St Kilda Bay

Restoration options

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20 March 2003

LIMITATIONS STATEMENT

The sole purpose of this report and the associated services performed by Delta Environmental Consulting is to conduct an environmental assessment of a range of options to improve the environment of St Kilda Bay, South Australia on behalf of the St Kilda Progress Association

Delta derived the data in this report primarily from visual inspections, examination of records in the public domain, sampling of the site and interviews with individuals with information about the site. The passage of time, manifestation of latent conditions or impacts of future events may require further exploration at the site and subsequent data, analysis and a re-evaluation of the findings, observations and conclusions expressed in this report.

In preparing this report, Delta has relied upon and presumed accurate certain information (or the absence thereof) relative to the site, provided by government officials and authorities and others identified herein. Except as otherwise stated in the report, Delta has not attempted to verify the accuracy or completeness of any such information.

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1. Introduction

St Kilda Progress Association approached Delta Environmental Consulting to examine the health of the St Kilda Bay in a discussion paper in 2001. After reading the discussion paper, which highlighted the presence of hydrogen sulfide in the waters of the bay, the members of the Progress Association suggested that they may like to consider what options were available to remediate the bay.

The City of Salisbury asked Dr David Blackburn to propose some options, and Delta Environmental Consulting spoke to Damian Maroney about possible Coastcare/Coasts and Clean Seas funding. The funding arrangement for these two programs was nearing its end, and as there was a considerable amount of background work to complete, it was not possible to obtain funding from these programs.

As both the City of Salisbury and Progress Association remained enthusiastic about restoring the bay, it was decided to develop an options paper that could be used to assist the Progress Association and local Council with the decision making process, as well as forming a background paper for use in seeking any funding in the future.

This paper necessarily contains much of the material from the previous discussion paper, along with the various options available to manage the Bay, the results of more detailed environmental studies conducted in the area and a matrix looking at the benefits/impact of the proposed options.

2. Consultant

Delta Environmental Consulting is an independent South Australian consulting business. The company has a policy of continuous improvement in the areas of:

- providing a quality service to our clients
- providing ongoing training and educational opportunities for our consultants
- maintaining high standards in the areas of health, safety and environment both within Delta and while working with our clients

Delta Environmental Consulting is a member of Standards Australia, and is currently working towards third party registration of its Management System, which incorporates the requirements of ISO 9000 (quality assurance) and ISO 14000 (environmental management).

The company provides services in the areas of: biological survey work, environmental education programs, saltfield technology and saline wetland ecology, scientific illustration & desktop publishing, preparation of herbarium and museum specimens, taxonomy and classification, revegetation and rehabilitation, and computer application development.

The consultants undertaking the project are detailed in *Appendix 2 - Details of Consultants.*

3. The location of the study

The coastal township of St Kilda is located on a small bay in the mangrove forest about 27 kilometres north of Adelaide on the eastern side of Gulf St Vincent, near the opening to Barker Inlet. Barker Inlet and the coastal wetlands to its east and north form a jigsaw of interconnected habitats of considerable variety and biological interest.

The area of interest for this study comprises the tidal flats, backing beach and salt marsh along with the surrounding mangroves of the bay directly in front of the St Kilda township.

4. Observational studies of St Kilda Bay and its beach

This study follows on from an earlier discussion paper on the environment of St Kilda Bay. The current study presents a summary of the environmental status of the benthic part of the bay (its floor), in comparison with a similar area at Middle Beach. A series of options to improve the environment are provided, along with a matrix that looks at the most likely impacts of each option.

4.1 St Kilda Bay – geographic changes over time

Early maps of the Bay show that the township was built on three small sand berms (or dunes), with drainage ‘creeks’ between them. A large creek was located at the southern end of the Bay. A thick stand of mangroves grew both to the north and south of the creek, and this allowed a deep channel to develop, that was navigable for boats. The central and northern creeks were not mangrove lined, and were shallow. Their locations were not fixed, and they tended to move as the sandy mud of the bay shifted in storms.

There was a thin rim of sand along the edge of the tidal flat, which extended from the southerly creek (behind the mangroves) to the north. Just north of the central creek there was a sand ridge jutting out into the bay that had accumulated shingles. At the most northerly extremity of the Bay a dune fronted the tidal flats and area of salt marsh grew adjacent to the northerly expanse of mangroves.

These details are shown in Survey Field Book 662 lodged in the Lands Titles Office and drawn by Thomas Evans in 1873. One of the pages from Thomas Evans field book is reproduced over the page, showing an overview of the township. The other pages, and reproductions of historic mapping, have been provided to the Progress Association as reference materials.

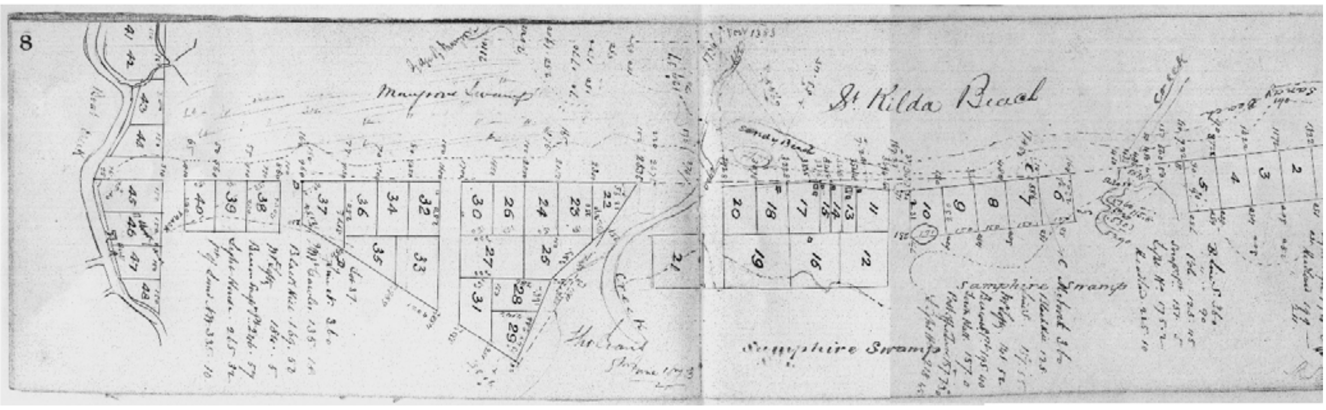

Figure 1 - Pages 8 & 9 from Survey Field Book 662 (Evans, 1873)

Photographs of the tidal flats themselves, taken at the turn of the century, show firm sand sprinkled with cockles. Picnic parties regularly strolled across the flats during visits to St Kilda.

For many years St Kilda was used for little more than holidaying. After World War I the government decided that South Australia should become self sufficient in chemical manufacture, and ICI established a saltfield in the saltmarsh areas behind the township. Then after World War II there was a significant population expansion in South Australia and this placed strain on existing infrastructure such as sewage treatment works and municipal dumps. St Kilda found itself impacted by the outfall of the new sewage treatment at Bolivar, used as a municipal dump, and became part of the route for a gas pipeline.

Figure 2 - St Kilda Hotel c.1950 (Photograph copyright Mortlock Library of South Australiana)

Tracking large-scale changes to the shape of St Kilda since 1949 is not difficult, as aerial photography has been used by the Lands Department on a regular basis since that time.

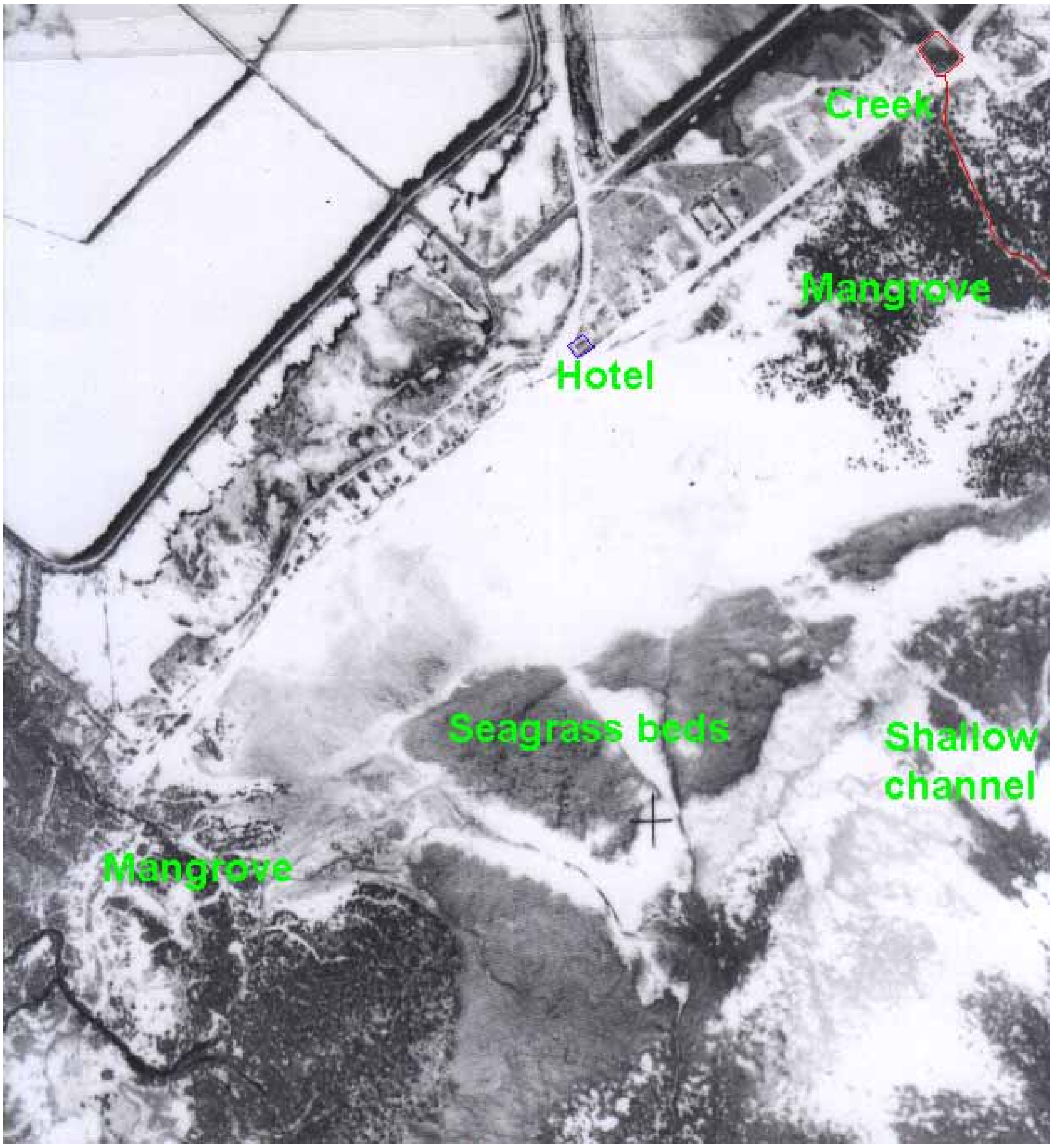

Figure 3 - St Kilda Bay, 1949

The 1949 photograph shows the mangroves growing in front of houses south of the hotel, and the deep, mangrove-lined creek where the boat channel is presently. The shallow boat channel came in to the hotel, and was used by limited draught boats at high tide. There were well-established seagrass beds just off-shore that came as close to the shore as the landward edge of the adjacent mangroves.

Not a lot had changed by 1961. The photograph from that year shows a very similar landscape to that of 1949. The seawall around the hotel had been improved. This was probably done in about 1950 as it can be seen in the photograph of the hotel in Figure 2.

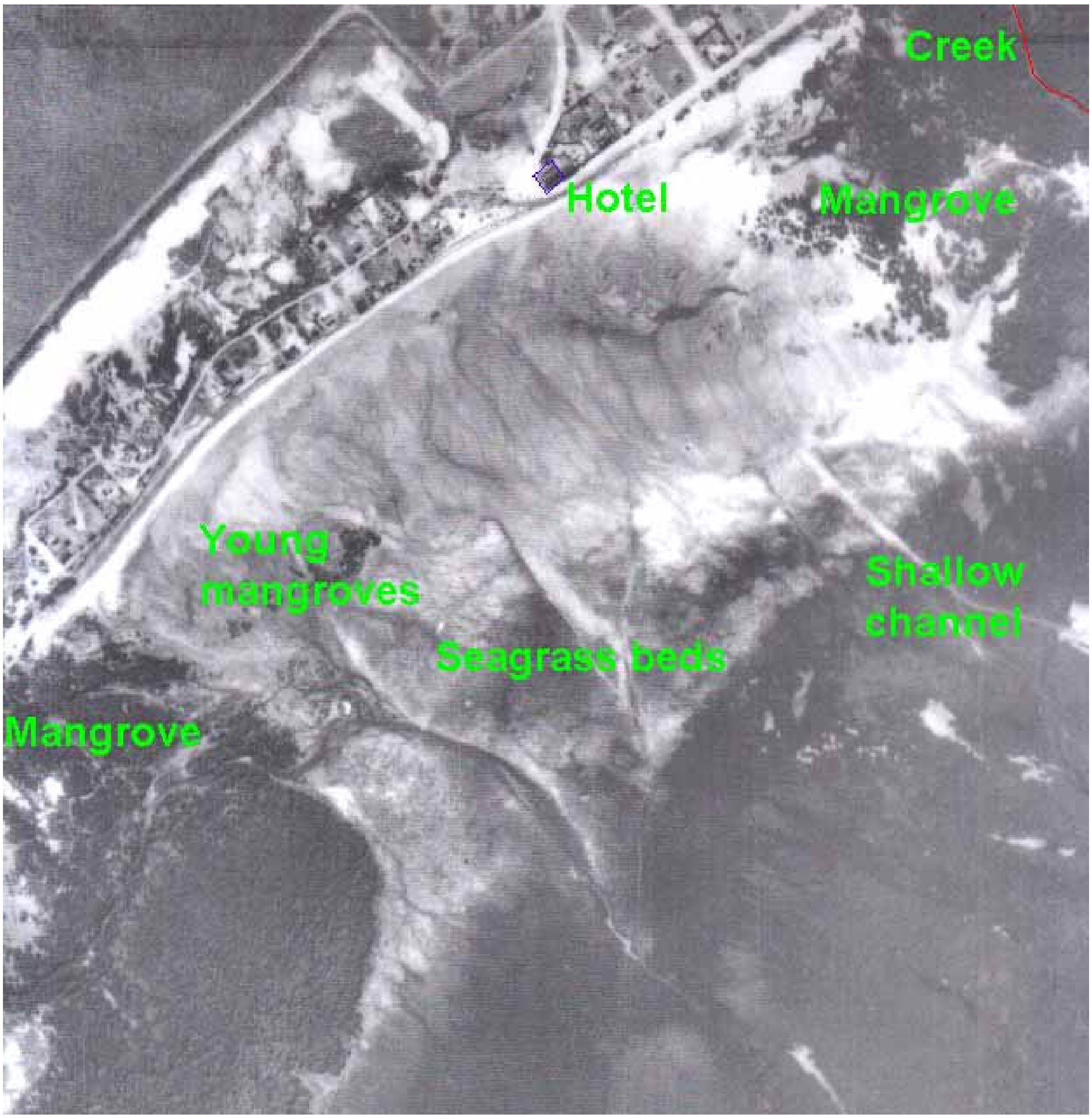

Figure 4 - St Kilda Bay, 1961

Some time in the late 1960's things started to change rapidly. Bolivar WWTP was installed and Adelaide's effluent flowed to sea at Chapmans Creek, a little north of St Kilda. The landfill rubbish tip for the City of Salisbury was begun, and it was established on the mangroves adjacent to the southern creek. This was a common practice in the 1960's, and many of the east coast mangrove forests have suffered a similar fate. Several northerly remnants of mangroves still remained on he northern edge of the landfill.

