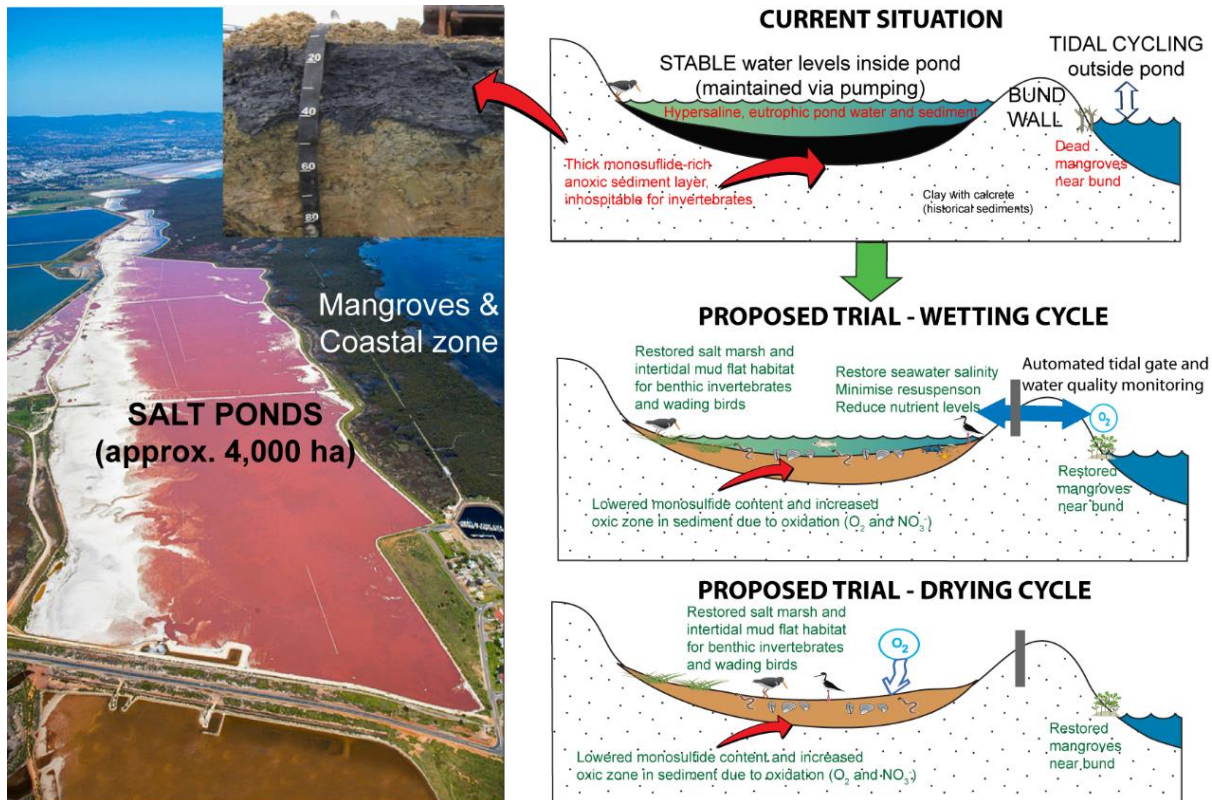


Figure 7 (left) Overview of the Dry Creek Salt Field showing a typical sediment profile with thick layer containing monosulfidic material and (right) conceptual model of project showing hypothesised outcomes of lower monosulfide concentration and benthic invertebrate and vegetation recolonisation while minimising external environmental impacts

The concept of re-introducing tidal flows was discussed and approved at the Dry Creek Salt Field's Strategy and Technical Advisory Group (STAG).

## 7.2 PRELIMINARY INVESTIGATIONS

Initial pre-trial research was undertaken by the University of Adelaide (Mosley et al. 2015). This involved field sampling in ponds of interest (PA12 and XB8A), laboratory resuspension experiments, critical sediment shear stress estimation (for resuspension), and hydrodynamic modelling. The results demonstrated that further investigations should proceed as water quality risks could be manageable based on this preliminary lab-based research. Following discussions with BDC on the most suitable pond for the tidal restoration trial, Pond XB8A was chosen.

Sub-Bottom profiling and sediment core sampling had been undertaken across Sections 3 and 4 by CSIRO Land and Water to assess the occurrence and thickness of monosulfidic black oozes and also acidification risks via incubation experiments (Baker and Fairbrother 2016). Only two layers were assessed as hypersulfidic and these were at depth >60 cm in the soil profile which was likely to remain saturated and unlikely to pose any significant risk. Hence the potential acid sulfate soil risks in Pond XB8A were assessed as low which supported further progression with the trial scoping.

The next key step was to determine the viability of restoring tidal connections to Pond XB8A. A survey was undertaken over the proposed tidal gate location and adjacent tidal creek region. Using this data, Tonkin Consulting developed a simple DRAINS hydraulic model used to determine pipe requirements to ensure adequate flows and flooding of the majority of the pond during typical high tide cycles (1.2m AHD max level) to fill the pond to a level of 1.1 m AHD (Tonkins 2016a). Following this it was considered beneficial to do some preliminary monitoring of water levels in the tidal creek to ensure whether the Outer Harbor tide levels (nearest tide gauge) were applicable. A small water level logger (HOBOTM) was placed in the creek on a surveyed pole near the proposed site of the tidal gate.

The timing and magnitude of water levels inside the pond corresponded well to the nearest tidal gauge site at Outer Harbor.

The bathymetry data from Baker and Fairbrother (2016) was then used to establish what seawater flooding might be achieved at different tide levels. The pond is at the upper end of the tidal range and hence only receives tidal inflow at water levels above about 0.1 m AHD, corresponding to a 1.55 m tide (above tidal chart datum) at Outer Harbor (see Figure 8). However, tidal levels of about 2.45 m chart datum (1 m AHD) are required to get the majority of pond XB8A inundated, with full inundation occurring at levels of around 2.70 m chart datum (1.25 m AHD)(see Figure 9). Tidal levels sufficient for full inundation are relatively infrequent, but levels sufficient for flooding a large area of the pond do occur regularly (see Figure 8 and Figure 9). On this basis a decision was made to proceed to detailed engineering design.

Initial discussions with environmental regulators also informed the need to have control of water entering and exiting the pond via tidal gates (rather than open pipes or culverts).

