A Marine 'Conservation Guide' to the proposed BHP Billiton Desalination Plant at Port Bonython, South Australia

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Executive Summary

The proposed location of the BHP Billiton Desalination Plant to supply Roxby Downs mine is at Port Bonython, at the tip of Point Lowly, Upper Spencer Gulf, South Australia. The Plant will have an initial 320 million liters (ML) intake of seawater, which after processing becomes 128 ML of freshwater and 192 ML of discharge water (brine). The capacity of the Plant could be increased to supply domestic or agricultural water to Eyre Peninsula, or for further industrial needs. Discharge will be 1.67 times saltier, 68 parts per. thousand (68.0 ppt) than the intake seawater (40.5 ppt).

Port Bonython is proposed by BHP Billiton as the most suitable site in the region due to high tidal flows off Point Lowly to disperse the discharge. Discharge is proposed to be more than 800 m seaward form the tip of Point Lowly at 20+ meters of water depth in the tidal channel between northern and southern Upper Spencer Gulf. Discharge methods, measured current flows across the tidal channel, and dispersion rates will be used to decide the exact discharge zone.

Discharge water is proposed to be dispersed by forcing upward through a 200 m discharge band at the end of the discharge pipe, which will de designed to almost immediately reduce salinity to background levels under most tidal flows. Under environmental regulations the resulting salinity is to be undetectable against background levels and therefore have no significant environmental impact. Satisfaction of this requirement will preclude increased regional salinity from the discharge.

To assure adequate dispersion an accurate knowledge of tidal and current flows is essential. The position of the discharge band should be decided by on on-site measurement of tidal flows, including flows during the lowest dodge tides.

The sustainable management of marine biodiversity in the region must include regional ecosystems, biomes and species, and the needs of industry, recreational and commercial fishers, and ecotourism and other uses. Upper Spencer Gulf has low biodiversity but includes some unique species and ecological assemblages tolerant of high salinities and warm temperatures. The shoreline reefs at Point Lowly and the surrounding areas support large and unique spawning aggregations of the Australian giant cuttlefish (*Sepia apama*) of high conservation and biological significance. The source the aggregating cuttlefish, and their migration routes and means of navigation to the close inshore reefs around Point Lowly are unknown.

The main protected fishes likely to inhabit the Pont Lowly area are numerous species of syngnathids (seadragons, seahorses and pipefish). However, in general our knowledge of protected syngnathids and other inshore demersal fish in the area is inadequate. The problem of inadequate marine biodiversity surveys is generic across South Australia. Surveys within the last five years of close inshore sites near metropolitan Adelaide, the capital of South Australia, have revealed previously unknown syngnathids and other inshore fish.

Consequently, for satisfactory conservation outcomes, targeted surveys to reveal any unknown syngnathids or inshore other fish should be undertaken in the Port Bonython area. These surveys should include components to enable the monitoring of long term changes to baseline inshore fish assemblages as indicators of environmental change.

There have been concerns that the processing of intake water from the Desalination Plant could result in damage to fish and crustacean larvae. The potential for damage to larvae from the Plant is comparative to the number of larvae in the area, and through estimates of current acceptable loss through industry or recreation.

Comparisons show daily intake volume is less than 0.05% of an estimate of seawater volume with 5 km of the plant, and that volume is only 2% of that in Upper Spencer Gulf. Thus, if all the larvae needed for fish and crustacean recruitment in the whole of Upper Spencer Gulf were evenly distributed within 5 km of the intake, the Plant could only affect one larvae out of two thousand a day. The volume of intake water is also more than 100 times less than cooling water taken by the Port Augusta power plant, Upper Spencer Gulf.

Therefore, comparisons show that the volume of intake water is unlikely to have a significant environmental impact through effects on the recruitment of fish and crustacean larvae. However, any possible minor impact could be amplified by the concentration of larvae around the intake.

Placing the intake over sand away from substrate offering shelter to juvenile cuttlefish, and having the mouth elevated and laterally extended could minimise their entrapment.

A major limitation on larval recruitment is the large numbers of brood fish captured by both commercial and recreational fishers. Further restrictions on the capture of broodfish, and particularly large old broodfish, could provide an increased source of genetically high quality larvae to supplement stocks. The provision of marine reserves should also greatly improve the sustainability of marine environments in the region.

Objectives and constraints

This 'Conservation Guide' provides a scientifically based perspective for the assessment of environmental impacts on the marine environment of the proposed BHP Billiton (BHPB) desalination plant at Port Bonython, Upper Spencer Gulf, South Australia (henceforth referred to as the 'Desalination Plant' or 'Plant').

The objectives of this guide are to; 1) define the project in terms of marine conservation; 2) provide information of relevant physical and biological parameters, and 3) identify and describe any marine conservation concerns.

The most common marine conservation concerns with the Desalination Plant are:

1) Dispersion of increased salinity in the discharge water (brine).
2) Regional increases in salinity.
3) Effects on the biota in the immediate area, particularly protected species.
4) Effects on spawning Australian giant cuttlefish (*Sepia apama*).
5) Effects on the larval recruitment of commercial and recreational fish and crustaceans.
6) Pollutants from Plant maintenance and their affect on local or regional biota.

This guide could not have been produced without the cooperation of government institutions, non-government institutions, industry including BHP Billiton, marine scientists, and community marine conservation groups (Browne 2007a).

This report was produced voluntarily and independently and at all times tries to present a balanced view. I attended two presentations on the proposed Desalination Plant by BHPB, one at a MLSSA meeting and one at a Scuba Divers Federation meeting.

Of marine conservation organizations, I am acting President of the Seadragon Foundation Inc, committee member of the Friends of Gulf St Vincent, and member of the Fishers for Conservation and the Marine Life Society of South Australia. I have been active in the conservation of inshore fish and their environments in South Australia since 2002 (Browne 2007a, b; Browne et. al. 2007; Browne and Smith 2007, in prep; Browne 2003).

Terminology and Conventions

The term “material impact” as used in some reports about the Desalination Plant is ambiguous in respect to the conservation of marine biodiversity. The alternative term “significant environmental impact” is used in this guide.

The term “discharge” (water) rather than “brine” (*def. seawater or water containing salts*), as both seawater and discharge water contains salts, seems a more encompassing and specific term.

The term “relict” has been used to describe some warm water species confined to the Upper Spencer Gulf, and northern Lower Spencer Gulf. This term seems inappropriate. In biogeography the term ‘relict’ describes species that are left in pockets of suitable habitat after major disruption of their broader range; ie. Relict headwater creeks of dry river systems, or relict species in cold elevated areas as the surrounding climate warms.

Therefore, the warm water species in Spencer Gulf cannot be relict due to the recent age of Upper Spencer Gulf of less than 10,000 years old. The origin of warm water species that inhabit Upper Spencer Gulf is enigmatic, with possibilities including the rafting of larvae, juveniles or adults from Western Australia in the Leeuwin Current.

This guide uses “discharge band” instead of “discharge point” as used in earlier reports because of the 200 m length of pipeline used for the proposed discharge

Upper Spencer Gulf does not appear to have consistently accepted boundaries, even within official publications. Publications consider Upper Spencer Gulf:
1) as the region from Point Riley to Shoalwater Point north (IMCRA; about the altitude of Port Broughton on included map p8).
2) as a hydrographic region defined by a salinity of greater than 38 ppt (Smith 2007) that found about the latitude of Wallaroo (Kadina on included map p 8) almost 100 km south of Port Bonython.
3) by a central depth in Spencer Gulf of less than 30m meters found south of Pont Bonython (SARDI pers. com).
4) as either ‘Spencer Gulf’ as the area north of a line from Tumby Bay to Corny Point or further south as Lower Spencer Gulf (GSA 2006).

