An Independent Expert Assessment of BHP Billiton's Draft Environmental Impact Statement Regarding Constructions and Operations of a Seawater Desalination Plant and a Landing Facility in Upper Spencer Gulf

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This work is dedicated to those who care.

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Note: Assoc. Prof. Kaempf uses his original family name "Kämpf" in most of his publications.

Outline

Summary and Recommendations

Upper Spencer Gulf accommodates an ecologically unique marine habitat in a region of extremely slow flushing. Pt. Lowly is outlined as 1 of 4 areas in Spencer Gulf to be identified as being of 'high conservation value" by the South Australian Department of Environment and Heritage (DEH) 2003 for biodiversity and social values.

The Draft Environmental Impact Statement (EIS) prepared by BHP Billiton acknowledges these facts. BHP Billiton's proposal to build a seawater desalination plant together with a landing facility in Upper Spencer Gulf is inconsistent with the first principles of marine conservation, namely that desalination outfalls should avoid regions of high ecologic value and slow flushing. The Draft EIS acknowledges that EPA's water quality standards will be compromised and the proposed development will not comply with South Australia's environmental legislation. Per se, this implies detrimental impacts on the unique marine ecology of the region, which is unacceptable and also can be avoided.

The most severe marine threats of the proposed development are:

- Formation of deoxygenated brine underflows which can have devastating impacts on the marine food chain and local fisheries
- Upwelling of toxic brine into shallow marine habitats accommodating the only known mass breeding aggregation of cuttlefish in the world.

The formation of brine underflows has not been adequately studied in the Draft EIS and events of critically low dissolved oxygen levels pose a severe hazard for bottom-dwelling marine organisms such as Western King Prawns and Giant Australian Cuttlefish.

Independent hydrodynamic modelling studies, presented in this document, demonstrate the possibility of upwelling of toxic brine into shallower near-shore regions—a scenario that according to the Draft EIS can never happen. It should be stressed that a single of such events has to potential to instantly "wipe out" large fractions of a species population. This situation is best avoided by choosing an outfall site <u>not located</u> in Upper Spencer Gulf.

Elimination of hazards, if possible, is generally the highest level in the hierarchy of hazard control mechanisms. This important principle should be employed here given the high likelihood of damage to the unique marine ecosystem of Upper Spencer Gulf. In no case should the proposal be approved with the hope that further monitoring will provide a better picture of possible environmental impacts. It is so obvious that the risks of environmental damage in Upper Spencer Gulf are far higher than in other regions of the gulf or outside the gulf. Given the high priority of conservation of this fragile and unique marine environment, the proposed siting of an outfall in Upper Spencer Gulf must be declined. This should be of the highest priority for decision makers. For the same reasons, the proposal to operate a deep-water port in Upper Spencer Gulf should also be declined as this substantially increases the risks of pollution associated with increased ship traffic and potential environmental disasters (e.g. oil spills).

It should be pressed that scientists including Assoc. Prof. Kämpf have presented and discussed possible detrimental marine impacts of brine discharges in public on numerous occasions over the last two years. No compromise should be made in this matter on the basis of existing environmental legislation, independent scientific expert advice (such as that reported in this document) and common sense.

As part of internationally accepted scientific standards, BHP Billiton should be obliged to provide a detailed response to all comments and suggestions made in this document. This (written) response should also be forwarded to us as to verify whether we believe BHP Billiton’s response addresses all points made and to enable us with the opportunity to provide further scientific advice.

1. Site Choice: a Critical Factor

1.1. Recommendations by international experts

Lattemann & Höpner (2008) give a number of recommendations regarding the site selection of desalination brine outlets. Guidelines proposed by these authors, who are leading international experts in the field, are reproduced in the following.

> *When selecting a site for a desalination project, a large number of site-specific features must typically be considered depending on the specific operational aspects of the plant in question. In order to minimize the impacts of the project on the environment, it is generally recommendable to take at least the following biological and oceanographic site features into account.*
>
> a. *Ecosystems or habitats should be avoided, if they are unique within a region or worth protecting on a global scale, inhabited by protected, endangered or rare species, important in terms of their productivity or biodiversity, or if they play an important role as feeding or reproductive areas in the region.*
> b. *The site should furthermore provide sufficient capacity to dilute and disperse the salt concentrate and to dilute, disperse and degrade any residual chemicals. [...] In general, exposed rocky or sandy shorelines with strong currents and surf may be preferred over shallow, sheltered sites with little water exchange.*

In the following, we critically review the BHP Billiton proposal to judge as to whether this meets the above recommendations by Lattemann & Höpner.