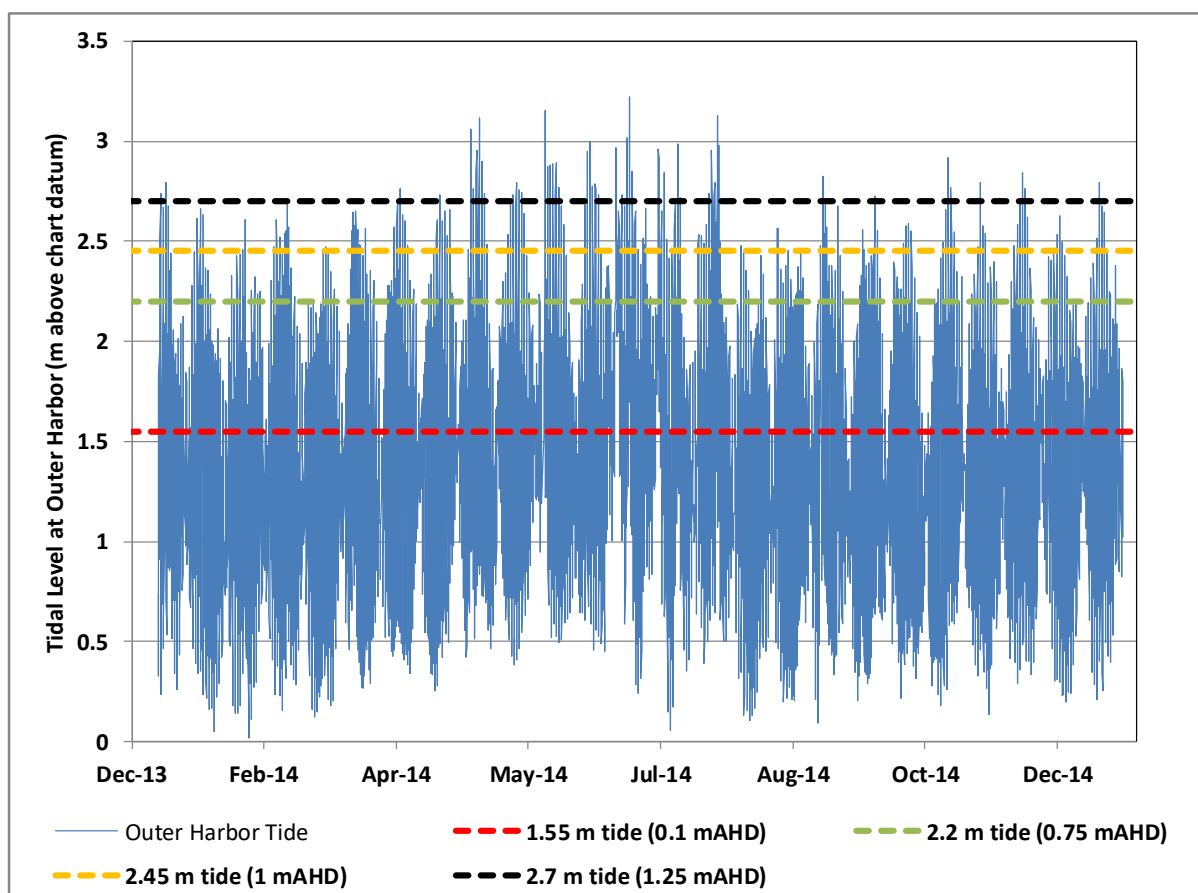
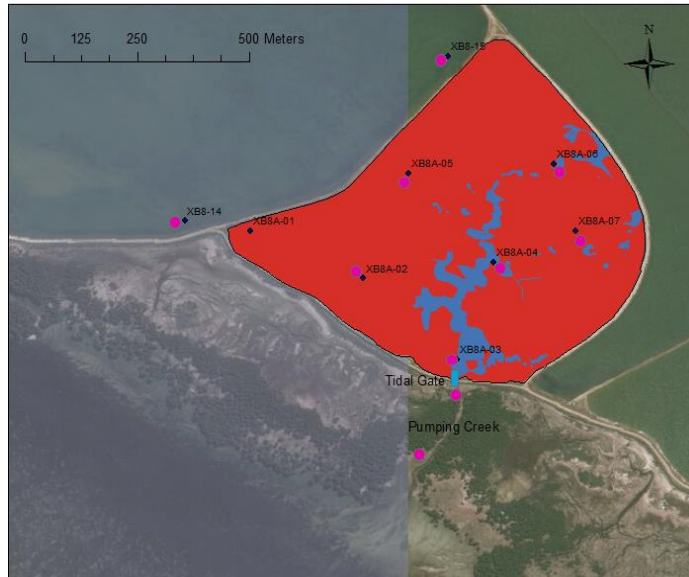
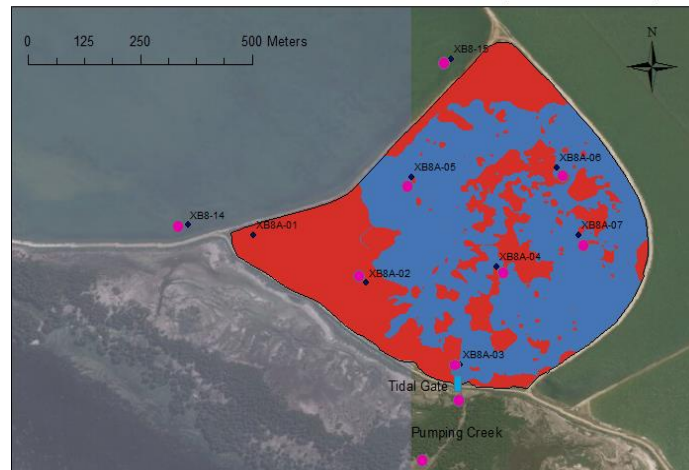


Figure 8 Tidal range at Outer Harbor over a 1 year period. Various levels are indicated on the Figure ranging from when the tide begins to flow into the pond (1.55 m tide CD, 0.1 m AHD) to when differing degrees of inundation occur (refer to Figure 9 inundation maps).

Pond XB8A - Inundation 0.75 m AHD (2.2 m tide)



Pond XB8A - Inundation 1 m AHD (2.45 m tide)



Pond XB8A - Inundation 1.25 m AHD (2.7 m tide)

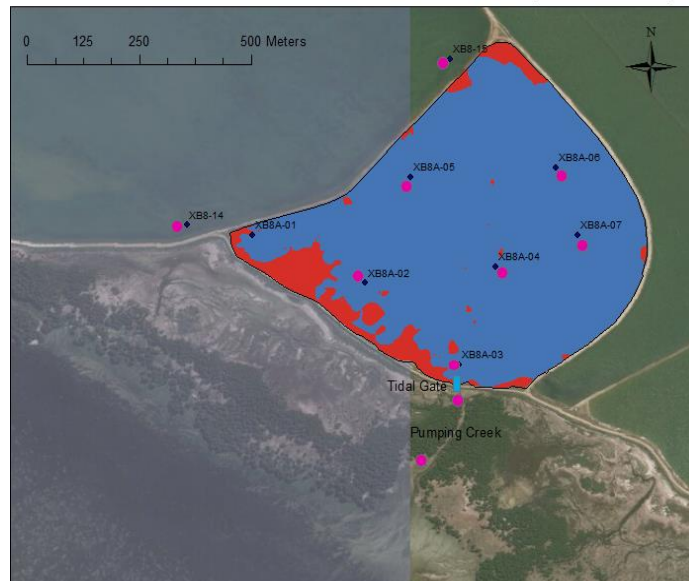


Figure 9 Predicted inundation maps in pond XB8A at three different water levels (m AHD and tidal chart datum at Outer Harbor)

### 7.3 ENGINEERING DESIGN

A detailed technical specification and drawings for the Pond XB8A tidal infrastructure construction and installation was prepared (Tonkins 2016b). The following list of work required was detailed in the specification:

- Construction of coffer dams and management of sea water flows as required.
- Setting out of works and control survey
- Removal and disposal on site of any unsuitable surface materials and organic matter
- Bulk excavation to achieve the design profile and levels, including channel excavation and filling for hardstand and turnaround areas
- Compaction of the base of excavation to allow for support and compaction of overlying fill layers.
- Pipe sizing, orientation and elevation in order to ensure suitable water exchange
- Supply and installation of pipework and electrically actuated tidal regulation infrastructure
- Detailed design, supply and installation of pole mounted solar power supply and electrical power storage batteries
- Detailed design, supply and installation of electrical switchboard, controls and cabinet
- Supply and installation of monitoring equipment and controls
- Supply, installation, backfilling and compaction of the geotextile retaining wall
- Design and establishment of GSM based communications, web based portal system and remote monitoring and control system.
- Installation of site access and security measures.
- Inspections and testing procedures
- Provide training in the function and operation of the installed works
- Provide records of all inspections and testing as required by this Specification.
- Provide operation and maintenance manuals, as constructed records and survey.