This Guide refers to Upper Spencer Gulf as defined by the Interim Marine and Coastal Regionalisation for Australia (IMCRA). Consequently, in this Guide the proposed Desalination Plant at Port Bonython is located at about the middle of Upper Spencer Gulf. Because salinity and temperature increase rapidly in the area above the Port Bonython site we use the terms northern Upper Spencer Gulf for this area, and southern Upper Spencer Gulf for the area south of Port Bonython.

INDEX

Possible biological impacts

Introduction

This 'Marine Conservation Guide' was prepared to provide an assessment of the potential impacts to the marine environment of the proposed BHP Billiton Desalination Plant at Point Lowly. Scientific assessment is becoming increasingly important to marine conservation as increased pressure on the marine environment demands serious conservation outcomes (Browne 2007a; Browne et al. 2007).

In general there is a considerable background of knowledge to support assessment of marine conservation issues surrounding desalination plants. There are more than 3,000 plants desalination plants operating globally and they have become essential in many areas as industries and populations develop. Currently, model green projects are considering desalination plants including Alcatraz Island, San Francisco Bay, http://news.sawf.org/Travel/39266.aspx.

A major desalination plant is operating in Australia at Perth, with a second plant proposed for Perth. The Perth Desalination Plant supplies 18% of Perth's water and is very similar in size to the proposed Desalination Plant at Port Bonython. For more information about technical aspects of desalination plants, extensive work undertaken for Perth and proposed Sydney desalination plants over the past five years is found at:
Perth: http://www.watercorporation.com.au/D/desalination.cfm
Sydney: http://www.sydneywater.com.au/EnsuringtheFuture/Desalination/

During this Guides preparation marine conservationists, NGOs, government institutions, and industry were consulted. Cooperation and communication is critical to sustainable management and these were provided by both individuals and organizations. There had been very few scientific studies of the biology of the region. However, substantial previous studies were available relating to tidal and current flows, pollution, and fisheries.

However, there was enough information to make limited assessments of specific marine biodiversity conservation issues including biodiversity and sensitivity. Biodiversity and sensitivity was heavily influenced by the Upper Spencer Gulf extremes of salinity and warm temperatures. Because of their unique breeding aggregation at Point Lowly the biology of Australian giant cuttlefish (*Sepia apama*) and their breeding aggregation on inshore reefs is reviewed. Recent work on the main protected fish group in South Australia, the syngnathids - seadragons, seahorses and pipefish -, enabled a limited assessment of their conservation in the Point Lowly region (Browne et. al. 2007, Browne and Smith 2007, in prep; Browne 2003).

This guide has not dealt in any depth with ecotoxicology. A good reference for ecotoxicology assessments is found at http://www.geotechnicalservices.com.au/EnvEcotoxHome.htm

Geophysical suitability of site

LOCATION AND HYDROLOGICAL CHARACTERISTICS

The proposed site for the desalination plant is at Port Bonython (-32º 59' S, 137º 45' E) located on Point Lowly, at the mid reaches of Upper Spencer Gulf, South Australia. Upper Spencer Gulf is an inverse estuary due to low freshwater inflow, limited current and shallow depth, and high evaporation resulting in very high salinities at Port Augusta at the northern end (Nunes and Lennon 1986).

Point Lowly located at (-32º 59' S, 137º 47' E) is the site of the proposed discharge pipeline. The area of Point Lowly has rapid current flows and high water turnover (Figures 1, 2, 3; Nunes and Lennon 1986). The discharge pipeline will extend more than 800 m south easterly into the tidal channel off Point Lowly. The depth at the last 200 meters where discharge will occur will be 20+ meters.

The northern part of Upper Spencer Gulf is subject to high yearly variations in temperature, with these reflected to a limited extent by seasonally varying salinities. The water temperature increase northward along the Upper Spencer Gulf from 12ºC in winter to 24ºC in summer at Point Lowly to 12ºC -29ºC at Port Augusta in the far north. Salinity increases northward in northern Upper Spencer Gulf from 40.5-42.0 ppt at Point Lowly to an extreme greater than 48.0 ppt at Port Augusta (Nunes and Lennon 1986).

The region has low rainfall in the south at Whyalla of 256 mm and Port Pirie 332 mm, and 237 mm at Port Augusta in the north. Average summer temperatures are around 30ºC and winter minimums around 7ºC. At Whyalla the wettest location regionally the rainfalls is relatively insignificant in comparison with annual evaporation rate of 2,400 mm. Rainfall decreases northward in Upper Spencer Gulf and evaporation increases.

Approximately 70% of northern Upper Spencer Gulf is inter-tidal or less than 10 m in depth, 20% is from 10-20 m in depth, and 10% is 20-28 m in depth. Spring tidal ranges are highest in the north and vary from 4.2 m at Port Augusta to 3.1 m at Whyalla and 3.4 m at Port Pirie. At the southern end of Lower Spencer Gulf at Port Lincoln the range is 1.8 m.

Spencer Gulf is the large water body to the left. Port Bonython is 20 km north of Whyalla.

Figure 1. Map showing the regional location of Point Bonython and the other large regional centers of the Whyalla, Port Pirie, and Port Augusta industrial areas in Northern Spencer Gulf, South Australia. The distance from Port Bonython to Port Augusta is 64 km. The four industrial centers are indicated by red circles.

Port Bonython (●), the location of the proposed desalination plant.

Previous Industrial History

Point Lowly is between three major industrial towns; Whyalla 20 km to the south with a history of iron smelting and shipbuilding; Port Augusta 64 km to the north, a regional center with large brown coal-fired power stations; and Port Pirie 24 km to the southeast, a regional center and the location of a large zinc, lead, and silver smelter (Figure 1, 2, 3; Noye 1984).

The region from Whyalla north across False Bay to Point lowly, has been subject to heavy pollution from Whyalla over most of the 2Oth century. Currents tend to flow northward on the west side of Spencer Gulf with historic transport across False Bay toward point Lowly of zinc, with iron and manganese from the Whyalla industrial area. The reefs that are the focus of the Australian giant cuttlefish spawning aggregations are mostly around Point Lowly and to the north including Black Point (Figure 2; Noye 1984).

Pilot Plant

The Port Bonython Jetty is being used for the intakes and discharge of the pilot desalination plant. The pilot plant is being used to assess the character of the intake water and plant function and because of its size has no possible significant environmental impact (BHPB).

The Total Daily Discharge Volume

This guide will use BHP Billiton figures of 320 ML total daily intake, 192 ML total daily discharge, and 128 ML of freshwater production resulting in a 1.67 increase in salinity compared with seawater in the discharge water (68 ppt). The measured background salinity is between 40.5 ppt and 42.0 ppt, the common value of 40.5 ppt is used in this guide for calculations.

Discharge band

The water depth at the provisional discharge point more than 800 m off Point Lowly is 20+ m deep with a discharge released from an additional 200 m diffusion band. If Point Lowly is the centre of a clock BHP Billiton are examining various discharge points at between 3 o'clock and 6 o'clock south (BHPB) (Figure 2, 3).