The boat haven was dredged and the tackle shop was built on the edge of the landfill, adjacent to the new boat channel and launching ramp. The dredged spoil from the boat channel was dumped on the northern side of the new channel.

A shallow channel established itself north of the dumped spoil. It may have been kept open by water being pumped out of the landfill area, where a deep collection area existed just behind the seawall. This channel and the collection area can be seen in Figure 5.

By 1972 the Bolivar Wastewater Treatment Works had been operating for seven years, and this, combined with the dredging and landfilling activities, may explain the dieback of seagrass, compared to 1961, that is visible in the photograph.

Figure 5 - St Kilda Bay, 1972

A photograph taken only seven years later in 1979 (Figure 6) shows how quickly the landfill progressed. An additional ‘cell’ had been added on the northern side of the landfill and now completely covered the mangrove forest, except of two small, isolated trees.

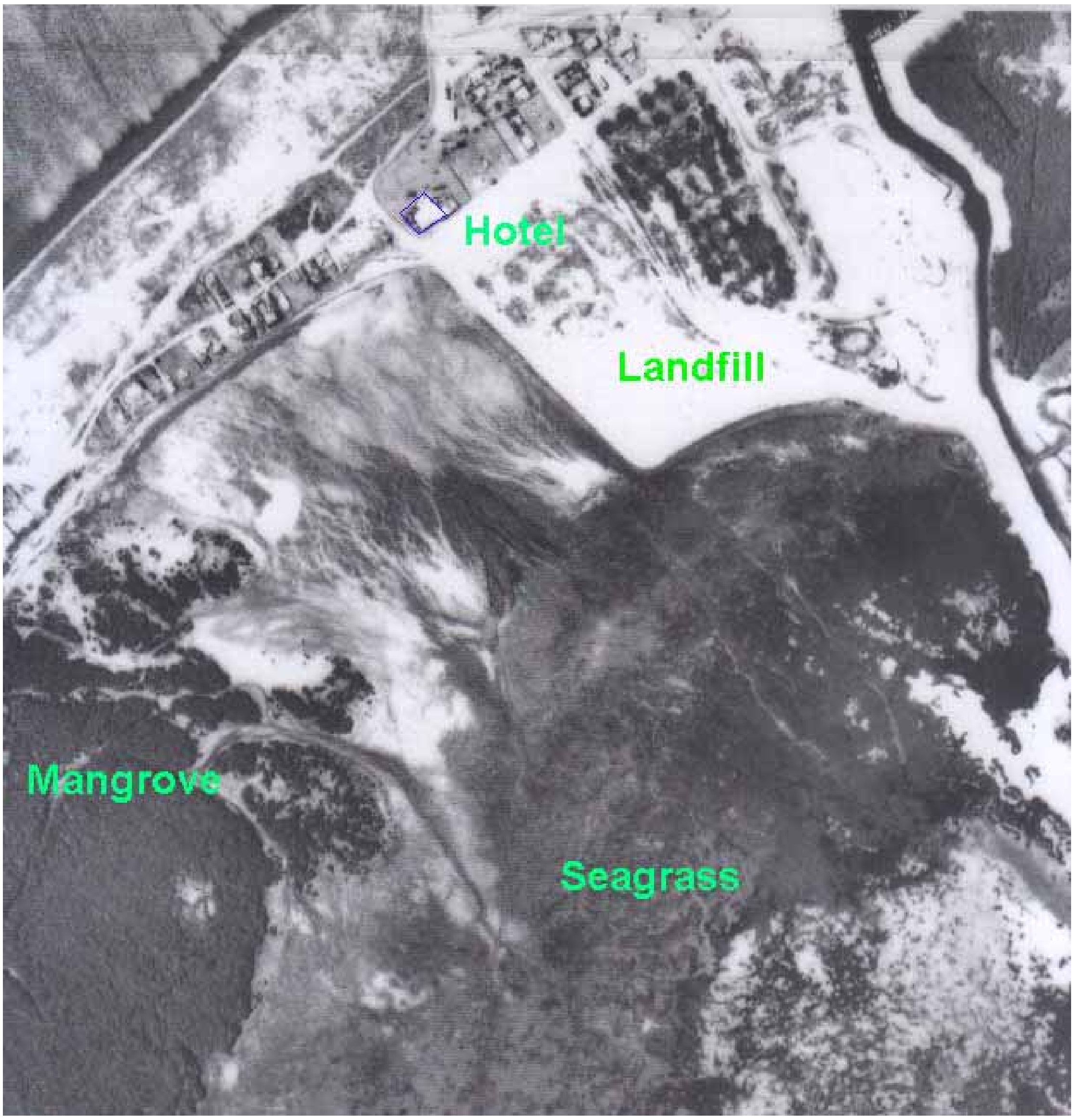

Figure 6 - St Kilda Bay, 1979

The photograph from 1979 clearly shows plantings and other improvements taking place on the southern cells of the landfill. There appears to be no further pumping out occurring at the landfill, and the channel to the immediate north of the boat channel dredge spoil embankment has filled in. The shallow channel to the hotel has almost disappeared.

Figure 7 shows the view in 1989. It is likely that the gas pipeline was installed by this time and the lumpy dredge spoil north of the boat channel would have been 'rocked' to prevent it slumping and to make a firm foundation for the pipeline.

Of note in the 1989 photograph is the presence of sea cabbage (*Ulva rigida*) growing on the floor of the bay where seagrass previously occurred. All *Ulva* species are nitrogen scavengers and they can blanket a nutrient-rich area completely, in Spring time. Further off-shore the

seagrass beds had deteriorated into separate little ‘islands’ with patches of bare sand between them.

Figure 7 - St Kilda Bay, 1989

The final photograph in the series shows the bay in 2000. The boat channel was being dredged again in this photograph, and a series of holding ponds on Whiting Street Common holds the dredge spoil. The water flow from the dredge spoil ponds passes through several holding ponds prior to discharge to sea through the drainage system at the south and through the samphire creek north of the last houses.

From the point of view of the marine environment, this process was better than the earlier practice of dumping dredge spoils adjacent to the boat channel, which would have raised the turbidity of the water considerably. The land disposal and holding ponds did not add further stress to the marine environment, and in fact, the flushing of the small northerly creek may have had a beneficial effect on the saltmarsh in that area. The negative aspects of the process were the salting and raising of the freshwater lens under St Kilda, which resulted in gardens and trees dying in Whiting and Beach Roads, and the necessity of building an additional holding pond that was not contained on the Common, in the saltmarsh itself.

Figure 8 - St Kilda Bay, 2000

What can also be seen in this last photograph is that the rapid retreat of the seagrasses is still continuing. One of the most recent areas of seagrass to die back was a patch just off the end of the playground (built on the old landfill). The rusty colour on the photograph marks the area that had recently died. Within a few years the area will simply look bare, as the rest of the bay does.

4.2 Visible changes in the environment of the bay

The changes in the bay at St Kilda are not limited to changes in shape. Some of the changes have been touched on in the section above, namely the death of seagrass and the destruction of mangroves.

St Kilda Bay and its beach today are noticeably degraded from the picture presented in early twentieth century photographs. At 'turn of tide' the odour of rotten eggs is marked. Deep drifts of rotting vegetation cover much of the area where there would have been sand. This dead seaweed and seagrass also covers much of the tidal flats, along with a coating of fine jelly-like mud. In some areas this coating is nearly 50 centimeters deep and is black, soft and smelly.

The surface of the bay remains wet at low tide, unlike the nearby beaches at Port Gawler and Middle Beach, and the pools of trapped water exhibit scums of white and purple sulfur bacteria.

At low tide, tidal flats in other parts of Gulf St Vincent reveal meadows of *Zostera* seagrasses with smaller amounts of green algae (*Ulva* and *Enteromorpha*) interspersed. The calm waters, fine sediment and dense growth of these beaches provide excellent habitat for invertebrates and small fish. Flocks of shorebirds pick through the flotsam at low tide hunting for small organisms, while black swans graze the seagrass.

At St Kilda the birds remain, but the invertebrates are gone. There are no meadows growing on the tidal flats, merely detritus delivered to the bay with the tide. We have changed the bay, and in response the bay's ecology is changing.

4.3 Preliminary interstitial (pore) water study at St Kilda, 15 June 2001

On 15 June 2001, samples of interstitial water (water trapped in the muddy sediments at low tide) were collected from the tidal flat directly offshore from four properties – 28 Whiting Street at the northern end of the township, Number 18 Whiting Street, Number 16 Beach Road and Number 6 Beach Road. The samples were collected from pore water that drained into very shallow (less than 10 cm deep) holes dug into the surface sediment. The samples were returned immediately to the laboratory, filtered to remove gross particulates and analysed for both sulfates and hydrogen sulfide.

Table 1 and Figure 9 present the results. They include a fifth set of values (the reference values for seawater from Baseggio, 1974), for comparison.

Sample	H_2S (mg/L)	SO_4 (mg/L)
1	42.5	1350
2	18.0	2400
3	13.6	2050
4	9	2450
Seawater	0	2708

Table 1 - Sulfates and hydrogen sulfide in interstitial water

The analyses showed quite clearly that the water trapped on the tidal flat had undergone a considerable change. It contained very high levels of toxic hydrogen sulfide, instead of sulfates (the oxygenated form of sulfur). This is typical of water from anoxic zones in Australia (Parsley Bay, Macquarie Lakes, Moreton Bay) and all round the world (the Black Sea, Arabian Gulf and the Gulf of Texas). These zones are becoming more common as a result of eutrophication (nutrient enrichment) and hydrological change.

Bacteria are responsible for converting the sulfates available in seawater into hydrogen sulfide. Section 6.3 contains information on this process.

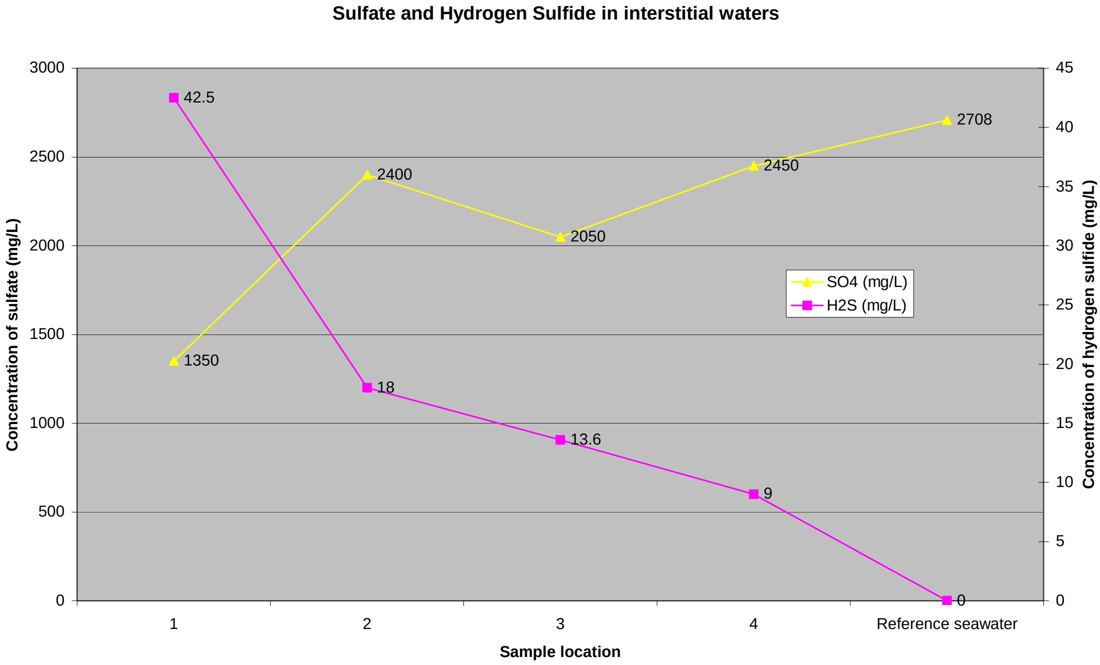

Figure 9 - Graphical representation of sulfate and hydrogen sulfide concentrations

4.4 Comparative studies of St Kilda and Middle Beach

In December 2002 a series of comparative studies were undertaken at St Kilda and Middle Beach. Middle Beach was selected as a suitable beach for comparison, as it has a similarly configured beach to the original St Kilda beach – a southern creek line, houses on the foredune, a long stretch of sand/mud flats before deeper water is reached, and mangroves expanding southwards from the northern part of the beach. Other similar beaches exist, such as Port Gawler beach, but have drawbacks such as their large size, or the lack of foredune housing.

