

Risk and opportunities:

A briefing paper on coastal habitat and shorebird conservation in the light of potential closure of the Ridley Dry Creek salt fields

Prepared for: AMLR NRM Board



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This report has been undertaken as part of the AMLR NRM Board's Samphire Coast Icon Project, the Samphire Coast Icon Project is supported through funding from the Australian Government's Clean Energy Future Biodiversity Fund.

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Document history:

Internal review: 21 May 2012 (PC)

First draft issued for client review: 21 May 2012 (PC)

Second draft issued for client review: 30/05/2013 (PC)

Third draft issued for client review: 26/06/2013 (PC)

Final version released: 27/06/2013 (PC)

GLOSSARY

alien	not native to Australia
AHD	Australian Height Datum
AMLR NRM Board	Adelaide & Mt Lofty Ranges Natural Resource Management Board
ASS	acid sulfate soil
bitterns	brine from which most of the sodium chloride has been crystallised
concentrator	saltfield ponds where brine is gradually concentrated
conservation interest	a taxon with status of uncertain, uncommon or poorly known
conservation significance	a taxon with status of extinct, endangered, vulnerable or rare
crystalliser	shallow saltfield pans where salt is precipitated
DEWNR	Department of Environment, Water & Natural Resources
DMITRE	Dept for Manufacturing, Innovation, Trade, Resources and Energy
endangered	in serious risk of disappearing in the wild within 10-20 years
EPBC Act	Environment Protection & Biodiversity Conservation Act
eutrophic	an environment with high availability of nutrients
exotic	not native to Australia
extinct	not collected or verified in the past fifty years
flyway	a general route followed by migratory birds
habitat	a broad classification based on vegetative/geomorphic/locational aspects
maiden brine	saturated brine
MHHW	mean higher high water
migratory	a birds that breeds in one country/region but overwinters in another
MSL	mean sea level
native	as for indigenous - native to Australia
NPW (SA) Act	National Parks and Wildlife Act of SA
oligotrophic	an environment with low availability of nutrients
poorly known	little is known about the population
rare	rare within Australia but not facing any identifiable threat
resident	a bird that spends its entire life within a region
Scheduled	endangered, vulnerable or rare within South Australia
shorebird	member of the Order Charadriiformes
SLR	sea level rise
taxon	a taxonomic group of plants or animals (usually species but not necessarily)
vulnerable	not presently endangered but at risk over 20-50 years
waterbird	wide range of bird orders that use standing water for habitat

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1. Executive summary

The seventy kilometres of coastline covered by the mining leases of the Dry Creek Saltfield (Ridley Dry Creek Pty Ltd) include a range of coastal and estuarine habitats rarely found so close to a large centre of population. The leases occur over land that hosts flora of local, State and National conservation significance. In particular, the salinas of the operating saltfield return counts in excess of 1% of the flyway population of red-necked stints and sharp-tailed sandpipers (Birdlife Australia Internationally Significant Sites database), while the interconnected sabkha complexes north of the River Light contains the largest Australian populations of the EPBC Act listed samphire *Tecticornia flabelliformis* (Coleman 2012), as well as one of the largest near-pristine deltaic estuaries in Gulf St Vincent.

In the light of a potential closure of the saltfields, the Adelaide & Mount Lofty Natural Resource Management Board seeks to identify achievable options for progressing decommissioning to minimise risk in the short and long term and provide guidance for stakeholders to achieve the best possible conservation outcomes for the area.

The Crown holds several thousand hectares of land underlying the approximately 10,000 hectares of mining lease. Ridley Corporation holds the remainder as freehold lands. The owner may develop these lands in various ways or dispose of them. The Crown also has options as to how it wishes to manage its lands, and some of the opportunities that have been raised include;

- improve conservation outcomes on high biodiversity value undeveloped mining leases
- have the pondages rehabilitated to self-sustaining tidal wetlands that will provide biodiversity benefits, carbon sequestration, stormwater management, coastal flood protection and sea level rise habitat retreat benefits
- utilising the pondages as detention basins or wastewater polishing ponds
- leasing operational ponds to aquaculturalists, biofuels developers, or conservation bodies as managed pondages
- utilisation by State agencies of some managed pondages for shorebirds
- reissuing the mining leases on the developed and undeveloped lease areas to another salt operator, shellgrit or gypsum miner

The opportunities are discussed in more detail in Section 5.1 (Possible Crown land end uses) and Section 5.2 (Area specific analysis).

As well as opportunities, there are risks. The major risks assessed in this briefing are;

- the increased disturbance to shorebirds through inappropriate development or activities, including potential loss of the salinas as a food resource for shorebirds
- changed land use risks to the endangered samphire *Tecticornia flabelliformis*, whose largest mapped distributions are in this area

- fragmentation impacts including off road vehicle impacts, weeds and feral animal impacts on a number of reserves, once the unified management and access restrictions of the mining leases are removed
- the risk potential acid sulfate soils being activated once ponds are dried out or if there is an attempt to mine gypsum deposits from the ponds
- possible impacts from the discharge of hypersaline brines
- sea based flooding risks from the removal or retreat/relocation of seawalls
- land based flooding risks resulting from increased density of land use
- risk of long term liability from failed ventures and insufficient remediation

These risks are summarised in Table 1, which follows, and the risk assessment forms Section 5.3 of this briefing.

Some aspects of the closure could result in immediate impacts, while other aspects are medium to long term. Section 5.4 contains a table that identifies some temporal priorities of the closure and rehabilitation process.

The briefing paper attempts to cover a wide range of issues over a long expanse of coastline. In order to retain readability and focus, much detail has been moved to the Appendices, where the reader will find;

- a map showing the flow paths and salinities of the salina ponds of the Dry Creek saltfields,
- a select literature review that summarises how tidal wetlands, coastal retreat and salina closure have been managed in other jurisdictions,
- a summary of the lessons that have been learned about saltmarshes and their rehabilitation (both natural and managed) in South Australia and elsewhere, and
- some recommendations on management of potential acid sulfate soils.

At present the State has an unparalleled opportunity to oversee the remediation of an extensive stretch of coastline by the existing miner. Amalgamation of undeveloped lands into the existing conservation estate where feasible and the rehabilitation of the salina pondages to self-sustaining tidal wetlands would appear to provide a wide range of environmental benefits and to be, in the longer term, the approaches that would minimise both environmental risks and financial liabilities.

Choosing to utilise portions of the area for various other small ventures rather than fully realising the potential to remediate these lands may attract some future liability to the State in the event that those ventures fail.

Potential habitat impacts and other risks resulting from conversion of the larger, freehold ponded parts of the site to other uses including housing are unlikely to be fully addressed by amelioration activities on the smaller, Crown portions of the site.

However all efforts to maximise the biodiversity benefits on the Crown lands should be undertaken to balance the risks

There is scope for negotiation on opportunities for biodiversity outcomes on Crown lands. The owner of the land underlying the mining tenements negotiates what standard of rehabilitation they reasonably require for their land.

Prior to relinquishment of a mining lease the miner must demonstrate that the general standards and agreed closure outcomes have been met. This should require sign-off by the landowner accepting the rehabilitation standards and criteria, and acknowledging that they are aware of the residual risks and accept the post-relinquishment arrangements is also required. Whilst the land does not have to be returned to “the way it was” before the mining activity, it has to be returned to a state that is fit for the purpose for which it is to be used.

Some aspects of the closure could result in immediate impacts, while other aspects are medium to long term. Section 5.4 contains a table that identifies some temporal priorities of the closure and rehabilitation process. Some of the immediate concerns include managing brine discharges to minimise high sodium impacts, stabilising drained ponds to minimise ASS production and prevent subsidence, making a decision about the ultimate rehabilitation targets for the site and determining whether the Crown wishes to allow the miner to pass some ponds over for other mining or commercial use.

Table 1 - Summary of major risks

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Increased disturbance to shorebirds through inappropriate development or activities, including loss of food resources for shorebirds	A	3	Set up appropriate hydrogeomorphological template across the site that will allow the evolution of self-sustaining tidal wetlands	B	3	High
			Operate some, or all, of the ponds on Crown land for shorebird habitat	B	3	High
Loss of <i>Tecticornia flabelliformis</i> habitat	C	2	Continued low intensity grazing use of freehold sabkha areas	D	4	Low
			Form a linked series of coastal reserves on Crown lands between Port Parham and Light Beach	E	4	Low
			Extend the Sanctuary Zone of the Upper Gulf St Vincent Marine Park to include the Crown lands of the conjoined deltas of Salt Creek and River Light	E	4	Low
Fragmentation of management of high biodiversity value Crown lands resulting in "edge" and "island" impacts, including ORV impacts and weed/feral impacts	C	3	Form a linked series of coastal reserves on Crown lands between Port Parham and Light Beach	E	4	Low
			Extend the Sanctuary Zone of the Upper Gulf St Vincent Marine Park to include the Crown lands of the conjoined deltas of Salt Creek and River Light	E	4	Low
			Incorporate tidal wetlands east of the Port Gawler CP into the park	E	4	Low
			Incorporate Buckland Park Lake into the Port Gawler CP or place it under some other form of protection	E	4	Low
Acid sulfate generation, soil subsidence and CO ₂ off-gassing in ponds that are isolated from tidal flows and allowed to dry out completely	C	4	An open inundation system is instituted in which tidal and fluvial inputs occur and where there is flushing to the estuary through existing tidal wetlands	C	5	Low

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Large quantum of acid generated by disturbance of gypsum ponds for mining	B	2	Mining is undertaken. A closed pond system is maintained and all acid generated is treated prior to allowing any discharge from the site.	D	4	Low
			Mining is not undertaken. An open inundation system is instituted in which tidal and fluvial inputs occur and where there is flushing to the estuary through existing tidal wetlands	C	5	Low
Discharges from the salt ponds may have hypersalinity impacts on the receiving environment	C	3	Discharge from marine salinity ponds to be returned to sea via local tidal drainages	D	5	Low
			Discharge from low to mid hypersalinity ponds to be returned to sea after dilution in the Bolivar WWTP discharge channel	D	5	Low
			Hypersaline ponds to be drained forward to the crystallisers, remaining brine (<5%) to be diluted by winter rains	D	5	Low
			Discharges to Dry Creek to be conducted overnight to catch the higher of the daily tides	C	4	Moderate
			Discharges to Dry Creek to coincide with stormwater flows down the creek wherever possible	D	5	Low
Flooding from draining saline waters from the ponds	D	5	Breaches should be at existing drainage lines, with clear drainage to the sea	E	5	Low
Sea flooding over inboard pond walls once the outboard seawalls are removed	B	4	Survey inboard pond wall before breaching outboard seawall. Raise inboard pond wall to meet CPB guidelines where necessary	D	5	Low
Sea level rise storm surges impacting on future commercial ventures that utilise the existing ponds	C	4	Rehabilitate the ponds to tidal wetlands rather than developing commercial ventures on them	D	5	Low

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Increased land-based flooding from urban development on, and adjacent to, the saltfield	B	4	Rehabilitate the ponds to tidal wetlands that receive stormwater and fluvial input	D	5	Low
Risk of rehabilitation requirements accruing to the Crown	C	3	Determine ultimate rehabilitation targets for all land now, and request the current miner meet them prior to rescinding the mining leases	D	5	Low

2. Introduction

The AMLRNRM Board has requested the provision of a briefing paper which outlines risks and opportunities to coastal habitat and migratory shorebirds associated with potential closure and decommissioning of Ridley Corporation's Dry Creek Saltfields and associated minerals leases, to inform decision making processes for the Board, the Department of Environment, Water and Natural Resources and other stakeholders.

While the briefing paper will not provide comprehensive advice on issues discussed, it is targeted to provide adequate guidance for interagency and stakeholder discussion and to identify future areas of investigation.

The mosaic of natural and artificial wetlands of Dry Creek Saltfields supports the greatest abundance of migratory shorebirds in the region. The seventy kilometres of coastline covered by the mining leases include a range of coastal and estuarine habitats rarely found so close to a large centre of population. The leases occur over land that hosts flora of local, State and National conservation significance. In particular, the salinas of the operating saltfield return counts in excess of 1% of the flyway population of red-necked stints and sharp-tailed sandpipers (Birdlife Australia Internationally Significant Sites database), while the interconnected sabkha complexes north of the River Light contains the largest Australian populations of the EPBC Act listed samphire *Tecticornia flabelliformis* (Coleman 2012), as well as one of the largest near-pristine deltaic estuaries in Gulf St Vincent.

In the light of a potential closure of the saltfields, the Board seeks to identify achievable options for progressing decommissioning to minimise risk in the short and long term and provide guidance for stakeholders to achieve the best possible conservation outcomes for the area.

3. Dry Creek Saltfields mineral leases

The mineral leases of the Dry Creek Saltfields (Figure 1) extend from the suburb of Dry Creek northwards for approximately 70 kilometres to Port Parham on northern Gulf St Vincent. During the nearly seventy years of its operation the saltfields' salinas have become a distinct series of biomes placed within the wider tidal wetland landscape. Recent reports (*Shorebird Management and Conservation* by Coleman & Cook, *Shorebird Monitoring & Habitat Mapping Project: Gulf St Vincent* and *Shorebird Population Monitoring within Gulf St Vincent: July 2011 to June 2012* by Purnell *et al*) have identified the shorebird values of the site and provided detailed mapping of the tidal wetlands and artificial salinas.

Salinas are artificially controlled saline ponds used to produce common salt. The salinas of the Dry Creek Saltfields are maintained at controlled salinities, spread out spatially with the ponds with the lowest salinities occurring in the north and the ponds (crystallisers) containing saturated salt solutions at the southern extremity of the site. A diagram showing the layout of the ponds, the brine flow paths and the salinity of each pond is attached in *Appendix 1*.

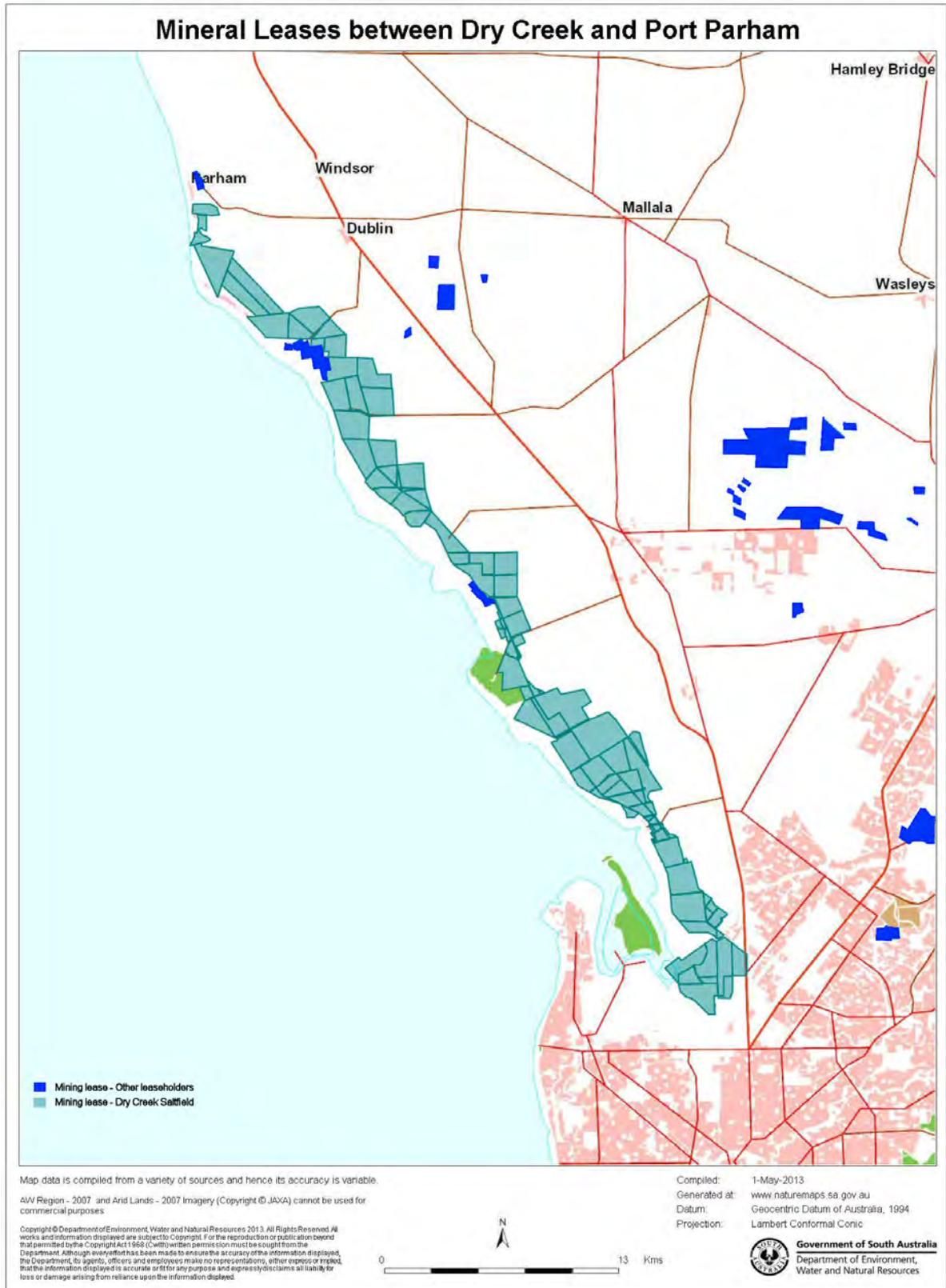


Figure 1 - Mining leases Port Parham to Dry Creek

The constant forward flow of water creates a range of lagoonal biomes with each pond being maintained at a specific salinity and depth at all times. As a result of the maintenance of stable salinity conditions and the constant supply of fresh brine with high oxygen concentrations, each biome contains a range of algal and faunal species specific to its salinity range.

Marine salinity concentrators in the Dry Creek salinas are located near Middle Beach and are fed by pumps. The rocky pumping basins replicate a high-impact coast, with oxygen-rich waters flowing rapidly past the rock walls. These pumping basins contain high densities of rocky shore marine species. The ponds themselves are shallow and sheltered, with salinities ranging (along a set of four or five ponds) from 39-65 g/L Total Dissolved Salts (TDS). These ponds are the youngest ponds in the saltfields, being built in the 1970s, and form nearly a half of the pondage in the Dry Creek Saltfields. They currently support seagrass meadows and a wide diversity of invertebrates and fish. These ponds are attractive to fishing birds like pelicans and to herbivores including black swans. Mangroves have colonised the first of these ponds, despite the lack of tides. Over the forty years since these ponds were built, there have been occasions when the dodge tides of the Gulf have made pumping sufficient flows of brine impossible, resulting in fish kills. These stressors are probably the reason that the benthic flora has gradually changed, with a move away from robust brown algae to the shorter lived chlorophyte species. Over the same period the native mud oyster and cockles have both disappeared from the benthic fauna of the first ponds.

The succeeding salinas (south of the Gawler River) are classed as low hypersalinity (65-110 g/L TDS) ponds and the species found in them are different. While some species of small fish occur in these ponds, gradually crustaceans, molluscs and insects become the dominant fauna, with an ever-changing array of plankton. In the medium hypersaline ponds (110-175 g/L TDS) where flos ferri (calcium carbonate) and gypsum (calcium sulfate) begin to precipitate, the remaining macrofauna are the brine shrimps, *Artemia franciscana* and *Parartemia zietziana*, along with larval stages of the brine flies (*Ephydrella* sp.). These ponds are much shallower than the early ponds and are good feeding grounds for shorebirds, particularly a high tide when the extensive tidal flats of Gulf St Vincent are submerged and unavailable.

Benthic microbial mats start to become a dominant feature of the salinas just north of St Kilda and south to Dry Creek. These ponds are highly hypersaline (175-287 g/L TDS). Microbial mats contain layers of microalga, mainly cyanobacteria (blue-green algae), diatoms and bacteria. In many salinas the mats grow into balls, and are referred to (incorrectly) as stromatolites as they resemble the fossil structures. The different layers of the microbial mats consist of a top layer of diatoms, a lower layer of cyanophyta and a lowest layer of purple bacteria. Benthic mats and planktonic microalgae provide food sources for brine shrimp. The two species of brine shrimp move between the ponds in response to slight salinity changes over the season. *Parartemia zietziana* dominates in the lower salinity hypersaline ponds north of St Kilda while *Artemia franciscana* is the sole crustacean in areas of highest salinity south of St Kilda.