The depth at the proposed discharge point is 20+ m, so the total daily discharge when undiluted in the shallowest 20+ m depth would occupy an area less than 100 m squared (97.5 m^2), the area of 7.9 Olympic swimming pools (25 x 50 meters), or less than one hundredth of a square km.

TONS OF DISCHARGE SALT

The amount of salts in the discharge water could be relevant to regional marine conservation if there was not adequate dispersion, or if the salt was to be harvested.

The 13,056 t of salts in the 320 ML total daily intake of seawater is the same amount as in the 192 ML total daily discharge. The amount of salt in 320 ML of seawater at 40.5 ppt is 12,960 t. The 192 ML of total daily discharge contain 5,184 t of additional salt or 27.0 ppt extra when compared with seawater.

DENSITY OF DISCHARGE

The density of water in relation to other water decides its tendency to float or sink. The discharge water would tend to sink in seawater as the density of water increases with increasing salinity.

There is a seawater density calculator at
http://www.es.flinders.edu.au/~mattom/Utilities/density.html

The densities of water at 15ºC of the most common salinities in this Guide are listed below.

Seawater (4.05%) 41.0 ppt = 1030.6 kg m^3.
Seawater (4.80%) 48.0 ppt = 1036 kg m^3.
Discharge water (6.80%) 68.0 ppt = 1051.6 kg m^3.

Figure 2. The proposed approximate position of the discharge pipe when shown 800 m off the tip of Point Lowly. Most of the cuttlefish spawning sites are around Port Bonython, with a small area on the breakwater at Whyalla and north of Point Lowly at Black Point (10 km to north of Point Lowly, not shown). The False Bay closure area is within the broken line.

Cuttlefish fishing exclosure

Cuttlefish spawning area

DISPERSAL

Tidal and current flow in Upper Spencer Gulf

Dispersal includes the immediate dispersion of discharge to safe salinity levels, and the regional salt accumulation in the region particularly Upper Spencer Gulf. If dispersion at the discharge band produces the required safe salinity levels the issue of regional salt accumulation becomes irrelevant.

The success of the immediate dispersion of discharge depends on the dispersion method and tidal flow rates across the discharge band. Salt accumulation depends on tidal and major current flows which control the exchange rate of water from Upper Spencer Gulf to Lower Spencer Gulf. Both tidal flows and current flows are mainly affected by the shape of Upper Spencer Gulf, tidal forces, other geophysical forces, and by water temperatures and salinities.

Spencer Gulf is a triangular shaped inverse estuary with the highest salinities at Port Augusta. From Point Lowly, at the entrance with a salinity of 40.5 ppt it is 60 km to the most northern point at Port Augusta where the salinity is 48.0 ppt. There is a long sandbar (Ward Spit) opposite Point Lowly that extends to shore on the east side of the Gulf. Tidal exchange between Upper Spencer Gulf and Lower Spencer Gulf passes through a deep channel between Point Lowly and Ward Spit.

Water temperatures in Upper Spencer Gulf and in Lower Spencer Gulf tend to increase from south to north and from west to east. This has been considered evidence for circular water movement in the gulf with water moving up the western side and down the eastern side.

Higher salinities are found toward the north and in shallow close inshore areas. Maximum salinities are limited by saline water being driven southward. The net movement of salt from Upper Spencer Gulf southward through mass current flow is the same as surplus salinity produced by net evaporation. In Lower Spencer Gulf during winter cold and salty pulses of water move south to the continental shelf (Nunes and Lennon 1986).

The tidal variation at Point Lowly is 2.5 m during spring tides and 1.0 m during neap tides, and variation can be negligible for up to 18 hours during dodge tides. Current speeds at the tip of the Port Bonython jetty vary from a maximum of 1 m per. second during spring tides to a maximum of 0.1-0.2 m per. second during neap tides. However, weaker tidal flow is in the channel is anticipated during dodge tides.

The computer model that BHP Billiton is building is an ELCOM Model (Estuaries, Lakes, Coastal and Ocean). ELCOM was also used for the modeling of the Perth Plant.

Computer models are limited by the amount and accuracy of data and the complexity of the subject system. A formula using salinity as a conservative marker can calculate the minimum exchange rates in Upper Spencer Gulf. From a conservative marker formula using salt the average exchange rate of water to maintain a salinity of 43.0 ppt in 5 m depth would be four times a year or every 3 months. Calculated exchange rates are graphed for a number of depths and salinities in Appendix 1.

The conservative marker formula calculates averages over time, and does not give accurate short term variations. These are best done in computer models with measured current flows and dispersion coefficients.

Near and mid-field dispersion

Dispersion is the mixing of the discharge with source water. Dispersion is generally considered as near-field, mid-field and far field. Near-field is the rapid dilution that occurs at the discharge point. Mid-field is the general mixing in the vertical water column. Far-field is the dispersion of the water column as a body of water in major currents.

Discharge rate per. minute will be 192,000 m^3 / 60 minutes x 24 hours = 133.3 m^3 per minute or 2.2 m^3 per. second.

The proposed pressure in the discharge band is as enough to eject the discharge more than one meter vertically into the water column.

The total water flow over the 200 m discharge band during the maximum flow of a neap tide of 0.1 m per. sec is 1,728,000 m^3 per hour. In the case of the neap tide at maximum tidal flow salinity within seconds after discharge using only 1 m of the 20+ m water column would be 43.0 ppt, with 2 m of the water column would be 42.0 ppt, and with 3 m 41.5 ppt.

Therefore, immediate dispersion could result in a dilution of salinity to about 43.0 ppt during most tides including a fair part of neap tides. However, there is far less certainty of adequate dispersion during dodge tides. During tidal change or neap or dodge tides on land storage of the discharge or other alternative means of dispersion may be required. This need can only be accurately calculated if accurate tidal flows are measured.

Neap tides are weak low tidal movement which occur twice monthly at the time of the first quarter phase and the third quarter phase of the moon.

Dodge tides are an uncommon and may only occur several times a year. Dodge tides occur in Spencer Gulf and Gulf St Vincent, South Australia, and in Torres Strait, the Persian Gulf and the Gulf of California.

Tide information:

www.bom.gov.au/oceanography/tides/MAPS/sa.shtml
Use Whyalla as the site and then look at the link for Dodge tides; you get the next week's tides. You should be able to find the dodge tides for four months by checking about 17 weeks of tides.

www.bom.gov.au/oceanography/tides/dodge/oh2007pre.pdf

Far field dispersion and regional salinity increases

Potential buildup of salinity levels in the Upper Spencer Gulf should be considered in respect to the relative removal of freshwater by the Desalination Plant compared to the natural process of evaporation, and mechanisms in the Gulf that maintain ambient salt levels. There are no significant freshwater inflows into Upper Spencer Gulf due low rainfall in the surrounding desert.

The Upper Spencer Gulf has a high annual evaporation rate of about 2 meters and in summer evaporates 21,979 ML of fresh water per day. This amount of freshwater is the same as removed daily by 183 Desalination Plants the size of the Point Lowly plant and yearly concentrates 346,000,000 tons of salts in the Upper Spencer Gulf. Nevertheless, salinity levels only reach a maximum of 48 ppt at Port Augusta in summer.