The locations chosen for sampling at Middle Beach are shown in Figure 10, over the page. The sampling regime was more intense at St Kilda, as extra data was required to enable the team to map the extent of variations in the habitat. Figure 11 shows the locations where sampling was attempted at St Kilda.

Sites 1-14 had mud cores and water samples collected from them. Site 15 at St Kilda was in the mid to upper littoral zone (higher and drier than the rest of the bay) and the sample holes there were dry, so no samples were collected from that site. Other observations were made, however.

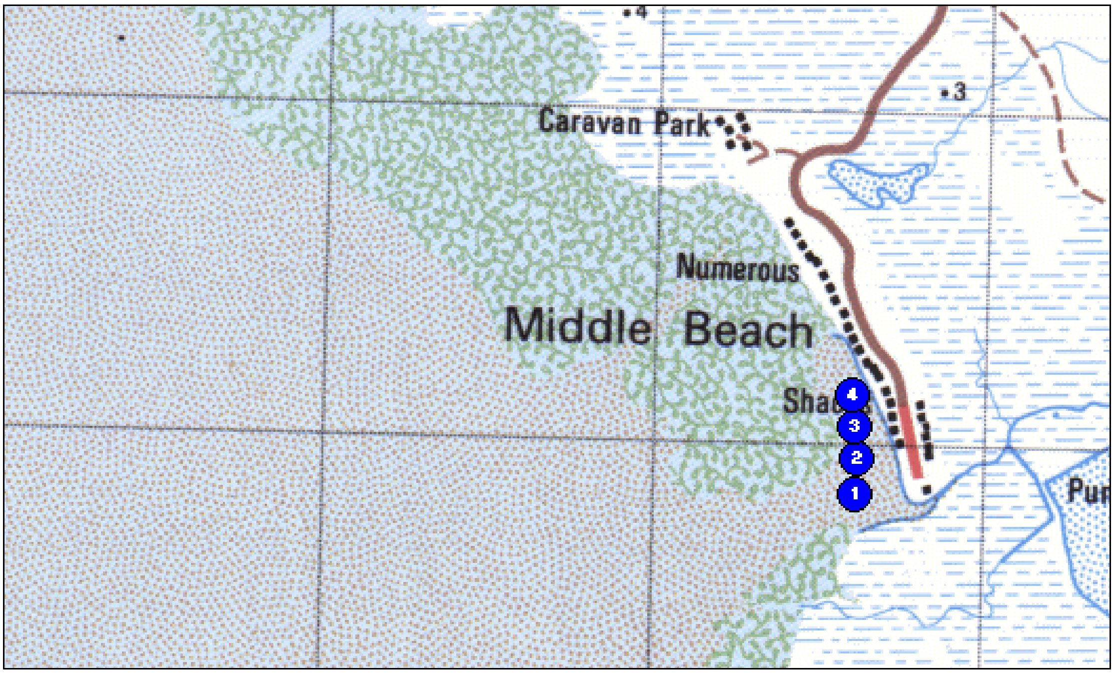

Figure 10 - Middle Beach sampling locations

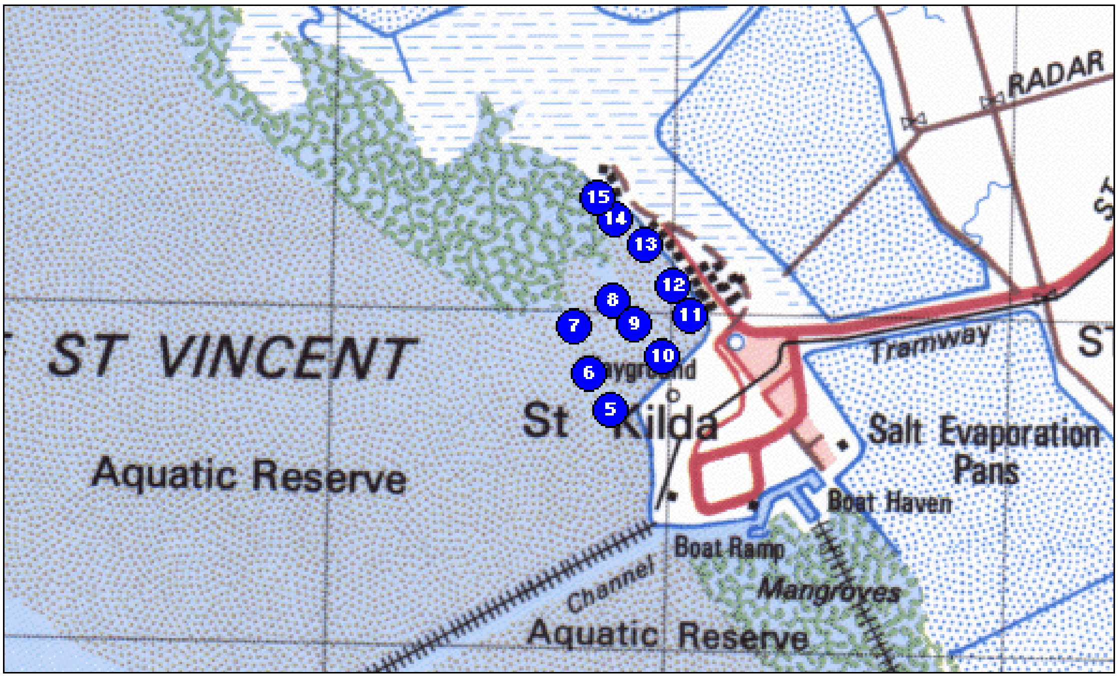

Figure 11 - St Kilda sampling locations

An aerial photograph with detailed locations sampled at St Kilda is provided in Appendix 1. The sites have very similar topography and also similar vegetation associations, as can be seen on the two following figures, extracted from the Coastal Atlas of SA (DEH, 2003).

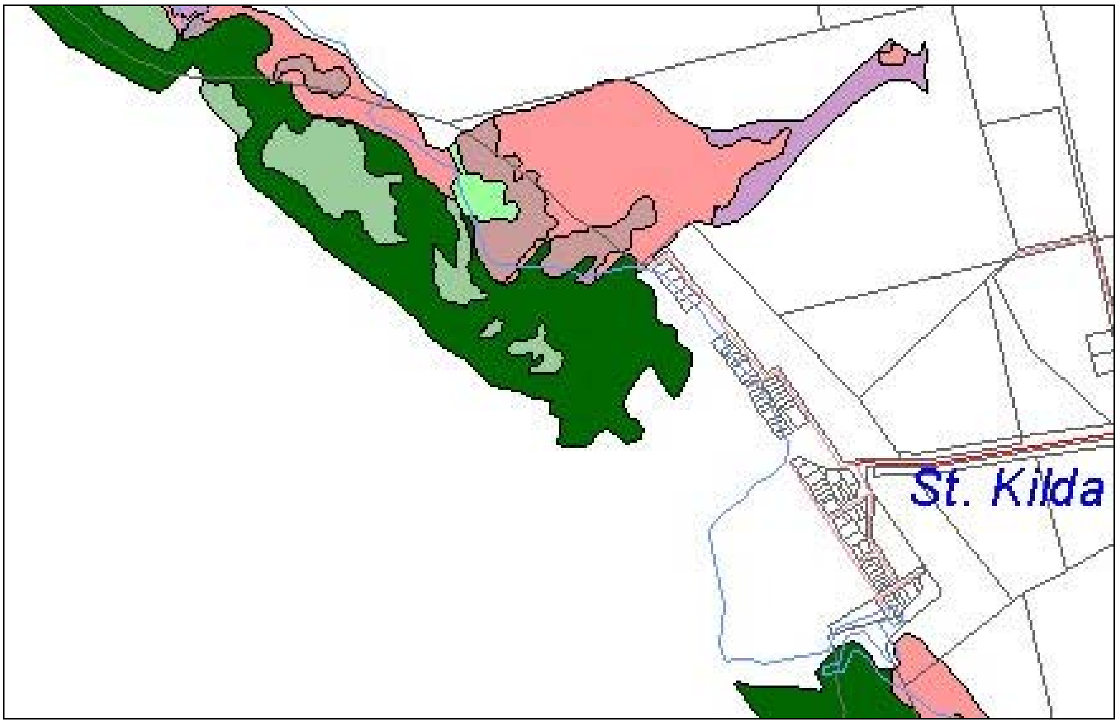

Figure 12 - St Kilda vegetation associations (DEH Coastal Atlas of SA, 2003)

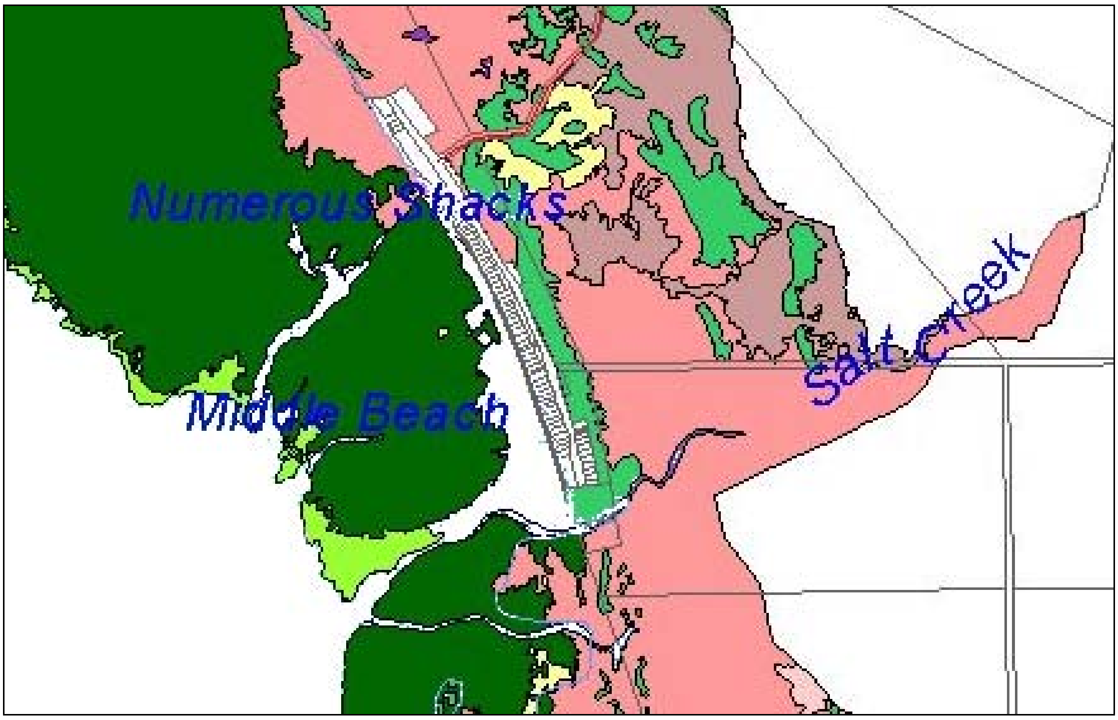

Figure 13 - Middle Beach vegetation associations (DEH Coastal Atlas of SA, 2003)

The two sites both have southern creeklines, a band of mangroves on the seaward side of the beach area (dark green, containing new areas coloured apple green and dying areas coloured

pale green), saltmarsh (pinks/browns) in the low lying areas behind the houses and sand berms in and around the houses (soft green in the landward areas).

4.4.1 Mapping hydrogen sulfide in mud at St Kilda and Middle Beach

At low tide on 4 December 2002, fourteen samples were collected from the two beaches. At each location, surfaces where samples were to be collected were free of surface water. Samples of interstitial waters were collected by removing a plug of sand/mud/sediment, of approximate dimensions 10cm x 10cm x 10cm. The plug was placed in a sealed bag for examination later.

The hole left after the plug was removed was allowed to fill with water draining from the walls of the hole. This water was captured in small containers, which were filled completely to prevent oxidation of any sulfides and returned to the laboratory immediately for testing.

In some cases it was difficult to obtain 'free' pore water from the holes. Holes 8 and 9 were dug into a thick layer of jelly-like slurry that did not release water easily. Samples of the slurry were obtained and the sediment centrifuged out of the sample to obtain clear water for testing.

At Hole 15 the topography was noticeably higher than the rest of the bay, and the muddy sand/composting seaweed substrate was well drained, resulting in no free water being present to sample.

Township	Sample ID	Easting	Northing	mg/L H_2S	pH
Middle Beach	1	262610	6166856	0.019	8.2
Middle Beach	2	262619	6166969	0.015	7.8
Middle Beach	3	262605	6167061	0.011	8.2
Middle Beach	4	262599	6167154	0.017	7.8
St Kilda	5	273835	6152697	0.052	8.2
St Kilda	6	273767	6152805	0.058	8.2
St Kilda	7	273718	6152944	0.041	7.8
St Kilda	8	273831	6153024	49.2	7.2
St Kilda	9	273899	6152953	147.2	7.2
St Kilda	10	273980	6152859	0.031	7.5
St Kilda	11	274060	6152981	2.6	7.1
St Kilda	12	274010	6153069	21.4	7.3
St Kilda	13	273924	6153187	32.2	7.2
St Kilda	14	273834	6153263	0.077	7
St Kilda	15	273782	6153328	--	--

Table 2 - Hydrogen sulfide and pH at St Kilda and Middle Beach

All samples collected from St Kilda contained higher concentrations of hydrogen sulfide than any of the samples collected from Middle Beach. The concentrations at St Kilda varied considerably as can be seen from Figure 14.

Similarly, the pH varied considerably, and was lowest (most acidic) at St Kilda. Normal seawater has a pH of approximately 8.2, and a reduction of that suggests that anaerobia or acidic pollutants may be present. When sampling sediments, the pH usually falls a little, in the zone where little oxygen is present.