1.2. Site selection by BHP Billiton

Although the Draft EIS generously states that 13 different sites in Spencer Gulf have been assessed for their suitability for brine discharges, an inspection of the locations reveals that most (10) of these locations are situated in close vicinity to each other near Point Lowly, and the other (3) sites include one near Port Augusta and two just south of Whyalla.

From the perspective of ecology and physical oceanography, all of these locations are found in Upper Spencer Gulf in a zone of slow flushing and, in fact, can essentially be classified as a single location, when ignoring slight variations of oceanic conditions that exist among these locations. BHP Billiton exclusively proposed Upper Spencer Gulf as discharge location, whereas other better flushed sites in lower Spencer Gulf (e.g. Cowell) or on the West Coast (e.g. Ceduna) have been largely ignored. To this end, the Draft EIS lacks of any alternative site options.

1.3. Ecology of Upper Spencer Gulf

The Draft EIS clearly acknowledges Upper Spencer Gulf as an ecologically significant and unique region. Given this, there is no need to repeat the ample references to various marine species that use Upper Spencer Gulf as breeding and nursery grounds including the Giant Australian Cuttlefish and Western King Prawns, to name a few. Obviously, BHP Billiton's site choice for the brine outlet (and the intake) in this region does not comply with the first recommendation by Lattemann & Höpner (2008).

Statements against this site selection can be even found in the Draft EIS. For instance, in Appendix O10.2 it is mentioned that Shepherd (1983) has suggested that the far northern section of the Spencer Gulf ecosystem is already under stress owing to the high salinity and temperature fluctuations, and it is explicitly stated that "additional stress, such as effluent discharges, may have more serious consequences than in less stressed environments further to the south". This is a clear call by an expert for an alternative site choice.

Despite the claim made in the Executive Summary of the Draft EIS that the toxic brine will never reach shallower water (<10 m), the brine discharge can have detrimental impacts on both shallow marine habitats via upwelling (see Section 4.2) and bottom-dwelling marine species via pooling of dense water in seafloor depressions and reduction of dissolved oxygen to critically low levels. Indeed, toxic discharges near the seafloor overlap with the habitat of bottom-dwelling organisms such as cuttlefish (hatchlings and adults), Spider Crabs, sponges, brown algae and prawns. The formation of brine underflows subject to oxygen depletion extending several kilometres poses a severe threat for these organisms. Occurrences of such underflows have been observed in Cockburn Sound (Okely et al., 2007). Section 6 gives more details.

Appendix O5.5 states that a recent survey in 2008 reports a substantial decline in the abundance of Australian Giant Cuttlefish. In Chapter 16.3.6 of the Main Report, it is suggested that this decline may partially reflect natural population variations, but this may also indicate a real decline. From inspections of sea surface temperature (SST) anomalies in the region over the period May-June 2008 from the CSIRO monitoring archive, it seems that there was a higher than normal SST in the region, of +0.5-1.2^{o}C for much of May until 10th of June of that year. This may be correlated to a late arrival or decreased abundances of cuttlefish at the time of the survey. It is also worth mentioning that previous studies of cuttlefish abundance included sites at the SANTOS jetty, whereas the 2008 survey did not include this location due to access reasons. This bias may have significantly skewed the abundance counts as the SANTOS Jetty is amongst a high density area of cuttlefish.

The uncertainty of natural variability of cuttlefish abundance make clear that a detailed understanding of the Upper Spencer Gulf ecology is required prior to any decision-making in favour of effluent discharges of possibly disastrous marine impacts on the fragile and unique ecosystem of this region.

1.4 Measures of Exchanges: Flushing Time & Water Age

Flushing time and water age are scientific concepts to determine the ability of a water body to disperse effluents. Flushing time is the time is takes for a region to exchange (most of) its water volume with water of a predefined source region. Usually, flushing time is defined on the basis of the e-folding timescale 1/e = 0.368 meaning that a region is considered flushed if 63.2% of its volume has been replaced by ambient water. For semi-enclosed seas, this concept can be used to derive three-dimensional flushing time distributions (e.g. Sadrinasab and Kämpf, 2004).