Artemia franciscana continues to be present in final area ponds south of Dry Creek, where brines are almost saturated for sodium chloride, even up to the crystallisation point of salt (330 g/L TDS). The halotolerant green microalga *Dunaliella salina* and several types of pink bacteria are found in the crystallizing pans.

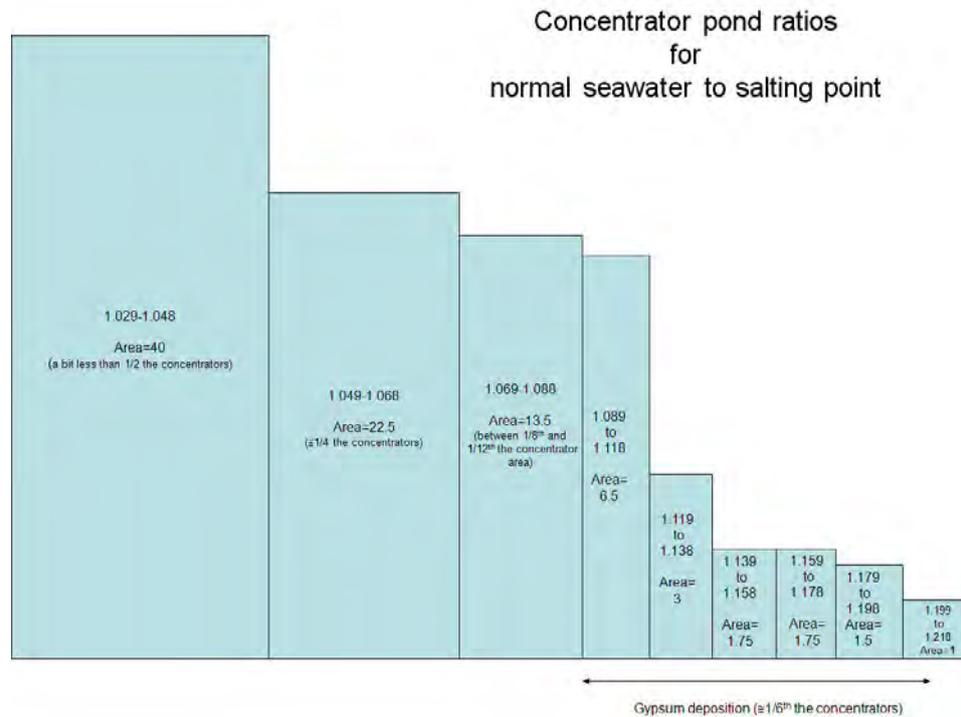


Figure 2 - Pond ratios in a series flow saltfield

In a steady state series flow saltfield the amount of area taken up by each succeeding salinity zone is driven by the net evaporation and is typically that displayed in Figure 2. A point to note are that zones such as those that support brine shrimp are dependent on the existence of a much larger area preceding them. For example, every hectare of lowest salinity brine shrimp pondage (SG1.089 to SG 1.118) requires 11.6 hectares of lower salinity ponds to produce sufficient brine to supply that single hectare of brine shrimp habitat.

In the event of closure of the saltfields there will be impacts on shore and other birds that have become dependent on the various biomes of the artificial salinas as a food supply. Studies overseas (Atkinson *et al* 2001) have found that although birds can move to other feeding sites, there is often a long-term negative impact on populations when this occurs. Essentially, populations expand to utilise the available resource. So the other feeding grounds to which the refugee birds relocate may be ones where there are lower numbers of prey species, or they may be already occupied to capacity. In the latter case the immigrant birds and the residents of that patch will interfere more with each other's hunting. Additionally, some benthic prey species respond to increased predation by burrowing deeper, so a larger population of birds can cause the prey to become less accessible to all the birds. The long-term implications of poor nutrition for migratory species are that fewer may successfully migrate, those that do may be more prone to disease, and that breeding success may fall.

The impacts of closure may be ameliorated only to a limited extent, depending on the approach taken to the closure and the ultimate remediation and proposed end usage of the land previously occupied by the saltfield ponds.

Potential habitat impacts and other risks resulting from conversion of the larger, freehold ponded parts of the site to other uses including housing are unlikely to be fully addressed by amelioration activities on the smaller, Crown portions of the site.

However all efforts to maximise the biodiversity benefits on the Crown lands should be undertaken to balance the risks.

4. Mining tenure

4.1 Closure and the Mining Act

According to “*Guidelines for Miners: Mining Approvals in South Australia, MG1, ver 1.9*” (PIRSA, 2009), prior to relinquishment of a mining lease the miner must complete a “mine completion report” that demonstrates that the general standards and agreed closure outcomes have been met. The report may be for an entire site, or for a section of a site comprising several mining leases, if progressive rehabilitation is being undertaken. The report must contain a residual risk analysis and proposed post-surrender action, including arrangements for maintenance and funding. This must include consideration of risks and liabilities associated with legislation other than the Mining Act (e.g. *Environment Protection Act 1993*, Contaminated Land Provisions) and any particular requirements relevant to post-surrender action in relation to these.

A sign-off by the landowner accepting the rehabilitation standards and criteria, and acknowledging that they are aware of the residual risks and accept the post-relinquishment arrangements is also required.

In South Australia land does not have to be returned to “the way it was” before the mining activity. It has to be returned to a state that is fit for the purpose for which it is to be used.

4.2 Implications of underlying ownership

The owner of the land underlying the mining tenements negotiates what standard of rehabilitation they reasonably require for their land. In the case of the Dry Creek Saltfields, the area of mining leases amounts to nearly 10,000 hectares. Only approximately 4,000 hectares have been developed as salina ponds and the remainder is undeveloped. Of the total 10,000 hectares under mining lease, approximately 75% is owned freehold by Ridley Corporation, the miner. This is a fairly recent increase from 50%, and is a result of the PLAF (Perpetual Lease Accelerated Free-holding) process undertaken by the Crown Lands department on undeveloped perpetual leases north of the existing pondages, between 2006 and 2009.

Any rehabilitation targets for the land owned by Ridley Corporation are likely to be dictated by the company’s proposed end use of that land and this use may not reflect amelioration of shorebird impacts as a priority.

The Crown still retains extensive landholdings underlying the mining tenements, including large undeveloped, essentially pristine, areas of the Light River delta, considerable areas of salina pondage south of Port Gawler, some areas of largely undisturbed, naturally rehabilitating tidal wetlands south of St Kilda that were cut off from the sea by the St Kilda-Dry Creek levee in the 1890s but that were reconnected to the tide via levee breaches in the 1930s and some Crown freehold land in the crystalliser area at Dry Creek.

The Crown (and its various agencies) will need to enter into negotiations with the miner to determine what standards of rehabilitation they reasonably require for Crown Lands that have been impacted by saltfield mining activity. The following section (Section 5) outlines some of the end use opportunities that may present themselves for the Crown land, and Section 5.2 analyses these opportunities by examining the saltfield mineral leases as a series of regions.

5. Risks and opportunities

5.1 Possible Crown Land end uses

5.1.1 Reissue mining leases

Other miners, including smaller salt operators, gypsum miners and shell grit miners, may be interested in obtaining mineral leases over currently undeveloped leases north of the existing ponds to build new saltfields or to mine shell grit deposits in the chenier formations.

Similarly, some of the existing ponds that occur on Crown Land may be attractive to gypsum miners, or to salt operators who may possibly be able to rework several ponds into a smaller field.

Any consideration of reissuing mining leases should take into account the objective in the Metropolitan and Northern Coastal Action Plan (MANCAP) identifying a need to reduce the loss of saltmarsh land. To meet that objective the MANCAP has recommended (*Action: 8.8.(j)*) the Natural Resource Management Board work with DEWNR and DMITRE to review mining tenements within saltmarsh areas, with a view to reducing the total area of potential mining, in particular in areas of high conservation value.

5.1.2 Issue Crown leases for other uses of existing ponds

Where existing salina ponds occur on Crown Land there has been some interest expressed by various organisations in using those ponds either for commercial ventures or for conservation-based outcomes. Commercial interests include reworking some of the ponds to support either aquaculture or biofuels development, while conservation organisations have suggested maintaining ponding for waterbird use or specific salinity ponds for different shorebird food sources.

5.1.3 Dedicate existing ponds to Councils or SA Water

There has been some suggestion that existing pondage may provide local Councils with area for stormwater detention purposes. Other suggestions have included using the ponds as polishing pondage for the Bolivar Waste Water Treatment Plant (WWTP).

5.1.4 Current miner to rehabilitate ponded Crown Land

An opportunity exists, under the Mining Act, to require the current miner to undertake rehabilitation works on ponded areas overlying Crown Land that will allow the ultimate development of self-sustaining tidal wetlands. Such wetlands would form a natural sea level rise buffer, a large area for an active and permanent carbon sink, a natural sedimentation zone for stormwater and a range of feeding and shelter opportunities for migratory birds, and a habitat for a full range of tidal wetland flora and fauna.

The evolution of tidal marshes is a process that has been shown, in studies overseas and in local experience, to occur over a period of many decades (Philip Williams & Associates *et al* 2004, Fotheringham 1994, Coleman 1998, Atkinson *et al* 2001, Sanzone & McElroy 1998). While it may not be feasible for the miner to retain responsibility for the evolution of the land over that period of time, they may reasonably be required to undertake all the necessary earthworks and hydrological reconnection to the surrounding tidal wetlands that will provide the geomorphological template for natural regeneration of the site.

The Crown, as a landholder, will need to negotiate the rehabilitation targets and determine what outcomes it would deem acceptable. Miners in South Australia can be asked to provide a rehabilitation bond for the full value of the rehabilitation of the site. The bond is held by DMITRE. It is not known whether such a bond could be used to support works beyond the immediate rehabilitation.

5.1.5 Conserve undeveloped mineral leases

The undeveloped mineral leases include some sabkha habitat between Port Parham and the River Light, a large and relatively pristine area that covers the conjoined deltas of the River Light and Salt Creek, an extensive area of saltmarsh and mangroves at Port Gawler and extensive areas of saltmarsh and mangrove between St Kilda and Gillman. Some of these areas are included in “multi-use” conservation zones such as Aquatic Reserves and Marine Parks. Some are completely unprotected. There is an opportunity to incorporate any unprotected areas that are immediately adjacent existing reserves into the conservation estate. There is also the opportunity to develop new reserves to capture specific areas of conservation significance and provide further buffers to minimise disturbance to shorebirds.

These different approaches will be examined more closely in Section 5 and 6 of this briefing paper, which will analyse the entire 70km of coastline in some detail and assess some of the more significant risks in the different approaches.

5.2 Area-specific analysis

5.2.1 Port Parham to Light Beach

Crown and public lands (shaded grey in the following maps) underlie limited areas of the northernmost mineral leases that are held by Ridley Corporation (red hatched lease outlines.) Other mineral leases also occur on Crown lands in this zone, mostly operated by shell grit mining companies).

The Crown land is present as a narrow coastal strip, except where there are estuaries and other areas of significant habitat. These larger areas of Crown land occur at the northern (Port Parham-Webb Beach- Baker Creek) and southern (Light Beach-Light River delta) extremities of this zone, as shown in Figure 3.

While smaller salt operators may be attracted to developing the northern undeveloped leases on Crown land, the two largest areas of Crown both host the EPBC Act listed species *Tecticornia flabelliformis* (yellow triangles in Figure 3). Detailed population estimates (Coleman, 2012) reveal that upwards of one million individuals of *T. flabelliformis* occur between Port Parham and Light Beach, mainly on lands owned by the Crown and Ridley Corporation. This is the largest population, and area of occupation, of this species so far mapped in Australia. The Metropolitan & Northern Coastal Action Plan (Caton *et al*, 2009) has identified the conservation of *T. flabelliformis* in Cells MA21 – Port Prime, MA22 – Thompsons Beach and MA23 – Port Parham as a high priority. There is potential to incorporate some of the coastal Crown land into existing reserves such as the Shorebird Trails north and south of Thompson Beach, or the land could be integrated into a network of Crown reserves along the Sapphire Coast (DC Mallala, 2003).

Coleman & Cook (2009) provide a shorebird biodiversity value for the coastal sabkhas of this zone varying from low to medium value (3-19 species), while recent count data (Purnell *et al* 2012) provides an abundance figure of >1600 individuals using these saltpans.

It is not known what Ridley Corporation intends as an end use for its freehold lands in this region. Possibilities would seem to include sale to existing tenant farmers, and if no change in land use occurs, the shorebird and *Tecticornia flabelliformis* values for the area are likely to remain intact. Any change in land use may trigger the EPBC Act if it would result in significant impacts on either shorebirds or *Tecticornia flabelliformis*.

Shell grit operators already have mineral leases over some of the land in the area above and some of the mineral leases held by Ridley Corporation cover lands with shell grit resources. No significant shell grit resources appear to be located in those parts of Figure 3 that are denoted as Crown lands under Ridley Corporation-held mineral leases.

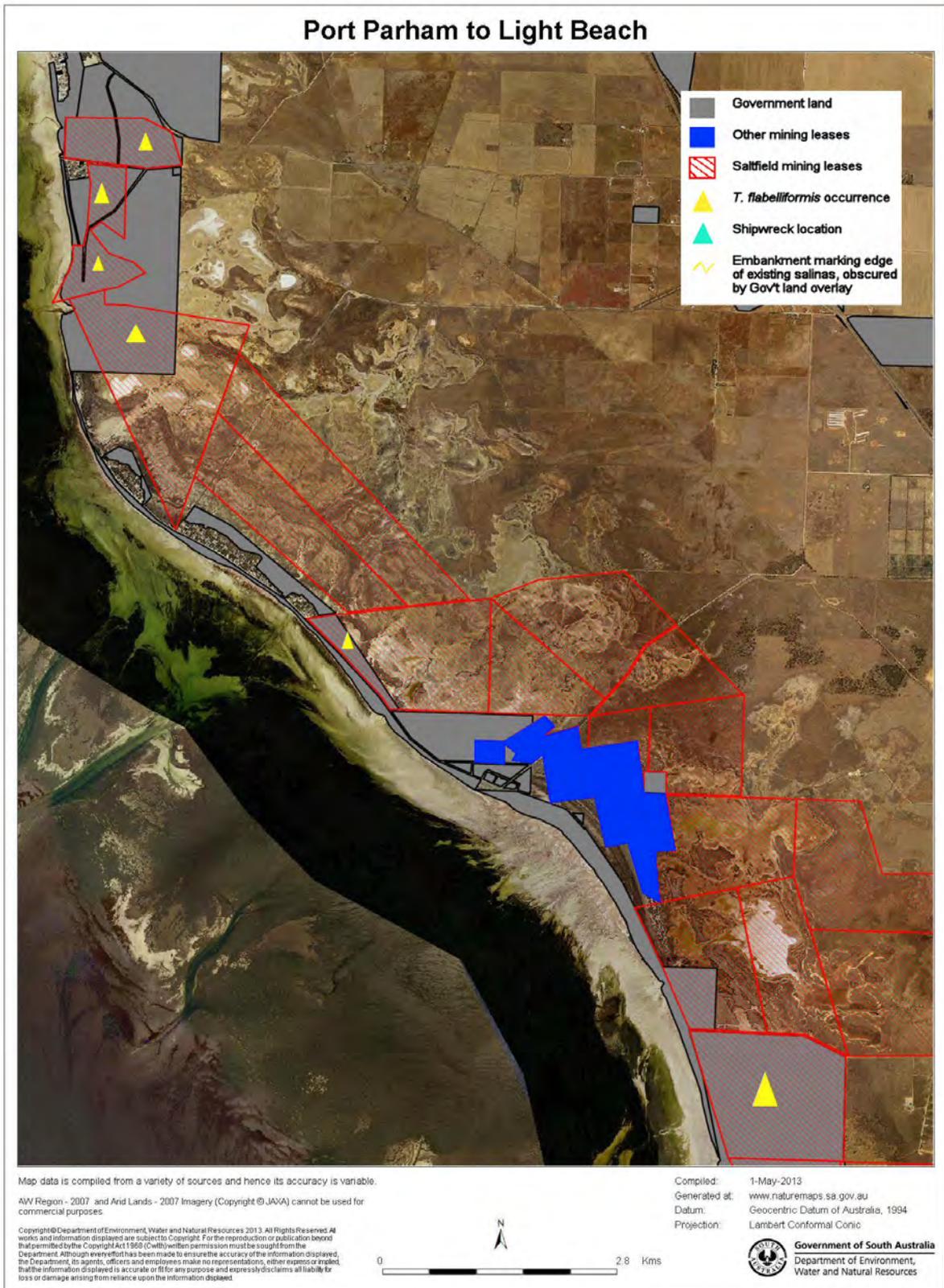


Figure 3 - Port Parham to Light Beach

5.2.2 Delta zone

There is a significant congruence between Crown lands and mineral leases in the area illustrated in Figure 4, referred to here as the “Delta zone”. A comparison with the zoning map for the Upper Gulf St Vincent Marine Park (Figure 5) reveals that a large portion of the delta of the River Light is already zoned as Sanctuary Zone within the Marine Park.

Coleman and Cook (2009) rated the saltmarshes of the Light River delta as having a high biodiversity value for shorebirds, supporting 20-29 species, while the sabkha areas of Light beach and Middle Beach had medium to low values, supporting 3-19 species.

Unfortunately the delta saltmarshes are not counted by Birdlife Australia’s monitoring (Purnell *et al*, 2012) due to difficulties in accessing this extensive area of tidal wetlands. There is potential to use drone technology to undertake counts for this section of coast, however the current difficulties for access mean that abundance values for the zone are not clear. Abundance data for the very small areas of intertidal salt marsh and mud flats at Middle Beach were ≤ 100 (Purnell *et al* 2012), while the same authors report abundances of shorebirds at Light Beach to be ≤ 3500 .

There is an opportunity to increase the Sanctuary Zone in two areas of the delta zone. Crown lands in the Swan Creek portion of the central-north River Light delta were excluded from the current Sanctuary Zone because these creeks would form the intake creeks for any expansion of the Dry Creek saltfields. To the south of the existing Sanctuary Zone the conjoined Salt Creek delta area was excluded from the current Sanctuary Zone because this land would form an essential pondage corridor for any northern expansion of the saltfields. These concerns no longer exists, and incorporating these areas into the Sanctuary Zone would provide increased protection for an area of medium biodiversity value shorebird habitat, as well as adding to the significantly sized pristine tidal wetlands with high value for migratory shorebirds that are already included in the Sanctuary Zone (Coleman and Cook, 2009).

The Metropolitan & Northern Coastal Action Plan (Caton *et al*, 2009) identifies the conservation of *Tecticornia flabelliformis* in Cells MA19 – Middle Beach and MA20 – Light River Delta as a high priority. Enlarging the Sanctuary Zone to include the southern conjoined Salt Creek delta area would increase protection for *Tecticornia flabelliformis*.