Figure 14 - Hydrogen sulfide concentrations in the mud at St Kilda

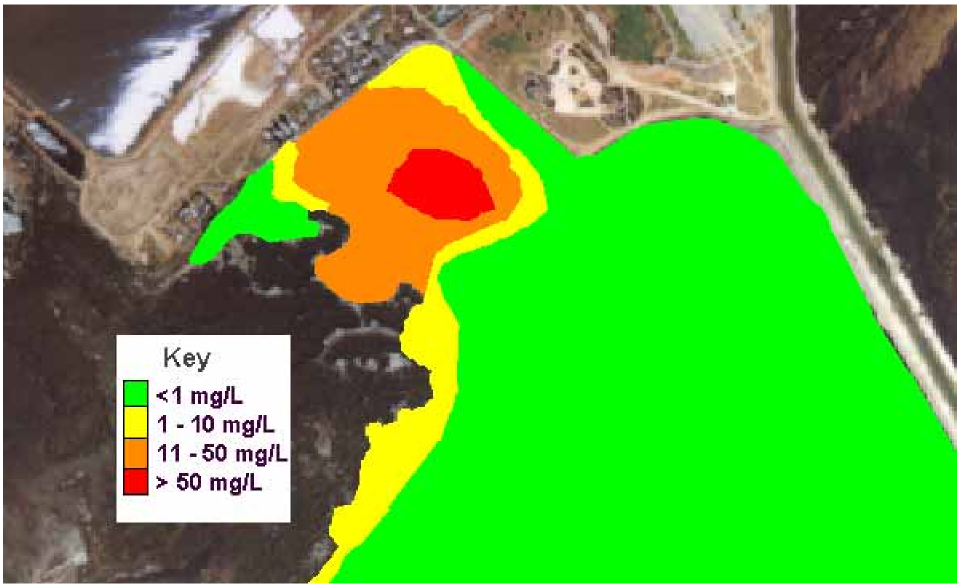

Figure 15 - Approximate distribution of hydrogen sulfide concentration

The concentrations obtained at each site can be generalized to a degree, to gain an idea of what pattern of sulfide concentrations are present across the bay. The figure above attempts

this, although the limited number of data points would suggest that the locations of each band may not be totally accurate.

St Kilda samples had a slightly lower average pH reading (7.4) than the Middle Beach samples (8). The figure below shows the pH readings at St Kilda.

Figure 16 - pH values for interstitial pore water at St Kilda

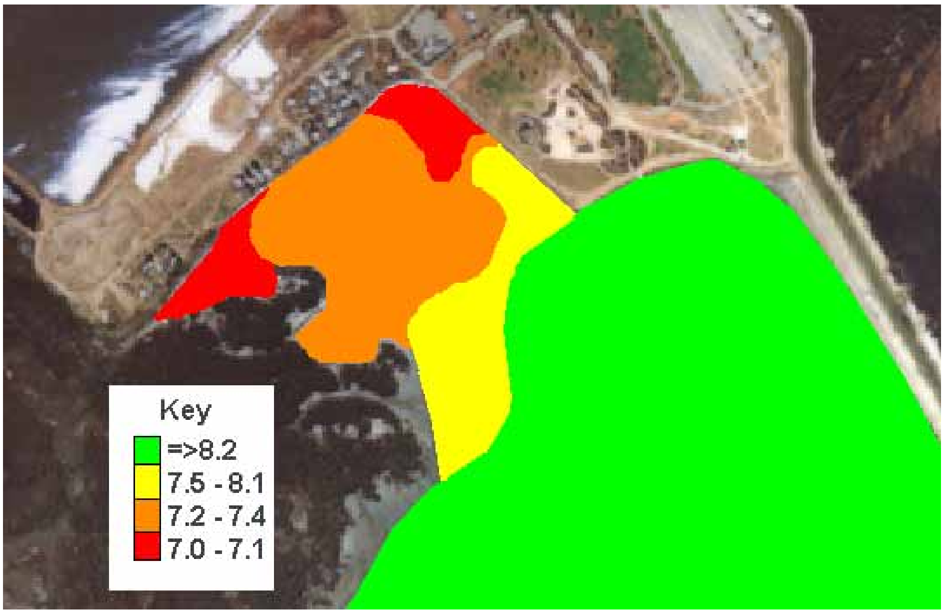

Figure 17 - Approximate distribution of pH in interstitial pore water at St Kilda Bay

The generalized pH readings produce a similar, though not identical, distribution pattern to that produced by the hydrogen sulfide readings.

4.4.2 Comparison of indwelling benthic macroinvertebrates at St Kilda and Middle Beach

Mudflats are usually very diverse areas. Underwood and Chapman (1995) suggest the range of inhabitants to be expected on a typical Australian mudflat in the illustration below.

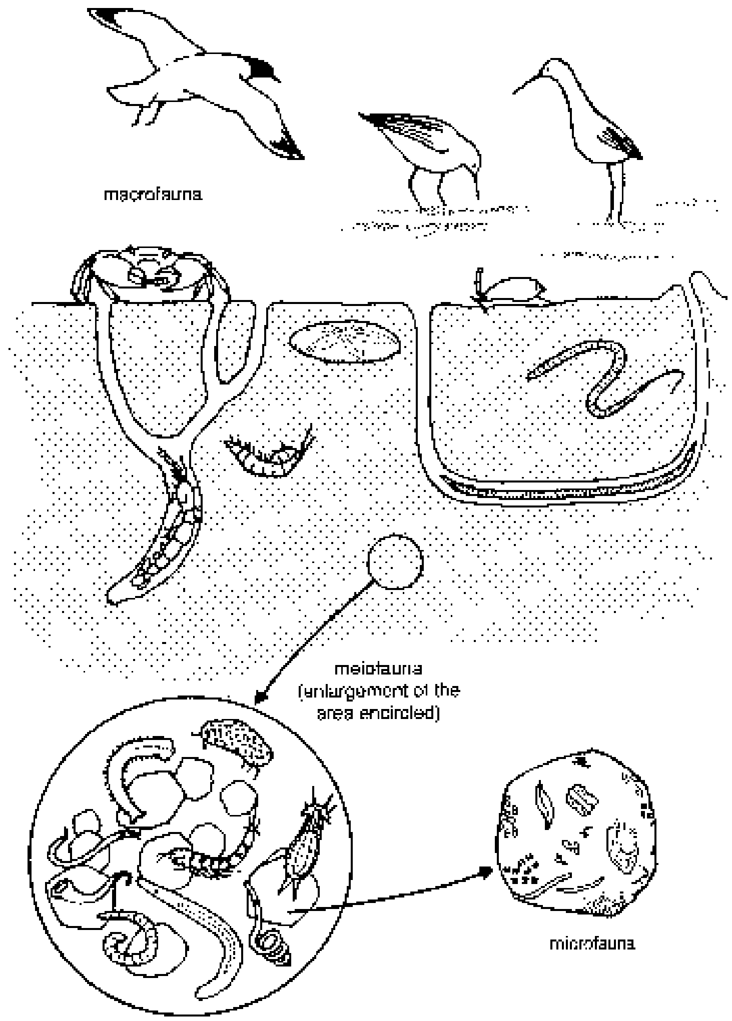

Figure 18 - Mudflat inhabitants (copyright Underwood and Chapman, 1995)

As described earlier in this report, fourteen sediment samples were obtained, measuring approximately 10cm x 10cm x 10cm, from Middle Beach and St Kilda. The samples from each of the sites were sieved and the small organisms that were living in the mud were noted. No dead shells were collected, as these could be historic shell deposits. The two beaches had very different organisms living buried in the sediments as can be seen from Table 3. The macroinvertebrates in the mud at Middle Beach were mainly small bivalves (mussels and little cockles), while St Kilda hosted several types of polychaete worms (bristle worms).

Township	Sample ID	Benthic macro invertebrates	Bivalve	Polychaete worm	Other worm	Anemone
Middle Beach	1	0	0			
Middle Beach	2	20	20			
Middle Beach	3	15	11	1		3
Middle Beach	4	10	10			
St Kilda	5	90		90		
St Kilda	6	16		16		
St Kilda	7	2		2		
St Kilda	8	0				
St Kilda	9	0				
St Kilda	10	7		7		
St Kilda	11	5		4	1	
St Kilda	12	0				
St Kilda	13	0				
St Kilda	14	0				

Table 3 - Benthic macroinvertebrates

The bivalves living in the mud at Middle Beach were *Xenostrobus* sp. (the small mud mussel) and *Anapella cycladea* (a type of cockle).

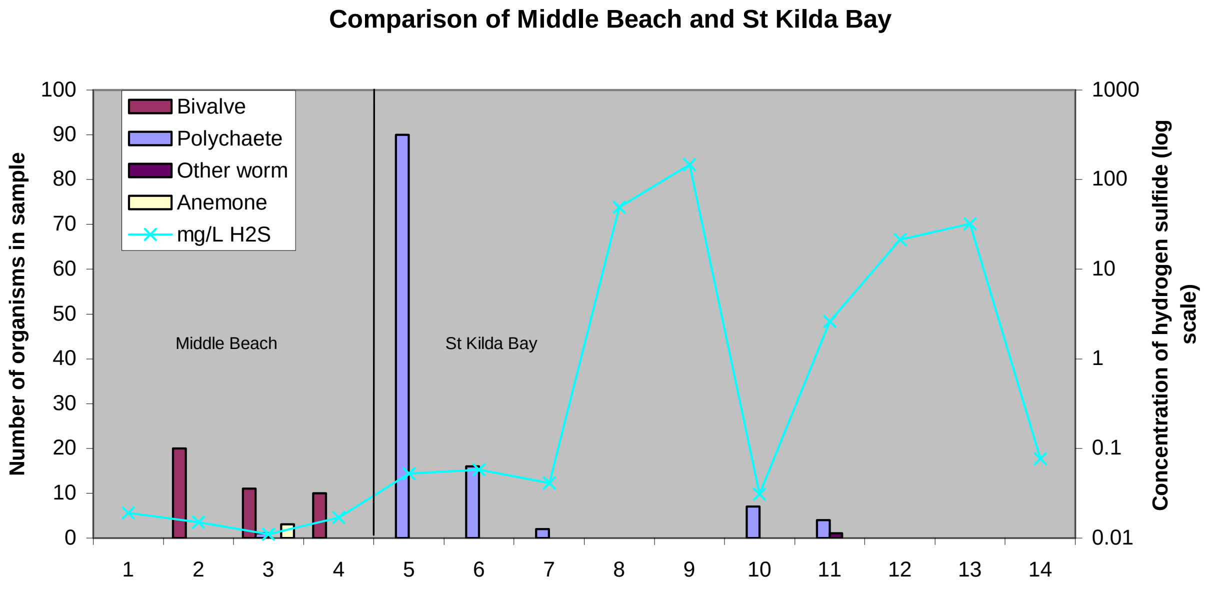

Figure 19 - Benthic organisms vs hydrogen sulfide

Most of the worms at St Kilda were found on the sites that had the lowest hydrogen sulfide readings as can be seen in Figures 17 and 18. Sites with very high sulfide readings contained no visible organisms at all in the samples, although they would have contained bacteria.

Figure 20 - Macroinvertebrate scores for St Kilda samples

The majority of the polychaete worms at St Kilda were *Capitella capitata*, a species known to occur in very high numbers in organically polluted areas (Shepherd and Thomas, 1982). The species has a high tolerance for low oxygen levels and high sulfide levels.

Figure 21 - Capitella capitata

4.4.3 Comparison of surface dwelling macroinvertebrates at St Kilda and Middle Beach

Animals that require air for at least part of the day are often found on the surface of mud and sand flats. At Middle Beach there were many small live snails and visible crab holes in the mud. For example, at location 4 there were 120 crab holes per square metre of surface. The snails were *Salinator fragilis* (fragile air breather, or sand snail), *Nerita atramentosa* (black periwinkle) and *Bembicium* sp. (the common winkle).

At St Kilda only one location had live snails on the surface (there were empty shells right across the beach). The site with live snails was location 15, in the higher littoral zone where the saltmarsh reaches the beach. The snails there were *Salinator fragilis*. Occasional crab holes are also visible at that site, but at nowhere near the density observed at Middle Beach.

Location 15 is shown on the aerial photograph (Figure 22 below) just adjacent to the annotation ‘crab holes’. The illustration also contains an observation of where stumps from old mangrove trees were found next to the playground.

Figure 22 - Observations at St Kilda

4.4.4 Observing bird use of St Kilda Bay and Middle Beach

Tidal flats in Gulf St Vincent host a wide range of shorebirds, both migratory and resident. The World Wildlife Fund has chosen northern Gulf St Vincent as one of five priority sites in Australia to be included in its shorebird conservation project. This reflects the fact that the Gulf hosts many birds listed on international migratory bird treaties. The tidal flats at St Kilda and other beaches host many birds, and it is not known how much impact the current

environmental conditions are having on those birds, nor what the impacts of any changes may be. A recent study of shorebirds in the Gulf St Vincent area (Smith, 2002) suggested that at least four species of shorebird are present in numbers exceeding 0.5% of the world's population for those species (Red-capped plover, Banded stilt, Sharp-tailed sandpiper and Red-necked stint). The same author reports that Greenshanks and Grey Plovers are present in populations of national significance.

Some basic observations have been undertaken at St Kilda, Middle Beach and Port Gawler, for this study.

At low tides wading and shorebirds make use of tidal flats to feed. An estimation of the type of food a shorebird is hunting may be made by examining the bird's beak. Underwood and Chapman (1995) report that curlews and godwits use their long curved beaks to obtain burrowing crabs and bivalves from as deep as 15 cm below the surface. The shorter billed knots dotterels and sandpipers catch small bivalves, snails and polychaete worms that live very close to the surface. Those birds with heavy beaks can open the shells of large mollusks and crabs.

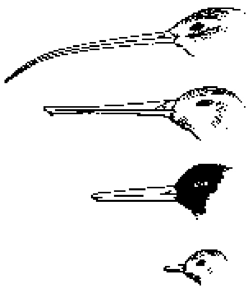

Figure 23 - Shorebirds beaks reflect their diet (copyright Underwood and Chapman, 1995)

At St Kilda the substrate only contains invertebrates in a few locations. Other parts of the bay have no invertebrates in the substrate. A considerable amount of sea wrack is deposited each day with the tide, and some invertebrates are likely to be found clinging to the decomposing vegetation.