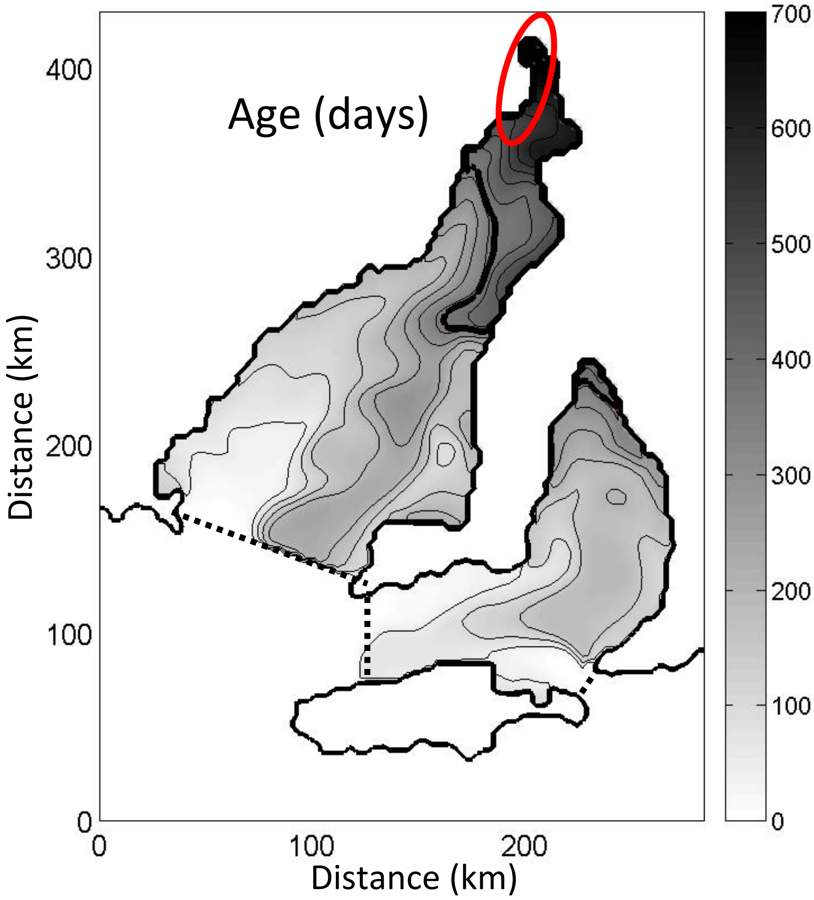

Figure 1: Simulated distribution of water age (days) for South Australian Gulfs. Thick lines highlight values of one year. Dotted lines are the assumed boundaries between gulf and shelf water used for the calculations. The ellipse indicates sites considered by BHP Billiton for brine discharge. From Kämpf et al. (2009).

The water-age concept is similar to the flushing- time concept. Here, the age of water (retention time) is predicted with reference to a region of zero age using a simple advection-diffusion equation with an additional aging term (Deleersnijder *et al.*, 2001). An equilibrium distribution of water age establishes in a semi-enclosed sea via a balance between ageing of a water volume and entrainment of younger ambient water.

This method is more robust than the flushing time method given that it is not based on an e-folding time scale. Sandery and Kämpf (2007) and Kämpf *et al.* (2009) derived age distributions for Bass Strait and South Australian gulfs, Spencer Gulf and Gulf St. Vincent, respectively.

Upper Spencer Gulf has a much longer flushing time (>1 year) compared with other parts of the gulf. This slow flushing supports a unique and rare marine habitat that must be protected from pollution including discharge of toxic desalination brine.

Water age and flushing time distributions can identify isolated regions of lower exchanges with ambient waters. A useful reference is to consider a stretch of an open-ocean region the same length as Spencer Gulf (~300 km). With a steady ocean current of 30 cm/s (a realistic value), this region becomes fully flushed within 11.5 days and the relative age of water found on the exit of this region is 11.5 days. In contrast to this, Spencer Gulf is a semi-enclosed gulf and longer exchange times are to be expected. Indeed, our recently published findings from hydrodynamic studies (Kämpf et al., 2009) reveal that the water age of Upper Spencer Gulf relative to that of ambient shelf water exceeds one year (Figure 1), which is substantially longer (>30 times) than the 11.5 days that we estimated for an equivalent stretch in the open ocean.

All outfall sites investigated by BHP Billiton are located in Upper Spencer Gulf in a zone of extremely slow flushing (see Figure 1). Given that this region also experiences dodge tides (particularly weak tidal flows at neap tides) and only little wave and wind mixing, the site selection conflicts with the second recommendation by Lattemann & Höpner (2008) (see Section 1). Disturbingly, hydrodynamic modellers for BHP Billiton derive a flushing time distribution (see Figure 3.80, Appendix O11.4) that is very similar to that shown in Figure 1. There can be only one conclusion drawn from these consistent findings: <u>Upper Spencer Gulf is the most unsuitable location for the proposed seawater desalination plant</u>.