This specification was used to describe the works as part of the approvals process, provide the specifications for the purchase of the tidal gate infrastructure, and to secure a contractor to undertake the works. Following cost estimates and discussions with the Contractor the as-constructed design was varied in some areas from the Technical Specification.

### 7.4 LEGISLATIVE APPROVALS

Various legislative approvals were obtained to undertake the tidal gate installation including:

- Inputting information to enable the Holding Pattern PEPR to be modified to include the tidal trial
- Development of Monitoring and Risk Management Plan in consultation with EPA to set water quality triggers and actions that was also included in the revised PEPR.
- Assisting the contractor with an application to the EPA for a dredging license with associated Dredging Management Plan
- Application for an exemption under the Fisheries Management Act 2002 for undertaking an activity that could affect the St Kilda – Chapman Creek Aquatic Reserve
- Liaise with Adelaide Dolphin Sanctuary representatives about the trial proposal and risk management procedures
- Liaise with Local Government re: potential need for any Development Approvals.



## 7.5 CONSTRUCTION AND COMMISSIONING

Once approvals were obtained construction and installation of infrastructure commenced. This involved the following:

- Site preparation works, including work on the entry road to the site to enable heavy traffic
- Closure of existing gaps/gates in Pond XB8A bunds and re-direction of the Salt Field flow path around the trial site
- Constructing coffer dams on the seaward and landward sides of the tidal gates. The coffer dam construction on the landward side of the bund proved difficult due to unconsolidated sediments. Hence a decision was made to alter the position of the tidal pipes so that the existing road could be used as the pond coffer dam during construction, with the road then diverted around the tidal gate.
- Installation of pipes and tidal gates in Pond XB8A bund and reinstatement of the bund wall. The infrastructure consisted of 4 x 1.2 m diameter x 10 m long polyethylene pipes and controllable tidal gates (AWMA i-gate)(see Figure 10). Note both the pipes and gates were custom-made products which added significant cost to the project as discussed further below.
- Dredge accumulated silt (approx. 250m<sup>3</sup>) to re-establish historic creek alignment to the design depth (-0.2 mAHD)
- Install tidal gate control systems which operated from batteries and solar power and were able to be controlled remotely
- Install monitoring equipment comprising of a multi-parameter water quality sensor (YSI EXO2) was installed in a conduit on the pond side of the gate and water level sensors also installed either side of the gate.

The initial commissioning phase of the tidal gates involved testing gate operations while the coffer dam was in place. Next the coffer dam was removed to allow water levels to equilibrate around the new infrastructure and turbidity created during these works allowed to settle. The tidal gates were then opened in July 2017 with the first operations were to drain the elevated head of hypersaline water from Pond XB8A. Initial monitoring indicated the tidal creek was hypersaline for periods during the tidal cycle. Based on this, and the intended net environmental benefit of the trial, the EPA gave in principle agreement for discharge of hypersaline water to occur down the Creek up to 2 hours either side of high tide (to obtain maximum dilution). Monitoring occurred in the coastal water during this time to assess potential risks to seagrass beds immediately offshore. Sufficient mixing and dilution was noted to occur prior to these areas (Mosley et al. 2017). Once the pond was drained, reintroduction of tidal cycles occurred successfully in accordance with the design.



Figure 10 Tidal gate infrastructure installed in the seaward levee bank of Pond XB8A at the Dry Creek salt fields

## 7.6 MONITORING AND ASSESSMENT

Monitoring and assessment occurred before tidal reconnection in April 2017 and then several times over nearly two years after tidal reconnection (see Mosley et al. 2018, 2019 in prep.). Monitoring included:

- Continuous water quality (conductivity, temp, pH, DO, turbidity) via the sensor at the tidal gate, and sensors placed downstream in the tidal creek for shorter time periods
- Water quality grab sampling at 10 sites in Pond XB8A, Pond XB8 (control site) and two sites in the tidal creek (Pumping Creek) Various parameters including pH, salinity, nutrients, suspended solids and organic carbon were assessed
- Sediment quality – various parameters include pH, salinity, and acid sulfate soil parameters were also assessed via samples taken at soil profiles at the same sites as the water quality monitoring
- Benthic invertebrates via sediment cores and sweep netting

Additional monitoring activities conducted by DEW included:

- Bird surveys
- Vegetation surveys and mapping
- Monitoring change in seagrass cover offshore of the tidal creek discharge using remote sensing methods

Key findings of the monitoring were:

- Tidal restoration resulted in major decreases in salinity in Pond XB8A from the hypersaline conditions present before the trial (Figure 11). When it receives reasonable tidal inflow, the trial pond now has salinities approaching seawater values (35-40 Practical Salinity Units, psu) while the control pond, as expected, remained hypersaline (approx. 2-3x seawater salinity)(Figure 11). There is an apparent seasonal trend of lower salinities in winter and higher salinities in summer, likely due to lower tidal and storm surge influences in summer and higher evaporation rates.
- pH, dissolved oxygen, dissolved metals, chlorophyll *a* and nutrients are variable but are being maintained at satisfactory levels during tidal exchange (see Mosley et al. 2017, 2019)
- The general characteristics of the sediments before commencement of the trial were a black (presumed monosulfide-rich) layer in the top 10–20 cm, a green-grey clay layer extending from about 20–45 cm, and a red-brown (presumed old mangrove root zone) peaty layer at >45 cm. The Pumping Creek (PumpC1 and PumpC-2) sediments had a coarser sand-shell grit and organic rich layer in the top 10 cm, grading to a grey clay. Following tidal restoration, there has been an apparent shift to more oxidised conditions in the top sediment layer, with lighter coloration present at many sites, see
- Figure 12) and substantial reductions in Acid Volatile Sulfide (AVS, measure of iron monosulfide material content) due to introduction of wetting and drying cycles. This demonstrates that monosulfidic hazards can be remediated in situ via wetting and drying with little environmental risk, providing large-scale resuspension does not occur. The regular drying cycles are conducive to oxygen penetration into the soil to enable oxidation reactions to occur. The soils at the site appear, in general, to be transitioning to normal salt marsh soils with low hazards.
- Soil pH has showed only minor decreases but remained circum-neutral with no acidification (pH<5) occurring in any soil layers following drainage. This was anticipated due to mostly hyposulfidic materials present in the initial surveys (Baker and Fairbrother 2016). There were some hypersulfidic materials at depth in the profile but these either did not oxidise (regular tidal wetting and drying cycles enabled sub-soil saturation to be retained) or there was sufficient neutralizing capacity in the soil and water to prevent any acidification.
- Reduction in soil salinity from the conditions in the hypersaline salt ponds prior to tidal restoration due to dilution and salt export. Saline minerals deposited on the pond surface (mostly gypsum, but also aragonite and halite) have also showed some apparent dissolution over time.
- Organic carbon has showed an apparent decrease in the upper sediment layer at this site, some other sites in the pond have shown some sequestration (likely due to seagrass inflow).
- Salt marsh vegetation rapidly recolonised the pond with the first vegetation observed in November 2017, approximately 4 months after tidal reconnection commenced (Figure 13). Vegetation transect data is being collected by DEW periodically, with quadrat data also collected by Flinders University as part of the Goyder blue carbon project at that site.
- There was increased tidal channel definition over time as tidal flow restored natural flow paths.
- A significant increase in macroinvertebrate diversity has occurred following tidal reconnection. The ecology has shifted from a simple (yet productive) hypersaline assemblage, to a diverse marine assemblage (see Cummings and Goonan 2018)
- Local and migratory wader bird activity has been observed (nesting and feeding). Particularly high feeding activity was observed during early morning high tides when water flowed over the mudflats (Figure 13).