An observation of bird use of several beaches in March 2003 at low tide (1pm – 3 pm), showed some differences in bird use. These were qualitative observations only, and to conduct a study that could produce qualitative results for statistical analysis would require many visits over varying tidal conditions and weathers. The area observed at each location was the beach, inside and adjacent to the mangrove fringe. Birds occurring on seagrass beds offshore from the outside edge of the mangroves were not observed.

At Middle Beach, the beach inside the mangrove fringe was in use by a hunting black kite, several red-capped plovers, resting silver gulls, an egret, and masked lapwings. The surface was clear of wrack.

At Port Gawler the beach inside the mangrove fringe was in use by several black kites, sacred ibis, masked lapwings, many red-capped plovers and flying barn martins feeding on small hatching insects. The surface was clear of wrack.

At St Kilda the area inside the mangrove fringe was coated with a thin layer of cast seagrass and seaweed from the recent windstorm. Only a single pair of magpie larks were picking through the surface drift. Once past the mangrove fringe, further out to sea however, it could be seen that there were black swans, masked lapwings, sacred ibis, silver gulls and two stilts.

At other times (high water for example), the bird numbers at St Kilda may be very large, particularly black swans. Given that black swans normally graze on seagrass, the low tide beach at St Kilda would hold little for them, as their body shapes are not ideal for sorting through cast deposits. At high tide the swans may be able to sort through the floating cast material as it is being washed into the bay, but it would provide poor quality foodstuffs compared to a living bed of seagrass.

At night-time stilts, gulls, swans and ducks come to roost in the area. The shape of the bay, and the presence of the breakwater and mangroves have resulted in a very calm environment, even in stormy weather. It may be that the bay presents a safe haven to birds, even though it has a paucity of food available.

4.5 Measuring airborne hydrogen sulfide at St Kilda

Hydrogen sulfide (H_2S) is a soluble gas, but it will only remain dissolved in water if the water is quite cold. A frequent odour pattern appears when the overnight tidewater is infused with H_2S from the interstitial waters. In the morning, as the tide retreats, the shallow tidewater remaining warms in the morning sun and rapidly loses much of its H_2S to the atmosphere, causing the characteristic smell.

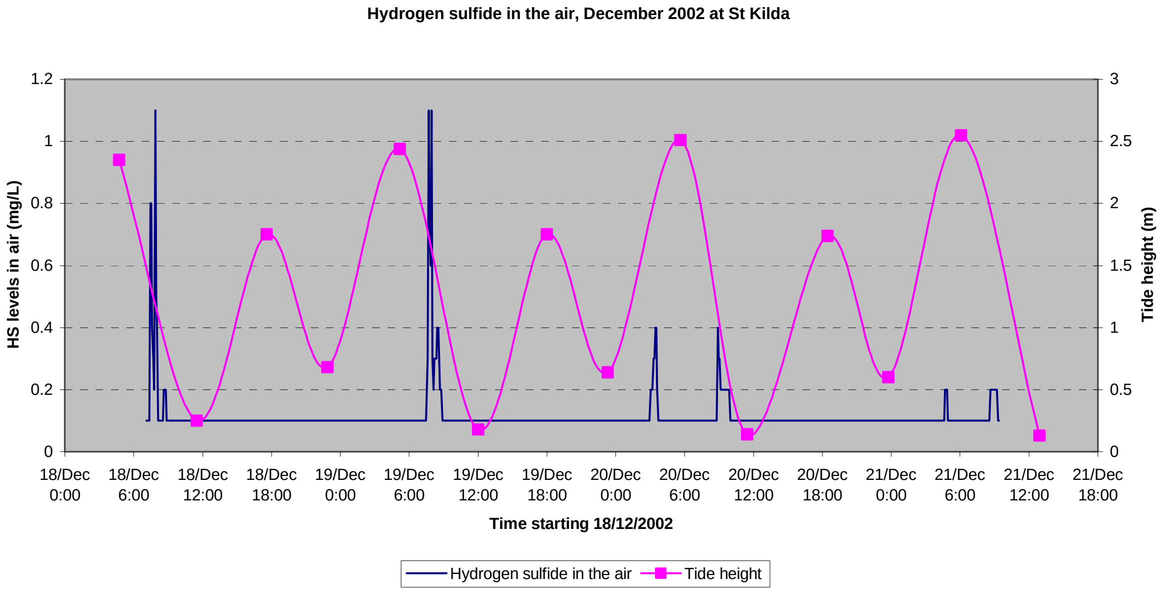

Figure 24 - Tides and hydrogen sulfide in the air, St Kilda 2002

The odour has been observed by many to 'disappear' after a while, and the use of air quality monitoring data loggers in December 2002 confirmed that bad air quality does indeed come in specific events. When the ‘bad beach’ smell is detectable, hydrogen sulfide levels in the air are above 0.1 part per million. Events monitored over a four-day period reached a peak of 1.1 mg/L. The events that were monitored lasted up to two hours at a time.

5. What do the studies mean?

5.1 The biodiversity aspects of degradation in the bay

Hydrogen sulfide (H_2S) is toxic to a very wide range of plants and animals, so it was reasonable to assume that the biodiversity of the mud flats must therefore be reduced to those few species capable of tolerating the extremely high concentrations. The observations in this study support that assumption.

All deep sediments in natural systems will contain some H_2S, as can be seen at Middle Beach. The toxic effects of hydrogen sulfide depend the amount that is present as **unionized** hydrogen sulfide. In seawater, at about 25^oC, this depends on the pH of the water. The approximate unionized hydrogen sulfide percentages shown in Table 4 are based on a table provided in the ANZECC water quality guidelines (Table 8.3.10, ANZECC, 2000).

The ANZECC water quality guidelines (ANZECC, 2000) suggest that to protect fish and other aquatic organisms, water (including interstitial pore water) should contain less than 1 part per billion of unionized H_2S (0.001 mg/L). One sample at Middle Beach and all the St Kilda samples had higher than acceptable levels of unionized hydrogen sulfide. The St Kilda sample with the lowest concentration was only marginally above the guidelines (1.1 times), but the worst St Kilda sample contained nearly 26,000 times the guideline concentration.

Township	sample ID	total H_2S mg/L	pH	approx % unionised H_2S	unionised H_2S mg/L	water quality
Middle Beach	1	0.019	8.2	2.20%	0.0004	OK
Middle Beach	2	0.015	7.8	6.55%	0.0010	OK
Middle Beach	3	0.011	8.2	2.20%	0.0002	OK
Middle Beach	4	0.017	7.8	6.55%	0.0011	exceeds criteria
St Kilda	5	0.052	8.2	2.20%	0.0011	exceeds criteria
St Kilda	6	0.058	8.2	2.20%	0.0013	exceeds criteria
St Kilda	7	0.041	7.8	6.55%	0.0027	exceeds criteria
St Kilda	8	49.2	7.2	17.64%	8.6789	exceeds criteria
St Kilda	9	147.2	7.2	17.64%	25.9661	exceeds criteria
St Kilda	10	0.031	7.5	9.79%	0.0030	exceeds criteria
St Kilda	11	2.6	7.1	21.57%	0.5608	exceeds criteria
St Kilda	12	21.4	7.3	15.68%	3.3555	exceeds criteria
St Kilda	13	32.2	7.2	17.64%	5.6801	exceeds criteria
St Kilda	14	0.077	7	25.50%	0.0196	exceeds criteria

Table 4 - Unionised hydrogen sulfide content of interstitial waters

While mobile organisms such as fish will avoid areas where the water has high H_2S, the immobile animals and seagrasses will be affected. Many parts of the bay have no visible organisms present in the mud at all. This is quite different to other nearby beaches, such as Middle Beach.

This study found that St Kilda's muds are inhabited largely by one species of polychaete worm that is known to have a high tolerance to pollution (*Capitella capitata*). The only part of the bay with evidence of surface dwelling snails was the upper littoral area at the northern end of the bay where the samphire grows. Small marine snails were found in the vegetated area.

Aquatic ecotoxicology studies conducted for the new ANZECC water quality guidelines (ANZECC, 2000) show that 0.0015mg/L of unionized hydrogen sulfide is sufficient to stop the growth of mussels (*Myrtilus edulis*), while 0.003 mg/L will stop the growth of the sea urchin (*Strongylocentratus purpuratus*), and 0.024 – 0.112 mg/L will kill the glass shrimp (*Palaemonetes pugio*) and amphipods (*Rhepoxynius abronius* and *Eohaustorius estuaius*).

The ecotoxicology studies confirm that hydrogen sulfide is toxic to many benthic macroinvertebrates. Recent draft legislation on industrial wastes in British Columbia seeks to address the sulfide pollution that happens underneath aquaculture finfish pens. The researchers in British Columbia determined that there was a negative relationship between sulfide levels and biodiversity (Bright *et al*, 2002).

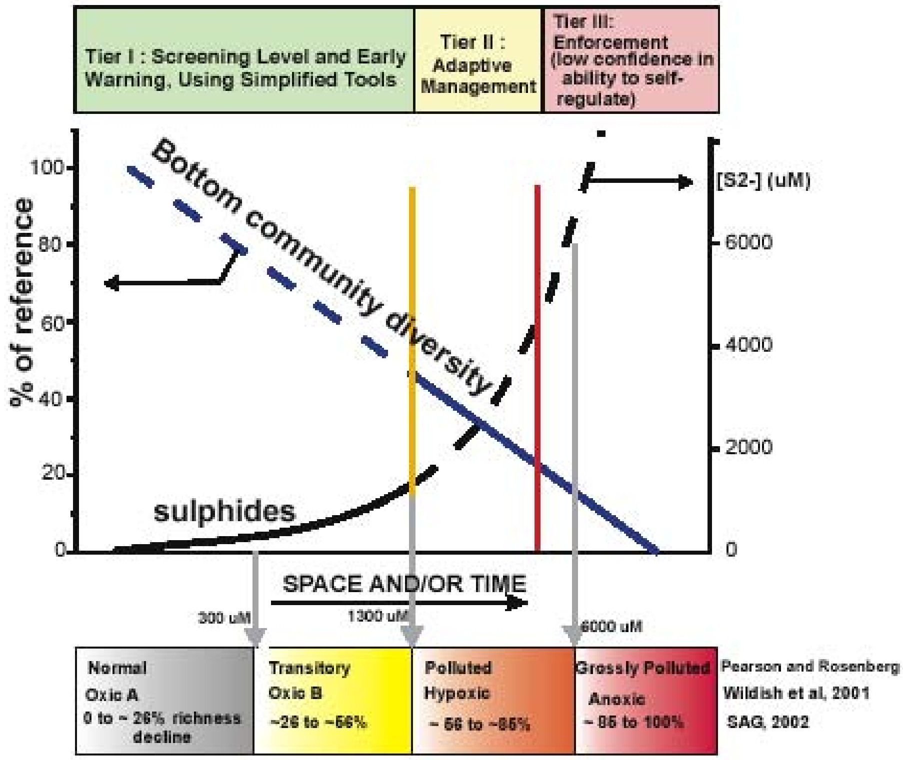

Figure 25 - Relationship between increasing sulfide and decreasing biodiversity (Bright et al, 2002)

Larger animals are also affected by hydrogen sulfide. While ecotoxocological data only exists for freshwater fish, there is no reason to suppose that marine fish are more tolerant of hydrogen sulfide. It is likely that fish will use the bay only at high water, ‘in passing’ as it were, when the large tidal volume dilutes the H_2S and small crustacean food sources may have been washed into the bay along with seaweed wrack.

Underwood and Chapman (1995) report that different types of fish inhabit areas of seagrass, compared to sandy, more open bottoms. In particular, pipefishes, leatherjackets, scorpion fishes, weed whiting, cardinalfish, Australian salmon, tommy rough and toadfishes are found in seagrass meadows. Fish on sandy shoals include the stingarees, small rays, whiting, and small baitfish such as the hardyheads and silverfish. The findings reported by Underwood and Chapman (1995) would suggest that the retreat of seagrasses from St Kilda Bay will have been mirrored in changes to the species of fish occupying the bay.

Abundance studies in other locations have shown that juvenile fish select the intertidal locations they visit by benthic vegetation pattern - vegetated bottoms are preferred to unvegetated bottoms (Minello et al, 1987). This suggests that the visitation rate of juvenile fish to the St Kilda Bay is likely to be low.

Seagrasses have been shown to die off in patches of the seabed where H_2S concentrations are high (Howarth et al, 2000). The areas of the bay further from shore, where seagrass used to exist, now do not support permanent vegetation. Instead short-lived seasonal stands of *Ulva* occur. Seagrass beds that once grew 500m offshore from the playground have reduced in size and retreated seaward over the past three to four years. The channels between the seagrass beds are no longer evident. In contrast, seagrass beds south of the breakwater and creek grow almost to the mangrove edge.

Aerial photographs taken between 1949 and the present suggest that seagrasses in the bay have retreated seaward by approximately 250m.

The ability of H_2S to convert to H_2SO_4 (sulfuric acid) either in the air or in small amounts of trapped seawater, has other environmental impacts. Conversion in the air may lead to episodes of acid rain in the immediate vicinity of the beach. This may affect sensitive species of plants. Some plants are also sensitive to H_2S gas itself. Signs of this sensitivity in plants include burning of the leaves, slow growth or a gradual death of the affected plant.

Acidic seawater may cause a disease called ‘red spot’ in fish, which affects their gills. It is possible that the rusty colour visible in aerial photographs, in areas where seagrass is dying is due to the presence of iron oxides such as jarosite, that are released from the sediments in acid conditions.

The effects of hydrogen sulfide (in water or air) on birdlife is unknown.

5.2 The aesthetic impacts of degradation in the bay

St Kilda Bay is the northern suburbs' nearest beach, and the City of Salisbury has undertaken many improvements in order to provide recreational facilities for residents of the northern suburbs. However, the beach is far from appealing in its current state.