2. Water Quality Policy

2.1. The mixing zone

The *Environment Protection (Water Quality) Policy 2003* (Water Quality Policy) has been introduced by the Environment Protection Authority (EPA) to provide a consistent approach to the protection of water quality across all South Australian waters. It encompasses marine, estuarine and inland waters (including underground and surface water), and replaces the *Environment Protection (Marine) Policy 1994* and certain other environment protection policies. The Water Quality Policy covers:

- water quality objectives (environmental values plus water quality criteria)
- management and control of point and diffuse sources of pollution
- obligations relating to particular activities
- water quality criteria, discharge limits and listed pollutants.

According to this policy, a *mixing zone* is an allocated area where water quality objectives for the receiving waters at the point of discharge may not be achievable. A number of requirements must be met before the EPA will endorse the allocation of a mixing zone. In particular, section 14 of this policy (version 25.6.2009) explicitly states:

(2) The following requirements apply in relation to a mixing zone:

(a) the establishment of the zone **must not—**

(i) **pose a significant risk to** aquaculture areas, potable water intakes or supplies or marine parks or **other areas of water with a high conservation value**; or

(ii) [...]

(b) **the zone must not be situated within waters that—**

(i) [...]

(ii) **have significant value as a spawning or nursery area for aquatic organisms**;

(c) in the case of marine waters (other than estuarine waters), **the zone must—**

(i) **have a radius not exceeding 100 metres**; and

(ii) [...]

(d) in the case of other surface waters, the zone must have a radius not exceeding 20 metres;

BHP Billiton states in its Executive Summary that the proposed brine outfall will not meet conditions of South Australia's Water Quality Policy. The proposal does not comply with existing legislation and, thus, should be rejected.

It should be noted that, technically, Spencer Gulf is classified as an inverse estuary, so strictly Clause 2 (d) should apply. Nevertheless, the following assumes a radius of 100 m as the permitted radius of the mixing zone in Upper Spencer Gulf, given that the Adelaide Desalination Project has used a similar definition (see EIS of this project). We suggest that the EPA be asked to clarify which part of legislation applies here.

Interestingly, the Draft EIS avoids the term *mixing zone* and, instead, introduces the term "*zone of ecological effect*". Essentially these terms are equivalent, but it should be highlighted that the Executive Summary (page 44) states:

> *There are several aquaculture leases in Upper Spencer Gulf. The closest is 5 km to the north of the proposed outfall. Even in periods of very low tidal movement when the zone of ecological effect covers the largest area, the closest boundary of the aquaculture leases would still be more than 2.5 km away.*

This statement implies a radius of the mixing zone of 2.5 km which clearly violates the Water Quality Policy. Hence, it is obvious that BHP Billiton implicitly asks the EPA for an exemption from this policy. This would be an allowance for enhanced marine pollution in the most ecologically valuable regions of South Australian Gulfs. Granting this request would undermine the central objective of the Water Quality Policy. The above statement by BHP Billiton is an admission that water quality standards will not be met with the proposed development. On the basis of this, any proposal that includes siting of an outfall in Upper Spencer Gulf should be rejected.

2.2. Target dilution & comparison with other developments

Dilution is the mixing ratio between effluent (brine) and ambient seawater. For instance, a dilution of 40:1 corresponds to 1 litre of effluent being mixed with 40 litres of ambient

The proposed discharge of brine in the Upper Spencer Gulf will cause substantially more marine pollution than any other Australian development.

seawater. In the case of desalination brine, dilution can be derived from salinity measurements near the outfall and is given by (e.g. Kämpf et al., 2009):

Dilution = Salinity excess of the brine / Measured salinity anomaly above ambient

Ecotoxicological tests are often used to derive a value of *safe dilution* at the edge of the mixing zone, whereby the mixing zone is usually based on a 100-m radius, in alignment with EPA's Water Quality Policy. Table 1 shows target dilutions for Australia's major desalination projects. It should be noted that the Victorian project started with a target dilution of 50:1 which, following ecotoxicity results, was lowered to 30:1. The Adelaide development was approved before completion of the ecotoxicological report and currently states a minimum dilution value of 50:1.

Using information stated in the Executive Summary (Page 44), the target dilution for the Point Lowly development can be estimated from the above formula with a salinity excess of approximately 40 g/kg and an expected salinity increase of up to 9% (equivalent to 0.09 times 40 = 3.6 g/kg) within 100 m distance from the outlet. Surprisingly, the resultant target dilution of 11:1 is much lower than for any other Australian development. This is remarkable given that Upper Spencer Gulf is the region of the slowest flushing. It should also be highlighted that this target dilution is much less than the safe dilution value of 45:1 (see Executive Summary). Hence, per se, the proposed brine discharge in Upper Spencer Gulf will severely affect marine species well beyond the usually accepted extent of the mixing zone and to a degree worse than for any other Australian development.