This total amount of 346,000,000 tons of potentially accumulating salt in the Upper Spencer Gulf must be removed annually by tides and currents to maintain existing background salinity levels. The higher salinity waters the north of Upper Spencer Gulf are removed by currents driven by tidal forces and increased density of saline waters.

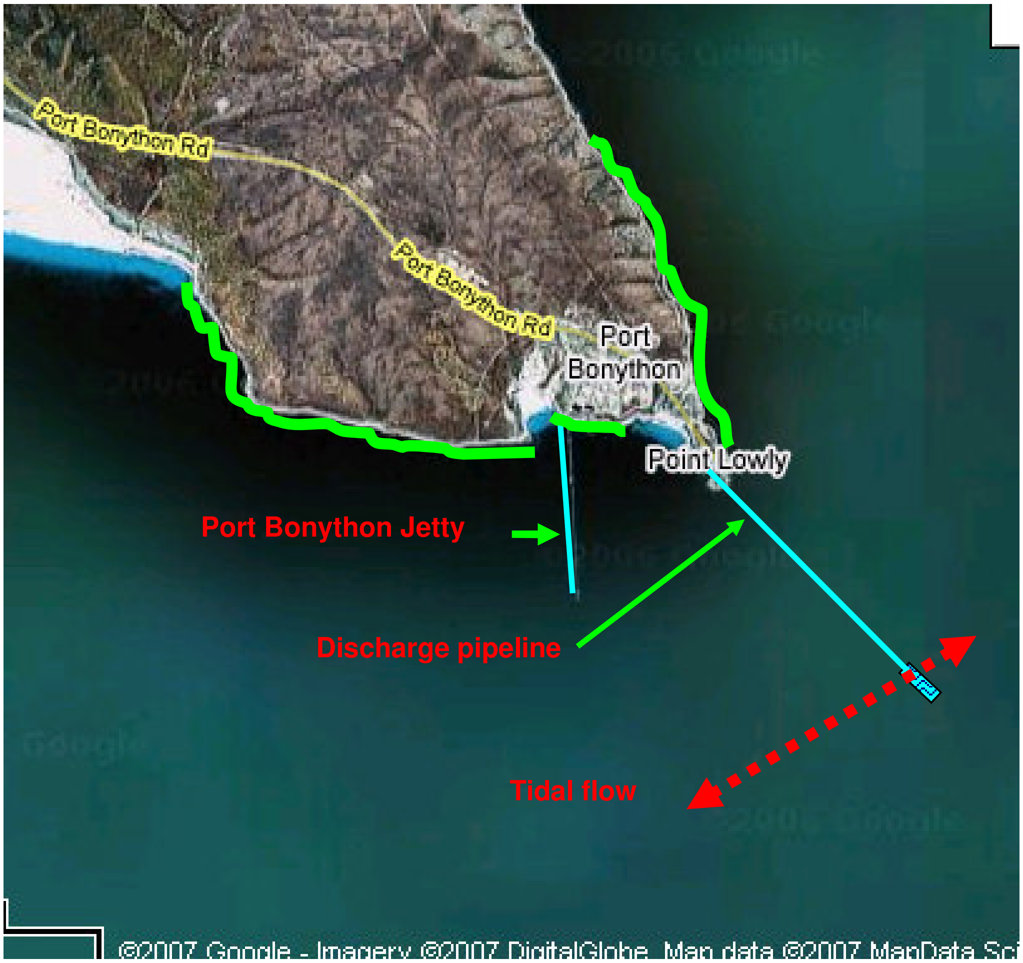
It would appear that this robust system would maintain salinities at close to the current levels even with far greater volumes of discharge than proposed from the desalination plant at Point Lowly. Appendix 1. shows the minimal exchange volume to provide stasis of salinity for different depths in Upper Spencer Gulf. The model is subject to the exchange water being 40.5 ppt., which gives a very conservative rate of turnover.

Chemical Contaminants in Discharge

Discharge of chemicals used in the plant maintenance could reduce water quality and cause contamination of nearby sediments. BHP Billiton has suggested that the Plant's waste materials could be released in on-site ponds and not in the sea.

The specific chemicals to be used at Point Lowly or their method for management were not available for assessment at the time of the preparation of this Guide.

Figure 3. The area immediately around the discharge pipeline showing Australian giant cuttlefish (*Sepia apama*) spawning areas and approximate current flow. Legends shown below map (areas are approximate).



Cuttlefish spawning area

ALTERNATIVE LOCATION

An alternative location suggested for the Desalination Plant is Thevenard, Ceduna Bay, Western Eyre Peninsula. Thevenard is a deep water port with good current flow. The pipeline distance from Roxby Downs to Port Augusta is 256 km, and in total from Roxby Downs to Port Augusta with the 64 km to Port Bonython is 320 km. From Roxby Downs to Port Augusta to Thevenard is 723 km. Therefore, this site would be more costly and use more energy to pump water to Roxby Downs.

In terms of tidal flow Point Lowly is superior to sites in Lower Spencer Gulf.

POWER USAGE

Perth desalination plant supplies 20% of Perth's water needs and uses 24 megawatts of electricity. The proposed desalination plant at Port Bonython would be of approximately the same capacity and have the same power demands at the Perth plant (BHPB).

Perth desalination plant is operating on 100% renewable energy generated by a wind farm. The South Australian State Government has indicated a preference for renewable energy with the Port Bonython Plant. Perth is proposing a second desalination plant that is expandable up to 275 ML per day, which is also committed to running on renewable energy.

ECOTOXICITY TESTING

Possible effects of the discharge on marine plants and animals have been assessed using a technique called Whole of Effluent Toxicity testing. The Whole of Effluent Toxicity technique derives a safe dilution that gives at least 99% protection of marine flora and fauna.

These toxicity tests are based on ANZECC/ARMCANS (2000) Guidelines which are well-established standards for ecotoxicity standards. Tests include fertilization, growth and balance assessments to ascertain not just lethal does but sub-lethal impacts on the species (BHPB).

Ecotoxicity testing of different salinities has or will be been done for marine animals including yellow tail kingfish, western king prawn, Australian giant cuttlefish, snapper; sardines, and two species of marine algae, the microalgae *Nitzschia closterium* and the macroalga *Hormosira banksii*.

Spencer Gulf ecosystems

AGE

The site of the proposed discharge of approximately 20+ m depth was dry land approximately 8,000 years ago. Eighteen thousand years ago during the later stage of the last glacial period the sea level in southern Australia were more than 100 m lower than the present. Since then the sea level rose to reach its present level about 8000 years ago. The sea level was one meter above the present level during the last major interglacial 125,000 years ago.

During the many known drying and inundations of Spencer Gulf in the previous 240,000 years there have been various shorelines at different depths compared with today. However, during much of the time Upper Spencer Gulf would have been dry when depths were below 25 meters form about 80,000 to 10,000 years ago, and most of Spencer Gulf during periods when the sea level was 50 meters below the current level (Hails et al. 1984). During this period the more northern resultant shallow basins would have been salt pans or shallow salt lakes (Fuller et al. 1994).