Minor regulatory issues that arose during the tidal trial included:

- Imported construction material (e.g. crushed brick and concrete) used by the contractor around the tidal gate were deemed unsuitable materials to use in this location by the EPA. These were removed and replaced with clean rock material.
- The EPA and DEM sought clarification on some low dissolved oxygen readings but these were shown to be a background phenomenon in the adjacent intertidal wetland areas (see Mosley et al. 2017).

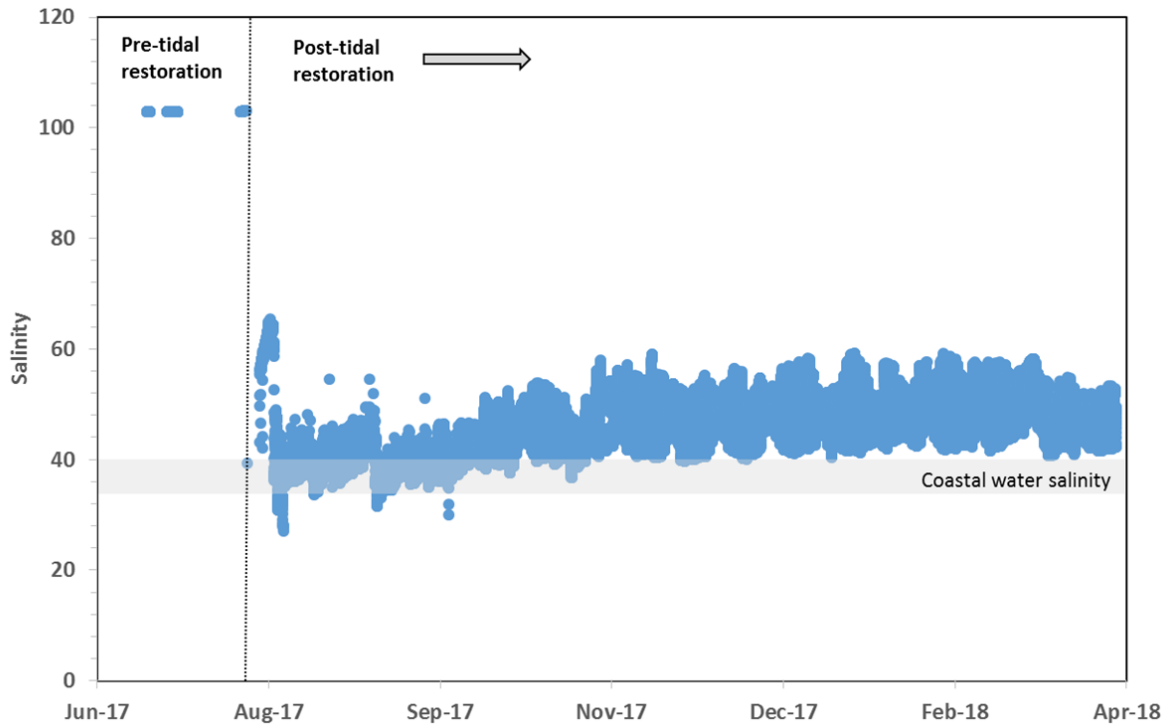


Figure 11 Salinity in pond XB8A pre- and post- tidal restoration. The typical range of coastal water salinity values is also indicated.



Figure 12 Sediment profile pictures from trial pond XB8A



Figure 13 Photographs (left) showing some salt marsh vegetation that rapidly recolonised the trial pond following tidal restoration (credit: Luke Mosley), and (right) showing wading birds on the margins of the tidal inflow at Pond XB8A (credit: Jason Quinn)

## 7.7 CARBON SEQUESTRATION POTENTIAL

A separate project funded by the Goyder Institute investigated the Blue Carbon potential and co-benefits of restoring coastal habitats in Pond XB8A. Over 1.5 years post re-connection, changes in several carbon pools were investigated inside the trial pond and in reference areas (Dittman et al. 2019). Assessments were made for several strata, defined by elevation and predicted vegetation classes. The processes of revegetation were experimentally studied. Findings from all field investigations were combined to calculate current carbon stocks and sequestration rates, and project potential benefits forward in time and space through upscaling for several scenarios.

The investigations on carbon dynamics showed a net gain of soil organic carbon stock following tidal re-connection, which could be partly attributed to influx of seagrass wrack (Dittman et al. 2019). Methane gas fluxes were negligible, and could be excluded from further carbon pool assessments. Sediment accumulation rates were highly variable across the strata and between the trial pond and reference areas. The carbon fraction for saltmarsh and above and belowground vegetation biomass was determined. While the greatest carbon capture will be in mangrove, saltmarsh can be a further important contributor to carbon sequestration.

Saltmarsh vegetation rapidly colonised the pond following tidal re-connection, dominated by pioneer species *Suaeda australis* and *Sarcocornia quinqueflora* which grew quickly to mature stages inside the trial pond. Experiments revealed the dependence of revegetation on nearby seed supply, and seasonal variation in seed dispersal. A net gain in carbon stock from the establishing saltmarsh inside the pond was estimated.

## 7.8 LONGER TERM OPERATIONS

Once water quality and sediment conditions were deemed to be stable the decommissioning of automated tidal control infrastructure occurred. The gates are still able to be closed manually if desired in the future.

The intention is to continue to monitor the ongoing recovery of the site into the future, subject to availability of sufficient funding and/or resources.