Table 1: Target and adjusted dilution values[b] for Australia's major desalination projects.

	Perth	Sydney	Cold Coast	Victoria	Port Stanvac	Point Lowly
Target dilution	**45:1**	**30:1**	**40-71:1**	**30:1**	**50:1**	**~11:1**
Adjusted dilution[a]	**20:1**	**-**	**-**	**-**	**-**	**-**

[a]Adjustment made on the basis of salinity measurements.
[b]Data sources: EES for Victorian Desalination Project, EIS for Adelaide Desalination Project, and BHP Billiton's Draft EIS.

According to the Draft EIS (Main Report, Vol. 1, pg. 505), dilutions of as low 10:1 (corresponding to a salinity increase of ~10% above ambient) can be justified with reference to "guidelines" by the World Health Organisation (2007). However, this guideline is a conservative estimate of the most extreme salinity increase that aquatic life can tolerate. The fact that the proposed outfall comes close to this limit is alarming and this even more knowing that the salinity tolerance of some marine species such as cuttlefish is much lower than this (Dupavillon and Gillanders, 2009).

It should also be pointed out that the dilution target is not necessary the final dilution requirement to be specified in the operator's licence. For instance, the dilution target has been lowered from 45:1 to 20:1 for the Perth desalination plant in Cockburn Sound following in-situ field observations of brine underflows of reduced oxygen content spreading over a distance of 1-2 km (Okely et al., 2007). See Section 6 for a more detailed discussion of the formation of brine underflows and their potentially harmful marine impacts.

3. Review of Hydrodynamic Studies

3.1 Salinity and current measurements

From the salinity calibration presented in Appendix O9.1of the Draft EIS it becomes obvious that most of the instruments used in the field surveys to derive salinity were unsuitable for the task. The YSI Model 650 MDS instrument used for all of the water quality profiling, as outlined in Appendix O11.2, has an accuracy of ±0.5% of the reading. Together with the temperature accuracy of ±0.15^{o}C, this gives to a maximum inaccuracy of ±0.4 g/kg in salinity values. This inaccuracy is scientifically unacceptable and the data presented are highly unreliable.

Similarly, the Greenspan Model CS304 used for moored measurements, as outlined in Appendix O11.2, has the same poor accuracy in conductivity and, thus, salinity. Appendix 09.1 states "some instruments are incapable of providing highly accurate outputs (e.g. portable refractometer)" whereas other "conductivity instruments may be near of beyond their upper limit of accurate measurement". This is unacceptable.

Most, if not all marine data loggers used in marine surveys undertaken for BHP Billiton to measure salinity were unsuitable and produced inaccurate and unreliable outputs.

High-accuracy instruments should have been used in the first instance. While scientists involved in the Draft EIS have used Assoc. Prof. Kaempf's research laboratory at Flinders University for the salinity calibrations, they easily could have borrowed state-of-the-art marine mooring and profiling equipment available at Flinders University for measurements of salinities at very high accuracy (±0.05 g/kg).

While the reliability of ship-based ADCP measurements (see Appendix O11.2) is highly questionable, the lack of measurements of near-bottom currents at the height of the brine discharge (1-2 m above the seafloor) is appalling. The only relevant information that we could find is ADCP data taken over a month and shown in Figure 4.5 in Appendix O11.2. Near-bottom values, however, can only be guessed visually from this graph. Knowledge of the speed of near-bottom currents is vital in order to determine the capable of the ambient flow to disperse brine underflows and to prevent their deoxygenation. There is some indication that BHP Billiton has acquired more field data in recent times. This data, particularly near-bottom current measurements, should be immediately released to the public.

3.2 Comment on far-field model predictions

There is some similarity between the far-field modelling results shown in Appendix O11.4 and findings recently published by Kämpf et al. (2009). Nevertheless, the retention times (water age) in the work done for BHP Billiton are somewhat shorter compared with values shown in Figure 1. This discrepancy is caused by a lack of adequate data for the ocean boundary (see Chapter 5.3.2 of Appendix O11.2). Since this boundary controls exchanges between the gulf with the ambient shelf water, the predictions of retention time and salinity distributions shown in the Draft EIS are questionable.

4. Additional Independent Hydrodynamic Studies

4.1. Findings of a recent publication

The numerical investigation of Kämpf et al. (2009) studied impacts of the virtual desalination plants of realistic discharges in South Australian Gulfs. Findings presented are of relevance to BHP Billiton's proposal and are therefore briefly summarised here.