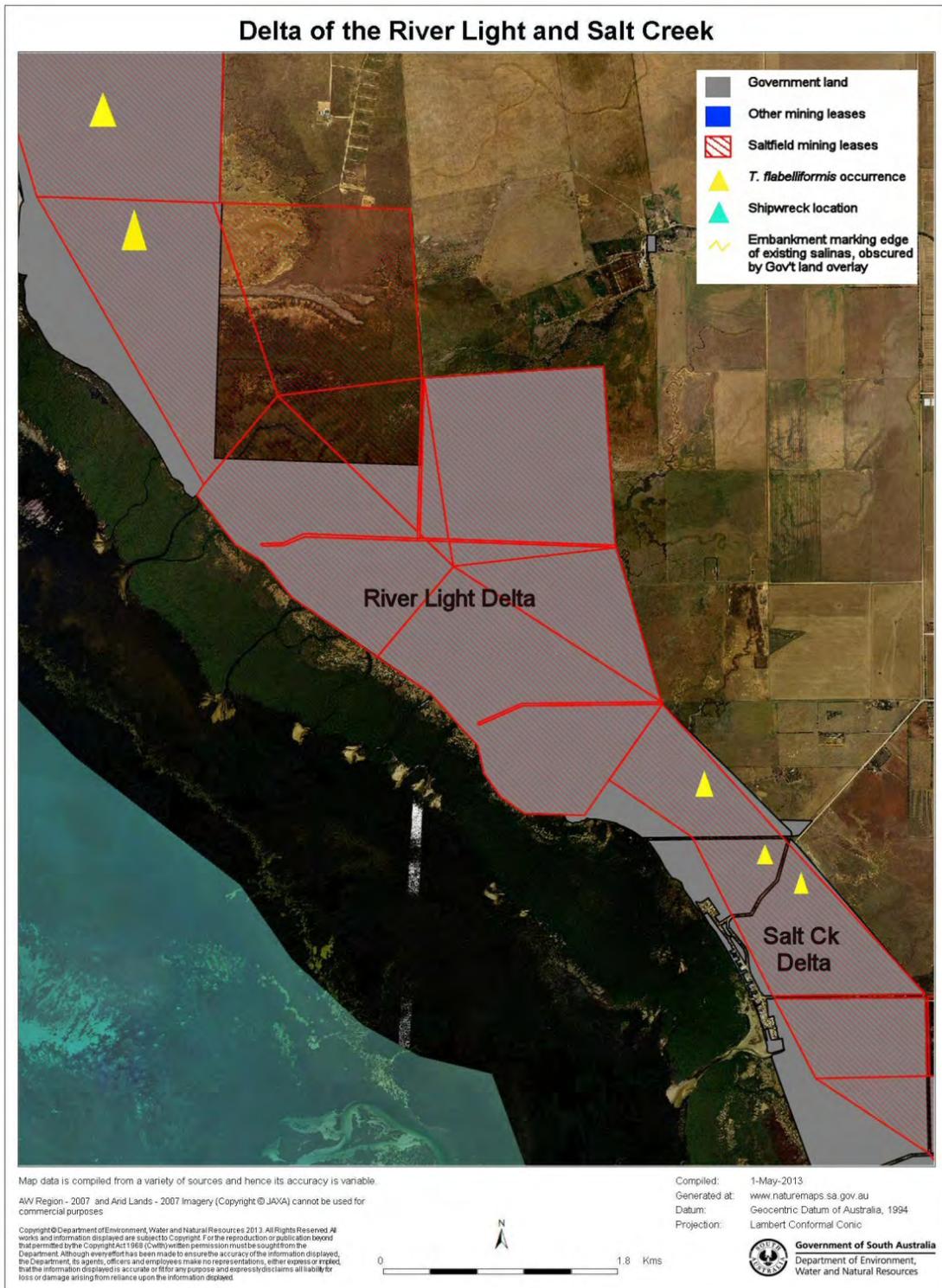


Figure 4 - River Light & salt Creek deltas

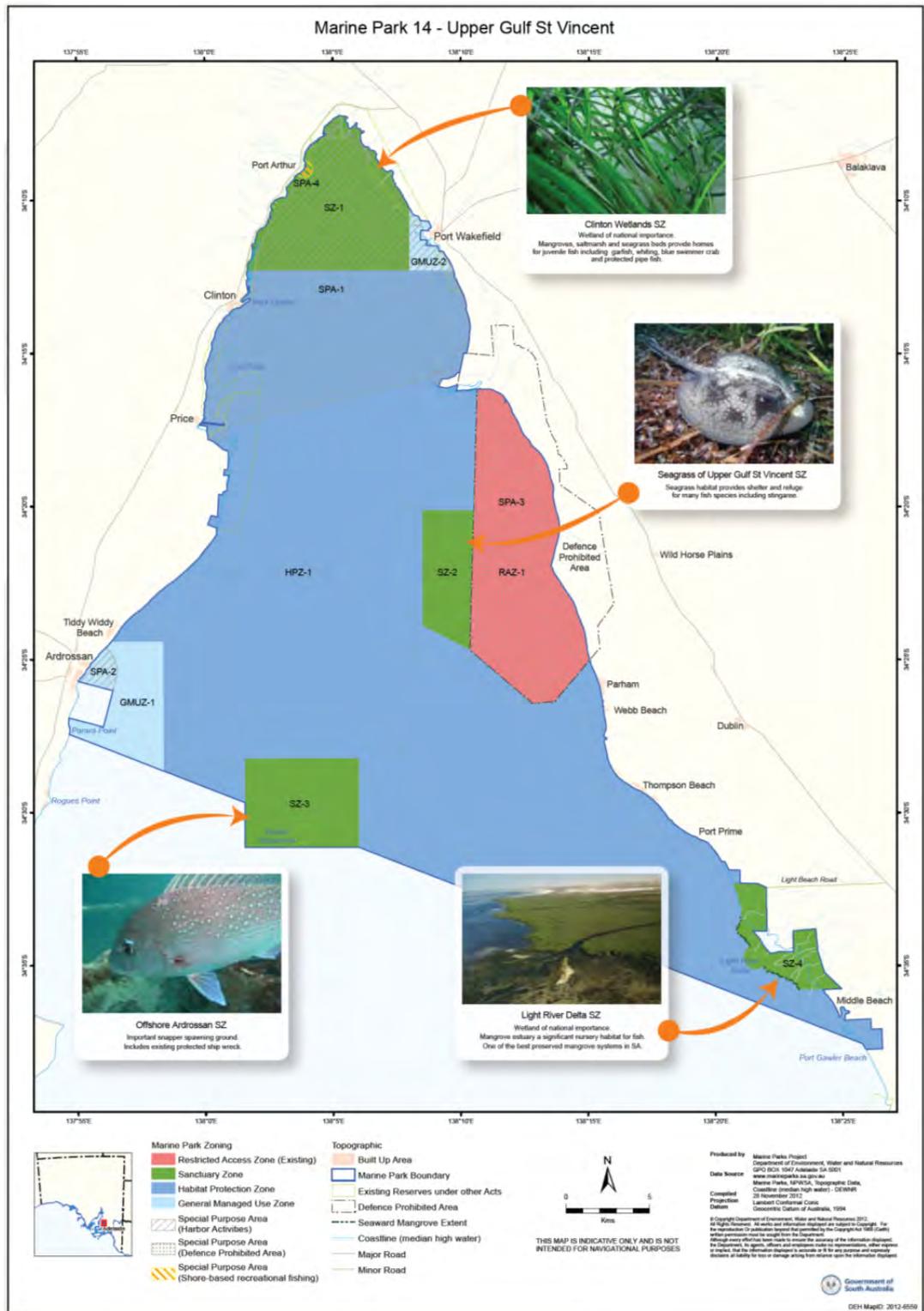


Figure 5 - Marine Park zoning

5.2.3 Salt Creek to Gawler River

The northernmost salinas of the Dry Creek saltfields can be seen in Figure 6. Most of the pondage occurs on Ridley Corporation's freehold lands, but portions of ponds XE1-3, XE5 and most of XE6 overlie Crown land. The embankments that would be hidden by the grey colouration of the public lands in Figure 6 have been added in as yellow lines to delineate the extent of these ponds. Once again, Ridley Corporation occupies only the bright red leases – the small leases west of the saltfield ponds are shell grit leases operated by others.

Current biodiversity in these mostly marine salinity ponds favours waterbirds over shorebirds, with these ponds providing medium diversity value (11-19 species) habitat for shorebirds (Coleman and Cook, 2009). Abundance data of approximately 600 individuals for the XE1-3 series of ponds, 350 for Ponds XE4 and XE5, and about 50 for the smaller XE6, XE7 and XE7a ponds have been reported by Purnell *et al* (2012).

Elevations of the floor of the ponds in this area are variable. The ponds currently placed over Crown land were formed in areas that had never been isolated from the natural hydrological regime, and so the land was at natural surface level and was being used as grazing land that was subject to occasional inundation, at the time the ponds were built. Pond XE1-3 has floor elevations typically ranging from 1.15mAH to 2.45mAH, suggesting that if drained and reconnected to the tidal wetlands north and west of the pond; the land would be flooded by the tides possibly fortnightly in the lowest parts and very rarely in the higher zones. The land would eventually develop a range of habitats that included a *Maireana oppositifolia* chenopod shrubland (emergent or mid-high marsh) and an *Atriplex paludosa* chenopod shrubland (high marsh).

The elevation of the base of Pond XE5 is unknown, but is likely to be similar to that of XE1-3. The elevation of Pond XE6, while unmeasured, is estimated to be about 1.45mAH based on water surface elevation, typical depth and proximity to Gawler River.

The pondages are approximately 40 years old and the constant presence of seawater over that period of time will have resulted in the deposition of some sulfide-rich sediments, but these should be relatively small quantities when compared to natural saltmarsh and mangrove areas that have evolved over some thousands of years.

There may be some production of acid sulphate runoff if these ponds are drained, as their floor elevations are mostly above mean higher high water (MHHW), which is around 0.9mAH for this part of the SA coast. Elevations below MHHW tend to maintain saturated soil conditions once freely reconnected to the local tidal hydrology (Philip Williams & Associates and Faber, 2004) so sediments below that elevation are unlikely to oxidise. However the extensive intertidal wetlands between the open sea and the higher parts of these ponds should provide a large area for carbonate-rich seawater to ameliorate any acid.

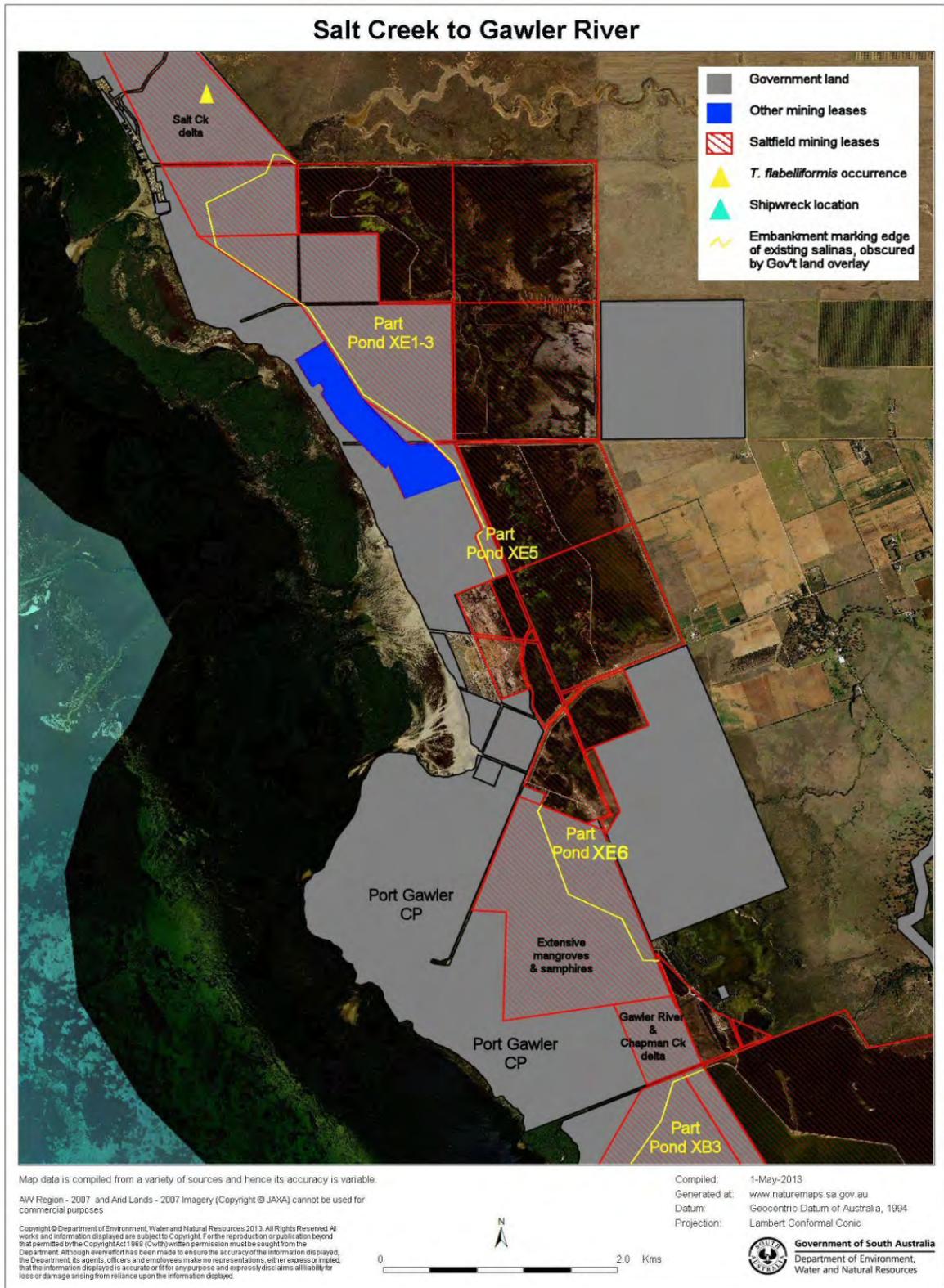


Figure 6 - Salt Creek to Gawler River

Crown lands west of the leases at Pond XE1-3 include an area of good quality tidal wetlands south of Middle Beach township between Salt Creek and Second Creek, an badly degraded area of shell grit leases (subject to ongoing illegal dumping) between Shell grit Road and Second Creek, and the Port Gawler Off-Road Park. These areas flood at the very highest of storm tides.

Land incorporating the eastern part of Pond XE1-3, along with the XF and XE4-5 series of ponds, is Ridley Corporation freehold and these eastern pondages and the adjacent land rises fairly rapidly. The land is well placed to eventually form a northern suburb for the proposed Buckland Park township. Should such a development eventuate, stormwater disposal and flooding may be an issue – Buckland Park Lake currently breaks north towards Salt Creek as well as south towards Gawler River when it floods. Crown lands in this area, if reconnected hydrologically to the surrounding wetlands, may form a useful sea-level rise buffer, stormwater detention area and ultimately evolve into a tidal/supratidal wetland with high biodiversity values for shorebirds and other flora and fauna.

The mineral leases west and south of Pond XE6 contain extensive tidal wetlands comprising saltmarsh and mangroves, and are immediately adjacent to the Port Gawler Conservation Park. These leases could be included in the Conservation Park, as could Pond XE6 if it were reconnected hydrologically with its neighbouring wetlands. To the east of Pond XE6 the Crown already owns land that forms the ephemeral freshwater Buckland Park Lake, so the inclusion of these leases and pondages into the conservation estate in one form or another would appear an excellent opportunity.

The Metropolitan & Northern Coastal Action Plan (Caton *et al*, 2009) identifies the incorporation of tidal wetlands in this zone (MA18 – Gawler River) into the conservation estate as a high priority.

The inclusion of additional intertidal wetlands into the Park is supported in a 2011 report by the Natural Resources Committee of the SA Parliament. Their report, tabled in the House of Assembly, recommended that the Minister for Environment and Conservation request that the Department for Environment and Natural Resources prepare a Cabinet Submission recommending that the boundary of the Port Gawler Conservation Park be enlarged to include Crown land that forms part of the habitat for migrating birds and which is being threatened by inappropriate off-road vehicle use; and upgrade surveillance of the park by NWPS officers (Parliament of SA, 2011).

5.2.4 Chapmans Creek to St Kilda

Figure 7 shows the area between Chapmans Creek (southern outlet of the man-made Buckland Park Lake) and St Kilda.

Roughly 60% of the nearly 2000 hectares of mineral leases in this area overlie Crown land. The salina ponds in this zone contain habitats with high to very high waterbird and shorebird diversity values of 20-38 species (Coleman and Cook, 2009). Purnell *et al* (2012) report shorebird abundances of up to 16,000 individuals in the shallower and more hypersaline of these ponds. Large parts of Pond XB3, the most north-westerly of these ponds are too deep for intense shorebird use, however.

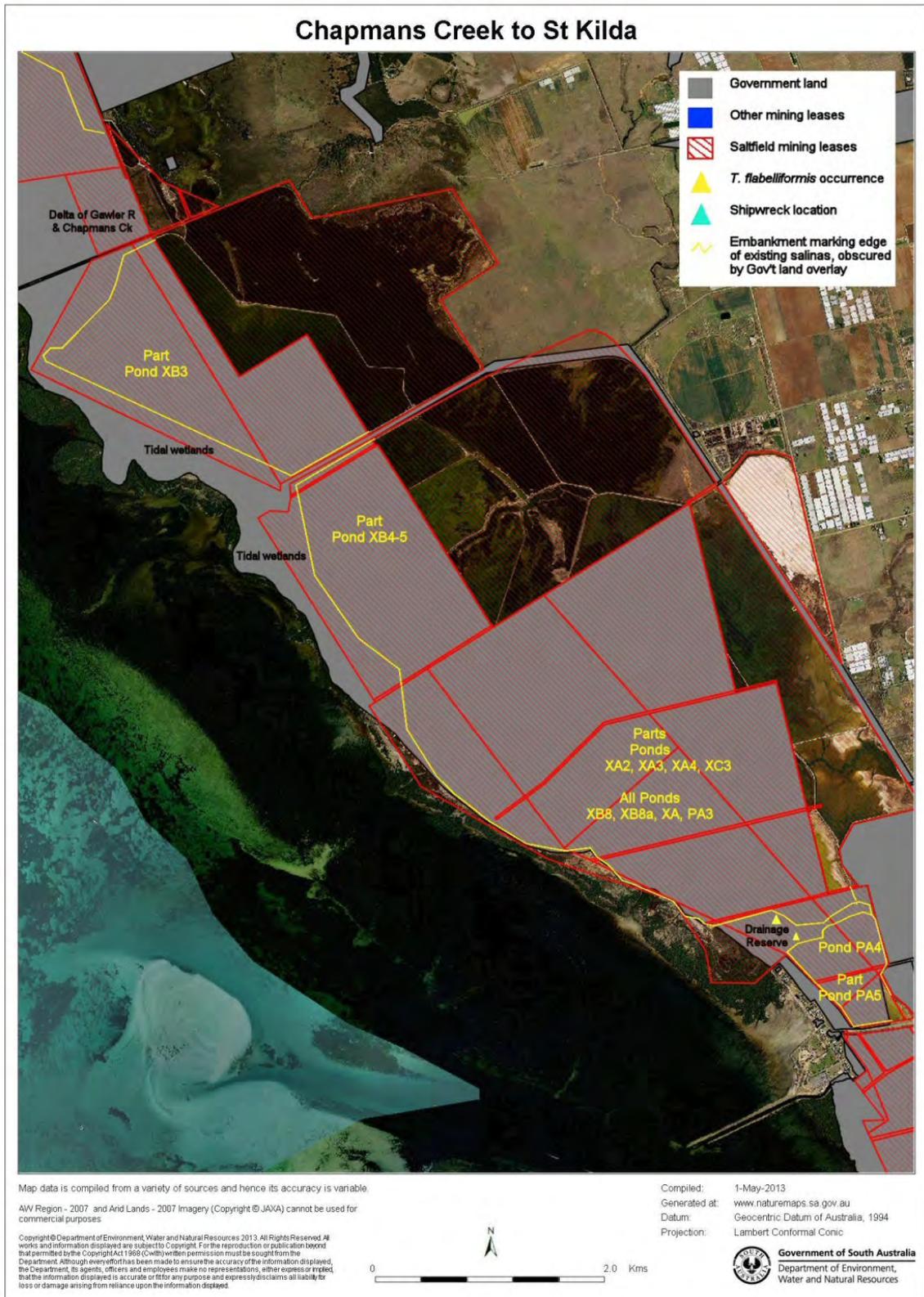


Figure 7 - Chapmans Creek (Buckland Park Lake) to St Kilda

There have been suggestions that some of the ponds in this zone could be managed to provide habitat for specific bird species, for aquaculture, for the development of a small saltfield, used as detention basins or polishing ponds, or remediated to allow the evolution of self-sustaining tidal wetlands. As this zone contains the largest area of ponds on Crown land, these various approaches are more fully explored in the following subsections.

It is not known to what use Ridley Corporation intend to put the freehold land they own in this zone. The eastern, higher, ponds are well placed to form a southern suburb eventually, for any township that develops at Buckland Park. Before discussing the wide range of alternative land uses proposed for the Crown land in this zone, the following significant risk is identified.

At present the State has an unparalleled opportunity to oversee the remediation of an extensive stretch of coastline by the existing miner. Choosing to utilise portions of the area for various other small ventures rather than fully realising the potential to remediate these lands may attract some future liability to the State in the event that those ventures fail.

This is particularly so in the cases of aquaculture, biofuels development and managed conservation pondage. These non-mining ventures would occur on Crown leases and there is no legislative power in the Crown Lands Act to take a "remediation bond" to ensure the site is eventually remediated to a standard that the Crown would accept. Mining ventures such as new saltfields would have to provide a bond to DMITRE and their remediation targets would be set out in the Program for Environmental Protection and Rehabilitation (PEPR) for the mine. In the event that the Crown were to consider that a new mineral (salt) extraction lease was an appropriate end use of this land, there would be an opportunity to negotiate the closure rehabilitation targets with the miner prior to the establishment of the mine.