## 8 SUMMARY OF POND XB8A TIDAL RESTORATION TRIAL LEARNINGS

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A summary of key learnings of the Pond XB8A trial to inform future implementation of tidal restoration strategies were:

1. The trial results showed relatively low environmental risk, apart from the initial period of pond draining, and large environmental benefits.
2. The costs of the trial was relatively high, >\$1 million when all the preliminary and detailed design, tidal gate and monitoring infrastructure, civil works and monitoring and assessment activities are considered. Civil work costs could potentially be substantially reduced if a simpler design process was followed and tidal reconnection was achieved via bund wall removal or “off the shelf” products without tidal gates (e.g. just pre-cast concrete culverts).
3. The design process could also be simplified to a more basic approach so as not to “over engineer” the process. This could include survey, basic hydrological calculations, and design drawings with required levels, pipe/culvert sizes, and orientation.
4. Longer pipes could be used than what was specified for XB8A. The geotextile bag headwall in the original design was replaced with armoured clay batter which would have benefitted from longer pipes to maintain sufficient batter.
5. Erosion protection on the landward side of structures may be required, the issues with the coffer dam and modification of the original pipe placement contributed to more erosion around the gate interface where water velocities are highest.
6. The tidal gates were not required for water quality management, except in the initial commissioning phase when hypersaline water was being drained from the pond around high tide. It may be possible to find other ways to drain hypersaline water as discussed below. For example, lowering the water level in the pond as much as possible, by draining the hypersaline water to downstream pond/s or evaporating ponds down over summer. This would mean less water (ideally none) needs to be released through the gate to the intertidal area before water exchange. This strategy would also reduce head pressure on the pond side against the construction area and gates/pipes/ reinstated bund and enable much easier construction in the drier conditions. A coffer dam may not be required then on the inside of the bund wall which would reduce cost and minimise associated turbidity. However, without the requirement for tidal gates, other even simpler options involving bund wall removal are possible.
7. There is a need to ensure an impermeable layer around/between and over pipes to avoid leakage and potential pipe failure. If using clay, effort must be meticulous about getting clay under and between the pipes and compacting this. Bentonite is possibly a better alternative to the on site clay that was used in the trial.
8. Timing is important – construction at the end of summer would be preferable and then autumn/winter commissioning when tidal inflows and dilution is most favourable
9. All imported fill must be clean and free of deleterious material.
10. Manual control is possible on tidal gates also.
11. It is important to define success and endpoints in the restoration process (e.g. water quality recovery, stable landform, ecosystem recovery, blue carbon benefits).

## 9 POTENTIAL FOR WIDER IMPLEMENTATION OF TIDAL RESTORATION

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The Pond XB8A trial demonstrated the feasibility of tidal restoration on the smaller scale and provided some key learnings. The potential for wider implementation of tidal restoration strategies at the Salt Field is outlined below.

### 9.1 CURRENT BARRIERS

A barrier to any wider tidal restoration is that the site is still operating in a Holding Pattern under the PEPR. Mineral leases are still maintained over the Crown Land at present and no decision has been made by BDC on their future plans for Sections 2-4, including whether to restart salt production operations at the site (BDC Pers. Comm.). High-level negotiations with the State Government are required to clarify future plans under the PEPR and requirements for closure and remediation of the site under the provisions of the *Mining Act*.

### 9.2 TECHNICAL FEASIBILITY

Provided tidal reconnection can be successfully achieved, large areas of the seaward margins of the salt field site are of suitable elevation to receiving tidal inundation enabling restoration of natural coastal ecosystems. To illustrate this, the predicted vegetation types (based on elevation) if bund walls were removed or breached are shown in Figure 14. It is noted that most of the Crown land (cross-hatched areas on Figure 14) is predicted to be either mangrove, intertidal or supratidal habitat following tidal restoration.

An assessment of ASS hazards has been undertaken for Sections 2-4 (see above section 5.2). An example of hazards that current exist in Section 3 is shown in Figure 15. These areas contain a mixture of hyposulfidic (lower risk) and hypersulfidic (higher risk) ASS materials. Some of the hypersulfidic materials may exist at depth, and based on the XB8A trial results, may not pose a risk if they stay saturated or there is sufficient neutralizing capacity in the soil or as provided by tidal exchange. A more detailed assessment and mapping of ASS hazards should occur in relation to any proposed wider tidal restoration scenario. This could include assessment of which areas are best suited to drying/reclamation and which areas may require closer monitoring during implementation.

Tidal reconnection could be achieved in different ways. An example of a potential strategy is shown conceptually for Section 3 in Figure 16 and Figure 17. Potential sites where tidal openings and/or removal of bund wall sections could occur to allow tidal exchange are shown. Internal ponds could be connected and utilized for ponding, treatment or reuse of fresh water sourced by redirecting stormwater and/or the SA Water Outfall into the ponds. Other opportunities for creating recreation and tourism benefits (Figure 17). Any wider tidal restoration concept should include integrated assessment and planning involving engineering, ecological, social and economic considerations.