The main scientific objectives of this work were to:

- Develop a hydrodynamic model that accurately simulates currents and variations of temperature and salinity in South Australian Gulfs.
- Calculate distributions of retention time (water age) for the gulfs.
- Implement virtual desal discharges and predict brine dispersal patterns both for the far field and the mid field.

Details of the calibration are given in Kämpf et al. (2009). In particular, it should be highlighted that this model accurately predicts the density-driven outflow occurring during winter (Figure 2) and establishment of a density front across the mouth of Spencer Gulf (Figure 3), in excellent agreement with observational evidence. Modelling undertaken for BHP Billiton does not capture this important exchange circulation which controls the salinity budget in the gulf.

Figure 1 already showed the distribution of water age predicted with the well calibrated hydrodynamic model. It should be mentioned for insiders that this prediction is more reliable than the predictions presented in the Draft EIS because the model domain includes portions of the ambient shelf and it is therefore capable of accurately simulating the exchange flow through the mouth of Spencer Gulf.

The mid-field studies in Kämpf et al. (2009) only include tidal forcing as the worst-case scenario. These predictions indicate dilutions of as low as 10:1 during neap/dodge tides (Figure 4). Predictions of salinity anomalies and dilution values at the discharge location are remarkably close to those concluded in the Executive Summary of the Draft EIS (page 44). Despite this agreement, these dilution values are critically low and pose a severe hazard for the marine ecosystem of this region.

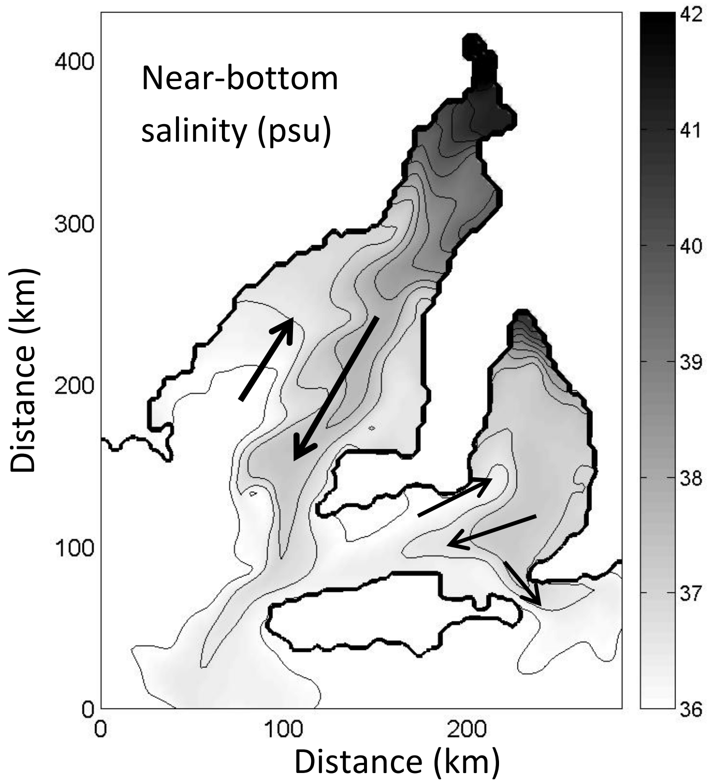

Figure 2: Far-field study. Simulated distribution of near-bottom salinity for austral winter. Arrows indicate flow directions. From Kämpf et al. (2009)