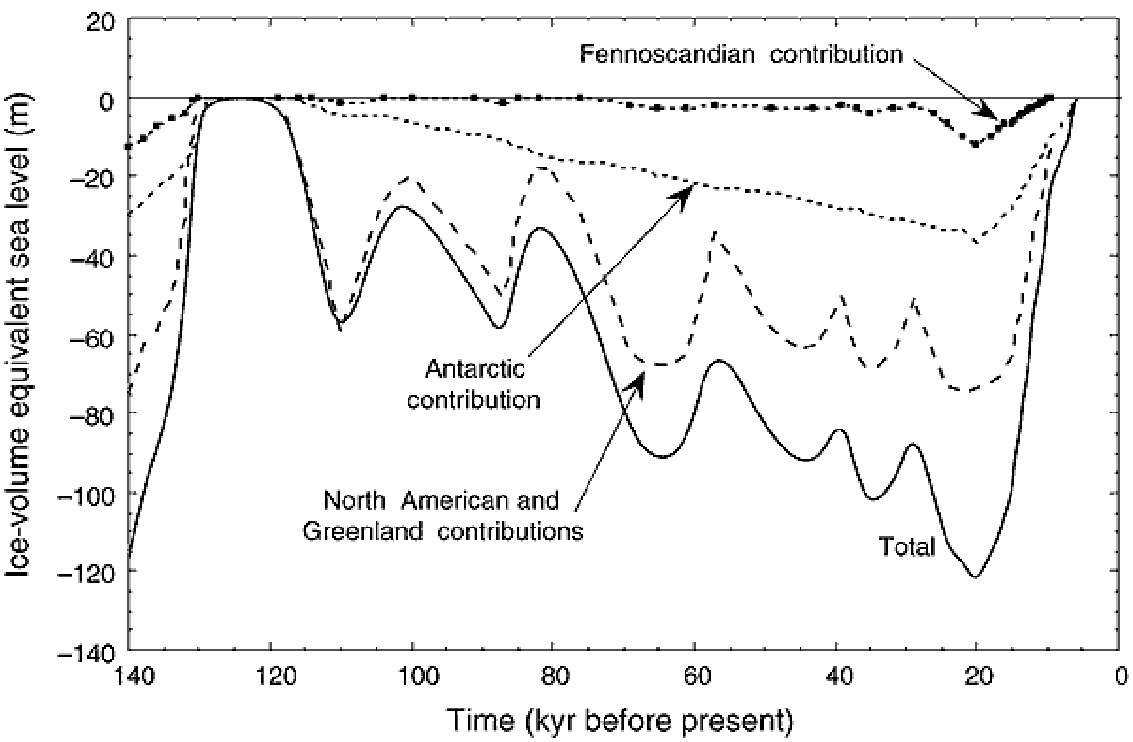


Figure 4. Estimates of global sea level change over the last 140,000 years (continuous line) and contributions to this change from the major ice sheets: (i) North America, including Laurentia, Cordilleran ice, and Greenland, (ii) Northern Europe (Fennoscandia) including the Barents region, (iii) Antarctica. (From Lambeck, 2002)

TYPES OF ECOSYSTEMS

The Point Lowly area is rated as Ecological Zone 1 which should only harbour activities that have no significant environmental on ecosystems or species (GSA; see “terminology” p 2.).

Broadly the types of ecosystems in the Upper Spencer Gulf are; sparse, medium and dense sea grass, dense seagrass patches, heavy limestone or calcareous reef, bare sand, soft sediment communities, intertidal mangrove, saltmarsh assemblages (GSA 2007; Shepherd 1983, 1974).

BIODIVERSITY

The unique conditions in Upper Spencer Gulf of high and fluctuating salinity and temperature variation have fostered unique ecosystems. The unique ecosystems in Upper Spencer Gulf are six seagrass communities (*Zostera mucronata*, *Amphibolis antarctica*, *Heterozostera nigricaulis*, *Halophila ovalis*, *Posidonia australis* and *Posidonia sinuosa*), two algae communities (*Caulerpa cactoides* and Red algae) and three animal assemblages (Sponge – *Telesto*, *Polycarpa-Echinogorgonia*, and *Lanceopora-Sycozoa*) (Shepherd 1983).

A number of fish, invertebrate, and plant species are only recorded in Upper Spencer Gulf, or restricted in South Australia to the Upper Spencer Gulf but known else where. The residence period, origin, and means of colonization of these Upper Spencer Gulf endemics is uncertain (see terminology this document p2; Shepherd 1983; Grasshoff 1982).

It has been proposed that some of these species are relicts of a previously warmer period across southern Australia that got trapped in northern Lower Spencer Gulf and Upper Spencer Gulf as sea temperatures cooled (Kuiter 2003; see terminology). An example from the syngnathids is the tiger pipefish (*Filicampus tigris*), a warm water species common on both the east and west coast of Australia from Sydney north on the warm east coast across and Ningaloo Reef north on the west coast (IFG 2007).

The tiger pipefish has been found to be widely distributed in the more northern areas of Lower Spencer Gulf and also occurs in the vicinity of Whyalla (Dawson, in Gomon et al., 1994); the Shoalwater Point area in mid-Spencer Gulf (S.A. Museum records, 1982); and various sites in northern Lower Spencer Gulf (Kuiter, 1996b). These including the Port Pirie area, and more recent records from further south in the mid-gulf waters between Fisherman Bay / Port Broughton area in the east, and Plank Point in the west (SARDI, unpublished survey data, 2003; Janine Baker pers. com).

Examples of warm temperate species dependent on Upper Spencer Gulf are algae from Western Australia, *Asparagopsis taxiformis* and *Paltysiphonia mutabilis*, and the brown algaes with sub-tropical affinities *Sargassum decurrens* and *Hormophysa triquetra* (IMCRA 1998; Shepherd 1983).

A number of invertebrates including the coelenterates, *Echinogorgia* sp. and *Scytalium* sp. are sub-tropical (Grasshoff 1982). The cosmopolitan species *Virgularia mirabilis* is known in South Australia only from Upper Spencer Gulf (Utinomi & Shepherd 1982). *Telesto multiflora* a tropical species is only known in South Australia from the region (Verseveldt 1982). An ascidian *Sycozoa pedunculata* is only known from Upper Spencer Gulf and in the cold waters of Investigator Strait (Kott 1975, 1972)

These unusual species add to biodiversity, however, the regional environmental extremes of Upper Spencer Gulf have resulted in an overall reduction of biodiversity (Sheperd & Womersley 1970).

In respect to regional biodiversity the Upper Spencer Gulf has a lower biodiversity than cooler less saline longer term habitats to the south, including the coastal surrounds of Investigator Strait. Most species in Spencer Gulf are also found in Gulf St Vincent, the coastal surrounds of Investigator Strait, and western Eyre Peninsula.

SENSITIVITY

Upper Spencer Gulf is a physiologically demanding marine region whose species are adapted to salinity and temperature extremes. Consequently, these ecosystems should be relatively resilient to variations in changes in salinity or temperature. Nevertheless, the close inshore fish and other marine biodiversity has not been adequately surveyed and sensitivity in the region can only be ascertained when the component species are know. Some species that thrive in highly salinity and highly variable temperatures may be regionally unique to Upper Spencer Gulf, and these appear to include endemic species.

Possible biological impacts

SYNGNATHIDS (SEADRAGONS, SEAHORSES AND PIPEFISHES)

All syngnathids are protected in South Australia. Known syngnathid species of particular interest in the region are the leafy seadragon (*Phycodurus eques*) and weedy seadragon (*Phyllopteryx taeniolatus*), the tiger pipefish, and the deepbody pipefish (*Kaupus costatus*). These species are all widely distributed in other regions and states except for the Tiger pipefish, which is locally endemic to Spencer Gulf (see BIODIVERSITY p 20).