**Dry Creek Salt Field Predicted Vegetation Classes and Land Ownership**  
**Sections 3 & 4 (St Kilda to Middle Beach)**

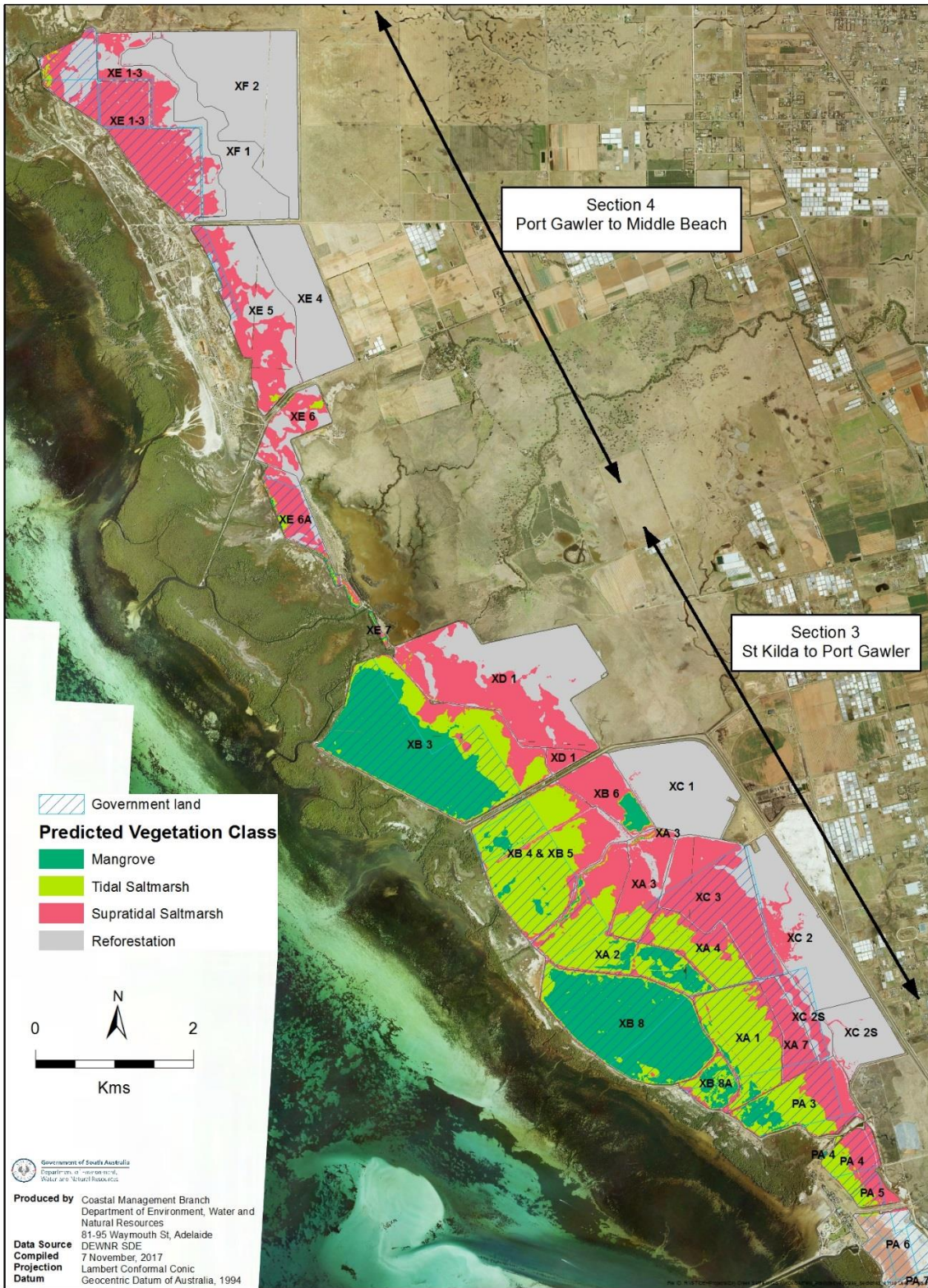


Figure 14 Predicted vegetation types based on digital elevation models



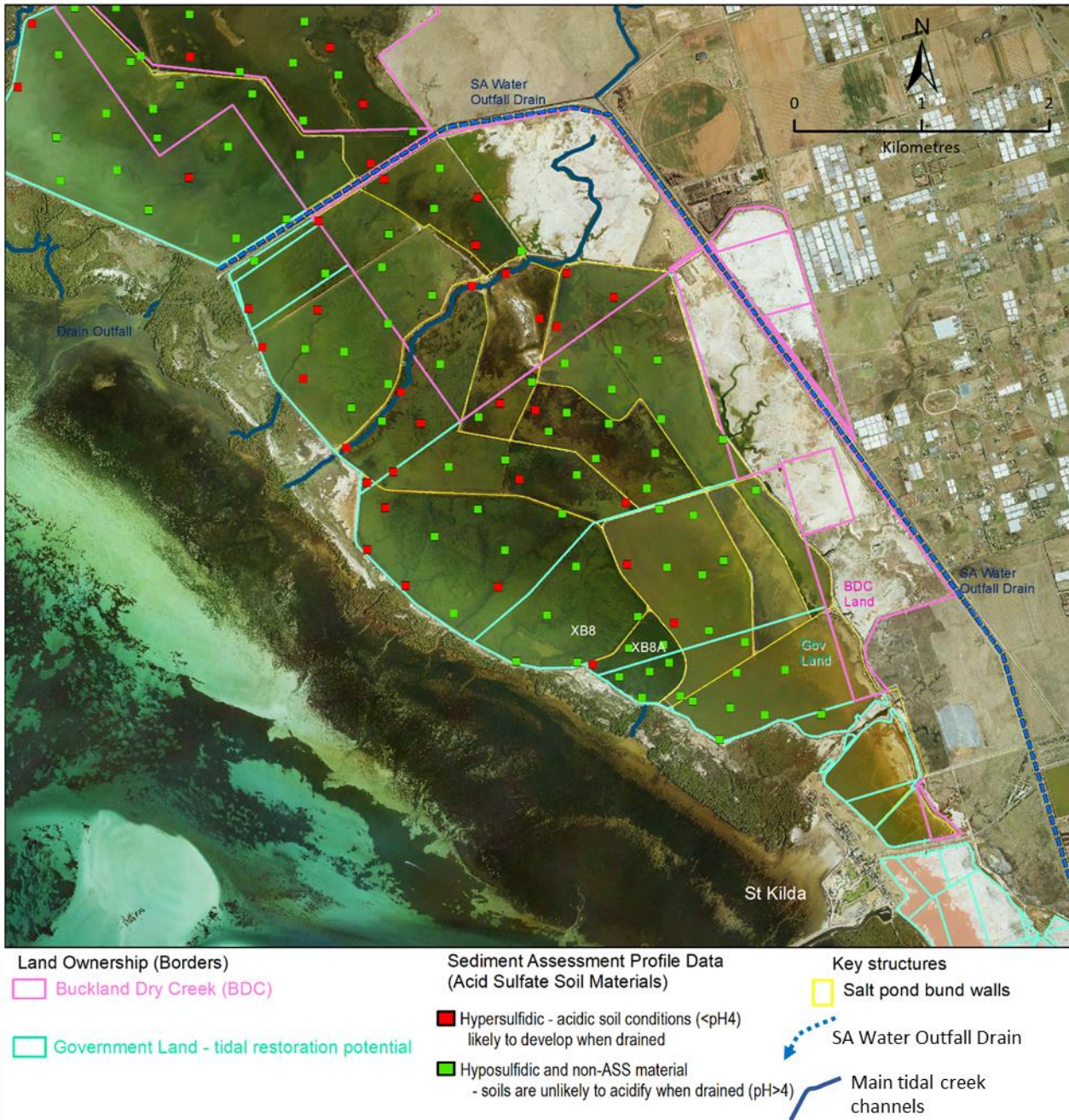


Figure 15 Example of existing Conditions within Section 3 of the Salt fields, illustrating current Land Administration boundaries and acid sulfate soil conditions.