5.2.4.1 Managed ponds for birdlife

Suggestions have included operating Pond XB3 only (by pumping in seawater at Chapmans Creek and releasing seawater at the Bolivar WWTP discharge channel) or operating all the Crown land ponds between Chapmans Creek and the drainage reserve just north of St Kilda. In all cases there would be a distinct change in the biomes of the existing ponds, as the salinity gradient would be altered significantly. This would necessarily result in these ponds eventually supporting a different range of flora and fauna.

Evaporation is the driving force when managing saline waterbodies. Unlike a freshwater lentic environment, simply adding more intake water will not keep the salinity stable, because the intake water adds more salt. Therefore it is not possible to run any pondage without producing a discharge at the end of the pond system that is of a higher salinity than the intake brine.

So, for example, Pond XB3 currently has an input salinity of 55 g/L and can have an output salinity of around 65-70 g/L in stable dry conditions. If a pump were installed at Chapmans Creek it would pump in brine with around 35 g/L. As the pond is shallow, wide and wind mixed, it would not be possible to maintain a stable salinity gradient from 35 g/L to 70 g/L down the length of the pond. This is

too large a variation and would result in unstable salinity patterns during windy weather, which would most likely result in the deaths of much of the pond flora and fauna. Artisanal salt ponds in Indonesia frequently have initial ponds with a very wide salinity gradient and such ponds nearly always have a benthos that is devoid of flora and poorly colonised with macroinvertebrates.

If a narrow salinity gradient were to be chosen, as similar to seawater salinity as possible so that discharge of hypersaline brine would not be necessary, the pond benthos would probably change from being dominated by *Ruppia* spp. and *Polyphysa peniculis* towards *Zostera* seagrasses and various seaweeds, providing it were maintained at its current depth. Such a lagoonal habitat would be attractive to waterbirds including herbivorous species such as black swans and fishing birds including egrets, herons, pelicans, ducks and grebes, but may be of lower value to shorebirds due to its depth. If the pond were maintained at a lower depth it is likely that the flora may change towards filamentous green algae such as *Chaetomorpha billardierii*. The shallower pondage would be more attractive to shorebirds, but less attractive to waterbirds, and its shallowness could lead to wide temperature and oxygen fluctuations.

In either case, once the initial volume in the pond was achieved, modelling (see *Appendix 5 – Volume calculations for artificial pond maintenance*) suggests that with current average annual evaporation, rainfall and seepage rates, in order to maintain a steady state discharge salinity of 43 g/L an annual pumping rate of 24,250,000 m³ of seawater would be required. This would result in a discharge volume of 18,605,220 m³ at the Bolivar WWTP channel. For a pump with a capacity of 6,800 kL/hour it would take more than 3,500 hours per annum (or an average of approximately 10 hours of pumping a day) to keep Pond XB3 supplied. A large capacity pump such as this requires regular maintenance which entails the use of heavy crane trucks, and so the embankments providing access to the pump must be maintained as all-weather roads with the capacity to safely utilise heavy trucks. Finally, since the pumps were removed from Chapmans Creek the electricity infrastructure has deteriorated and it is likely that a new transformer would be required at Gawler River along with replacement lines from the transformer to Chapmans Creek.

If the larger area of pondage was to be used, discharging to the drainage reserve just north of St Kilda, the same volume of intake brine would result in a continuous hypersaline discharge at St Kilda of 176 g/L, similar to the current operating salinity of Pond PA3. The salinity gradient within the ponds would be lower in the initial pond (XB3) than currently, however the gradient would gradually align with the existing gradient in the ponds further south, until it matched the current regime in the last pond (PA3). This would provide the widest range of habitats in the ponds, from marine through to hypersaline ponds that support both the native fairy shrimp (*Parartemia zietziana*) and the introduced brine shrimp (*Artemia franciscana*), which are a preferred food for some shorebirds.

Unfortunately there would be no commercial requirement for the salt in this concentrated brine to feed crystallisers and disposal would result in a high sodium discharge at St Kilda. Unlike bitterns from the crystalliser area at Dry Creek that already has most of its sodium chloride removed, this brine would still contain a high sodium concentration, suggesting it would be likely to have deleterious impacts on the flora and fauna of the tidal wetlands into which it

discharges. The drainage reserve contains a small population of the EPBC Act listed samphire, *Tecticornia flabelliformis* (yellow triangles in Figure 7).

If the larger area of pondage was to be maintained as ponds with a very small increase in salinity, so that the discharge posed less risk to the receiving environment, a discharge salinity of 46 g/L could be achieved by pumping 70,000,000 m³ of brine into the pond system from Chapmans Creek annually. As the dilution curve is exponential, trying to manage the discharge salinity to anything below 46 g/L requires pumping increasing orders of magnitude of brine. The discharge of 48,682,323 m³ would create an artificial creek at the drainage reserve north of St Kilda similar in size to the Bolivar WWTP discharge. This would change the chemistry of the soils of the drainage reserve, making it unlikely that the EPBC Act listed *Tecticornia flabelliformis* would be able to persist in the area. Additionally, the ponds would not be saline enough to support either native or introduced brine shrimp, reducing their attractiveness to some species of shorebirds.

It is possible to run a parallel series of ponds, where the salinity gradient could increase down one side and then decrease down the other, using redilution from the first series of ponds. Discharge would occur close to the initial intake. This would provide a range of habitats varying from marine to hypersaline. It would require a large quantum of engineering to set up such a system, and no attempt has been made here to model the quantity of brine that would need to be pumped in order to increase the salinity up to the point where brine shrimp thrived, and then reduce it back down to a level suitable for discharge to the environment. The quantum would be extremely large, and the area of "target habitat" (brine shrimp habitat) would be quite small.

Studies overseas (Sanzone & McElroy, 1998) have shown that managed pond systems are more prone to drastic variations in dissolved oxygen, salinity and temperature than adjacent tidally unrestricted marsh areas, and that the macroinvertebrates in the substrates of managed ponds are vulnerable to these changes, resulting in a lower overall biodiversity value. Just because an area has free water on its surface, this tells one nothing about the state of its benthic macroinvertebrate populations. As mentioned in Section 3 where the ponds near Middle Beach are described, even in ponds where the intake water is of high quality and where pumping is maximised to produce salt, there has been a gradual decline in the biodiversity values of the pond benthos over the last twenty years.

5.2.4.2 Aquaculture development

The existing ponds have been mentioned by private, local government and State agencies as having potential to provide pondage for specific aquaculture projects. While the embankments may appear to provide a ready-made asset, there are operational aspects any potential aquaculture venture would need to consider prior to establishing an operation.

The nutrient-rich intake water from Chapmans Creek has proved inimical to oyster growing in the past, and in recent decades the lower salinity ponds have become infested with the invasive marine bryozoan *Zoobotryon verticillatum* (Coleman F, 1998).

If the ponds were managed to produce hypersaline brine the issue of invasive species would not arise, and such ponds may be useful for culturing microalgae such as *Dunaliella salina*, a source of beta carotene and glycerol. In this latter case, the resulting hypersaline discharge would need to be managed.

Research aquaculture ventures would not necessarily provide a long-term occupancy of the ponds however, and may leave the State with the liability to remediate the area after the project has finished.

5.2.4.3 Detention & polishing ponds

Agencies such as SA Water and local government may be interested in using the ponds either as detention basins for stormwater or as final polishing ponds for the Bolivar WWTP discharge.

In both these cases it is a matter of conjecture as to whether the ongoing maintenance requirements of the ponds would make using them for detention basins as cost efficient as disposing of sediment-rich stormwater and the WWTP discharge directly into an extended network of remediated tidal wetlands (see *Section 5.2.4.5 Remediation to tidal wetlands*). Tidal wetlands, in particular saltmarshes, are after all, the natural repository of sediments leaving the land via creeks and rivers, provide excellent shorebird and other biodiversity values, and are self-sustaining with minimal ongoing management costs.

5.2.4.4 A small saltfield

Approaches from other salt operators have suggested that converting the existing Crown land pondages in this area into a small saltfield would retain the biodiversity values of these ponds. This would appear a spurious position, as it would be necessary to squeeze the entire salinity gradient, which currently occurs in 4,000 hectares of pondages, into a bit more than one quarter (Crown land only) or a little less than one half (Crown and Ridley freehold between St Kilda and Chapmans Creek) of the current area. There would be an equivalent alteration in salinity and depth regimes and reduction in the size of each habitat zone. This area would then also need to support a crystallising area as well as stockpiling and refinery areas. These “industrial” areas would have negligible biodiversity values and typically account for between 9% and 12% of the area of any saltfield.

While the most northerly of the ponds south of Gawler River (Pond XB3) was the initial intake pond in the 1950s and 60s, this changed when the ponds further north were built in the 1970s, and pumping from Chapmans Creek into Pond XB3 was reduced. By the 1990s the impacts of nutrient concentrations in Chapmans Creek, which is influenced by the discharges from the Bolivar WWTP, were sufficiently high that all pumping from the creek was ceased and Pond XB3 is now fed from the northern ponds and from a small hypersaline bore. Reliance on Chapmans Creek as a source of seawater for any proposed saltfield in this area would expose the salt operator to the risk of biological perturbations that could impact significantly on the production of salt.

From a financial point of view, the Crown land area alone would support a saltfield with an annual capacity, based on local evaporation and standard

saltfield yield calculations, of approximately 175,000 tonnes per annum (tpa). If the freehold land currently occupied by ponds were included, yield could be 300,000 tpa. Salt is a cheap mineral commodity, but requires a large initial capital investment compared to other surface extraction minerals, and reworking the existing pond configuration may well cost nearly as much as starting from scratch.

It is unknown whether the domestic Australian market has room for another 175,000 – 300,000 tpa, but is considered unlikely considering that price discounting between the major salt suppliers can be observed at any local retailer of swimming pool salt. The Dry Creek saltfields supplied one specific customer who no longer requires salt. This leaves the export market, where a salt operator would be competing with multi-million tonne operations in NW Australia that have their own port facilities etc. An export saltfield based in the St Kilda-Chapmans Creek area would need to use road to transport salt at least to Port Adelaide's port facilities, and possibly to Outer Harbor.

Placing a smaller saltfield over the larger Crown and freehold land area currently supporting ponds may also require at least the agreement of the current landowner of the freehold land (Ridley Corporation) under the Mining Act, as salt mining is a surface extractive operation, which means that the landowner may have a right of veto ("*Guidelines: landowner rights and access arrangements in relation to mineral exploration and mining in South Australia, MG4, ver 2.1*" DMITRE, 2013).

5.2.4.5 Remediation to tidal wetlands

Tidal wetlands provide a huge range of ecosystem services and there is opportunity here to rehabilitate the existing salina ponds back to tidal wetlands. The benefits of doing this, as distinct from managing the pondages as ponds for one specific use or other, are multiple. Tidal wetlands:

- Have wide ranging flora and fauna biodiversity benefits, being a major high tide feed resource for juvenile fish, as well as providing feed and roosting habitat for shorebirds;
- Provide area for sea level rise habitat retreat, an issue that is currently impacting on Barker Inlet tidal habitats;
- Provide a storm surge buffer for both current sea levels and projected future sea levels, minimising the need for costly coastal protection works;
- Act as a carbon sink, with saltmarshes in particular being amongst the highest sequestration habitats known. Additionally, the carbon buried in saltmarshes is not subject to methanogenesis, as conditions are too saline, so carbon in saltmarshes is considered to be permanently sequestered;
- Function to keep Potential Acid Sulfate Soils saturated, thus preventing them converting to Acid Sulfate Soils; and
- Provide natural stormwater management functions including sedimentation of stormwaters (which both "grows" the saltmarsh and ensures offshore habitats like seagrasses are protected from turbidity) and wide area dissipation of floodwaters that can prevent upstream "backing up" as can occur when floodwaters are diverted to sea down narrow drains and channels.

The ponds currently placed over Crown land were formed in areas that had never been isolated from the natural hydrological regime, and so the land was at natural surface level. The land was being used as grazing land that was subject to occasional inundation at the time the ponds were built. Pond XB3 has floor elevations typically ranging from 0.8m AHD to 1.8m AHD, suggesting that if drained and reconnected to the tidal wetlands north and west of the pond, the soils in the lowest parts of the pond would remain saturated as they are lower than MHHW, while the highest zones would flood only annually. The land would eventually develop a range of habitats, most likely including *Sarcocornia quinqueflora* dwarf chenopod shrublands (in the submerged or low marsh), *Tecticornia* spp chenopod shrublands (emergent or mid marsh), *Maireana oppositifolia* chenopod shrublands (emergent or mid-high marsh) and *Atriplex paludosa* chenopod shrublands (high marsh).

The elevation of the base of the ponds on Crown land further south is lower, varying from 0.6m AHD to 1.3m AHD, with most ponds having a base elevation of approximately 0.9m AHD. Elevations below 0.7m AHD, such as those in parts of Pond XB8A are likely to eventually support mangroves (*Avicennia marina*). The freehold land to the east is considerably higher, and some of the southernmost ponds may have variable depths of gypsum above the natural surface.

The ponds in this section of the saltfield are over 70 years old and the constant presence of seawater over that period of time will have resulted in the deposition of some sulfide-rich sediments. If these ponds are drained to dryness there would be some oxidation that may produce acid sulfate runoff and considerable compaction and subsidence. However if the hydrology of these ponds is reconnected to the tides with no restrictions it is unlikely the lower ponds will generate acid as their floor elevations are mostly at, or below, mean higher high water (MHHW). Elevations below MHHW tend to maintain saturated soil conditions once freely reconnected to the local tidal hydrology (Philip Williams & Associates, 2004) so sediments below that elevation are unlikely to oxidise. There may be small amounts of oxidation from sediments on the higher parts of these ponds, however by ensuring all the ponds are freely connected to the tides there will be a large area for carbonate-rich seawater to ameliorate any acid.

If reconnected hydrologically to the surrounding wetlands, these ponds should form a useful sea-level rise buffer allowing landward migration of tidal wetlands, attenuation of erosion, an appropriate area for the settlement of sediments from stormwater, provide a useful quantity of carbon sequestration, and should eventually evolve into a tidal/supratidal wetland with all the biodiversity values for shorebirds and other flora and fauna that entails.

A summary of the findings of a range of studies into saltmarsh regeneration locally and overseas is included in *Appendix 2 – Lessons in saltmarsh restoration*, and a select literature review of relevant papers relating to saltmarsh restoration is included in *Appendix 3 – A select literature review*.

5.2.5 St Kilda to Dry Creek

South of St Kilda the mineral leases of the Dry Creek saltfield are placed mainly over Crown land. Ridley Corporation has freehold pondages at the estuaries of

the Little Para and Dry Creek (part of Pond PA10, all of Ponds PA11 and PA12). It is not known to what end use Ridley Corporation intends this land.

Only a small portion of the mining leases on Crown land support pondages (PA6, PA7, PA7A, PA8, PA9), with the majority of these leases overlying extensive naturally regenerating tidal wetlands west of the salina ponds. The salina ponds in this location are hypersaline and support only the introduced brine shrimp, *Artemia franciscana* and planktonic and benthic microalgae. The introduced *Artemia* is attractive to some shorebird species whose natural prey range is of a similar size to the brine shrimp. Coleman and Cook (2009) found these ponds and adjacent salt marshes had a medium shorebird diversity value (11-19 species), while Purnell *et al* (2012) reported low densities of common species of shorebirds in the ponds themselves. Shorebirds in this region also use the naturally regenerating tidal wetlands to the west and the treatment ponds of the Bolivar WWTP to the east for feeding and roosting opportunities.

The St Kilda-Barker Inlet Aquatic Reserve covers the naturally regenerating tidal wetlands between the salina ponds to the east and the old St Kilda Embankment to the west, as well as the historic mangrove forests outboard of the old embankment. The same area of Crown lands under mining lease is included in the Adelaide Dolphin Sanctuary. There are general duty of care provisions under the Adelaide Dolphin Sanctuary Act (2005), and additionally the Minister has a function to provide advice with respect to the approval of activities proposed to be undertaken within the Sanctuary, or that may have a direct impact on the Sanctuary. These two multi-use conservation zones provide some level of conservation protection for mineral lease areas outside the small areas of pondage. The Metropolitan & Northern Coastal Action Plan (Caton *et al*, 2009) has identified the following issues for cell MA17 – Barkers Inlet: degradation of the intertidal saltmarshes by off-road vehicles used for mosquito control, invasion of weed species into the saltmarshes and the need to ensure there are well connected landward migration routes to allow the tidal wetlands to retreat as sea levels continue to rise.

The naturally regenerating tidal wetland area described in Figure 8 as “extensive tidal wetlands” was originally saltmarsh that had been enclosed by the St Kilda Embankment between the 1890s and 1930s. The land proved poor for agricultural purposes and acid sulfate generation in the drying soil profile resulted in subsidence. No measurements of the subsidence were undertaken before the salt ponds were built, however similar embanked areas of Gillman and Outer Harbor “subsided” by about 0.7m as a result of ASS development (Thomas *et al* 2003, Cook & Coleman 2003).

Once ICI built the salt ponds in the 1930s, the St Kilda Embankment was breached at multiple locations including the Little Para, Shooting Creek, Burrows Creek, Post Creek, Garnets Creek and Barque Creek. No formal studies of the regeneration of this site were undertaken, however in recent years some studies of the resulting habitats have been undertaken. Fotheringham (1994) examined the rapid mangrove migration across the subsided parts of the Little Para estuary and mapped the vegetation associations, while Coleman & Cook (2008) established that the tidal prism in the saltmarshes of the same estuary was unrestricted at least as far inland as the old ICI salt flume. Coleman, Cook and Eden (2005) undertook research into the soils types and sedimentation occurring in Barker Inlet tidal wetlands including both the regenerating and historically undisturbed marshes.

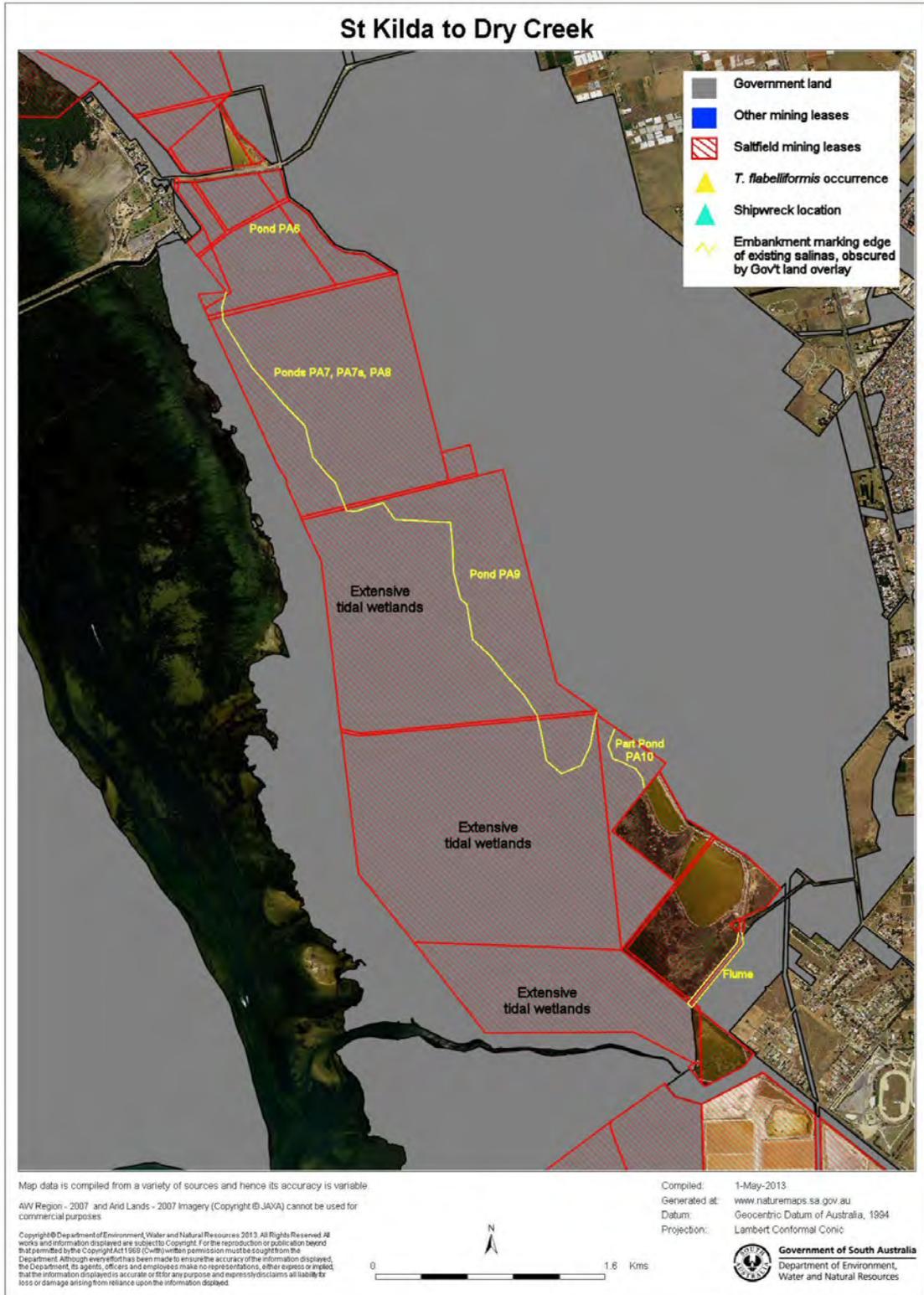


Figure 8 - St Kilda to Dry Creek

These local studies, and studies conducted overseas, provide a degree of confidence in the evolutionary path that could be followed by any salt ponds that were unrestrictedly reconnected to the tides so that tidal wetlands could redevelop. A summary of the findings of a range of studies into saltmarsh regeneration locally and overseas is included in *Appendix 2 – Lessons in saltmarsh restoration*, and a select literature review of relevant papers relating to saltmarsh restoration is included in *Appendix 3 – A select literature review*.