However, the conservation of syngnathids in the region is by no means secure because of uncertainty of their biodiversity or distribution. This uncertainty makes it difficult to protect syngnathids, particularly the protection of smaller close inshore species that are not normally sampled during fisheries surveys (Browne et. al. 2007; Browne and Smith 2007; Browne 2003).

The Point Lowly area has not been properly surveyed for inshore demersal fish including syngnathids. Considering the recent number of inshore fish discoveries in South Australia a good possibility in the area exists for the discovery of species unknown in the area, and a possibility of the discovery of new species.

Recent studies in South Australia have revealed species of close inshore syngnathids of very limited range, even near metropolitan Adelaide, and these include species of high significance to biodiversity (Browne and Smith 2007; Browne et. al. 2007, Browne 2003). A corresponding recent inshore fish biodiversity survey of gobies showed four species new to South Australia, at Port Adelaide (Hammer 2006).

This area had been subject to numerous previous fish surveys, and some of the gobies were easily found in easily accessible locations. Overall, these discoveries question the reliability of many previous inshore fish surveys in South Australia in identifying species and recording their inventories (Browne et. al. 2007).

AUSTRALIAN GIANT CUTTLEFISH

The Australian giant cuttlefish (*Sepia apama*), protected syngnathids, recreational and commercial fish, and unique ecosystems are of significance to the sustainable management of marine biodiversity in the Port Bonython area (SFI 2007). Port Bonython is located on Point Lowly. The Australian giant cuttlefish is a species of special consideration because of their large spawning aggregations at Point Lowly and at other sites in the region (Steer and Hall 2005; ABC 1, 2 provide news stories). The spawning dynamics of the Australian giant cuttlefish at Point Lowly are unsurpassed in sophisticated sexual mimicry (Hanlon et al. 2005).

The shoreline reefs at Point Lowly and the surrounding areas support large and unique spawning aggregations of the Australian giant cuttlefish (*Sepia apama*) of high conservation and biological significance. The specific geographical source the aggregating cuttlefish, and their migration routes and means of navigation to the close inshore reefs around Point Lowly are unknown (Steer and Hall 2005).

The Australian giant cuttlefish is a very large, widespread and abundant cuttlefish species. Estimates of maximum size vary of mantle length (mantle length is the body only excluding the head and tentacles) but a published value is 520 mm mantle length and a weight of 6.2 kgs (PIRSA 1,2,3., 2007; Steer and Hall 2005). Divers claim to see much larger Australian giant cuttlefish especially in the Solitary Islands, NSW (N. Skinner pers. comm.).

Australian giant cuttlefish range across the whole of southern Australia from northern New South Wales, south to the north coast of Tasmania, and west to Ningaloo, Western Australia. The east coast and southern Australian populations of Australian giant cuttlefish form one relatively continuous population (Kassahn et al. 2004). However, within this population there are 5 discernable groups with the breeding aggregation north of Whyalla representing a separate sub-population from the rest of SA, with the zone of overlap is about Wallaroo (B. Gillanders, pers. com).

Over most of their range, usually only two or three Australian giant cuttlefish are found mating and laying eggs in caves on reefs. However, every winter in the Whyalla area, South Australia, tens of thousands of giant Australian cuttlefish aggregate to spawn over the shallow inshore rocky reefs and artificial rocky structures close inshore in about 3-10 meters depth. The cuttlefish start arriving from Whyalla, and 20 km north east across False Bay to Point Lowly then north all along the coast to Black Point (B. Gillanders pers com), in early May and reach peak numbers by the start of June (Steer and Hall 2005).

Between 4 on average and up to 11 males compete for one female. Females can mate seventeen times a day with two to eight males. Successful fertilisation did not differ between males paired or unpaired with females, or depend on size or sneaker males. Sneaker males are males than mate with females while the females are primarily consorted by another male. There are several strategies adopted by sneaker males to approach females with a consort, to approach while the consort is repelling another male, by using hidden stealth for example mating with female hidden under rock, and most unique to these cuttlefish mimicking the appearance and behavior of females (Hanlon et. al. 2005, Hall and Hanlon 2002).

The male cuttlefish mimic females by hiding their obviously specialized male arms, adopting the mottled skin pattern of females, and shape their other arms to look like female laying eggs. The sneaker males can change from the male to female appearance ten times in five minutes. This strategy is successful about 50% of the time in achieving mating and two out of three times in achieving fertilization (Hanlon et. al. 2005, Hall and Hanlon 2002).

Females used all their sperm as well as sperm from previous matings to fertilize eggs, and 70% of clutches have multiple sires. Therefore, the mating system of Australian giant cuttlefish has a high level of multiple mating and multiple paternity and that males of any size or status can obtain successful fertilizations (Naud et al. 2004; Hall and Hanlon 2002; Norman et. al. 1999).   In the Point Lowly area the spawning dynamics of the Australian giant cuttlefish, driven by the high operational sex ratio and the high densities in the aggregation, are unsurpassed at a global scale in sophisticated sexual mimicry.   The operational sex ratio is exceptional because of the fluidity of change between one type of sneaking behavior and the sneak behavior of female mimicry (Hanlon et. al. 2005). The elaborate colour and pattern displays of the Australian giant cuttlefish are legendary (Hall and Hanlon 2002) and it is intuitive that the cuttlefish would have exceptional colour vision to match.

Cuttlefish can see clearly. They have a unique arrangement of an invertebrate's visual system with a vertebrate like one. Cuttlefish have an active iris and a rectangular expanding and contracting pupil. They also change the position of their lens to focus like a camera lens system and this part of their visual system is excellent. However, in spite of the mechanical advantages their vision is restricted by a low number of photoreceptors.

The skin colour of some fish groups (Ramachandran et al. 1996) and many cephalopods change in response to visual stumuli (Hanlon and Messenger 1988). Eyes need at least two colour pigments to see colour. However, there is only one color pigment in the eyes of the common cuttlefish (*Sepia officinalis*) (Bellingham et al. 1998). How cuttlefish mimic chromatically rich environments, found in shallow well lit waters is unexplained (Mathger et al. 2006).

Colour changes in cephalopods are controlled by nerves and muscles and can occur rapidly. Other animals slowly change their body colors mainly through hormones. Cuttlefish can match black and white backgrounds from birth and are good at mimicking contrasting backgrounds and quickly mimicking patterns contrasting in shade of greater than 15% difference in intensity (Mathger et al. 2006). For comparison owls can differentiate 1% contrast (Porciantti et al. 1989) and human 2% (Lythgae 1979, p279). However, backgrounds of different colour such blue and yellow of the same shade are recognized as uniform (Hanlan and Messenger 1996). Cuttlefish can see polarised light like many marine animals. This possibly enables cuttlefish not to be disorientated by flare caused by scatter from above.

After mating females lay about 5-39 eggs a day and 200 eggs in total, individually within protective casings, with the eggs attached to the underside of flat rocks and in tight hard to get at spaces among crevices in reefs (Hanlon et al. 2005). Australian giant cuttlefish appear to use artificial as well as natural substrata for deposition of their eggs. Anecdotal evidence suggests that cuttlefish will fix eggs to other man-made objects, such as corrugated iron thrown into the water in the vicinity (Steer and Hall 2005). Cuttlefish spawn in the rock walls of the Whyalla Boat Harbour as well as on the more extensive artificial rock walls adjacent to the steelworks. The eggs hatch within three to five months, depending on the water temperature, with hatchlings looking similar to their adult form. Hatchlings appear in early September (PIRSA 1).