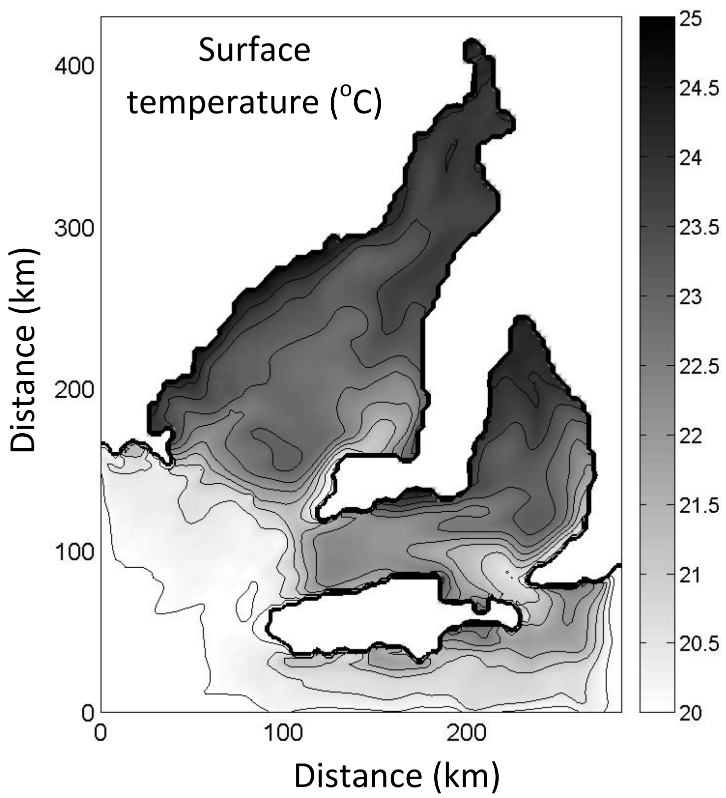

Figure 3: Far-field study. Simulated distribution of surface temperature (^{o}C) for austral summer. From Kämpf et al. (2009)

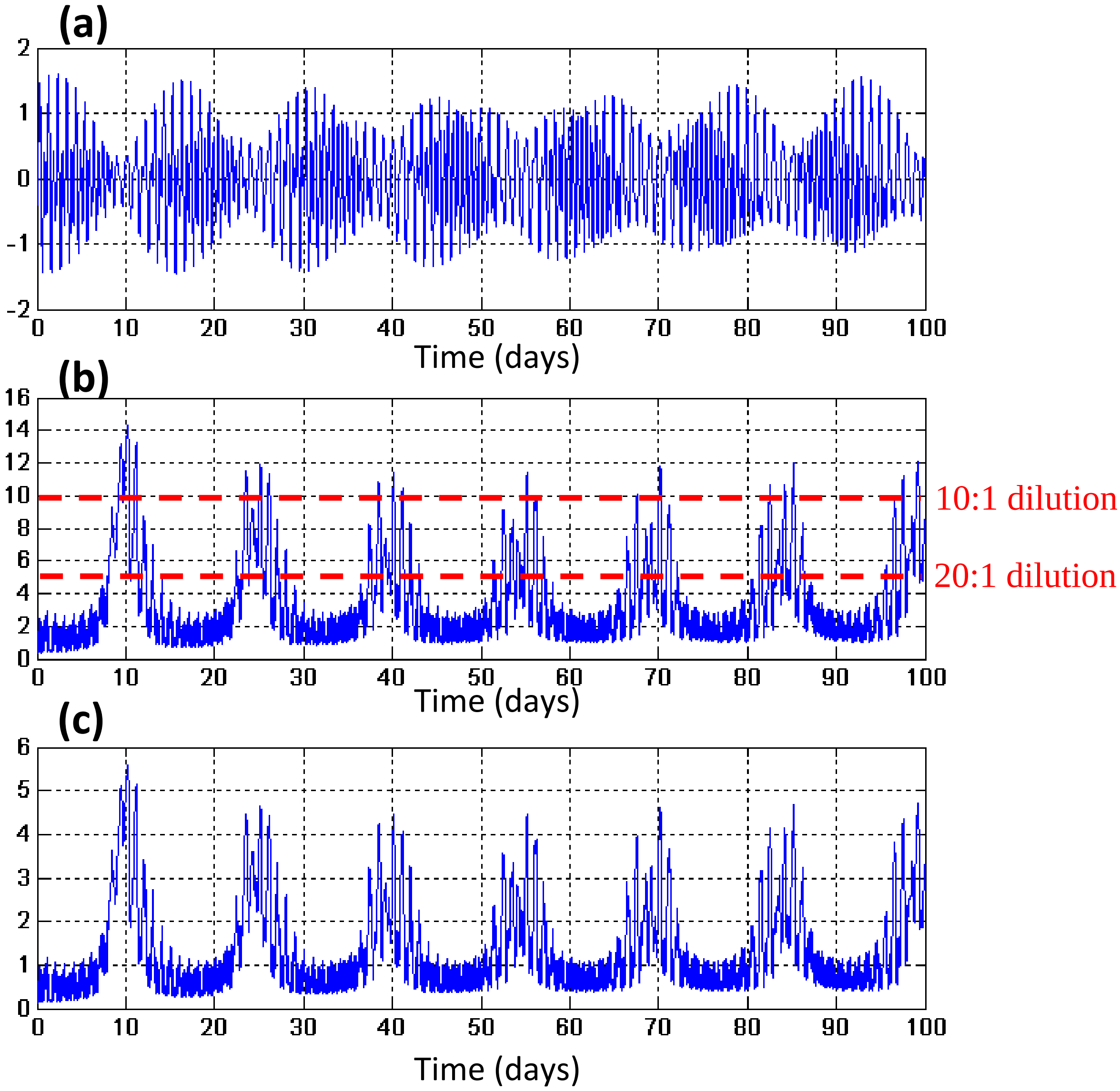

Figure 4: Mid-field study. Evolutions of a) sea level (m), b) concentration of discharge water (%), and c) salinity excess at the Point Lowly Gulf discharge site. From Kämpf et al. (2009). Red dashed lines in b) highlights the 10:1 and 20: 1 dilution values.