The salina ponds that were built in this area were constructed on already subsided land that had largely oxidised. In the more than 70 years the ponds have been in this location a relatively thick deposit of gypsum (calcium sulfate) has been deposited above the natural surface, although the topography of that surface (including dendritic creek lines) is still clearly visible from the air. As a result of the gypsum deposition, it is estimated that the elevation of the top of the gypsum varies from lower than 0.7mAHD up to about 1.5mAHD. Under the thick crust of gypsum, microbial action has eaten away at the gypsum resulting in the formation of an underlying sulfide-rich sediment layer. This layer is likely to be present at elevations lower than 0.9mAHD, or Mean Higher High Water (MHHW).

If this sediment can remain saturated (through tidal or freshwater means) and the gypsum crust remains undisturbed, the potential production of actual acid sulfate can be minimised. Additionally, the extensive areas of tidal wetlands to the west and reconnection to tidal waters would provide a virtually unlimited buffering capacity for any acid that did develop (Hicks *et al*, 2001). A discussion of the management of ASS is attached in *Appendix 4 – Pond stabilisation for ASS & subsidence minimisation*.

Besides controlling the generation of acid, tidal reflooding of the ponds on Crown land has an additional advantage. Gypsum is only sparingly soluble in freshwater, but is considerably more soluble in seawater (Willey, 2004). Over time the gypsum in the portions of the ponds that are regularly inundated (the creeklines) will dissolve and be scoured out, allowing the re-establishment of natural creek lines through these areas.

Interest in utilising these pond areas has been shown by the City of Salisbury who have wondered if a combined reconnection to tidal flows on the west and to sediment-rich stormwater and estuarine drainage (Helps Road drainage network and the Little Para) on the east would allow these ponds to evolve towards a regenerated tidal wetland that would provide a full range of biodiversity benefits while providing a sea level rise buffer, habitat migration zone, carbon sequestration area and an appropriate place for the natural sedimentary processes of settling estuarine and stormwater.

While it is possible that similar arguments could be made for using these ponds (either as ponds or as evolving tidal wetlands once reconnected to tidal inundation) as polishing areas for discharges from the Bolivar Waste Water Treatment Plant (WWTP), this would seem to be a more dubious proposal. The discharge is nutrient-rich and sediment-poor, resulting in eutrophication implications on the receiving environment. The current discharge occurs across tidal wetlands about 7km north of St Kilda, outside the confined reaches of Barker Inlet. Allowing discharge to occur across tidal wetlands into the southern parts of the Inlet would risk insufficient tidal exchange and this could cause eutrophication

of the saltmarshes, mangroves and offshore seagrass beds. Eutrophication of North Arm Creek was a problem when treated sewage was discharged to that creek from the sand filters of the Islington Sewage works, before Bolivar was built and the discharge moved north (Hodgson *et al*, 1966). Should the discharge be treated at the WWTP to reduce its nutrient concentration, then disposing of it into a tidal wetland should not have such an impact on the receiving environment.

Finally, there have been suggestions that the pondages in this zone could be dried out and the gypsum in them mined under new mining leases or as a new mining activity under the current leases. Besides any issues related to placing an extractive mining operation in close proximity to housing at St Kilda and at Globe Derby, drying these pondages to the extent necessary to allow machinery to work them and then digging the gypsum out would necessarily cause oxidation of the underlying sulfidic sediments and possibly release odorous compounds. It would be necessary to implement a strict program of ASS control and treatment of any dewatering from ponds being operated as a gypsum mine. As well as constructing bunding and installing pumps to keep operational areas dewatered while retaining all brines with potential to generate acid, there would be costs for chemical treatment of those brines and the necessity for a monitoring program to manage the brines, through the treatment process and during discharge.

Final remediation targets would need to be negotiated in any PEPR that was developed for either a new mine or a new activity on existing mining leases, prior to the establishment of gypsum mining. These remediation targets may include shaping the final topography to allow the most unobstructed tidal prism to develop across the mined surfaces at closure.

5.2.6 South of Dry Creek

The Crown land in this area includes:

- freehold land owned by the Crown, managed by Renewal SA (land inside the ponded area inside the old seawall, delineated with yellow lines, and containing the Final Areas ponds and Crystallisers A, B, C & K),
- unallocated Crown land to the north-east of the freehold land, outboard of the seawall, where the mining leases overlie extensive tidal wetlands that include mangroves and saltmarshes,
- land under the care and control of local councils to the east and south, which is used for stormwater wetlands and that has not been utilised by the miner even though some of it has mining lease overlying it (small area in the Greenfields Wetlands Stage III).

Where mining leases overlie freehold lands (both those owned by Ridley Corporation and those under the control of Renewal SA) this land has been earmarked for ultimate residential development and supporting infrastructure. These hypersaline ponds have a low diversity value for shorebirds (3-10 species), according to Coleman and Cook (2009), with Purnell *et al* (2012) recording that this zone is “only occasionally used by low densities of common shorebirds”. One species is however, dependant on the area for breeding. Red Capped Plovers annually nest on the crystallising pans after the harvest has removed the salt layer.

Proposals for increased housing and population increases in this region will need to have due planning consideration for adequate protection of the coastal zone and minimising disturbance to migratory shorebirds from recreational activities.

The mining leases that overlie unallocated Crown land to the north and west of the seawall embankment support extensive mangrove woodlands and small areas of saltmarsh. There are several ship wrecks in the lease areas or closely adjacent to them. Any interference with historic wrecks is prohibited under the Commonwealth *Historic Shipwrecks Act 1976* and the South Australian *Historic Shipwrecks Act 1981*.

The St Kilda-Barker Inlet Aquatic Reserve covers the natural tidal wetlands outboard of the seawall embankment. The same area of Crown lands under mining lease is included in the Adelaide Dolphin Sanctuary (and subject to provisions of the ADS Act). These two multi-use conservation zones provide some level of conservation protection.

The Metropolitan & Northern Coastal Action Plan (Caton et al, 2009) has identified the following issues for cell MA17 – Barkers Inlet:

- degradation of the intertidal saltmarshes by off-road vehicles used for mosquito control,
- invasion of weed species into the saltmarshes, and
- the need to ensure there are well connected landward migration routes to allow the tidal wetlands to retreat as sea levels continue to rise.

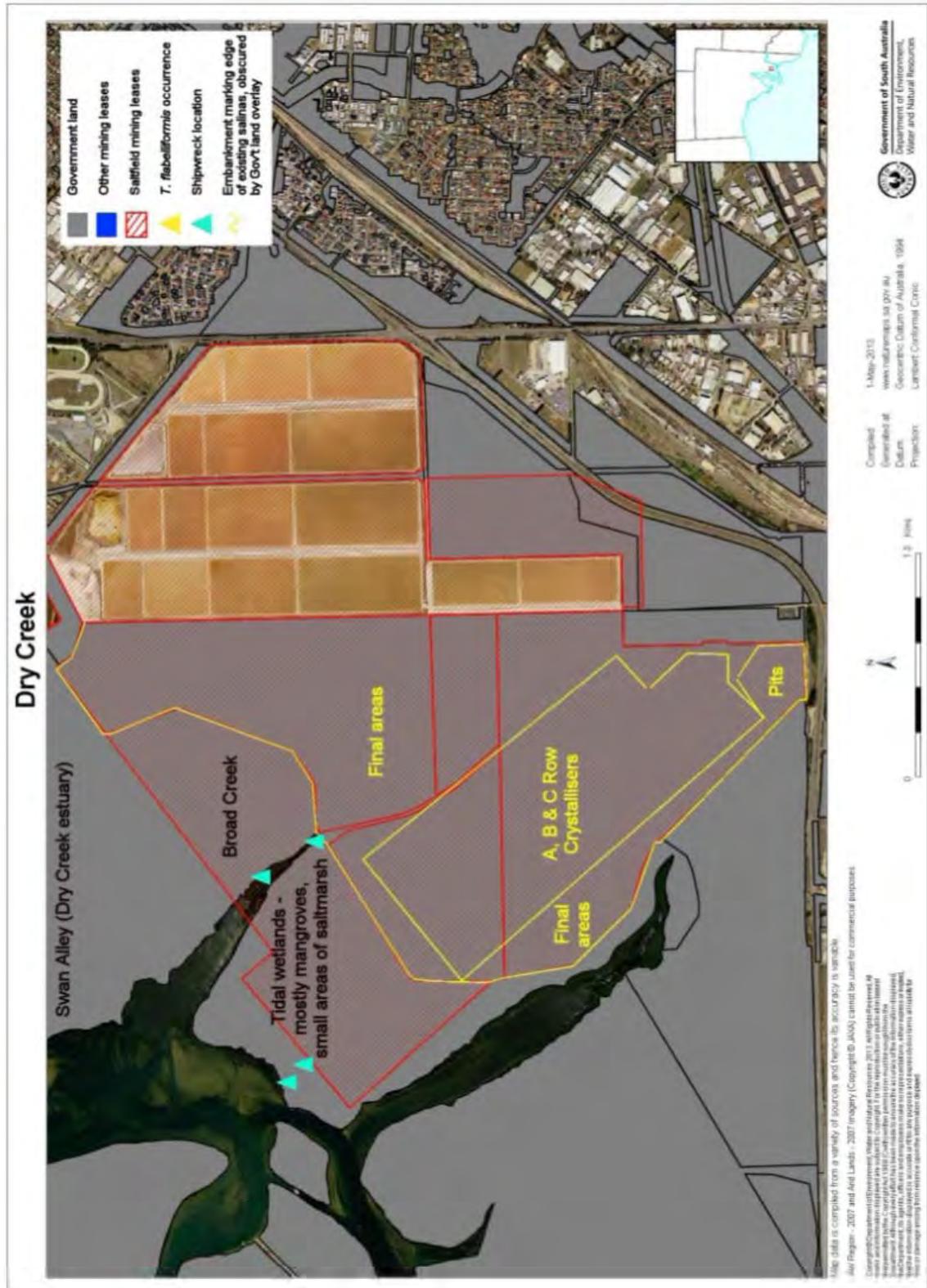


Figure 9 - South of Dry Creek

5.3 Risk assessment

Qualitative assessment of risks for shorebirds and their known and potential habitat, resulting from proposed developments in the study area, is presented here following the process outlined in AS/NZS 4360.

In a qualitative risk assessment the risk associated with any particular event can be classified for comparative purposes using the following matrix:

			Likelihood of consequence				
			E Rare	D Unlikely	C Possible	B Likely	A Almost Certain
Severity of consequence	5	Insignificant	Low	Low	Low	Moderate	High
	4	Minor	Low	Low	Moderate	High	High
	3	Moderate	Moderate	Moderate	High	High	Extreme
	2	Major	High	High	Extreme	Extreme	Extreme
	1	Catastrophic	High	Extreme	Extreme	Extreme	Extreme

Figure 10 - Risk matrix

For this analysis, **Likelihood of consequence** is defined as:

- Almost certain - will occur, or is of a continuous nature, or the likelihood is unknown
- Likely - will probably occur
- Possible - could occur over a decade or so
- Unlikely - is not likely to occur in the average lifetime
- Rare - has never occurred but conceivably could

While **Severity of Consequences** are defined as:

- Insignificant - possible impacts but not easily noticed
- Minor - very **local** or **temporary** consequence
- Moderate - significant **local** or **temporary** changes, but can be rehabilitated, remediated or mitigated with difficulty at significant cost
- Major - substantial and **widespread** changes, only partially able to be rehabilitated or alleviated.
- Catastrophic – extreme, **widespread permanent** changes to natural environment (not able to be practically or significantly rehabilitated or alleviated)

In the analyses that follow, the risk of future impacting events occurring is assessed. It may be possible to reduce the likelihood of risks occurring, and risks that eventuate may be mitigated. If it is possible to take action to further reduce the likelihood of a risk eventuating or the severity of the consequences, it may be considered that the residual risk may be reduced, and this is reflected in the risk tables.

5.3.1 Loss of salina food resources for shorebirds

The land ownership of the salinas (as distinct from the wider leases) is approximately half private and half Crown. It is not known what intentions Ridley Corporation has for any of its salina ponds north of Dry Creek, although the company's intentions for its land south of Dry Creek (housing redevelopment) has been the subject of many newspaper articles. It is possible that over the longer term their lands north of Dry Creek will ultimately be incorporated as northern and southern suburbs of the proposed new Buckland Park township. Clearly, the company cannot continue to pump brine into Crown ponds, or their privately owned ponds, for no return. Therefore there will be a loss of locally significant areas of feeding grounds for migratory shorebirds. That loss is most likely to be felt in the upcoming summer.

At present the ponds are at extremely low levels, and this is probably providing extra food for nomadic species such as stilt and also local residents such as red capped plovers. The majority of migratory birds are likely to have departed already. The birds will return in Spring and it is then that the reduced feeding opportunities are likely to become apparent, as the weather warms up and the ponds finish drying down.

Whether this impact on shorebirds will be considered "significant" under the EPBA Act is a determination that would be made by the Commonwealth, but it is possible, considering that the salinas of the saltfield are utilised by more than 1% of the flyway population of red-necked stints and sharp-tailed sandpipers (Birdlife Australia Internationally Significant Sites database).

Table 2 - Risk assessment - loss of salina food resource

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Increased disturbance to shorebirds through inappropriate development or activities, including loss of food resources for shorebirds	A	3	Set up appropriate hydrogeomorphological template across the site that will allow the evolution of self-sustaining tidal wetlands	B	3	High
			Operate some, or all, of the ponds on Crown land for shorebird habitat	B	3	High

There is some opportunity for the miner to mitigate the impact, using the Crown land portions of the site, but no matter whether a choice is made to start the long process towards developing naturally self-sustaining tidal wetlands, or to attempt to manage some of the ponds as artificial shorebird habitat, there will still be a reduction in feeding area.

The development of a self-sustaining tidal wetland, or a combined tidal wetland with stormwater treatment functions will evolve over decades, once the engineering to set up an appropriate hydrogeomorphological template is completed. A discussion of some of the matters that would need to be addressed in order to allow the most rapid restoration is contained in *Appendix 2*. The initial works are capital intensive; however the long term aim is for a self-sustaining tidal wetland that would require minimal management input.

The resultant tidal or tidal/stormwater wetland should provide a wide range of biodiversity values, as well as functioning as a carbon sink, sea-level rise buffer and a natural area for the sedimentation of runoff (stormwater) from land. Its ultimate value for shorebirds will evolve along with the rest of the marsh, but may not ever provide a food supply that supports the full density of birds found in the currently operating mid-hypersaline to hypersaline salinas.

Operating some of the ponds as pondages for specific shorebird habitats is not a simple solution either, evaporation and saline waters being what they are. Depending on how the salinity is managed, there would be a significant reduction in the area that is most favoured by shorebirds, saline brine from mid-hypersaline and hypersaline ponds will need to be discharged from the ponds and will have detrimental effects on the receiving environment (the surrounding tidal marshes), or very large quantities of seawater could need to be pumped, and a new discharge creek could be created with impacts on an existing sabkha habitat that supports the EPBC Act list species *Tecticornia flabelliformis*. From a biodiversity point of view, managed marsh habitats have not proven to be robust in other jurisdictions, with unintended, unanticipated, and sometimes undesirable effects (Sanzone and McElroy 1998).

While the initial capital costs of managed pondages would vary from small to substantial, depending on the design choices made, there would be a large ongoing operating cost no matter which type of managed pond system was chosen.

5.3.2 Changed land use risks to *Tecticornia flabelliformis*

It is not known what intentions Ridley Corporation has for its freehold lands north of the River Light. If the land were to remain used for grazing purposes only, the threats to *Tecticornia flabelliformis* would remain similar to current threat levels, as identified in Coleman (2012).

Intensification of land use is likely to result in significant impacts, and any proposals to develop the sabkhas that contain the largest populations of the protected species may trigger the EPBC Act.

Relatively little of the land that supports *Tecticornia flabelliformis* is Crown land however there are several opportunities that could improve the protection of the

species where it does occur on Crown land. These include linking the northern coastal Crown lands into a continuous coastal reserve, as outlined in the Sapphire Coast Strategy (DC Mallala 2003) and extending the Sanctuary Zone of the Upper Gulf St Vincent Marine Park southwards across the Light River delta to capture the conjoined delta of Salt Creek, which has several sabkhas that support the species. While these actions will result in good outcomes for the populations they capture, the Crown land populations are relatively small when compared to the neighbouring freehold areas.

Table 3 - Risk assessment - impacts to *T flabelliformis*

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Loss of <i>Tecticornia flabelliformis</i> habitat	C	2	Continued low intensity grazing use of freehold sabkha areas	D	4	Low
			Form a linked series of coastal reserves on Crown lands between Port Parham and Light Beach	E	4	Low
			Extend the Sanctuary Zone of the Upper Gulf St Vincent Marine Park to include the Crown lands of the conjoined deltas of Salt Creek and River Light	E	4	Low

5.3.3 Fragmentation of high biodiversity value lands

The presence of mining leases that covered both freehold and Crown lands over an extensive length of coastline has resulted in a unified management of the entire coastal strip under the leases. The relinquishment of management of these areas may mean that Crown land with high biodiversity values may now be separated from other areas with similar management requirements, by tracts of freehold whose management regime is unknown. Additionally, because the current mineral leases are managed to minimise access, the loss of that unified management and the fragmentation of areas of high conservation value could result in “edge” and “island” impacts to the fragments, including off road vehicle (ORV) impacts and weed/feral animal invasion. The Metropolitan & Northern Coastal Action Plan (Caton *et al*, 2009) highlights the current ORV threat to a range of areas, notably areas around Port Gawler.

Table 4 - Risk assessment - fragmentation of high biodiversity Crown lands

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Fragmentation of management of high biodiversity value Crown lands resulting in "edge" and "island" impacts, including ORV impacts and weed/feral impacts	C	3	Form a linked series of coastal reserves on Crown lands between Port Parham and Light Beach	E	4	Low
			Extend the Sanctuary Zone of the Upper Gulf St Vincent Marine Park to include the Crown lands of the conjoined deltas of Salt Creek and River Light	E	4	Low
			Incorporate tidal wetlands east of the Port Gawler CP into the park	E	4	Low
			Incorporate Buckland Park Lake into the Port Gawler CP or place it under some other form of protection	E	4	Low

There is opportunity to incorporate some of the high biodiversity value Crown lands areas into the conservation estate in one form or another.

As outlined in the previous section, it may be possible to link the northern coastal Crown lands into a continuous coastal reserve. Extending the Sanctuary Zone of the Upper Gulf St Vincent Marine Park southwards across the Light River delta to capture the conjoined delta of Salt Creek and including areas of the River Light delta around Swan Creek should also be simple to progress. The latter areas were excluded from the SZ in order to ensure access to seawater and new pond areas for the miner should expansion of the saltfields ever eventuate, and this is no longer an issue.