After spawning most adult cuttlefish then mysteriously disappear again by the end of August (PIRSA 2). Australian giant cuttlefish are solitary animals when not breeding. Daytime activity cycles showed individualistic behavior. Australian giant cuttlefish live in dens, or hover under rocks and emerge during daylight for short food excursions. The cuttlefish enhances this conservative lifestyle with efficient foraging while exposure to predation is minimized (Aitkin et al. 2000).

A straight line between the One Steel Jetty at Whyalla to the east at Point Lowly encloses False Bay (a closure area for cuttlefish fishing) where tens of thousands of cuttlefish aggregate to mate and spawn. The closure area includes all waters enclosed by a line from the light house at Point Lowly to the southern end of the Port Bonython jetty, then in a south westerly direction to the eastern most point of the One Steel jetty, position latitude 33º 02” 12.63’ south and longitude 137º 36” 1.98’ east, near Whyalla, then to the high water mark at the base of the jetty, then following the high water mark along the shoreline in an easterly direction back to the point of commencement (Map grid GDA94). Australian giant cuttlefish also spawn at Black Point northward form Point Lowly across Fitzgerald Bay (Steer and Hall 2005).

In the mid-1990s, an overseas market was discovered for the Australian giant cuttlefish and export licenses were granted. In 1997, 26 boats took 262,000 kg: that is approximately 60,000 cuttlefish over a full breeding season and cuttlefish numbers dropped dramatically. The boats and commercial fishers were black with cuttlefish ink. Thousands of dollars a day could be made by harvesting the aggregated spawning cuttlefish. The Australian giant cuttlefish fishery in the area has since been regulated and a closure created in False Bay. Australian giant cuttlefish are also caught by recreational fishers in the Whyalla (Steer and Hall 2005).

ECOTOURISM

Upper Spencer Gulf is home to an expanding marine-based ecotourism industry. Recreational fishing and commercial fishing have severely stressed many populations of fish and crustaceans. However, similar to the restrictions on the fishing of Australian giant cuttlefish, restrictions in catches of fish species will hopefully stabilized the populations of snapper, whiting and garfish. Nevertheless, the taking of the highly fecund and genetically competent large brood fish is allowed.

The unique spawning aggregations of the charismatic Australian giant cuttlefish were devastated by excessive fishing. Now with greater protection from fishing the cuttlefish are now recovering. However, the minimum biological and practical requirement for eco-tourism should be recovery of the spawning aggregation to pre-fishery levels.

A boat based and shore based diving industry exists in the area dependent on the giant cuttlefish. At Point Lowly platforms are in place for divers to walk down to the water. From the platform, divers cover about twenty meters over flat rock and then swim into six meters of water. Water temperatures during the spawning season can be as cold as twelve degrees centigrade.

Suggestions from the public of how ecotourism could contribute to Australian giant cuttlefish conservation are; the establishment of spawning reefs including rock walls and breakwaters, monitoring of sites, and provision of exclusion zones to fishing for around all Australian giant cuttlefish aggregation reefs in the region. There are unprotected spawning aggregations to the north of Point Lowly. Artificial spawning sites need depth as Australian giant cuttlefish normally spawn in 3 -10 m of water.

Australian giant cuttlefish spawn in the rock walls of the Whyalla Boat Harbour as well as the more extensive artificial rock walls adjacent to the steelworks. It appears that there is potential to establish additional artificial habitat south of Whyalla and north of Point Lowly into Fitzgerald Bay.

SEAGRASS

The discharge appears unlikely to have significant environmental impact on seagrass communities in the vicinity of Point Lowly, or in Upper Spencer Gulf. The range of seagrass communities in Upper Spencer Gulf appear to be adapted to high and varying salinities (Nunes & Lennon 1986; Shepherd 1983, 1974)

The sea grass *Posidonia* spp., cover extensive areas Upper Spencer Gulf to a depth of about 10 m. *Posidonia* spp. are insensitive to higher salinities and form extensive communities near Port Augusta where salinities reach 47-48 ppt. There is no seagrass in the vicinity of the discharge as the water is too deep (> 20 m). The nearest large seagrass communities occur in False Bay and Fitzgerald Bay, which are 5-10 km from the outfall.

EPIFAUNA

It has been suggested that the algal epiflora and macroepifauna on seagrass could be affected by the Plant. The different seagrass species in the area – and their invertebrate communities - are found in a high a range of salinities. There is evidence that epifauna are more specific to seagrass species than to plant form or strucure. However, even globally there are few documented analysis of the effect of the environmental extremes or low levels of pollution on epifauna.

Virnstein et al. (1984) only showed weak latitudinal global patterns in epifaunal or fish diversity in seagrass with slightly more amphipods and decapod crustaceans but not isopods and fish toward the tropics. Seagrass species were the major determinant of epifauna composition in seagrass beds in Florida with biomass and vegetative structure insignificant (Lewis 1987).

MANGROVES

The monotypic stands of mangroves (*Avicenna marina*) in both Lower Spencer Gulf and Upper Spencer Gulf are tolerant to extremely saline environments and form extensive communities even near Port Augusta where salinities reach 48 ppt.

TURTLES AND SHARKS

The three types of turtles occasionally drift into Upper Spencer Gulf, the Loggerhead turtle (*Caretta curette*), Green turtle (*Chelonia mydas*) and Hawksbill turtle (*Eretmochelys imbricate*). The provision of intake grids and passive intake of the desalination plant should prevent damage to sea turtles. Similarly sharks and other large fish would be excluded from the intake.

GENERAL FISHERIES

It has been suggested that larval recruitment of commercial or recreational fish in the region could be affected by loss of fish and crustacean larvae particularly through loss in intake water. Unfortunately, it difficult to predict the effects of intake water on larval recruitment even if the numbers of affected larvae were known. Factors relating to larval recruitment include minimum viable recruitment, brood stock size and numbers, spawning location, non-random behavior of larvae, unusual seasonal and current variations, and many other factors that can variably effect the survival of larvae at different growth stages.

There are several main practical approaches to predicting the potential effect of water intake on fisheries including; 1) a comparison of the intake volume of the proposed plant with that of other industries in the region, 2) a comparison of the intake volume of the proposed plant with that of the regional volume, 3) the potential number of larvae that may be damaged during the desalination process compared with potential larval recruitment.

Approach 1. The regional volume of water in m^3 within a 5 km from the proposed discharge band - assuming a very conservative average depth of 15 m (Nunes and Lennon 1986, Fig. 1.) and 50% of the circle as water - is $(15 \text{ m} \times 3.14 \times (5{,}000 \text{ m})^2)/2$ = 589,000,000 m^3. The daily intake of water by the Plant is 0.05% of the volume in the half circle; calculated as a percentage of intake water divided by the area of water in the half circle, (320,000 m^3/589,000,000 m^3) x 100. Thus if larvae were evenly distributed within 5 km of the intake the Plant's intake would only affect one in two thousand larvae a day. The area considered in the model above is 39.3 square km or 2% of the area of Upper Spencer Gulf. This area of Upper Spencer Gulf is 2048 square km.