Visually, the thin rim of sand and sand flats scattered with shells has been replaced (necessarily) with a hard 'grit' access rim that allows Council vehicles to access the beach to remove the continually accumulating rotting mass of seaweeds and seagrasses.

The olfactory experience is likewise unpleasant, and anyone foolish enough to venture onto the flats needs to know where to walk if they do not wish to use gumboots and determination to master the boggy conditions.

The famous ‘sunset views with swans’ continue to exist, possibly because of the sheltering mangrove peninsula and breakwater that keep the bay’s waters calm even in stormy conditions. However, the use of the tidal flats at low-tide flocks by foraging birds appears considerably reduced when compared to those found on tidal flats at Port Gawler and Middle Beach.

5.3 The human health issue

Hydrogen sulfide gas (H_2S) is toxic to people. At low concentrations (3-27 ppm) the gas has a nauseating odour. At concentrations above 10ppm in the air the gas may cause eye irritation to the ‘average’ person, followed by lung and skin irritation at higher concentrations again. Extremely high concentrations (over 1000ppm) may be immediately lethal. The concentration of the gas in the air at St Kilda is relatively low (usually less than 3 ppm), but the exposure is chronic (ongoing), and may be irritating to people with conditions such as asthma. Low-level chronic exposure may result in a range of symptoms from mental depression, dizziness, and fatigue to loss of appetite and insomnia (Thrasher, 2001). The gas has both a toxic effect and an irritant effect. The irritant effect is a result of the gas converting to sulfuric acid in the moist conditions inside the lungs (Pepper *et al*, 1996).

An aspect of H_2S intoxication frequently overlooked is its ability, when dissolved in water, to penetrate the skin. While the amount of H_2S absorbed in this manner by an adult walking in the tide pools or through the mud may not be significant, it may be an issue for toddlers that play around the ‘pirate’s ship’ at the playground.

If hydrogen sulfide converts to acid in small tide pools it may become quite concentrated, resulting in a stinging sensation in the eyes if any water splashes in them.

6. How did it happen?

An understanding of the changes that may have taken place over time in the St Kilda Bay is necessary to inform any management actions that could be undertaken to improve the health of the bay in the future. Most habitat degradation is the result of a combination of factors, and the decline of the bay is no exception. Some aspects of that decline are outside the control of local management agencies, but it is not always necessary to rectify all sources of impacts to see a dramatic improvement.

The major changes that have occurred in the St Kilda Bay area in the last 50 years relate to nutrient concentrations and changes in the topographical and hydrological regime. These facets have combined to cause the current state of unhealthy in the bay’s ecosystems.

6.1 Topographical and hydrological change

As stated earlier, the bay at St Kilda was originally backed with three low dunes and drainage lines (creek lines) between them. The bay was longer (north to south) than it was deep, and at low tide all the water drained from between the sand /mud particles, leaving a relatively firm surface.

A municipal dump operated at St Kilda during the 1970's, and in this manner a peninsula of land was gained from the bay. The peninsula (comprising the adventure playground and car parks) effectively shortened the north-south axis of the bay by half, changing its shape to one that was deeper than it was wide. This has the effect of increasing the portion of the bay that is in 'corners' and increases the likelihood of sediment deposition.

The peninsula also closed over some of the drainage lines that ran across the bay, but the most important alteration to a drainage lines was the erection of a breakwater along the northern side of the boating channel at the southern edge of the bay. As the tide regresses, water chooses the easiest route to exit the tidal flats. It is much easier to flow down a creek than to seep all the way out to sea through the mud, and where drainage lines exist the water on and within the neighbouring tidal flats usually exits rapidly into the drainage line. The surface muds near a drainage line usually lose most of their interstitial water as well, resulting in a firm surface at low tide. The slight scouring effect to the mud surface that occurs near drainage lines ensures fine sediments are not deposited on the tidal flat.

Unfortunately, such drainage lines may accumulate material as a result – and this is not welcome in boating channels. The breakwater's presence suggests that such scouring did occur at St Kilda, and the breakwater was necessary to prevent material leaving the tidal flats from depositing in the channel. It has been very effective in this regard.

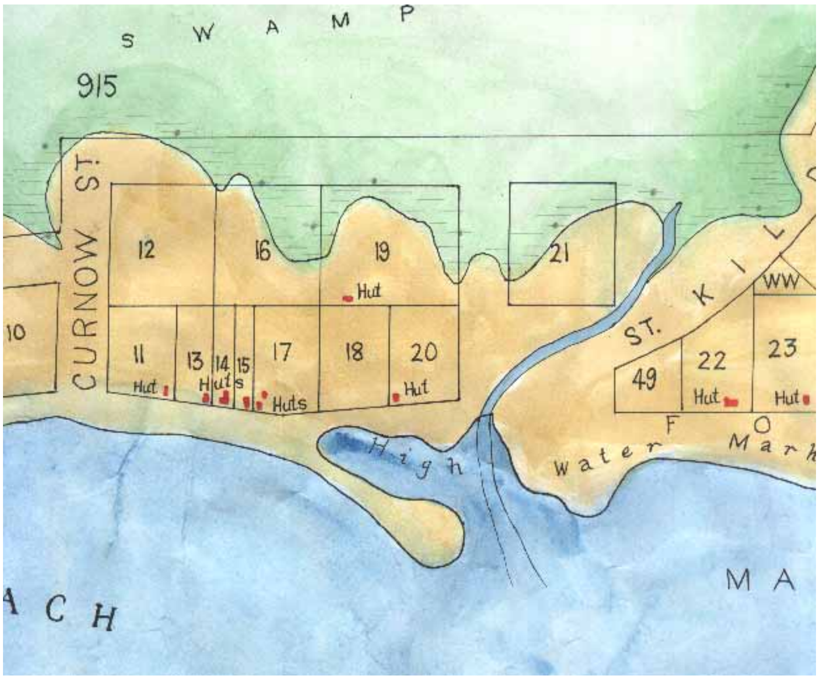

Figure 26 - Shingle ridge at St Kilda (derived from map deposited in the Lands Office in 1873)

Retreating tidewaters in the St Kilda Bay have no 'rapid exit' channels and the tide gently lowers over the hours, depositing everything that came in with the last incoming tide onto the floor of the bay. In this way, organic sediment has built up on the floor of the bay, obliterating slight variations in the height of the sandy floor, such as the shingle ridge that ran south from near Curnow Street to form a small spit where the old shallow channel ran out across the tide flats from the Hotel.

Once the water level reaches the floor of the Bay the retreat of tidal water becomes even slower, with the Bay acting as a large mud 'sponge', holding the water interstitially until the next tide. The exchange of water in the surface layers of mud that normally occurs with each tide is reduced in St Kilda Bay, because the water never leaves the sediment. Therefore freshly oxygenated tidewater merely runs over the surface, and the interstitial water is essentially stagnant.

6.2 Nutrient enrichment

Plants form the primary production portion of the world's food web, and they use chemicals they obtain from the soil and water along with photosynthesis to produce matter. The major chemical nutrients that plants require are nitrogen and phosphorus. While these chemicals are necessary for growth, an excess of them leads to eutrophication (over enrichment) of the ecosystem. This is particularly so for nitrogen compounds.

The nitrogen gas that forms the major part of our atmosphere is not in a form that is accessible to plants. In the natural ecosystem N_2 gas is converted into a usable form by the action of nitrogen-fixing bacteria and by the action of lightning in thunderstorm clouds. The largest single alteration to the nitrogen cycle of the planetary ecosystem was the discovery by man of how to generate nitrogen fertilizers from N_2 gas using electricity. Since the 1950's application of artificially produced nitrogen has increased steadily. This, combined with the extra human induced fixation occurring as a result of burning fossil fuels and planting extensive nitrogen-fixing crops such as soybeans, has led to the point where human production of fixed nitrogen each year now equals that produced naturally from all land surfaces of the globe. In other words, we are fertilizing the world at twice its normal rate (Howarth *et al*, 2000).

Much of the fertilizer applied to land eventually finds its way to sea, where it can cause a range of impacts. Additionally, humans tend to agglomerate, building cities of millions of people. Sewage treatments for such concentrations result in major effluents that impact on relatively small areas. Barker Inlet and Gulf St Vincent are subject to both point-source (sewage and septic effluents) and diffuse (agricultural) nutrient pollution. St Kilda Bay is impacted by the general enrichment of Barker Inlet, and possibly also by effluent from local septic systems.

The small naturally occurring amounts of nitrogen and phosphorus that are found in pristine waters tend to be in proportion to the other elements in the water, such as silicates. Diatoms need silicates to make their glass-like shells, and will stop reproducing when this element is scarce, even if there is plenty of available nitrogen and phosphorus.

In an enriched system such as that found in Barker Inlet, the three elements (N, P and Si) are out of balance. This seems a small point, but diatoms are a mainstay of marine ecosystems and provide the right type of food for small grazing crustaceans such as copepods, which in turn feed fish. Where there is an excess of nitrogen and phosphorus, other plankton types that don't need silicates will start to dominate, with significant impact on the food webs of the marine environment.

In particular there may be large blooms of green algae such as the sea-cabbage *Ulva* (a nitrogen scavenger), red-tide dinoflagellates and small flagellate algae, some of which are toxic to people and fish. In all documented cases of long-term decreases in the ratio of silicate to nitrogen and phosphorus there has been a correlated rise in harmful algal blooms (Howarth *et al*, 2000). The toxic dinoflagellate *Alexandrium minutum* now blooms for up to nine months of each year in the Port River estuary (Parker and Blackburn, 2000).

Howarth *et al* (2000) have suggested that the shift in dominance towards flagellated plankton leads to changes in dominance in the grazer community. Salps, jellyfish and soft bryozoans like *Zoobotryon verticillatum* may become dominant in place of crustaceans and finfish. As Barker Inlet is the nursery area for most of Gulf St Vincent's fisheries, such a change may have catastrophic ecological (and financial) consequences.

The sheer mass of plant matter present in a highly eutrophic (nutrient enriched) marine system may cause a severe depletion of oxygen in the water. This is called anoxia (no oxygen) or hypoxia (low oxygen). Anoxia and hypoxia are more common on warm summer nights. Plants cannot photosynthesise at night, so they start to use the oxygen in the water. Warm water does not hold as much oxygen as cold water, so on warm nights the dissolved oxygen may be completely depleted, leading to the death of algae and fish. The dead plant and animal matter is deposited on the floor of the Bay.

The shallow puddles and surface muds of the Bay, saturated with stagnant water and blanketed with the rotting debris of Barker Inlet's algal overgrowth require much more oxygen than is present in the small amount of water. They use up all the oxygen as the tide retreats, and the stage is set for the sulfur bacteria.

6.3 Sulfur cycling

Where anoxia (lack of oxygen) is a regular occurrence, organisms that are usually restricted to the deep sediments where there is never any oxygen can migrate to the surface of the mud, and even into the water column. The sulfate-reducing bacterium *Desulphovibrio* is one of these organisms. *Desulphovibrio* is a small, colourless bacterium that lives in anaerobic conditions (conditions with no oxygen). It can't use free oxygen, yet it requires oxygen to live. It gets a supply of oxygen by using the sulfate in seawater. Calcium sulfate is the second most common salt in seawater (sodium chloride, or table salt is the most common). *Desulphovibrio* reduces (strips the oxygen from) the sulfate to obtain its oxygen, leaving hydrogen sulfide behind in the water.

The hydrogen sulfide may be in either of two forms: H_2S gas, or the HS^- ion. The amount of each depends on the pH of the water. At a pH of 7, as is found in the black interstitial (pore) waters of the bay muds, about 60% the sulfide present is water-soluble hydrogen sulfide gas.

At a pH of 8.2, as is found in the sandy areas, only about 10% of the sulfide is present as hydrogen sulfide gas, with most being the hydrogen sulfide ion, which does not smell.

The hydrogen sulfide (H_2S) gas in water, will volatilise (off-gas) if the water gets warm, producing the well-known 'rotten-egg' smell. The HS^- ion is usually adsorbed to any metal ions that are present, creating insoluble metal sulfides that remain in the sediment. This process can usefully strip toxic heavy metals out of water, but they then accumulate in the black sulfidic sediments.

The resulting anoxic, hydrogen containing-containing water provides a habitat for another group of anaerobes (bacteria that dislike the air) called the 'green and purple sulfur bacteria'. These bacteria like sunlight, but cannot tolerate oxygen gas, either in air or dissolved in water. They live in the anoxic shallow pools on the mud surface where there are high concentrations of hydrogen sulfide. They use the H_2S during photosynthesis, effectively removing sulfur from the water and gathering it into globules within themselves. This reduces the odour-generating potential of the pools. Colonies of these very useful bacteria can be seen as pink, purple and green 'scums' on the mud surface. Common species in the St Kilda Bay include *Chromatium* and *Thiospirillum*.

These green and purple sulfur bacteria are not the only bacteria that can use hydrogen sulfide. At the interface where hydrogen sulfide dissolves into the oxygen-rich fresh tidewater another group of organisms live. *Beggiatoa* is a 'giant white sulfur bacterium' that forms mats in the daily tide pools. It uses the H_2S that seeps out of the interstitial waters to help it obtain nitrogen from the rotting seaweeds that coat the surface muds of the Bay. In the process, it turns hydrogen sulfide (H_2S or HS^-) into sulfur (S^-). Some of the sulfur is stored in *Beggiatoa*'s body, but some becomes available to a final group of organisms.

The last organisms that are part of the sulfur cycle in the Bay are the acid makers, *Thiobacillus denitrificans*. Like *Beggiatoa*, they are present in the piles of rotting seaweed and surface pools, and play an important part in using up the nitrogen from the seaweed. They cannot use hydrogen sulfide to do this, but they can use sulfur (S^-). In the process, the sulfur is turned into sulfuric acid (H_2SO_4).

Summaries of the reactions that occur in the sulfur cycle are presented in the table below.