Further south, near Gawler River, Crown land to the east of the Port Gawler Conservation Park that supports tidal wetlands including mangroves and saltmarshes could be incorporated into the park. It may be worth considering whether to incorporate DEWNR land at Buckland Park Lake into the park as well, or place it under other protection, as this artificial lake is one of the few sources of freshwater for birdlife north of the metropolitan area. The inclusion of additional intertidal wetlands into the Park is supported in a 2011 report by the Natural Resources Committee of the SA Parliament (Parliament of SA, 2011).

Tidal wetlands on Crown land south of St Kilda are already included within the Barker Inlet-St Kilda Aquatic Reserve and the Adelaide Dolphin Sanctuary and would not appear to need additional protection.

5.3.4 Potential ASS drainage

Marine sediments have the potential to produce acid once they are drained and oxygen can penetrate the soils. Where this has happened in the past around Barker Inlet (Coast Protection Board 2003) there has been resulting land subsidence of 0.7m to a meter. Acid production in shelly, carbonate-rich subsoils such as those found in the St Kilda Formation also results in the off-gassing of carbon dioxide as a by-product of the generated acid reacting with the soil carbonate particles. Large acid runoff events cause red spot in fish and can also cause direct fish mortality.

The Coast Protection Board advises on development applications within coastal zones (as defined in the Development Regulations 2008), including advice over Potential Coastal Acid Sulfate Soils. Farm drainage schemes and mining activity that have the potential to generate acid have not usually been referred to the Board for assessment, however the Development Regulations 1993 (schedule 2, para.5) define any excavation or filling exceeding 9 cubic metres within the coastal zone as development which requires approval.

Soils underlying the existing ponds are not currently oxidising, but contain potential acid sulfate soils. Quantities are small in the younger ponds and larger in the older ponds. The gypsum ponds contain a well-buried sulfidic layer underneath the thick gypsum crust.

A degree of oxidation could start to occur in all the ponds from Middle beach southwards over next summer, when the soils fully dry out. Any venture to mine the gypsum ponds would definitely result in a very large acid production potential.

This risk is one that needs immediate action. Stabilising the ponds, once they are drained, is essential. The simplest way to stabilise them would be to ensure they remained saturated. Reflooding with tidal waters and with stormwaters (see *Appendix 4*) has the potential to stabilise the potential acid sulfate soils, minimising the risk of acid production and soil subsidence, while speeding the colonisation of vegetation across the site.

Should the gypsum ponds be mined, the area would need to remain isolated from neighbouring tidal wetlands and any acid generation treated prior to the permitting of discharge from the ponds. Additionally there may be a risk of the production of hydrogen sulfide gas, which may decrease aesthetic values and pose perceived community health concerns.

Table 5 - Risk assessment - acid sulfate generation

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Acid sulfate generation, soil subsidence and CO ₂ off-gassing in ponds that are isolated from tidal flows and allowed to dry out completely	C	4	An open inundation system is instituted in which tidal and fluvial inputs occur and where there is flushing to the estuary through existing tidal wetlands	C	5	Low
Large quantum of acid generated by disturbance of gypsum ponds for mining	B	2	Mining is undertaken. A closed pond system is maintained and all acid generated is treated prior to allowing any discharge from the site.	D	4	Low
			Mining is not undertaken. An open inundation system is instituted in which tidal and fluvial inputs occur and where there is flushing to the estuary through existing tidal wetlands	C	5	Low

5.3.5 Potential salinity impacts of brine discharges

Risks around the impacts of discharging hypersaline brines from the saltfield are time-specific. The risks are current.

Discharges to the marine environment are handled in South Australia under the Environment Protection Act 1993. Potentially polluting activities, such as operating a saltfield, operate under an authorisation. The authorisation sets out what may or may not be discharged, the locations from which discharge is permitted and any monitoring or other requirements. Application to the Environment Protection Authority must be made prior to varying or altering activities controlled under the authorisation. It is most likely that the discharge of brines from the saltfield, other than the usual spent brine (bitterns) that is usually discharged, would require a modification to the saltfield's environmental authorisation.

The saltfield ponds contain a range of salinities of brine. The neighbouring tidal wetlands are reasonably tolerant of low hypersalinity, as this occurs naturally in saltmarsh areas due to the high evaporation rates experienced along the Gulf of St Vincent.

The Dry Creek Saltfields were constructed somewhat unusually, stretching for 35 kilometres along the coast in a very narrow strip. This layout results in a salinity

gradient that gradually increases from north to south (see map in *Appendix 1*). The field, being so extensive, crosses a number of catchments, and “flood gaps” were left between the ponds to allow each major catchment to drain to sea. At one point the Bolivar WWTP discharge channel passes through one of the flood gaps, carrying approximately 50,000 ML of freshwater a year to the sea.

In order to minimise any risk of hypersalinity on the receiving environment, it is possible to handle the draining of the ponds as four separate zones. The marine salinity ponds north of Port Gawler contain large quantities of shallow marine salinity water than can be released to sea through the Gawler River and several local tidal creek and tidal drainage lines with minimal impact on the receiving environment.

Low and mid hypersalinity ponds south of Port Gawler and north of St Kilda can drain south and north respectively, into the Bolivar WWTP discharge channel, where the brine will be diluted by the freshwater.

Table 6 - Risk assessment - Salinity impacts from brine discharges

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Discharges from the salt ponds may have hypersalinity impacts on the receiving environment	C	3	Discharge from marine salinity ponds to be returned to sea via local tidal drainages	D	5	Low
			Discharge from low to mid hypersalinity ponds to be returned to sea after dilution in the Bolivar WWTP discharge channel	D	5	Low
			Hypersaline ponds to be drained forward to the crystallisers, remaining brine (<5%) to be diluted by winter rains	D	5	Low
			Discharges to Dry Creek to be conducted overnight to catch the higher of the daily tides	C	4	Moderate
			Discharges to Dry Creek to coincide with stormwater flows down the creek wherever possible	D	5	Low

Highly hypersaline ponds around and south of St Kilda appear (visual inspection from high points at St Kilda) to have been drained forward along the salinity gradient towards the crystalliser area at Dry Creek over the past three months.

There appears to be a minimal quantity of brine remaining in these ponds (probably less than 5%). Winter rainfall will dilute this small quantum of brine. The bared-off parts of these ponds will act as a rainwater catchment, so it is likely that the remaining brine in these ponds will have innocuous salinity concentrations by Springtime.

The ponds south of Dry Creek contain hypersaline brines and solid salt. This will be disposed of under an existing, or new, environmental authorisation under the supervision of the EPA. Sodium-rich brines are more problematic to the receiving environment than bitterns (the residual brine after the salt has been crystallised out).

That said, the discharge will be a “pulse” rather than a “press” impact and the receiving environment is likely to tolerate a short period of salinity increase better than a continuous impact. The existing discharge points at Dry Creek are into fast-flowing tidal creeks with large tidal exchanges. Good dilutions could be obtained if discharges were timed to coincide with the larger tides of the day (ie discharge overnight to catch the largest of the twice daily high tides). They could also be timed to coincide with stormwater flows down Dry Creek, which has an annual stormwater flow of 13,500 ML (13.5GL) per annum.

5.3.6 Sea and land based flooding risks

There are several risks related to flooding, with the closure of the saltfield. The risk of land based flooding as a result of discharge of the brines in the ponds is not one of them. The ponds are shallow and are located at a lower elevation than nearby housing. They are surrounded by drains on their landward side and bank breaches on the seaward side can be made into existing tidal creeklines. Nevertheless the risk has been placed in the risk table below.

The seawall currently forms a barrier that protects low lying housing in Globe Derby and the St Kilda Causeway from storm surge inundation. The landward pond walls are not always as high as the outboard seawall.

There is a small risk that in some places breaching the seawall may allow storm surge tidal flooding of landward areas. Where the outboard seawall is being breached, surveys should be taken of the inboard pond wall to ensure it meets the Coast Protection Board’s required elevation for protection against tidal flooding. Materials to raise any low points could be obtained either from the breaches made in the outboard seawall (small tonnages) or by material won by grading down lengths of the outboard seawall.

Sea level rise is occurring at the top end of international estimates and in the Barker Inlet area there has been approximately 99mm of sea level rise since 1990. Tidal wetlands form excellent sea level rise buffers. The vegetation attenuates water movement so that the higher water levels have minimal erosion impact. Not placing development on low elevation land minimises the future liability for seawall works – lower walls are required, with less armouring. Using the land that is currently ponded for commercial ventures may attract protection costs in the future.

Proposals and possibilities to develop housing in a northward corridor from Dry Creek towards the proposed Buckland Park township, on the elevated areas of the saltfield to the east of the Crown land, on the crystallisers at Dry Creek, and on neighbouring freehold lands will see additional sealed surfaces increasing land-based stormwater runoff. This extra water will drain to sea down creeks and rivers that have evolved for smaller runoff events, causing erosion and allowing plumes of turbid water to reach the sea where it will impact offshore seagrass beds. In the short term, while the drainages scour themselves larger channels, the water may back up and overflow the channels.

Rehabilitating the western low lying saltfield ponds so that they can evolve into tidal wetlands with fluvial and stormwater input should provide additional detention area for land-based floodwaters, reducing the likelihood of creeks “backing up” into developed areas. They will also provide an area for sedimentation to occur, improving the quality of water reaching the sea.

Table 7 - Risk assessment - Flooding risks

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Flooding from draining saline waters from the ponds	D	5	Breaches should be at existing drainage lines, with clear drainage to the sea	E	5	Low
Sea flooding over inboard pond walls once the outboard seawalls are removed	B	4	Survey inboard pond wall before breaching outboard seawall. Raise inboard pond wall to meet CPB guidelines where necessary	D	5	Low
Sea level rise storm surges impacting on future commercial ventures that utilise the existing ponds	C	4	Rehabilitate the ponds to tidal wetlands rather than developing commercial ventures on them	D	5	Low
Increased land-based flooding from urban development on, and adjacent to, the saltfield	B	4	Rehabilitate the ponds to tidal wetlands that receive stormwater and fluvial input	D	5	Low

5.3.7 Accrual of liability for eventual remediation

The manager of the unallocated Crown lands overlaid by the mining leases that contain pondages has the opportunity to either request the miner rehabilitate the land to the point that it will continue its own evolution towards becoming a tidal wetland, or can decide to utilise the existing assets (ponds) on the Crown lands for other commercial purposes. Should those purposes be mining purposes,

liability for the eventual rehabilitation of those lands will accrue to the miner-of-the-day, or to DMITRE via the rehabilitation bond they would hold for the mining operation. Should those commercial ventures not be mining, and should they fail or cease to operate, the Crown may be left with a liability for ponds that need rehabilitation, with no rehabilitation bond.

The simplest mitigation for this risk is to determine the ultimate end use requirements for all the Crown land under the mining leases now, and where rehabilitation would be required to meet those needs, reasonably request they be undertaken by the current miner.

Table 8 - Risk assessment - Accrual of remediation liability

Risk event	Risk prior to implementation of controls		Possible control or remediation methods	Residual risk if controls implemented		Residual level of risk
	Likelihood	Consequence		Likelihood	Consequence	
Risk of rehabilitation requirements accruing to the Crown	C	3	Determine ultimate rehabilitation targets for all land now, and request the current miner meet them prior to rescinding the mining leases	D	5	Low

5.4 Timeframes

The closure and rehabilitation of the mineral leases of the Dry Creek Saltfield will necessarily take a considerable time. The possible end uses of the Crown and freehold lands are varied. Where rehabilitation to natural habitats is required the process could take many decades to reach maturity.

Despite the long ultimate time frames, there are a number of subsidiary issues that pose immediate risks if not addressed promptly.

In order to minimise the risks, a timeframes table has been provided here which identifies issues that need addressing immediately, those that can be managed over the next several months to a year, and those that have an extended timeframe.

Table 9 - Timeframes

Immediate concerns and actions	Items to be undertaken over the next few months to year	Long term aspects
Manage brine discharges to minimise high sodium impacts	Identification of what engineering works need to be done by the miner on lands marked for restoration to tidal wetlands, to meet the Crown's closure requirements	Evolution of tidal wetlands across rehabilitated parts of the pondages will take many decades to mature
Stabilise drained ponds to minimise ASS production and prevent subsidence	Undertaking of engineering works to prepare the sites' hydrogeomorphology to support the ultimate natural evolution of tidal wetlands in rehabilitated areas	Monitoring programs and studies conducted over this time will allow lessons learnt at this site to be applied to other sites. Monitoring should include soil and inundation comparisons with natural tidal wetlands, flora distribution and fauna use (especially shorebirds)
Make a decision about rehabilitation of ponds to tidal wetlands, OR whether pondages are to be maintained for shorebird use (given that the latter will either produce hypersaline brine or will require pumping huge volumes to prevent hypersalinity)	Determine how to protect high biodiversity Crown lands including the River Light delta and Crown sabkhas. Consider inclusion into existing reserves like Port Gawler, expansion of the Sanctuary Zone of the UGSV Marine Park, or developing a unified set of Council/State reserves along the Samphire Coast	
Determine whether the Crown wishes to allow the miner to pass some ponds over for other mining or commercial use, OR whether the Crown would prefer them to be remediated to tidal wetlands		

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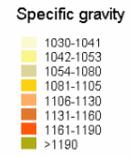
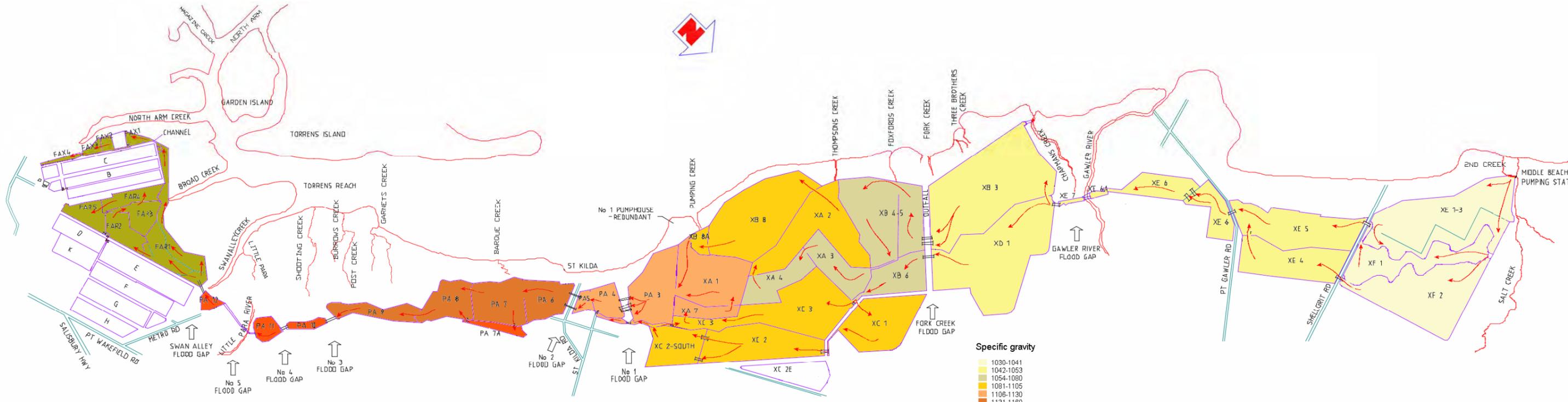
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Appendices

A1 – Layout of the existing saltfield ponds

Figure 11 - Saltfield layout (next page)



1 km

A2 – Lessons in saltmarsh restoration

Local learnings

The Swan Alley Mangroves (St Kilda Embankment)

From the late 1890s up until the 1970s seawall embankments were used to “reclaim” land around Barker Inlet and the Port River. The earliest embankments were built in the 1890s and included the St Kilda Embankment that was built south of St Kilda and around Barker Inlet to Gillman. In the 1950s another series of embankments were built from Gillman to the Port River. In the 1950s-1970s embankments were used to reclaim land at Outer Harbor.

Some of these reclaimed lands (eg Gillman) are still cut off from tidal inundation. Others have been reconnected to the adjacent tidal wetlands. All of the enclosed lands developed acid soils, all suffered significant subsidence, and none of them proved suitable for agricultural use.

When ICI built the Dry Creek Saltfields in the 1930s, the existing St Kilda Embankment was breached in several locations near old creeklines, as it was considered that the new saltfield would act as a seawall. The land south of St Kilda and north of Dry Creek, lying between the old seawall and the new seawall and called here “Swan Alley Mangroves” is a naturally rehabilitating tidal wetland that has evolved towards maturity over the last 70-80 years with no further financial or engineering assistance from mankind.

The main watercourses in this area include Dry Creek to the south, which drains into Swan Alley, the estuary of the Little Para, then Shooting Creek, Burrows Creek, Post Creek, and Garnets Creek to the north, which receive runoff from the Bolivar area and Helps Road Drain. The northernmost creek, Barque Creek, just south of St Kilda is cut off from all land based flows but historically received water now carried to sea by the drain from Waterloo Corner.

The area can be seen clearly in aerial photographs because the borrow pits that edged the old seawall have become straight, linear waterways, which are easily identified as unnatural features. As the land that was newly reconnected to the sea had subsided, mangroves were able to colonise across it, penetrating much further inland than their original distribution.

Burton (1982) examined aerial photography from the 1930s through to the 1980s and recorded that landward migration of mangroves was progressing at a peak of 17m per annum while Fotheringham (1994) found this represented an average advance for the entire period of 10.2m per year over a front of 15 kilometres. Over the time since the breaching of the seawalls, mangroves have migrated more than a kilometre inland in some areas.

Studies in small sections of the Barker Inlet (Coleman 1998) suggest that the rate of landward migration has been slowing from the mid-1980s. This may suggest that the effects of subsidence are no longer the main driver for landward migration in this zone, with the smaller incremental process of sea level rise being the current and future driver.

Coleman, Cook & Eden (2005 unpub) undertook studies of natural (ancient) saltmarshes and subsided, rehabilitating saltmarshes in the Barker Inlet and Port River estuary in order to characterise the basic soil parameters in these marshes, in relation to the distribution of zones of saltmarsh flora.

Sands and loamy sands appeared to be the dominant soil types in ancient marshes and in subsided marshes that had only recently been reconnected to tidal inundation, but in subsided marshes that had been reconnected to tidal inundation for many decades there was a thick deposit of fibric and hemic peats. These peaty organic soils were very moist (nearly double the moisture content of the mineral soils in the same inundation zone), and retained salts at higher concentrations than the mineral soils. The pH of the peaty soils was a little lower than the mineral soils. Despite the differences, the zonation of saltmarsh plants was similar in all the marshes.

Aspects this study highlights include that sedimentation appears to occur rapidly in the subsided marshes once they are reconnected to tidal inundation, that much of that sedimentation includes organic material such as shed seagrass and cast sea lettuce, as well as mineral sediments and that even after 70-80 years there is still a measurable difference in soils between the ancient natural saltmarshes and these regenerating subsided marshes.



Figure 12 - Naturally rehabilitating tidal wetlands south of St Kilda

At the estuary of the Little Para, Coleman & Cook (2008) established that the tidal prism in the saltmarshes was unrestricted at least as far inland as the old ICI salt flume. The flume apparently acts as a sill, restricting at least the common tides from penetrating further inland, although not impacting on the

largest tides. The course of the estuary had been realigned in the 1960s and manually excavated many times up until the 1990s. The waste was laid on the banks, where it formed a levee. The combination of riverbank levees, the old flume and a large growth of *Phragmites* (reeds) where the new course of the river debouched into the samphires, created a very complex pattern of tidal restrictions.



Figure 13 - Restoration and retreat zones, Little Para

In the early 2000s the levee on the northern side of the river west of the salina ponds and east of the old flume (West Area) was removed and the ground reshaped to its natural level. Recolonisation with saltmarsh species was rapid and this area now hosts good quality saltmarsh.

At the same time the levee north of the river, inland (east) of the salina ponds was removed and the land north of that was reshaped to allow riverine floodwater detention and tidal ingress (North Area). Due to this land being higher than the West Area and due also to the tidal restrictions mentioned above, regular tidal inundation is not a feature of this area but the riverine inputs occur through winter. The area has gradually recolonised, mostly to high marsh and saltbush species, and it is expected that it will form a useful saltmarsh retreat zone as sea levels continue to rise.