Approach 2. In terms of relative volume of intake the Desalination plant using (192,000 m^3 per day) would use 3.5% of the cooling water used by the Port Augusta Power Station. The Post Augusta power station uses 5,500,000 m^3 of seawater per day, which is heated 7ºC above ambient temperature to 20ºC in winter and 36ºC in summer. Certainly in summer and probably in winter the rapid 7ºC rise in temperature would be expected to damage fish larvae. The Port Augusta Power Station has been operating since 1980 and loss of fisheries catches in Upper Spencer Gulf has not been attributed to its operation.

Approach 3. The potential number of larvae that may be damaged during the desalination process compared with potential larval recruitment is difficult to approximate. For instance even with a constant number of brood fish larval recruitment of some species is highly variable from year to year.

It has been suggested that in the Upper Spencer Gulf that whiting and snapper are fished to a critical level and garfish are possibly in the same situation. If this is that case then debates about the effect of the proposal for the Plant on commercial and recreational fish hopefully may offer an opportunity for the implementation of secure, scientific, and sustainable management of these species. At a minimum this management would include the establishment of more fishing exclosures, more restrictions on harvesting large brood fish, and reduced bag limits for all species to provide a safety margin. Genetic resource banks of heavily fished species should be established.

Appendix 2; takes a superficial look at the potential fecundity of species fished in Upper Spencer Gulf and the factors that can affect larval recruitment.

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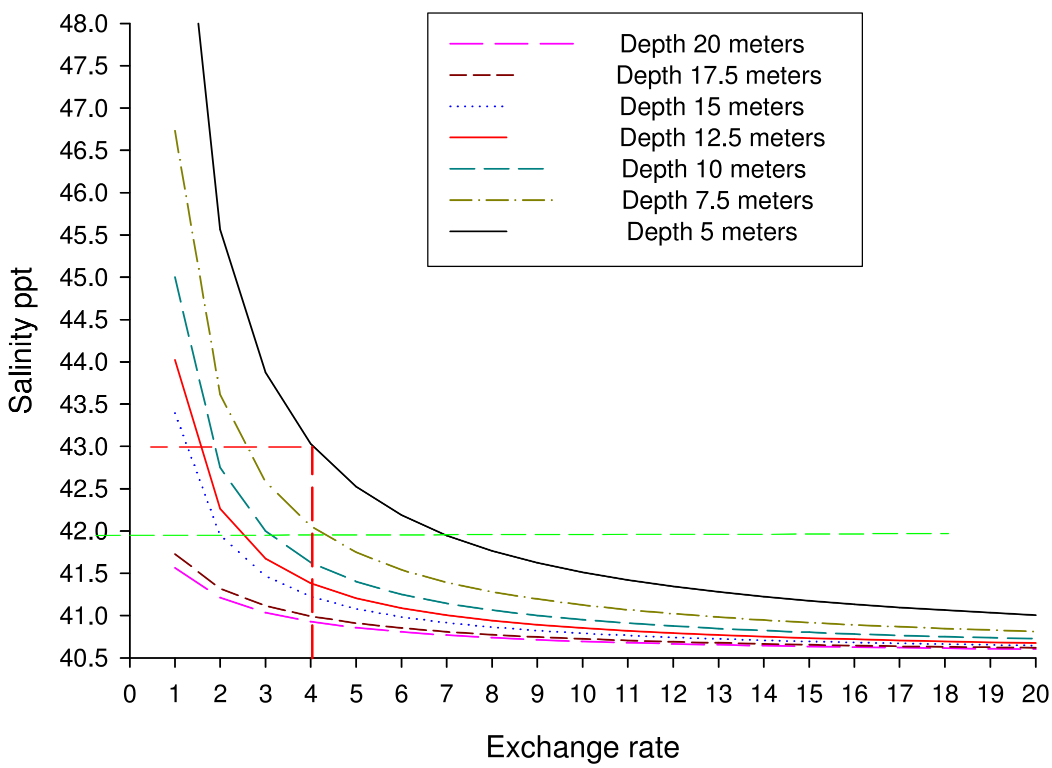
Appendix 1. Minimal exchange rates

The graph below shows the minimal exchange volume to provide stasis of salinity for different depths when the initial salinity is 40.5 ppt. At 5 meters depth to maintain a salinity of 43 ppt an exchange rate of 4 is needed, and a salinity of 42 ppt an exchange rate of 7 is needed. The salinity of 40.5 ppt is conservative and all other input salinities further up the gulf will give a higher exchange rate. The exchange rate is total dilution, ie. 4 is 1 part of the original saline water with 3 parts water.

Salinty as a conservative marker can be used to calculate exchange rates of water. Over a period of time a conservative marker formula (CMF) with the background salinity (40.5 ppt), water depth x, evaporation rate y (constant at meter per year), and water exchange rate A (at 40.5 ppt) will calculate final salinity; salinty ppt =(((40.5*(x/(x-y)))+(A*40.5)))/(1+A) (Figure 1). The initial salinity is not very critical to the formula.



Appendix 2. Fish larvae numbers.

The numbers of larvae has been considered as 200 larvae per 10,000 m^3 being a reasonable number for evaluation of loss at Port Bonython (Young 1986). This number was used to calculate a total loss of 2,628,000 larvae per. year. A concentration of fish larvae of 50 per 100 m^{-3} was recorded in the Mexican Caribbean Sea. This is 25 fold higher concentration than Young 1986, at 5000 per. 10,000 m^3 or would mean for the Plant 65,700,000 larvae per year.

However, whatever their value, what do these numbers mean in terms of larval recruitment? Both studies pooled all larval fish most of which were of no commercial or recreational significance. This information can be measured accurately. However, even with accurate information of larval loss what proportion of these larvae would survive to maturity? How much of the potential fish spawn would this number represent?

We will consider all fish larvae in both cases as 100% commercial or recreational fish. The real percentage is more likely to be much less than 10%. Most larvae don't even get to half way to being juvenile fish. However, to put the potential loss of larvae from the Plant in some perspective lets consider the number of adult fish that fishers can catch that could represent the number of 2,628,000 larvae for two important commercial and recreational species, King George whiting and snapper.

King George whiting produce an average of 30,000 eggs and snapper 250,000 eggs. They may spawn several times in their life but we be conservative and consider one spawning per. female. We will also assume equal numbers of females and males caught by fishers and kept.

With King George whiting 2,628,000 larvae represents the spawn from 15 fishers one days bag limit (12; 6 females and 6 males) (15 x 6 x 30,000 = 2,700,000), or 5 boats limit. Older brood fish whiting from the spawning grounds in Investigator Straight can produce up to 150,000 eggs (Fowler et al. 1999; PIRSA 2007).

Even with the higher larval concentrations of 5,000 per. 10,000 m^3 the potential yearly loss only represent or 73 fishers one day bag limit, or 20 boat limits. The catch of King George whiting in South Australia is about 1000 tons. At 250g per fish this represents approximately 2,000,000 female fish, or the loss of 60,000,000,000 eggs per season.

With Snapper one 1.5 kg female fish can produce 500,000 larvae and the boat limit of 30 (15 females) fish 7,500,000 larvae more than the desalination plant could possible damage in one year with a larval concentration of 200 per 10,000 m^3. One big 10 year old snapper could alone produce 5,000,000 larvae (PIRSA 3, 2007).