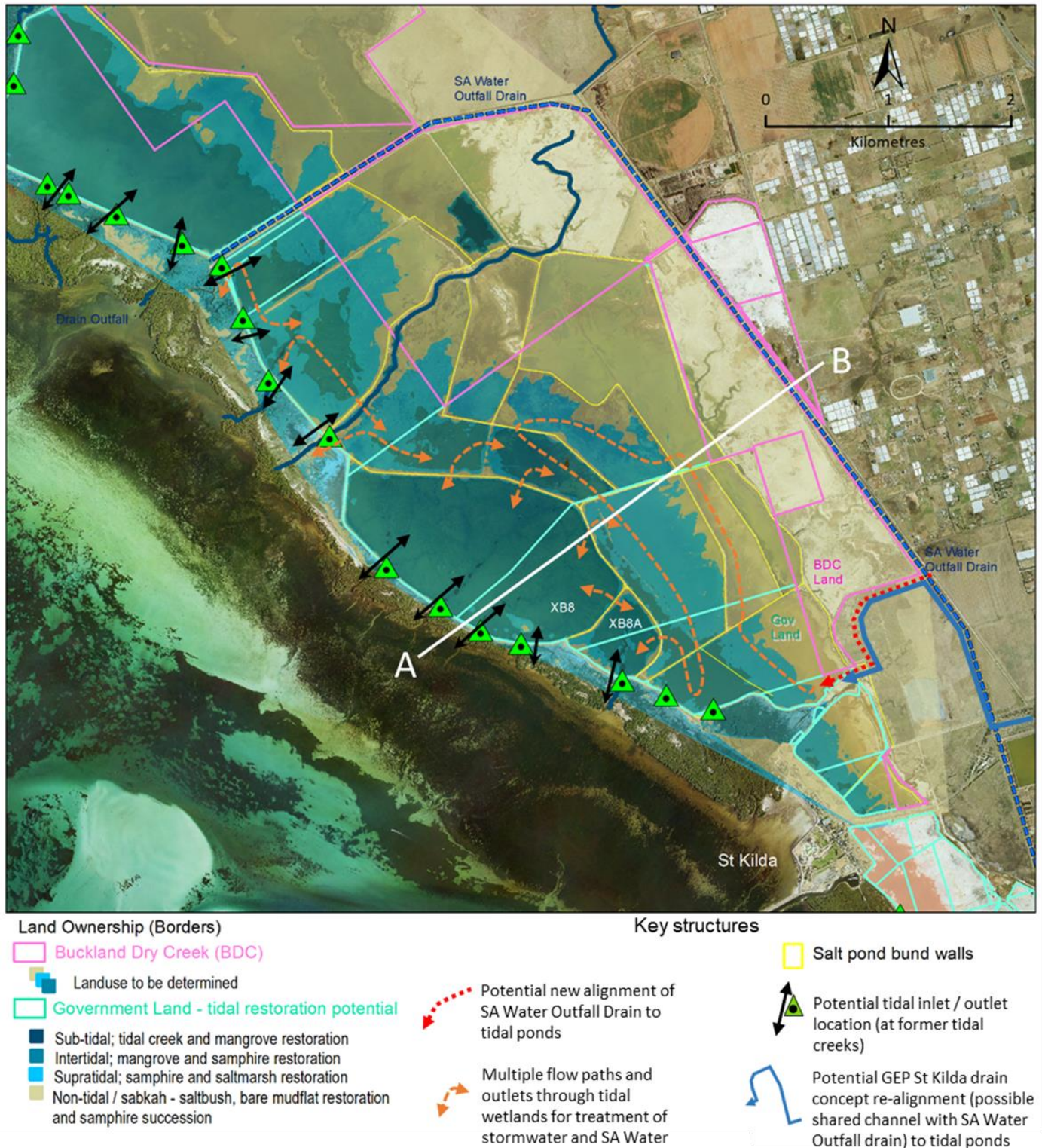


Figure 16 Potential sites where tidal openings (green point labels) and/or removal of bund wall sections could occur to allow tidal exchange. . Internal ponds could be connected and utilized for ponding, treatment or reuse of fresh water sourced by redirecting stormwater and/or the SA Water Outfall into the ponds. The orange arrows illustrate the potential for utilizing existing bund walls to maximise water flow paths within the ponds. Cross-section A-B is represented in Figure 17below.

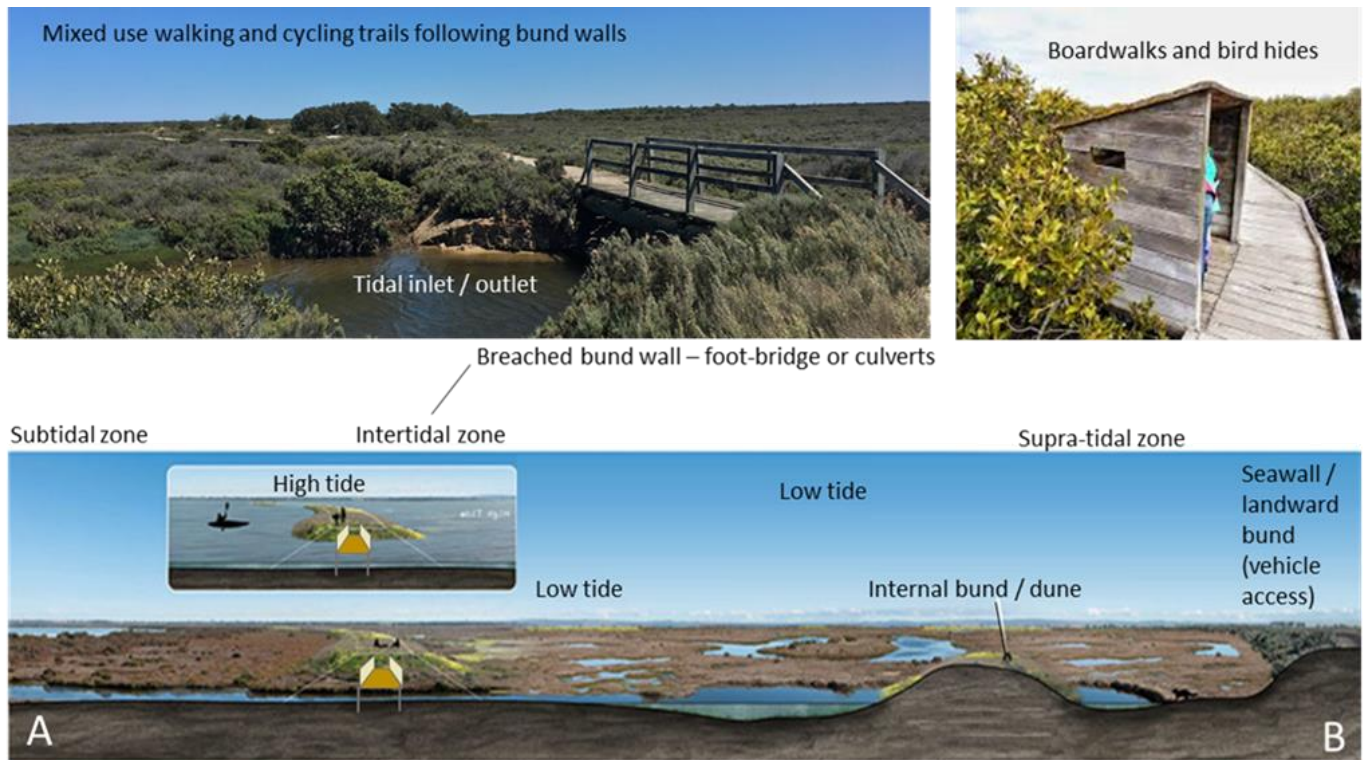


Figure 17 Cross-section A-B. Conceptual model for tidal restoration of salt evaporation ponds at Dry Creek (cross-section image modified after Watkin McLennan)

### 9.3 OPTIONS TO REDUCE COST OF ACHIEVING TIDAL RECONNECTION

There are likely more cost-effective ways to do tidal restoration on a large scale. If ponds could be drained before tidal reconnection (e.g. by draining in a sequence to adjacent ponds or pumping to adjacent ponds) then this would reduce the initial large volume of hypersaline water present. This would also make construction easier and cheaper.

In regard to construction, the current tidal trial, being the first in the salt field, had strict environmental regulations and hence had sophisticated control gates installed. These were not regularly required after the initial period (<2 weeks) of tidal restoration as water quality was satisfactory and tidal cycle dilution processes were effective. Hence in future simple culverts or simple openings/removal of the bund wall would be a possible lower cost option based on the results of the trial. Whole sections of banks could be removed. Complete removal of bund walls would likely enhance the recovery rate and outcomes of the site as tidal exchange and ecological connectivity is maximised. This strategy has been applied in parts of the major San Francisco Bay salt field restoration project<sup>1</sup>.

### 9.4 RISKS AND RISK MANAGEMENT

Draining or evaporating over spring-summer the hypersaline water from the ponds in a sequence would be beneficial to reduce point source discharges of high volumes of hypersaline water during the restoration process. Alternatively, a staged process could be undertaken following a similar strategy as in the XB8A trial where discharge occurred around high tides. However this process could take a very long time if applied over a large area (i.e. it took approximately one week to drain 38 ha XB8A pond).

<sup>1</sup> See <https://www.southbayrestoration.org/>

Caution needs to be applied however, in translating the rapid positive results of the XB8A trial to the southern sections of the salt field where thick gypsum and halite crusts are typically present and recovery may be slower or require additional strategies (e.g. removal of gypsum crusts following drainage).