In 2005 a further area (South Area) had its riverside levee removed and a new levee built surrounding the south and east of the site. Drainage swales were placed through the site to allow the site to drain towards the river. The site was designated as a saltmarsh retreat zone and as a sedimentation area for overflow from the estuary. No other earthworks were undertaken.

The construction of a gas pipeline through the area occurred shortly thereafter, and the engineers placing the pipe agreed to remove the top 5cm of topsoil from the area they would impact and take it off site, removing weed seeds with it.

Their finished site elevation was to be as smooth as possible, and nowhere higher than the adjacent natural surface.

South Area has some lower lying areas than North Area and the drainage channels allow connection to the river. The entire site has been inundated during storm surge tides such as that occurring on 4 July 2007, and much of the site regularly receives riverine overflow. Infrequent tidal inundation currently occurs along the drainage channels and in the lowest parts of the site. There have been some observed changes away from grasses towards saltmarsh species. The area disturbed by the pipeline, in particular, rapidly recolonised to native supratidal species. Coleman and Cook (2008) have produced a digital elevation model of the site and have used this to predict the changes to the vegetation that may be observed as sea level rise continues.

Gillman

At Gillman the stranded saltmarsh is still isolated from tidal inundation. The site has been well studied in relation to its potential to produce acid and demonstrates the extent of subsidence (approximately 0.7m) that commonly has occurred in tidal wetlands isolated from their natural hydrological flows in this region (Thomas *et al* 2003, Hicks *et al* 2001, CPB 2003).

Mutton Cove

The northern parts of LeFevre Peninsula were bunded off from the sea and used as settlement ponds for the disposal of fluvial fill. The last remaining drainage from the filled areas was the creekline of Mutton Cove, which while bunded, contained three pipes to the sea that allowed some tidal exchange and drainage to occur. Once filling of neighbouring areas ceased the Cove was abandoned and the pipes partially filled in, stranding the tidal wetlands. The tidal pattern was not only attenuated by volume limitations of the pipes, but it also had a time lag that meant that significant attenuation (truncation) occurred at both the higher and lower ends of the tide.

At Mutton Cove, as the restriction advanced towards complete closure of the creek, the mangroves that lined the creek died, possibly through drowning as a result of higher low-tides. Mangroves can live in permanent or tidal waters, however they manage this by developing different sized pneumatophores. This occurs while the mangrove is still a young seedling, and once the mangrove has grown the appropriate gas-exchange organs, it cannot easily adapt to a change in inundation regimes.

The saltmarsh portions of the site suffered significant acid generation and subsidence (Cook and Coleman 2003) as a result of the lower high-tide waters causing a drying out of areas that would normally be reached by Mean Higher High Water (MHHW).

Tidal truncation essentially causes the lower parts of a site (even one that has not subsided) to remain wetter, while the higher parts remain drier, than would occur with an unrestricted tidal prism. This has an effect on tidal wetland

vegetation, which is distributed according to the percentage of time the soil is flooded. New mangrove propagules set up in the still waters where normal wave action would create a band of bare mud or support mudflat seagrasses, and they also find conditions wet enough to grow up into the area where saltmarsh normally grows. The truncation of the top of the tide creates drier conditions down into the upper saltmarsh, allowing saltbush, grasses and other upland species to invade. The saltmarsh species that require mid-levels of moisture, as shown in the conceptual diagram in Figure 14, are “pinched” in between the expanding mangroves and upland species.

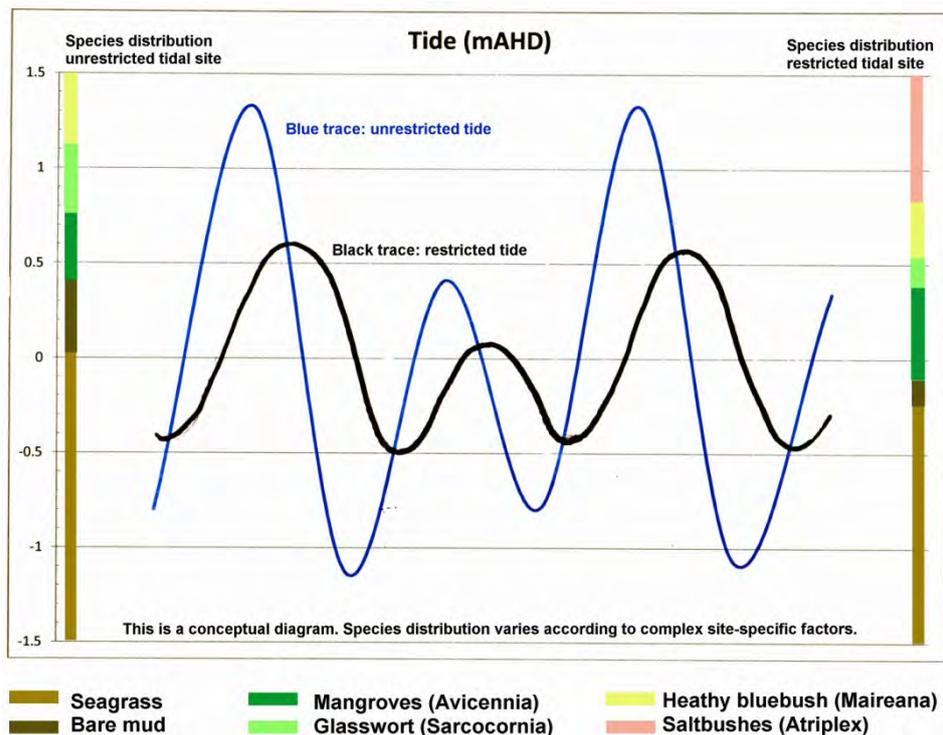


Figure 14 - Tidal restriction effects on vegetation

Rehabilitation of the small (less than 40ha) site at Mutton Cove saw pipe cleaning and the addition of two extra pipes at a higher level in the bund wall, in order to replicate a similar tidal inundation pattern to that occurring outside the Cove, through both the Spring and neap stages of the tidal cycles with a smaller lag time than before the rehabilitation and a limited attenuation. This should prevent mangroves from invading across the entire site while allowing them to re-establish along the creekline. The system is entirely a passive structurally managed marsh rehabilitation, and in the event that sea level rise should see mangroves starting to colonise into the saltmarsh, one of the upper pipes can be blocked with a bag of cement.

Other costs for this site include maintenance of the bund wall. As this is adjacent to the Port River it suffers badly from ship wash, which is increasing as the mangroves that once existed outside the Cove bund have been eroded away through a combination of increased sea levels and increased ship traffic. In the decade since this site was rehabilitated, it has required approximately

\$5000 per annum on bund wall repairs and other small maintenance items. This small budget has proved difficult to find in the current economic climate, which could sound a caution for those considering the use of structurally managed marsh or pondage habitats for other tidal wetland areas in the region.

Managed ponds

The salinas of the Dry Creek Saltfields are essentially structurally managed wetland habitats, in the form of coastal lagoons. While ponds and banks appear deceptively simple, they are in fact capital and maintenance intensive assets, with ongoing rocking and topping of embankments to correct for subsidence and sea level rise, the cost of operating and maintaining pumps (pumping at Middle Beach in the peak summer season has reportedly cost up to \$180,000 a month in electricity alone) and extensive maintenance of water gates and other control structures.

Saltfields worldwide monitor the biology of their pond systems because aberrations in the biology can lead to the production of slime that can cause salt production to fail. Dry Creek was no exception and has monitored many aspects of the pond biology over the past twenty years. The shallow nature of the ponds, the occurrence of 'dodge' tides, high humidity and still weather has led, on occasion, to excursions in temperature and oxygen and over the years these events have caused temporary and permanent changes in the biota of the ponds.

In 1997 a very large anaerobic event at Pond XE1-3 caused the death of over thirty species and many thousands of individuals of fish and invertebrates (Coleman 1997). The changes to the water quality flowed through to succeeding ponds over the next 18 months and the changes could be detected in the salt floors of the crystallisers in 1998 (Coleman F, 1998). The seaweeds that had been present in the pumping bays of Pond XE1-3 had been rocky shore species including leafy browns and large heavy green algae. After the anaerobic event only a fine filamentous brown algae (*Giffordia* sp) grew for the first six months. After about a year large quantities of filamentous green *Enteromorpha*, several large green algae (*Codium* sp and *Ulva lactuca*) and a red algae (*Hypnea* sp) gradually established themselves (Coleman F, 1998). The large leafy brown rocky shore algae have not recolonised the ponds. Further permanent losses to the marine salinity ponds, from the 1997 anaerobic event were the cockle beds and mud oysters that had previously been found in those ponds.

This was not the first such event to affect the Dry Creek Saltfields. In 1989 an anaerobic event in Pond XB3 led to the total death of all fish, invertebrates and marine flora of that pond, after pumping in highly nutrient-rich seawater from Chapmans Creek. Local folk lore has the starfish "crawling out of the pond to die on the banks". For the next seven years the pond suffered from a huge, ongoing picoplankton (bacterial cyanophyte) bloom that left the brine looking like pea soup – aerial and satellite imagery from the years 1989-1996 show this quite clearly. Eventually *Ruppia* spp began to colonise the pond and the brine started to clear, particularly after low phosphate groundwater from a hypersaline aquifer was added to the pond and pumping was redirected away from Chapmans Creek. Despite some recovery there has been a permanent change in the biota of the pond.

Artificially managed pondages suffer from restricted flushing, and their lack of connectivity to natural tidal planes also limits the ability of their biota to move to more congenial areas when weather conditions make the pondages untenable, while restricting the potential recolonisation of areas after anaerobic and other events have occurred. While these ponds look large, when compared to natural tidal wetlands they are little more than large aquariums and require the intensive management that all artificial habitats require.

Light River delta

The geomorphology of the delta has changed significantly since settlement (Burton 1982) and recent evidence of sea level rise can be seen in the changing vegetation patterns. In 1949 the most prominent feature of the delta was a huge mud bank to the seaward of a line of cheniers and a narrow fringe of mangroves. It is likely that the line of cheniers marked the original coastline, as can be seen further south between Chapman Creek and St Kilda.

Apparently the mud bank appeared quite quickly and changed the shape of the coastline into the typical 'bulge' commonly associated with deltaic floodplains. The relatively sudden appearance of the mud bank may well have been related to catchment clearance. The mangroves of the delta colonised across the mud bank over the next thirty years. This seaward progradation at the River Light was in clear contrast to other areas of mangrove further south along the Gulf, which were already starting to transgress landward by the early 1980's in response to local relative sea-level rise.

Over the period of Burton's observations (1949-1982), landward colonisation of the mangroves was occurring, although very slowly, in response to sea level rise. The most recent site observations and aerial photography reveal that most of the cheniers in the central zone of the delta are now being overtopped at high tides and some have eroded away completely. Mangroves have penetrated well past the cheniers and small areas of open pooled water are starting to form inland. Significantly, numerous small dendritic drainage lines have formed along the main creeks, in response to the flow requirements from more regular tidal inundation across the saltmarsh. These dendritic creek patterns are typical of low to middle marsh, compared to the smoother, more linear creek patterns found in high marsh and sabkha areas (Coleman 2012).

It is interesting to note that these small creek lines have scoured themselves out in response to a very small increment of sea level rise, of approximately 99mm since 1990. It does highlight the potential ability of naturally rehabilitating tidal wetlands to create the appropriate drainage lines, providing the general site topography slopes appropriately towards the sea and towards local sub-catchment creek lines.

Weed management in evolving tidal wetlands

Several invasive species of weeds have become established in natural wetlands in the Barker Inlet. Evolving wetlands may have temporary open areas. These open areas provide beneficial shorebird roosting habitat, however opportunistic

weed plant species can rapidly invade and build up to large numbers. The following weed species are problematic in local saltmarshes and would need managing in rehabilitated areas;

- *Juncus acutus*, sharp rush (brackish to marine salinity)
- *Aster subulatus*, aster (brackish areas)
- *Spartina* hybrids, rice grass (marine salinity intertidal)
- *Limonium* species, sea lavenders (supratidal)
- *Suaeda baccifera*, Russian sea-blite (supratidal)
- *Caulerpa taxifolia* and *Caulerpa racemosa*, two exotic types of green algae related to sea-grapes (sub tidal areas like creeks and pannes)

Other Australian and overseas learnings

Time frames for evolution to “mature” marshes are very long and must be viewed in the context of the wider evolution of adjacent tidal wetlands as they respond to natural and human induced changes in physical processes (Philip Williams & Ass and Faber 2004).

The prime drivers for restoration success have been identified in most studies in Australia and overseas as being the restoration of hydrology coupled with the reinstatement (through reshaping if necessary) of appropriate geomorphological conditions (Saintilan 2009, Atkinson *et al* 2001, Brand *et al* 2012).

Where subsidence is not a large issue, site topography considerations should include ensuring that most of the site has elevations that drain towards local sub-catchments (Zedler 2001). Better penetration of the tidal prism and natural development of dendritic creeklines in salt pond areas can be encouraged by ensuring embankment breaches are located at historic creeklines and that “blocks” are placed in any embankment-parallel linear borrow pits which would otherwise encourage tidal inundation around the perimeter of the site (Philip Williams & Ass and Faber 2004, Brand *et al* 2012).

Particularly in subsided marshes, the sedimentation requirement may be high. Restoration projects (and unplanned restorations) that took advantage of natural sedimentary processes to form an accretionary marsh have performed as well or better than highly engineered projects that attempted to replicate the form of a mature marsh (Philip Williams & Ass and Faber 2004). There is a place for incorporating stormwater and estuarine sedimentary processes into rehabilitating tidal wetlands to assist with accretion (Atkinson *et al* 2001).

Managed impoundments may suffer degraded water quality (salinity, temperature and dissolved oxygen extremes, and mobilisation of sulfate) with occasionally drastic results for marsh biota (Sanzone and McElroy, 1998). Both Sanzone and McElroy (1998) in the United States and Atkinson *et al* (2001) in Britain have sounded a caution about the hubris of mastery solutions in so far as attempting to produce a highly engineered managed solution for specific species is concerned.

More recent objectives have been focussed, worldwide, on a broader attempt to assist the habitat to evolve towards a naturally self-sustaining (if somewhat

different to neighbouring) habitat, comprising mosaics of evolving interim habitats (Philip Williams & Ass and Faber 2004).

While the published work from overseas all recommend careful planning and the following of rigorous design methodologies (Atkinson *et al* 2001, Philip Williams & Ass and Faber 2004), there is a growing acceptance of the fact that not everything is known, outcomes may be unpredictable, and ongoing monitoring is required to identify areas where evolution towards a satisfactory habitat is stalled and further intervention is necessary.

This monitoring should be coupled with ongoing research projects over several decades, especially if it is hoped that the lessons learnt can be transferred to future rehabilitation sites (Richardson *et al* 2002).

A3 – A select literature review

L. Arriana Brand, Lacy M. Smith, John Y. Takekawa, Nicole D. Athearn, Karen Taylor, Gregory G. Shellenbarger, David H. Schoellhamer, Renee Spent, 2012
“*Trajectory of early tidal marsh restoration: Elevation, sedimentation and colonization of breached salt ponds in the northern San Francisco Bay*”
Ecological Engineering 42 (2012) 19– 29

Tidal marshes maintain endemic and endangered vertebrate species and key ecosystem services, but have undergone substantial habitat loss worldwide. With growing recognition of their ecological value, numerous tidal marsh restoration projects are underway. A tidal marsh restoration project in the northern San Francisco Bay consisting of three breached salt ponds is one of the largest on the west coast of North America. These diked sites were subsided and required extensive sedimentation for vegetation colonization, yet it was unclear whether they would accrete sediment and vegetate within a reasonable timeframe. Early restoration efforts included site grading, manipulation of water levels through ongoing water management, and extensive plantings of *Spartina* (rice grass) spp.. Some early restoration efforts lost a substantial proportion of planted vegetation, progressed slowly, or were unfeasible to maintain. The results suggest that while restoration may proceed more slowly compared to smaller sites, passive sedimentation at large sites is feasible within a reasonable timeframe in areas with adequate suspended sediment supply. Documented colonization elevations of *S. foliosa* within each pond, perhaps enhanced by tidal muting, may reduce the hydroperiod in higher portions of the tidal range.

While these saltmarshes were grass dominated, not samphire dominated as South Australian marshes are, the key drivers in saltmarsh habitats worldwide are hydrogeomorphological. Elevation is a key predictor of both sediment accretion and vegetation colonization. Results suggest that sedimentation to elevations that enable vegetation colonization is feasible in large sites although may occur more slowly compared with smaller sites.

Significant points

- Results suggest that tidal marsh restoration projects in large (≥ 300 ha), subsided, formerly diked sites will be feasible given sufficient local sediment loads.
- Erosion particularly, borrow ditches, took the place of primary channels in some locations. Further effort is needed to refine design elements, such as ditch blocks, if the goal is to encourage development of historic and new site-interior channels, providing benefits to foraging shorebirds should mudflats become a long-term transitional feature.
- Inundation and thus inorganic accretion will likely decrease as the restoration area fills with sediment, and the effect of sea level rise remains a concern in this as in other restoring marshes

Steve Crooks (Project Manager), Michelle Orr, David Brew, Jette Findsen, Kristin Igusky, 2009 *“Greenhouse Gas Mitigation Typology Issues Paper: Tidal Wetlands Restoration”* Report prepared by Philip Williams & Associates for California Climate Action Registry.

Due to global warming and climate change an interest in sequestering (storing) carbon in land and biomass has developed. Tidal wetlands present an opportunity for carbon sequestration and GHG (greenhouse gas) offsets by virtue of their potential for wetlands creation, restoration, enhancement, and avoided loss. This report includes a discussion of possible tidal wetlands classifications that could be used for GHG accounting framework.

The bulk of carbon stored within wetlands is derived from below-ground biomass, the accumulation of roots and rhizomes associated with standing above-ground crop of vegetation. There is some indication that below a permanent water table this rate of decomposition decreases and long-term sequestration occurs. Both saline and freshwater tidal wetlands have potential to accumulate carbon particularly on long-term restoration projects. Restoring freshwater wetlands potentially offer higher capacity to store carbon than restoring saline wetlands. Developing a carbon budget for tidal wetlands requires that we not only consider carbon sequestration potential but also account for the release of by-products such as organic decomposition by bacteria in wetland soils. If tidal saline wetlands are able to maintain their elevation with accelerated sea-level rise, then the capacity of carbon sequestration will be sustained. However, if sediment supply to the wetland and organic matter accumulation cannot maintain the elevation of the wetland relative to sea-level rise, there is the potential for the wetland to drown.

In this report three different types of measurements undertaken to quantify the net GHG flux of a wetland: the carbon content of the soil, the carbon content of the biomass, and the flux of GHGs between the wetland surface and the atmosphere over time. These measurements can be useful for establishing the baseline amount of carbon associated with a particular wetland before restoration or enhancement. A further explanation of methods of measurements of net GHG flux offered to the reader. Each of these methods has benefits and limitations, multiple methods could be used during the lifetime of the project in order to obtain the most robust GHG flux measurements. The report goes on to review US federal initiatives and regulations that impact wetlands protection or restoration and state wetland restoration goals. Discussion regarding the barriers to meeting restoration and conservation requirements from lack of monitoring, weak infrastructure, costs, coastal population increase and public perception of wetlands are reviewed. Finally the report offers a summary and recommendations for implementation in USA. Recommending standardised classifications, tools, methods, and data base requirements to allow monitoring and comparison for future reviews.

K Richardson, S Jacobs, D Rissik, M Svikis, L Schaeper, and M Brock. 2002
"Compensatory Wetland - Working towards the ecologically sustainable conservation, management and wise use of wetlands in NSW" A discussion paper under the NSW Wetlands Management Policy.

The NSW State Wetland Advisory Committee (SWAC) prepared this discussion paper to outline the major principles, options and issues associated with compensatory wetlands. It was hoped that one of the outcomes of this document would be the development of guidelines on the compensation principle under the *NSW Wetlands Management Policy*. This policy (developed 1996) is a whole-of-government policy for the ecologically sustainable conservation, management and use of wetlands and specifies nine wetland management principles.

Central to the issue of compensatory wetlands is Principle Six: natural wetlands should not be destroyed, but when social or economic imperatives require it, compensation through the rehabilitation or construction of a wetland is required.