SO_4 (in water with no oxygen) →	reduced (oxygen stripped) by *Desulphovibrio* →	H_2S and HS^-
H_2S (in water with no oxygen) →	used in photosynthesis by green & purple sulfur bacteria →	S stored in bacteria's body
H_2S & HS^- (in water with oxygen) →	oxidized (oxygen added or H removed) by *Beggiatoa* when using N →	S^-
S^- (in water with oxygen) →	oxidized (oxygen added) by *Thiobacillus* when using N →	H_2SO_4

Table 5 - Sulfur cycle

The processes outlined above are all perfectly natural and occur in all intertidal habitats to a certain extent. The major difference is the quantities involved. In a low-nutrient system, there is only a very small amount of sulfur cycling going on – definitely not enough to be able to smell hydrogen sulfide, or to be able to measure acid production. In St Kilda Bay the extreme nutrient enrichment, along with the lack of drainage, has resulted in a massive increase in the sulfur cycling that occurs.

7. Where else has this happened ?

St Kilda Bay is not the only coastal bay in Australia, or the rest of the world, to experience nutrient induced degradation. Tuggerah Lakes (a series of coastal lagoons) in New South Wales has very similar hydrology and problems. Kennedy (1997) describes the actions of the local Wyong Shire Council to address the problems:inshore removal of silt, beach cleaning, and dredging to deepen channels.

At Tuggerah Lakes approximately 56 kilometres of foreshore has been earmarked for silt removal. The operations are necessarily large-scale, and may be considered 'overkill' for a small area such as St Kilda Bay. However, the principles behind the approach are directly relevant.

Wyong Shire Council uses two methods to remove silt and vegetation – 'wet dredging' for offshore areas and 'dry dredging' for beach cleaning. In wet dredging mud and weeds are skimmed from the Lakes floor and disposed to land. This has proven effective, but is only a short-term solution, as the sediment continues to accumulate. The tidal range at St Kilda makes this an impractical solution for the Bay.

In dry dredging, walls of mud and fabric are built offshore and the water is pumped out of the inshore area. The area is allowed to dry, and then bulldozers remove the silt and vegetation, and bury it on the foreshore beneath a permanent layer of soil. The walls are then collapsed, allowing water to flood back in, and sand is pumped to cover the beach area. The Wyong Shire Council has had considerable success with this method, and it has some aspects in common with the City of Salisbury's use of excavators to clear away the worst affected areas of the St Kilda Beach.

Wyong has found that the mounded area can be planted with coastal vegetation (mainly coastal grasses) and provides a good buffer zone between the water and nearby urban development. This method can reclaim up to 30m of beach at a time, but does not address the sulfur cycling occurring further offshore, or the deposition of silt and vegetation.

While the shallow tidal flats at St Kilda are not permanently inundated (Tuggerah Lakes has a micro tidal range due to its narrow entrance), the City of Salisbury's beach cleaning has had some success on the areas the small front-end loaders can reach. It may be possible to use larger equipment and bury the gained silts and seaweeds under a layer of sandy soil along the existing seawall. This could then be vegetated with native dune plants such as *Myoporum insulare*, *Atriplex cinerea* and the creeping pigfaces to stabilize the frontage.

At Moreton Bay in Queensland mangroves near Luggage Point started to die after nutrient enrichment caused massive algal wrack to deposit in drainage lines through the mangroves. The area became waterlogged and sulfidic, and the trees died. WBM Oceanics undertook a project to restore drainage channels in the mangroves for Brisbane Water, as part of the expansion plans for the Luggage Point sewage works. The project required two channels to be opened to drain the affected area and allow tidal flushing to re-establish. The channels were opened in October 2000 and in the 2002 edition of Brisbane City Council's newsletter *The*

Regenerator the council was able to report that mangroves were now recolonising the area and fish were using the new 'creeks' (Brisbane City Council, 2002).

In Europe the effect of nutrient enrichment combined with silicate depletion leading to changes in the biology has led to excess hydrogen sulfide in landlocked seas such as the Black Sea. The effect is referred to as "the Nemesis Effect". The seagrass in the Black Sea has died, diatoms, mollusks, sponges and marine worms are disappearing, cholera is living in the shallow water, and hydrogen sulfide has killed the fish and permeates the air (Bright, 2002). At present an international team is researching how to reverse the damage, however the Black Sea is a vast area surrounded by impoverished countries, making the task monumental.

The examples outlined above are not isolated. They are part of a problem that is becoming more widespread and better recognized. As the recognition of the problem grows, more information will also become available on remediation options. This options paper presents several options for consideration by the St Kilda Progress Association. However even after an initial course of management is chosen for the bay, there may be further opportunities to incorporate new management methods as time passes and more information becomes available.

8. Why wouldn't we try to remediate the bay?

Several residents have voiced concerns about improving the environment of the bay. The concerns fall into several broad categories :

Increased visitation (reduction in privacy)
Increased visitation (impact on birdlife)
Increased visitation (increased hooliganism)
Increased land values (and therefore rental costs, and cost of living at St Kilda)

The first two issues (reduction in privacy and disturbance of birdlife) are focused on the bay area, north of the playground. This area of the bay is currently part of the St Kilda-Chapman Creek Aquatic Reserve. Under the Reserve conditions currently, no person may disturb the seabed, or remove or interfere with any aquatic or benthic flora or fauna, or discharge, release or deposit matter in the Reserve, with the exception of using their hands, a crab rake or hoop net for the taking of blue crabs only.

Residents' concerns about increased visitation to the bay itself once the muds become more firm could be addressed through adding restrictions under the Aquatic Reserve legislation, by using the Local Government Act to create by-laws prohibiting motor vehicles, land sailing, dogs and horses from the intertidal area, or by creating 'coastal restricted areas' under the Coast Protection Act.

Increased visitation to the terrestrial parts of St Kilda has both good and bad aspects. Families and others visiting the playground, Mangrove Trail, Tramway Museum, or launching their boats are a welcome part of St Kilda. They contribute to the economy, and are a major reason the Council invests capital into the township. The presence of such visitors allows small businesses such as shops that cater to them to flourish in the township. These small businesses

are also a convenience to the residents. Pleasant smelling surroundings are likely to increase this type of visitation.

Hooliganism occurs mainly at night time (rarely in the early morning when the smell is at its worst). Much of the behaviours centre around motor vehicle use (and misuse) and such activity is unlikely to be either increased or decreased by an improvement in St Kilda's environment.

An increase of family visits may make daytime hooliganism an even less attractive option than it currently is. The issue of policing is one that many small seaside communities grapple with, as the permanent population is too small for police presence, but there is a large weekend visiting population.

Anything that increases the attractiveness of a location also tends to increase land values. A downside of this is that the cost of rental accomodation may increase over time. This is a concern to people with limited or fixed incomes. At present land and houses in St Kilda are very cheap, and many of the residents own their own property, freeing them from this concern.

Sales at St Kilda are not a frequent occurrence, and so it takes a long time for the effect of changes in the market to be felt in prices at St Kilda. The township's proximity to Adelaide has meant that it has not been seen as a retirement destination, while its lack of services (buses, sewage, phone lines, policing) and environmental issues have resulted in the township being overlooked as a metropolitan beachside suburb.

Whether an improvement in the environment of the bay will create a rise in land prices at St Kilda may depend on how the market perceives the other issues mentioned in the previous paragraph.

9. What remediation options are available?

Four major options (one with two sub-options) are presented here. The options are not mutually exclusive. There is nothing to stop the Progress Association from deciding to undertake one, two or more of these options, at once, or sequentially. The options are presented separately so that people can assess the benefits and impacts of each. Chairman Mao, on starting the Long March, told his followers that 'the longest journey starts with a single step' and the remediation of St Kilda Bay may well be a long journey. A small single step is all that is needed to begin this journey.

9.1 Do nothing

Not taking any action is an option that needs to be considered. In natural systems many 'insults' to the environment tend to be self healing, and require nothing more than the cessation of the cause of the problem.

If St Kilda Bay was a creek with a high nutrient input, the one act of removing the nutrient input may enable the creek to return to normal.

The case at St Kilda is more complex, as the changes that have occurred (sewage outfall, installation of breakwaters, landfilling) are either here for the medium term or for the long term. Even so, global changes such as sea-level rise, or man-made alterations to the bathymetrics of Barker Inlet, undetaken by others, may eventually resolve the immediate problem at St Kilda. Such changes would doubtless bring their own problems, such as protecting housing from higher sea levels or increased wave action, but may increase tidal flushing in the bay to the point where evidence of hydrogen sulfide becomes a thing of the past.

At present the degree of sea level rise that may be anticipated is unknown, as is the time-scale over which it may occur over. Such a course of action would result in little improvement in the environment of the bay for at least another decade, and probably longer.

9.2 Nutrient reduction

Large point source nutrient inputs such as the effluent from sewage treatment works are outside the control of local management groups. Other, more immediate sources of nutrient could however, be addressed locally.

Septic tanks should be maintained regularly if they are not to have an impact on groundwater. The St Kilda Progress Association may consider providing a leaflet to all residents that contains information on managing septic tanks to ensure they have a minimal environmental impact.

There are other options available to reduce septic tank impacts. The City of Salisbury could consider applying for assistance from the Local Government Association, to install a STEDS (Septic Tank Effluent Disposal Scheme) for St Kilda. These schemes operate by pumping the contents of each house’s septic tank to a centralized treatment plant a little further inland. However, there is a long waiting period for funds for the LGA’s STEDS program, and because St Kilda is a metropolitan area, there may be other alternatives. The grant scheme requires a co-payment from residents, that is usually collected through the annual Council rates.

The Bolivar Waste Water Treatment Plant has historically been a freshwater plant, and although St Kilda is physically near to Bolivar, the waste from septic tanks at St Kilda would have been too salty for inclusion into the plant. However, recently a new salt water treatment plant has been commissioned at Bolivar, to accept the sewage from Port Adelaide. It may possible to develop a modified STEDS scheme, where waste from household septic tanks is pumped to the new saltwater treatment plant at Bolivar. If this idea were to be adopted, then it would need to be progressed by the City of Salisbury and SA Water. It is unknown how funding for this may be arranged, although Environment Australia has some grants available for actions that may improve the water quality of the Port River and Barker Inlet. SA Water and the City of Salisbury would need to explore funding for this option.

Another source of nutrients that is within the control of residents is fertilizer use. The overuse of fertilizer on coastal gardens is common as sandy soils leach rapidly. The application of compost and other organic matter will slow the leaching of fertilizers from the sandy soils, while reducing the amount of water required. In St Kilda’s shelly sandy soils, pale leaves on a plant may not mean a plant needs more nitrogen – they may be a pointer that the plant that

does not like lime (shells) and is short of iron. Tea-leaves and iron filings may be what is required. The St Kilda Progress Association may consider producing a leaflet on gardening in coastal conditions, for the information of residents.

While the nutrient reduction options would not address the hyrological issues, they would ensure that the residences at St Kilda are not contributing to the problem, and when combined with nutrient reduction from Bolivar (a commitment from SA Water to the EPA) over the next five years, this option may eventually reduce the amount of sulfur being produced to the point where it is no longer evidenced by its smell.

This option would not increase the firmness of the mud in the bay except in those areas currently very deep in sediment, as it would not increase the amount of water that could drain out of the muds at low tide.

9.3 Reinstate historic drainage channels

The main objective in any improvement program that seeks to address the full range of degradation should be the interruption of the sulfur cycle and the prevention of sediment deposition. Increasing the exchange of water and oxygen in the sediments of the Bay, and encouraging ‘scouring’ may achieve this.

A ‘soft engineering’ approach has been used at Tuggerah Lakes to increase tidal exchange – the local council have chosen to use a small purpose-built dredge to broaden and deepen existing channels near the entrance to, and across, the Lakes. Silts removed from the channels are deposited ashore. According to Kennedy (1997) the approach has allowed natural scouring and flushing to proceed unhindered.

This approach may provide a benefit to the beach at St Kilda. Observations at neighbouring beaches (Middle Beach, Pt Gawler) would seem to indicate that large channels are not necessary. Even quite small, shallow channels allow drainage to improve and natural scouring to occur.

Should such an approach be selected, the methodology of channelising would depend on the location of any channels. If an attempt was made to deepen the old creek lines that run diagonally across the Bay, some form of dredge may be needed, although the daily desertion of the tide would pose a challenge. Alternatively, a very small excavator supported on swamp plates may be able to work on the surface of the tidal flats during periods of low tide. Material won from the channels could be used to create areas of intertidal salt marsh or mangrove accession areas along the breakwater or playground seawall.

Dr David Blackburn was approached by the City of Salisbury to develop a possible scenario, and the following information was provided by him:

> “It is proposed to interrupt the sulfur cycle by firstly removing the organic cover, down to the level of the underlying sands, and secondly by reopening natural tidal channels which have become silted and no longer effectively drain the tidal flats. This will allow the beach sands to once again become well oxygenated, will remove the immediate source of unpleasant odours and should in the long term maintain a beach that is free of excessive organic detritus.

> The upper intertidal flats are to be cleaned of organic detrital accumulations. These form a layer up to about 15 cm in thickness and their extent is shown on the accompanying map. It is planned to remove this layer, using suitable mechanical excavators or scrapers and dispose of the recovered material on land, at a site yet to be identified.
>
> Approximately 21 ha will be scraped of organic sediments, representing about **21,000 m^3 of material**.
>
> Tidal channels which were in existence before breakwater construction have been identified in aerial photography. These will be re-excavated to approximately their original depths and widths. Typically they would be excavated to a depth of about 50 cm and widths up to about 10 m. The excavated material would consist of a mixture of organic detritus, silts and sands and would be disposed of on land.
>
> Approximately 6.5 ha of channels would be restored, representing **about 35,000 m^3 of sediments.**
>
> Restoration of tidal channels would impact upon marine benthic communities only within the areas of intertidal seagrasses. The upper intertidal areas to be scraped clean of organic detritus are almost devoid of macroscopic marine animals as a result of low oxygen conditions in the sediments and the presence of toxic hydrogen sulfide.
>
> The intertidal seagrasses are dominated by *Heterozostera tasmanica* and *Zostera muelleri*. These species have seasonally variable growth patterns, can colonise disturbed areas rapidly, and are abundant along the north-eastern coast of Gulf St Vincent. Access corridors for excavating machinery would be kept to a minimum practical width and any wheel or track ruts would be re-profiled to provide suitable surfaces for seagrass recolonisation.
>
> It is expected that the restoration of St Kilda beach will add to the amenity and environmental values of the area. Conditions suitable for incursions of fish, crustaceans, molluscs and other marine fauna and the recolonisation of bare intertidal flats by benthic fauna and seagrasses should be restored by the proposed treatments. Unpleasant odours will be reduced. These are not only a nuisance for residents and visitors, but may also pose health risks (chronic respiratory and eye irritation problems."
>
> (Blackburn, 2001)

Dr Blackburn's proposal is quite extensive in nature and would require a considerable amount of equipment and capital. Funding would be needed and may be available under the new Integrated Natural Resource Mangement Plan for the Mt Lofty Region.