Acid sulfate soils risks are a consideration that require monitoring. There are some areas with higher acidification hazards than in Pond XB8A, in particular in Section 4 (see Figure 5 and Figure 15). There is additional neutralizing capacity provided from the seawater, and saturated conditions may be maintained between wetting and drying cycles, which will reduce the risk profile. Additional acid sulfate soil management strategies (e.g. spreading limestone) can be used as a contingency if monitoring suggests it is required.

Current mangrove and salt marsh ecosystems are at risk due to sea level rise because there is limited succession area on the seaward side of the bunds. Furthermore, if the bunds were to breach due to storm surges and/or higher sea level conditions, this could result in major environmental and infrastructure risks. If seaward bunds are retained then ongoing maintenance will be required.

It should also be noted that any wider Dry Creek salt field restoration strategy involving bund wall removal and pond configuration should also ensure that storm surge and flood hazards to adjacent communities and infrastructure do not increase as a result of restoration. However, there may be good opportunities to utilise decommissioned ponds to reduce existing stormwater flooding risks at adjacent residential areas (e.g. St Kilda-Buckland Park).

## 9.5 OPERATIONAL AND ACCESS CONSIDERATIONS

Bunds are required in the short-medium term if access to the seaward pond margins is to be maintained. Over the longer term (>30-50 years) sea level rise predictions suggest that it will be difficult to maintain a seaward bund wall. It is also recommended the bund wall is removed to enable the coastal marshes to “build” to potentially keep pace with sea level rise. This provides a buffer for coastal assets in the future. Mangroves and coastal marshes also absorb wave energy whereas bund walls deflect it. There would be high maintenance cost to maintain seawater levees/bunds on the Crown land.

There are other access roads throughout the site that could be used/adapted if the seaward bund wall was removed or lost in places. It is suggested that the landward margin of the government land be used as a general guide to where an access road should be maintained. Fill removed from the seawater bund wall could be used to supplement existing roads in places. Cycle paths and walking trails should be integrated into future access considerations. There is potential for a linked recreational network along a large area of the coast and connecting to the Adelaide International Bird Sanctuary National Park trail network.

## 9.6 POTENTIAL TO INCLUDE CARBON SEQUESTRATION ACTIVITIES IN RESTORATION PROJECTS

The ability to utilise formal and/or voluntary carbon markets in tidal restoration projects is one potentially attractive option to offset costs and provide benefits for climate change mitigation. One of the primary mechanisms the Australian Government is using to meet international greenhouse gas (GHG) targets is the Emissions Reduction Fund (ERF). The ERF sets the budget for the purchase of carbon abatement projects at lowest cost by the Government through the Clean Energy Regulator (CER) (‘reverse auction’). Registering a carbon abatement project activity with the CER is only possible if a respective method exists in the ERF. At present, there is no accredited method for Blue Carbon, although this is under active investigation by the Australian Government. The most widely used methodologies for carbon accounting on the voluntary market come via the international Verified Carbon Standard (VCS) program<sup>2</sup>, which offers the most advanced global GHG scheme for verifying and issuing carbon credits. The VCS has an approved methodology (VM0033) for wetland restoration, and for Coastal Wetland Creation (VM0024), which

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<sup>2</sup> See <https://verra.org/project/vcs-program/>

are the most applicable methods for Blue Carbon project activities. Both the ERF and VCS methods have strict criteria to ensure additionality (the abatement is unlikely to occur by maintaining the status quo), that C changes can be monitored and verified, and permanence can be demonstrated (carbon is sequestered and not lost over longer term). South Australia is currently finalising a Blue Carbon Strategy that will provide further policy and strategy direction at the State level (expected to be released in 2019).

A preliminary assessment of the potential for tidal restoration at the Dry Creek tidal trial site to deliver blue carbon benefits was provided as part of the Goyder Institute funded “Salt to C project” (Dittman et al. 2019a,b). The results, based on the XB8A pond trial, control pond and reference site assessments, indicated a wider restoration project would have a positive outcome in terms of GHG removals. Soil organic carbon stocks remained steady under baseline scenario, and increased significantly under the project scenarios. For ‘with project’ scenarios, the modelled carbon stock changes from soil and biomass show increases over the coming decades. The net GHG emissions reductions in 30 years crediting time could exceed 400,000 to 500,000 t CO<sub>2</sub>e for hypothetical scenarios with further ponds re-connected, which could generate an estimated market value of \$6-8 Mill with a carbon price of ca. \$15. However, permanence could potentially be affected by sea level rise over a 100 year time period, unless the project area would be large enough to encompass landward retreat areas. The landscape slope and low development of the hinterland offers good potential for maintaining wetland resilience. Project planning, GHG accounting and permanence considerations will need to factor in whether to extend the site boundary landward beyond the current extent of marsh to account for future sea level rise. Tidal re-connection can be a recommended Blue Carbon project activity under the ERF (when an approved method is available), and meets criteria for tidal wetland restoration projects under the International Verified Carbon Standard, and also under Australia’s integrity offset standard.

Baseline assessments of carbon should be conducted before tidal restoration where possible. These are relatively simple in the sense that no vegetation is present in most ponds so the assessment can focus on Soil C stocks.

## 9.7 APPROVALS

A streamlined process should be sort for approvals for any wider tidal restoration process. Under Section 46 of the *Development Act 1993*, the Minister for Planning can declare a proposed development a 'Major Development' if he or she believes such a declaration is appropriate or necessary for proper assessment of the proposed development, and where the proposal is considered to be of major economic, social or environmental importance. This triggers a thorough state-run assessment process with opportunity for public comment before any decision is made on whether the proposal warrants an approval. Based on the XB8A trial outcomes, the net environmental and socio-economic benefits of large-scale restoration are considered to greatly outweigh potential risks and have widespread public benefit outcomes as outlined below.

Discussions should also occur with the Commonwealth about any required approvals under the EPBC Act. Restoring a natural tidal mangrove-coastal marsh ecosystem, while maintaining and enhancing a diversity of migratory shorebird habitat, would lead to beneficial outcomes at a national level.

## 9.8 OUTCOMES AND BENEFITS OF WIDER TIDAL RESTORATION

Key outcomes and benefits for South Australia would result from tidal restoration:

- Restoration of degraded coastal ecosystems
- Enhanced fishery nursery areas
- Provision of new shorebird habitat and realizing the vision of the Adelaide International Bird Sanctuary
- Enhanced recreational opportunities and access to the coast for the public
- Greatly enhanced eco-tourism and associated economic and employment benefits
- Blue carbon sequestration to mitigate climate change and provide funding for site operations via carbon markets

- Opportunity to utilise the coastal wetlands for stormwater and flood management
- Provide buffer against sea level rise and storm surge events
- Reduce current pumping costs and liabilities to BDC while providing opportunities for enhancing development outcomes on private land at the Salt Field.

## 10 SUMMARY

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In summary the Pond XB8A trial demonstrated that tidal restoration is a feasible strategy for suitable parts of the Salt Field, in particular the more seaward areas of Crown Land. Key learnings from the trial were used to assess how tidal restoration could be achieved over a wider area of the Salt Field. This included preliminary assessment of technical feasibility and options to reduce cost. There would be positive environmental and socio-economic outcomes for South Australia if a tidal restoration strategy was implemented across wider areas of the salt field.

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