In NSW, there are approximately 4.5 million hectares of wetlands, which equates to approximately six per cent of the State's area. An attempt to use social and economic imperatives to set the parameters for defining what is acceptable loss of natural wetlands against development and compensation faces challenges as all wetlands are important, some are of extremely high value (eg Ramsar wetlands) and some rare types (eg peat bogs and acid fens) cannot be recreated. The need for base line assessment, containing approaches and minimal information to be collated is discussed. To ensure no net loss it is usually necessary to replace greater areas of wetlands than those being destroyed/modified. Banking, compensation monetary and other, and protection of catchments were reviewed.

Restored or recreated wetlands require long term (20years) monitoring. The possible use of individual management plans was muted, going on to reflect the need for initial assessments and data collection prior to compensatory action. To determine valuation of wetlands references to methods of assessment were recommended. This was followed by a review of U.S. and NSW progress to date. Unfortunately losses continue to occur and current data is scarce. The conclusions reflect a need for a consistent approach to the implementation compensatory actions and managing and monitoring them over the long term. In particular, defining who is responsible for what, and the development of consistent guidelines for implementation across the State, is crucial. A set of minimum requirements was offered.

Philip W. Atkinson, Stephen Crook, Alistair Grant, & Mark M. Rehfisch 2001
"The success of creation and restoration schemes in producing intertidal habitat suitable for waterbirds" No 425 English Nature Research Reports.

This review summarises information collected about sediments, invertebrates and birds from creation or restoration schemes overseas. A summary of the theoretical and actual effects of intertidal habitat loss on bird populations reflects that estimates of the impacts of habitat loss on waterbird populations is difficult to predict because of the role of density-dependent factors. Habitat loss or change has been shown to impact locally by reducing both the abundance of waterbirds using a site and also at the population level by changing mortality and productivity rates. More thorough methods of recording not just numbers of birds but their relationship with the wetland is required.

The success of mitigation and compensation schemes at creating intertidal habitat presents a significant challenge. Their geomorphology is complex; they are biologically diverse; and they are vulnerable to sea-level rise. Surface topography and creek density largely determine the whole range of other ecological interactions. The linkages between habitat form and function are very poorly understood, even for natural intertidal habitats, and so predicting how a specific habitat will develop on restoration, is subject to great uncertainty. Restored intertidal flat and saltmarshes given time and suitable environmental conditions (tides, sediment supply etc) have different physical characteristics and environmental functions to those of nearby natural marshes. Time is a major component in restoring intertidal habitats and if engineering works are used to create a creek network then the restored form should be based upon natural hydraulic laws. The life cycle and biology of marine invertebrates impacts on restoration times. Abundance and biomass values usually take between two and four years to recover, even longer before the largest individuals of long lived species are found. This is particularly so in saltmarshes, where infaunal recovery can take much longer. Until the reasons for these delays are clarified, it is not possible to claim that a mitigation scheme will be successful in terms of the invertebrate communities, and therefore in terms of the supply of food available to waterfowl. Any replacement/restoration wetland should be created in advance of it being first required as a replacement habitat for waterbirds. Indications are that waterbirds will colonise new areas, however differences between restored and natural bird assemblages are present. Some of these differences are due to the immaturity of the new site. The causes for these differences are mostly due to habitat characteristics which impinge on food supply or some aspect of a species' behaviour. The restoration outcome is not always predictable given current knowledge, but future mitigation schemes should take an experimental approach and have clear criteria determining success. Therefore a greater ability to predict the success of mitigation schemes or new habitat must be created and judged to be an acceptable substitute before development takes place.

Damning reviews of the 20 year mitigation track record in replacing displaced wetlands in the US highlights that where and when possible habitats designated to be of high value to society should not be destroyed. When, for overriding public interest designated habitats are likely to be adversely affected and mitigation provided then the suggestions for best practice for wetlands habitat restoration laid down in Section 7.1 should be considered.

Stephanie Sanzone and Anne McElroy (Editors), 1998 *“Ecological Impacts and Evaluation Criteria For The Use Of Structures In Marsh Management”* United States Environmental Protection Agency Washington, DC 20460.

Marsh management is defined as “the use of structures (such as canal plugs, weirs, gates, culverts, levees and soil banks) to manipulate local hydrology in coastal marshes.” This includes managed pondages, the use of pumping to maintain water levels and the control of tidal flows in and out of sites. The report focuses on summarising the state-of-science as it relates to structural marsh management (SMM), including what is known and not known about the ecological impacts of intentional or unintentional changes to marsh hydrology. An overview of SMM issues on the national level is included in Section 3. A primary focus is on scientific and technical criteria that should guide the assessment of ecological impacts of proposed SMM projects (Section 4). Recommendations for monitoring and priority research to improve our understanding of the impacts of SMM are also included (Section 5). This is complemented by more detailed discussions of the circumstances and concerns in various regions of the country (Section 6).

In most cases, SMM has resulted in trade-offs in which certain wetland values have been maintained at the expense of other values. The determination of management objectives is a reflection of societal choices at the national, state, and local levels, rather than a scientific debate.

In conclusion, unintended, unanticipated, and sometimes undesirable effects have often resulted from structural management of marsh hydrology. It is strongly recommended that decisions regarding proposed SMM projects take into account the potential impacts of the project from an ecosystem, rather than single-species or single-resource, perspective.

Significant points

- In a managed system, water levels can be manipulated to compensate for subsidence, but at the cost of continued intervention. Without adequate soil formation, this effort is ultimately a losing battle. Conversely, in areas with a net sediment surplus, loss of tidal flushing can result in elevation of the marsh surface and conversion to upland, terrestrial habitat, either as a result of accumulation of organic detritus.
- More attention is required to hydraulic and hydrologic design criteria for SMM projects, especially to the quantitative drainage capacity under different weather conditions. Drainage capacity should always be oversized in SMM projects since it is easier to later cut down a culvert flow than add drainage capacity.
- Fish and invertebrate species diversity in pump-controlled diked wetlands (eg maintained bird lagoons in decommissioned salt ponds) may be considerably lower than in undiked systems. The conundrum here is that if deteriorating marsh is not protected or restored, the wetland habitat needed to sustain fishery resources may be lost altogether. Thus, in some cases it may be necessary to make some concessions regarding reduced value for fisheries over the short-term, if this will ensure the sustainability of the habitat over the long term.

Kerryn Stephens, Dayle Green, Dr David Rissik, Phil Anderson, Dr Pia Laegdsgaard, Dr Brian Wallace, Dr Ian Turner, Peter Nelson, Dr Julie Phillips and Ann Finnigan. 2008 "*Saltwater wetlands - rehabilitation manual*". Department of Environment and Climate Change 59–61 Goulburn Street PO Box A290 Sydney South.

Wetland habitats of NSW have been severely depleted, it is estimated that over 60% of the State's coastal wetlands have been lost. The aim of the Saltwater Wetlands Rehabilitation Manual is to provide technical information and guidance to assist with the rehabilitation of degraded saltwater wetlands. Saltwater wetlands have complex hydraulic, physical, chemical, biological and ecological interactions which need to be understood and addressed before rehabilitation is undertaken. The manual offers principles to consider when starting wetland rehabilitation. The implications of social, environmental and economic values on management of saltwater wetlands are reviewed, listing challenges and benefits and processes for developing management plans from funding to data collection are offered. Some of the specific information requirements to be considered include collating current and historical tidal and survey information, surface and groundwater flows and their possible interactions, vegetation communities native to the site, use of the wetland by fauna, soil types and changes in sediment processes, water quality (within the wetland and entering it from its catchment), Aboriginal and European heritage and cultural values.

Section 4 discusses construction considerations in saltwater wetlands and the implementation of structural and non-structural works. Section 5 discusses the need for planned management, it reviews: the impact of weeds, litter, storms and floods, bioaccumulation of toxins, surrounding land use, cattle, pests and mosquito control, and vandalism. Finally the manual examine monitoring and data collection, offering a framework for designing a monitoring and tables that assist in developing minimal standards for data collection and a review of methods.

Significant points

- Locate hydraulic structures with care so as not cause localised erosion and consequent sediment deposition further downstream. Hydraulic structures used to control the tidal flushing of saltmarsh rehabilitation areas may require screens to prevent mangrove seeds entering and establishing within the area.
- In wetlands controlled by weirs, a permanent pool can make up a large proportion of the total detention storage of a wetland compared to one controlled by a riser. Such systems need ongoing staffing for operation and maintenance.
- Drainage systems in estuarine wetlands should typically be constructed to a dendritic or branching pattern comprising, in descending order of size, channels, ditches and runnels.

Philip Williams & Associates, Ltd., and P. M. Faber (2004). *Design Guidelines for Tidal Wetland Restoration in San Francisco Bay*. The Bay Institute and California State Coastal Conservancy, Oakland, CA.

Approximately 90% of the tidal marshes that fringed San Francisco Bay have been destroyed as a result of progressive diking and filling for agricultural, salt pond, and commercial development. Today's community seeks not only to protect existing marshes, but also to restore former marshes as functioning wetland ecosystems. The report gives a comprehensive description of characteristics of the diverse wetlands that are the Bay today. The paper describes a conceptual model of how restored marshes evolve and function based on observations and other researchers' assessments of restored marshes. Guidelines offered to assist the process of restoring tidal wetlands as healthy ecosystems requiring minimal external support or intervention for management. Restoration projects are best planned and designed as multi-objective projects that integrate social and ecologic objectives in a rigorous, explicit, planning methodology. Allowing objective assessment through monitoring pre-selected indicators ensuring continued improvement in design. In restoring tidal wetlands from an immature state, we have to recognize that the mature restored marsh may differ from, or take a very long time to achieve, the same functions as the ancient marsh.

The paper addresses the major design questions that dictate the grading of the site template prior to reintroduction of tidal action and recommends reducing uncertainties in restoration design by an adaptive management program incorporating an experiment within the restoration project. The rigorous planning methodology requires that objectives be made "operational" by defining measurable indicators of their performance. A framework of questions is offered to help design decisions, and formalised generic objectives and constraints set out to aid restoration. The guide is based upon observations and experience from monitoring the evolution of restored sites. There are uncertainties related to wetland restoration. By highlighting these uncertainties, suggested avenues of research are offered in Section 5. The report is a "living document" with data provided in future years by continued monitoring. There is opportunity to continue to improve design decisions by incorporating explicit adaptive management experiments within future restoration projects.

Significant points

- When marsh plains were diked for agriculture or salt pond production 135 to 35 years ago, they subsided by up to 3 m (10 ft). Typical total subsidence for diked tidal marshes throughout the Bay range between 0.6 and 2 m (2 to 6 ft), which means that unless fill material is used to raise ground elevations prior to breaching; many sites are initially below minimum elevations for vegetation colonization.
- Restoration projects (and unplanned restorations) that took advantage of natural sedimentary processes to form an accretionary marsh that evolved over time have performed as well or better than highly engineered projects that attempted to replicate the form of a mature marsh.

Shafer, D. J., and Yozzo, D. J., eds. 1998. "*National guidebook for application of hydrogeomorphic assessments to tidal fringe wetlands*," Technical Report WRP-DE- 16, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This guidebook is for people who can adapt the information provided to tidal fringe wetlands to specific physiographic regions. By adapting from the generalities of the class to specific regional tidal fringe subclasses, the procedure can be made responsive to the specific conditions found there. The Hydrogeomorphic (HGM) Approach is a suite of concepts and methods used to develop functional indices and apply them to the assessment of wetland functions. The HGM Approach is implemented in two phases:

- 1) The Development Phase; an interdisciplinary team of regional experts is responsible for developing a guidebook classifying wetlands, characterizing a regional subclass, developing assessment models for that subclass, and calibrating the models with data from reference wetlands.
- 2) The Application Phase, utilization of the regional guidebook to assess and apply components at a particular site or project.

Chapter 1 provides background information on the HGM Approach, outlines basic principles, and sets the scope and objectives of the National Tidal Fringe Guidebook. Each of the seven wetland classes defined under the HGM classification system is briefly described. Under the HGM classification system, wetlands are grouped using three fundamental criteria that influence wetland function: geomorphic setting, water source, and hydrodynamics.

Chapter 2 presents a detailed characterization of the tidal fringe wetland class and a rationale for defining regional tidal fringe wetland subclasses. Tidal fringe wetlands are defined as vegetated habitats occupying the intertidal zone of marine, estuarine, or riverine systems. Specifically, these wetlands occur along the fringe of drowned river valleys, barrier islands, lagoons, fjords, and other coastal waterways; receive their water primarily from marine or estuarine sources; and are affected by astronomical tidal action. The concept and role of reference wetlands is also presented. The reference wetlands provide a concrete, physical representation of wetlands ecosystems that can be observed and measured, demonstrate the range and variability of conditions in the reference domain and they provide the data necessary for calibrating assessment model variables and functional indices.

Chapter 3 contains the definitions of the functions and variables which make up the conceptual assessment models and is quite technical. For example, several factors may potentially affect the process of Sediment Deposition (SD) in tidal marshes including elevation, flooding duration, suspended solid concentration, flow baffling by vegetation, and proximity to source.

Chapter 4 outlines a generic assessment protocol for assessing the functions of tidal fringe wetlands.

J.B. Zedler, H. Morzaria-Luna, & K. Ward, 2003. "*The challenge of restoring vegetation on tidal hypersaline substrates*" Plant and Soil - Kluwer Academic Publishers. San Francisco, CA, USA.

The establishment of the full complement of species in a natural marsh is a cumulative process that depends on a range of micro sites occurring over long time periods. This paper delineates the knowledge gained from restoration projects on hypersaline substrates.

To establish diverse vegetation in restoration all species cannot be planted at once. For example, the paper suggests transplanting seedlings just before gentle rainfall to reduce stress, and seeds grown to about 17 weeks before planting (allows growth to appropriate size plus 3 weeks for hardening).

Every project reveals unexpected constraints on biota. Those that lack benefits of rainfall can be watered. Sites with coarse sediment can be amended to improve water-holding capacity. Finer soils alleviate concerns about drought. Shallow depressions across a site readily impound saline water causing inundation stress. Sediment deposits might cause reduced light interception and clogged stomata. Sedimentation very likely affects germination and recruitment of volunteer seedlings and sowed seeds. Sediment loads as low as 0.25 cm significantly reduced the number of species and total number of individuals recruited from seed bank samples; addition of sediment decreased the number of individuals appearing for most species. During the rainy season, prolonged rainfall and flooding are necessary to lower soil salinity enough to persist beyond the next high tide. Planning timing cannot be predicted, in part because flooding is a function of rainfall throughout the watershed and flooding causes sediment influx and deposition. The soil salinities explain some of the site-to-site difference in survival, as well as the seasonal difference within site. Other stresses noted concerned sedimentation, algal smothering, and animal activities, but there were many variables that went unrecorded, e.g., soil moisture, water logging, soil redox potential, sulphide concentration, soil and water temperature, water percolation rates, and pH change in response to variations in salinity. At excavated sites where the bulldozer cut a 2:1 slope to form upland to the marsh plain some seedlings established at the fringe of a natural canopy, benefiting from shade and lower surface soil salinities. In large open unshaded space more prone to hypersalinity, survival occurred only under the more favourable conditions, namely low salinity.

It might take decades for a natural marsh to accumulate a dozen halophyte species, just as it might take multiple replanting of a restoration site to get all desired species in place. It is extremely difficult to determine the cause of mortality after the fact.

Future experiments to test the importance of timing on plant establishment are planned, with continuous recording of soil salinity at multiple depths, moisture, air temperature and humidity, wind speed, and observations of rooting depth. Experimentation with plant age and differential hardening would be beneficial. Events such as algal smothering and coot trampling can rarely be anticipated, and at least the latter is difficult to test experimentally. Therefore transplant mortalities can be explained by differential stresses from extreme hypersalinity and chronic sedimentation, neither of which is readily predictable in salt marsh restoration sites.

A4 – Pond stabilisation for ASS & subsidence minimisation

Basic principles of ASS remediation are to:

- avoid or minimise disturbing sulfidic materials;
- contain acidic leachate within soil profile using barriers;
- neutralise acidity and at the same time manage the movement/discharge of toxic oxidation products; and,
- dilute acidic leachate before discharging into the receiving waters (Thomas *et al* 2003).

The basic principles of acid sulfate soil remediation are to curtail pyrite oxidation and to neutralise or leach existing acidity, at the same time managing the discharge of acidic water and toxic oxidation products.

In the case of the Dry Creek Saltfields the acid sulfate aspect is Potential Acid Sulfate Soils. Although some of the ponds were built on Actual Acid Sulfate Soils that had already oxidised and suffered Compaction and reduced elevations, soils underlying the existing ponds are not currently oxidising.

This could change once ponds dry out next summer, when a degree of oxidation could start to occur in all the ponds from Middle beach southwards. The gypsum ponds from St Kilda to Dry Creek provide a slightly more complicated situation, as the thick layer of CaSO_4 is not an oxidation risk in itself; however it overlies an anaerobic layer where sulfate-reducing bacteria are using the sulfate from the lowest layers of gypsum as their oxygen supply, discarding sulfides in the process. This sulfide- rich buried layer (in places nearly 50cm below the surface) has very high acid generating potential if oxygen can penetrate to it. Harvesting the gypsum would be the type of activity that would trigger acid formation in these ponds.

In order to minimise acid production, the benthos of the drained ponds should remain saturated, and this is possible with reflooding, either from seawater or freshwater sources.

The aim of re-flooding is to neutralise actual acidity and reduce new pyrite oxidation rate. However, re-flooding has not always been successful in halting the production of acid or halting the continued oxidation of pyrite in situations where acid production is already well established. In contrast, regular seasonal re-flooding of rice paddies is a successful ASS management tool in South-East Asia (Hicks *et al* 2001).

Re-flooding with seawater has an advantage over freshwater in that it uses the inherent virtually unlimited acid buffering capacity of seawater that is regularly tidally exchanged. Ideally, if elevations permit, the use of seawater avoids the need for pumping. In principle, reflooding with seawater should trap any existing acid leachate and force it deeper into the soil profile limiting the export of oxidation products to the slow diffusion into the tidally exchanged water.

Any small amount of leachate that is produced in areas that receive regular tidal would enter the tidal water and be easily neutralised by its acid buffering

capacity. The method would appear to be at least a preliminary remediation method that would stabilise the lower elevations of any drained salt ponds and reduce the likelihood of production of acid and soil compaction leading to elevation loss.

In gypsum ponds the use of seawater has the advantage that gypsum will dissolve approximately 30% faster than it does in freshwater, suggesting that historic creeklines through the gypsum pond areas would be likely to flush clear of gypsum over time, allowing further penetration of the tidal prism into the site.

That said, freshwater, fluvial or stormwater sources often bring in significant sediment loads, which provide an additional burying capacity and this would lead to more rapid vegetative colonisation of saltmarsh flora across the ponds.

An open system, in which tidal and fluvial inputs occur and where there is flushing to the estuary through existing tidal wetlands, seems the approach most likely to minimise the disturbance of Potential Acid Sulfate Soils and reduce the risk of Actual Acid Sulfate Soils developing.

Such a system would most likely include:

- breaching of the outboard seawalls at historic drainage (creek) lines,
- placing blocks in any embankment-parallel borrow pits to prevent the tide spreading along the site perimeter and instead encouraging scouring of the historic creek lines to increase tidal penetration across the site
- redirection of stormwater and reconnection of historic creeklines into the ponds on the landward side (eg the Helps Road drain south of St Kilda, and the Smith and Adam Creek catchment that currently drains through Fork Creek instead of Thompson Creek north of St Kilda).

A5 – Volume calculations for artificial pond maintenance

24,250,000 m3 input brine

Pond	Area (ha)	Outflow TDS conc (g/L)	SG at Pond exit
XB3	344	43.3	1.031
XB4-5	215	51.1	1.037
XA2	161	59.4	1.042
XA3-4	100	66.3	1.047
XC3	163	82.7	1.058
XB8	219	130.3	1.090
XB8a	28	140.4	1.097
XA1	48	162.6	1.112
PA3	24	176.6	1.122
	1,302		

70,000,000 m3 input brine

Pond	Area (ha)	Outflow TDS conc (g/L)	SG at Pond exit
XB3	344	37.4	1.027
XB4-5	215	39.1	1.028
XA2	161	40.4	1.029
XA3-4	100	41.4	1.030
XC3	163	42.9	1.031
XB8	219	45.3	1.033
XB8a	28	45.6	1.033
XA1	48	46.2	1.033
PA3	24	46.5	1.033
	1,302		