Approvals from government agencies, including the Environment Protection Authority and the Coast Protection Board amongst others, would be necessary. A location for disposing the

organically rich sediment layer would be needed. The sandier material won from the drainage lines may be suitable for use as beach material next to the seawalls.

Such an extensive program of work may have impacts of its own. The issues would depend on the type of machinery used for the project. Dredging may have immediate impacts on water quality. The discharge of sediments raises turbidity and may require a bunded area. If this is on the beach, there may be disturbance to bird life, while handling dredge spoils on land could impact the freshwater lend underlying St Kilda, causing plant deaths in local parks and gardens.

The alternate method of using machinery out on the tidal flats brings risks such as fuel spillage, bogging and disturbance of bird life. All such issues would need exploring thoroughly before such an extensive program was undertaken.

An illustration of the works that would be required to undertake this scenario is provided in the following figure.

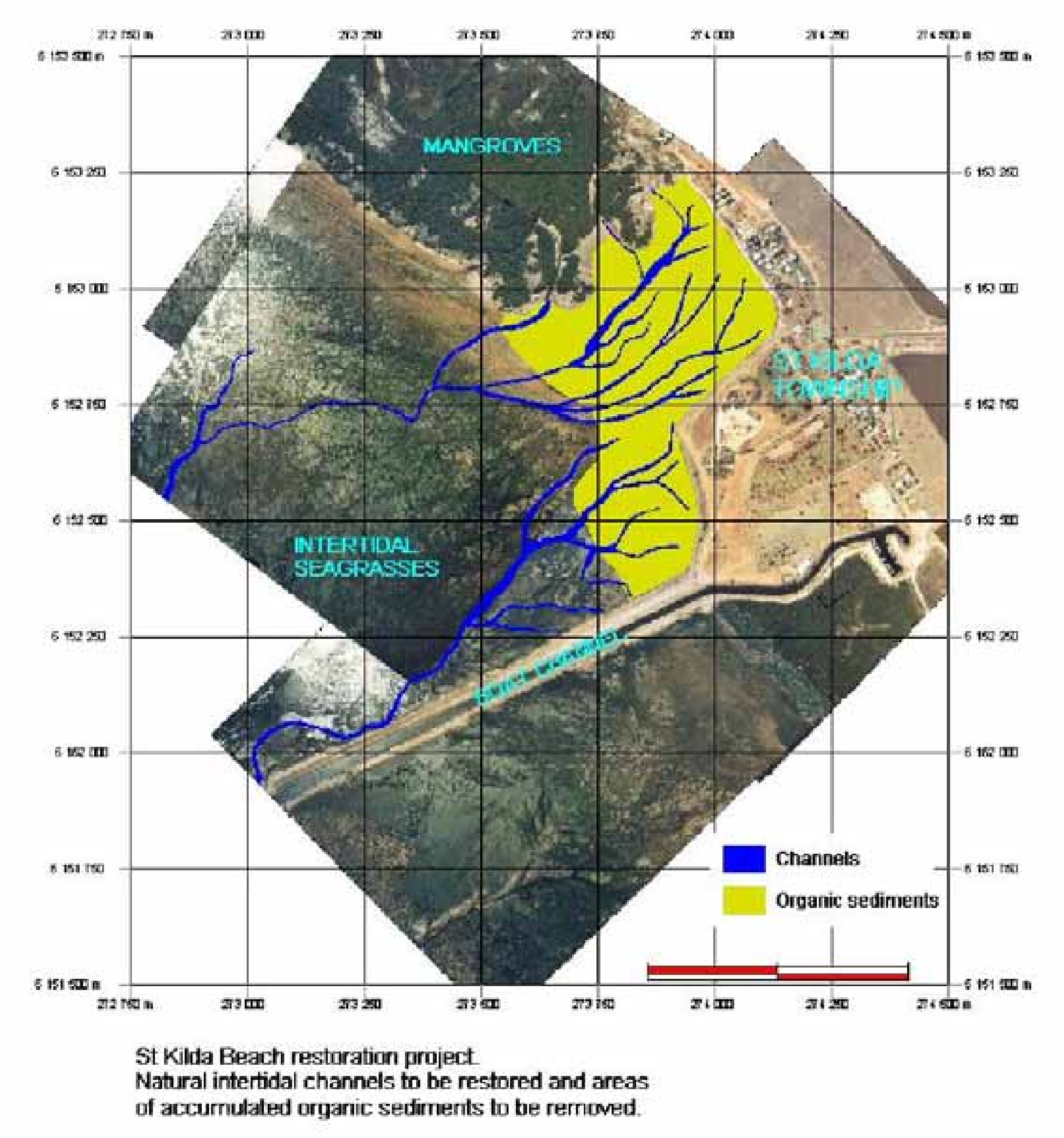

Figure 27 - Restoring historic drainage channels at St Kilda (Blackburn, 2001)

9.4 Single channel alongside the playground and boat channel breakwater

A less extensive option may be the digging of a single channel alongside the northern side of the playground and boat channel breakwater. In this case, a long-reach excavator may be able to dig most of the depression, while standing on the dry ground of the landfill area and breakwater. A small area between the playground and breakwater may require machinery to traverse the tidal flat, but this area no longer hosts seagrasses, so has a low bird visitation at low-tide. By not using a dredge, and limiting the use of machinery on the tidal flats, many of the impacts of the more extensive program outlined in the previous section could be avoided.

The material won from such a channel may be quite sandy, as studies undertaken for this report have revealed that the area of the bay nearest the playground is not currently covered by deep sediments. If the material is sandy, it could be placed adjacent to the seawall in two locations – the corner next to the boat channel where a small beach exists currently and in front of the rock wall along Beach Road and Whiting Street.

Some of the proposed channel has existed at various times in the past (see the 1972 aerial photograph, earlier in this report), and so cleaning it out may possibly be considered a maintenance activity. Whether an activity is considered to be maintenance or a new development will have implications on the types of planning approvals that may be required.

Figure 28 - Single channel proposal

Approximately **13,000 m^3 of material** would need to be removed, to form a channel 3m wide at its narrowest and 50cm deep. The channel would be wider where it traverses the tidal flat adjacent to the playground.

10. Options matrix

Option	What environmental aspects will improve?	What other benefits of this action?	What are possible environmental negatives of this action?	What other issues?	Time frame?
Do nothing	Tidal flushing **may** improve with sea-level rise. Until then the soft mud keeps the visitation levels to the bay low, maintaining privacy for occupants and low disturbance rates for the birds.	Very cheap option.	Further degradation of seagrass beds, macroinvertebrates, air quality and fish life until such time as sea-level increases enough to improve the tidal flushing.	Sea-level rise may bring increased wave action and flooding.	10-50 years
Nutrient reduction (a) **Leaflets about septic tank maintenance and gardening in coastal areas**	Less nutrients into the bay **may** gradually reduce the amount of sulfur cycling, and this **may** reduce the formation of black sediment, and the smell, although there would still be the nutrient inputs from the wider Barker Inlet, in the form of seagrass and seaweed wrack.	Reduction in smell (should this action be sufficient to affect this aspect) may improve public perception of St Kilda. Renewed interest in gardens may improve public perception of St Kilda. Reasonably cheap option (leaflet cost for Progress Association, more frequent septic tank maintenance for some residents)	No improvement in drainage, and anoxia may persist in the sand/mud, so there may not be an improvement in benthic macroinvertebrates (shorebird food) or seagrass beds. The nutrient contribution from outside the bay may be so large that the small improvement may not be noticeable.		Only a couple of months to implement
Nutrient reduction (b) **STEDS or pipe to Bolivar**	Less nutrients into the bay **may** gradually reduce the amount of sulfur cycling, and this **may** reduce the formation of black sediment, and the smell, although there would still be the nutrient inputs from the wider Barker Inlet, in the form of seagrass and seaweed wrack.	Reduction in smell, (should this action be sufficient to affect this aspect) may improve public perception of St Kilda.	No improvement in drainage, and anoxia may persist in the sand/mud, so there may not be an improvement in benthic macroinvertebrates (shorebird food) or seagrass beds. The nutrient contribution from outside the bay may be so large that the small improvement may not be noticeable.	Both options require a reasonably large input of capital from the residents (may be via Council rates)	STEDS – 30 year waiting list, unless other funding can be found. Tie-in to new saltwater plant at Bolivar – unknown
Reinstall historic drainage channels	This option removes existing sulfidic sediments and allows drainage to occur to firm up the mud. This should result in reduction of smell, as well as improvement of macroinvertebrate life, which will benefit bird and fish life. Seagrasses should recolonise the cleaned areas rapidly.	Reduction in smell and improvement of bay muds should improve public perception of St Kilda. Any sandy material won could enhance the 'corner beach' or be used to provide sand infill in front of the seawall near the houses.	Dredging (if used) may impact on immediate water quality. Machinery on tidal flats (if used) may disturb bird life. Disposal of dredged or won materials may be problematic. Post restoration bay muds may be firm enough to attract increased visitation, disturbing birdlife (this can be addressed).	Expensive project. May require extensive government agency consultation and development approvals. Post restoration bay muds may be firm enough to attract increased visitation, reducing privacy (this can be addressed).	Development approvals – up to a year. Project once approvals obtained – some months Environment after project – improvement immediate
Single channel option	This option improves drainage and relies on the increased penetration of oxygen and slight scouring effect near the drain to reduce the existing sediment over time. This should result in improved firmness of the muds and reduction in smell, with a slower improvement in macroinvertebrate life. Seagrasses may gradually recolonise the bay as sediment clears.	Reduction in smell and improvement of bay muds should improve public perception of St Kilda. Most of the channel is located in areas with the smallest depth of sulfidic muds. Any sandy material won could enhance the 'corner beach' or be used to provide sand infill in front of the seawall near the houses.	Some disturbance of water quality during the excavator's operation (but no more than current beach cleaning produces). Some disturbance of birds may occur in the corner where machinery may need to be used on the tidal flats. Eventually post restoration bay muds may be firm enough to attract increased visitation, disturbing birdlife (this can be addressed).	Government agency approvals will depend on whether the project is seen as maintenance or development. Post restoration bay muds may be firm enough to attract increased visitation, reducing privacy (this can be addressed).	If development approvals are required – up to a year. If the Council can conduct the project as maintenance, immediate. Project itself – some weeks. Environment after project – may several years for improvement to reach its peak.

Table 6 - Options matrix

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Appendices

Appendix 1 – Sampling locations in St Kilda Bay – GIS

Township	Sample ID	Easting	Northing
St Kilda	5	273835	6152697
St Kilda	6	273767	6152805
St Kilda	7	273718	6152944
St Kilda	8	273831	6153024
St Kilda	9	273899	6152953
St Kilda	10	273980	6152859
St Kilda	11	274060	6152981
St Kilda	12	274010	6153069
St Kilda	13	273924	6153187
St Kilda	14	273834	6153263

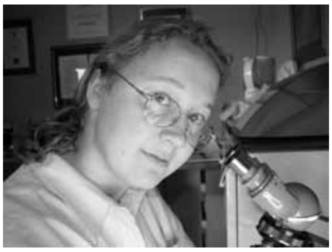
Appendix 2 - Consultants' details

Delta Environmental Consulting has a core staff of three, supported by a range of contract and resource personnel.

Peri Coleman (M AppSc - Environmental Management and Restoration) has extensive experience in identifying marine and terrestrial flora and fauna of the mainland states and Tasmania, conducting biological surveys, producing reports and educational materials. Her main interests include biological survey work, revegetation and rehabilitation, scientific illustration and desktop publishing, preparation of herbarium and museum specimens, management plans, taxonomy and classification, solar saltfield biology, environmental education programs, computer application development, wetland studies and mangrove and samphire ecosystems.

Peri owns, and is senior consultant for, Delta Environmental Consulting. She is a member of the South Australian Coast Protection Board, Barker Inlet Port Estuary Committee and chair of the Northern Adelaide & Barossa Regional Steering Committee of Waterwatch. Peri has a strong commitment to research, with several recent papers accepted for international publication. She is a fellow of the Royal Society of South Australia and member of the International Society for Salt Lake Research.

Faith Cook (Grad Dip GIS & Remote Sensing, Dip Env Man) is employed by Delta Environmental Consulting to provide technical and consulting services. Faith has strengths in remote sensing, statistics and biometrics. She provides services in the GIS and mapping areas, development of computer database and spreadsheet applications, environmental risk assessments, archival searches, water testing and laboratory work, fieldwork, and desktop design and publishing.



Faith's interests include radio telemetry and she has a Novice (limited) Amateur Radio Operator (WIA) licence and also holds a Marine band licence.
Faith is a fellow of the Royal Society of South Australia and a member of the International Society for Salt Lake Research. Her current research interests include diatom ecological preferences and samphire ecology.

Jenny Larter (B Technology, Forensic and Analytical Chemistry) is employed on a permanent part-time basis to provide laboratory and forensic expertise. Jenny brings a wide understanding of testing methodologies, and legal evidentiary requirements, to her position. When Jenny is not examining samples from assorted drains, or quantifying the minute concentrations of contaminants in water samples, she enjoys choral singing and bushwalking.

For further information on any Delta Environmental Consulting staff member, or information on the projects the company has been involved with, please visit our web site at http://www.deltaenvironmental.com.au or look at the details of Consultants in *Appendix 1*.