4.2. Can there be upwelling?

One of the key statements used in the Draft EIS to justify brine discharge in close vicinity of the cuttlefish aggregation is the claim that:

> *The return water from the desalination plant would not affect the Australian Giant Cuttlefish because the zone of ecological effect and the breeding habitat are well separated vertically and would NEVER overlap (Figure 23). This is because the higher salinity water is heavier than normal seawater and would therefore fall towards the seafloor. This natural process creates a vertical separation between the higher salinity return water and the cuttlefish breeding habitat, which extends from the surface to a depth of less than 10m.*

Authors of this statement, found on page 44 of the Executive Summary, have overlooked the process of upwelling brought about externally by the stress of seaward winds in shallow waters (so-called "Leewirkung") (Hela, 1976). This type of upwelling can be rather important in shallow coastal areas (Svannsson, 1975) and it has been observed in lake environments. Upwelling in a restricted water body, such as a lake or reservoir, results from a surface wind stress being balanced by a horizontal pressure gradient, causing denser water to rise at the upwind (lake) boundary (Monismith, 1985, 1986; Stevens & Imberger, 1996; Farrow & Stevens, 2003). Figure 5 illustrates this process.

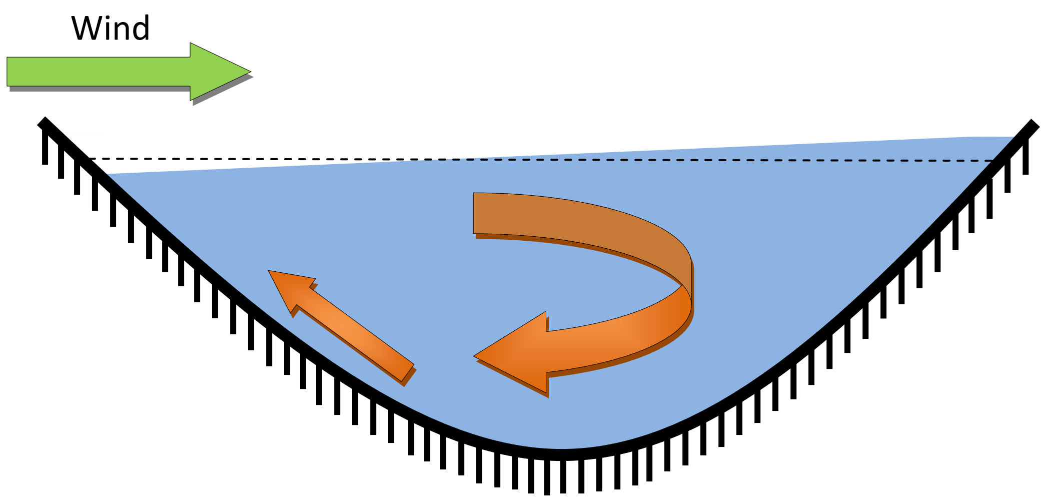

Figure 5: Illustration of the direct upwelling process in shallow waters.

Owing to its narrowness, Upper Spencer Gulf is a likely candidate to support such a direct wind-driven upwelling. Given that this upwelling may move toxic brine directly into the cuttlefish aggregation, marine consequences could be devastating.

To demonstrate this upwelling process for Upper Spencer Gulf, Assoc. Prof. Kaempf has applied the state-of-the-art hydrodynamic model Coherens (Luyten et al., 1999) to a 2-dimensional cross-section of Upper Spencer Gulf just south of Point Lowly. The model is run with sophisticated settings including TVD advection schemes and *k*-ε turbulence closure scheme. The terrain-following model uses 50 vertical levels with a very fine vertical grid spacing of 20 cm in the lowermost 5 m of the water column. The ambient water column is void of density stratification.

Brine concentrate is prescribed in water deeper than 16 m with a salinity anomaly that increases linearly to a bottom value of 2 g/kg. This corresponds to a dilution of 20:1 at 20 m water depth. The model is driven by westerly winds (blowing seaward at Point Lowly) of a speed of 15 m/s. The duration of the experiment is one day.

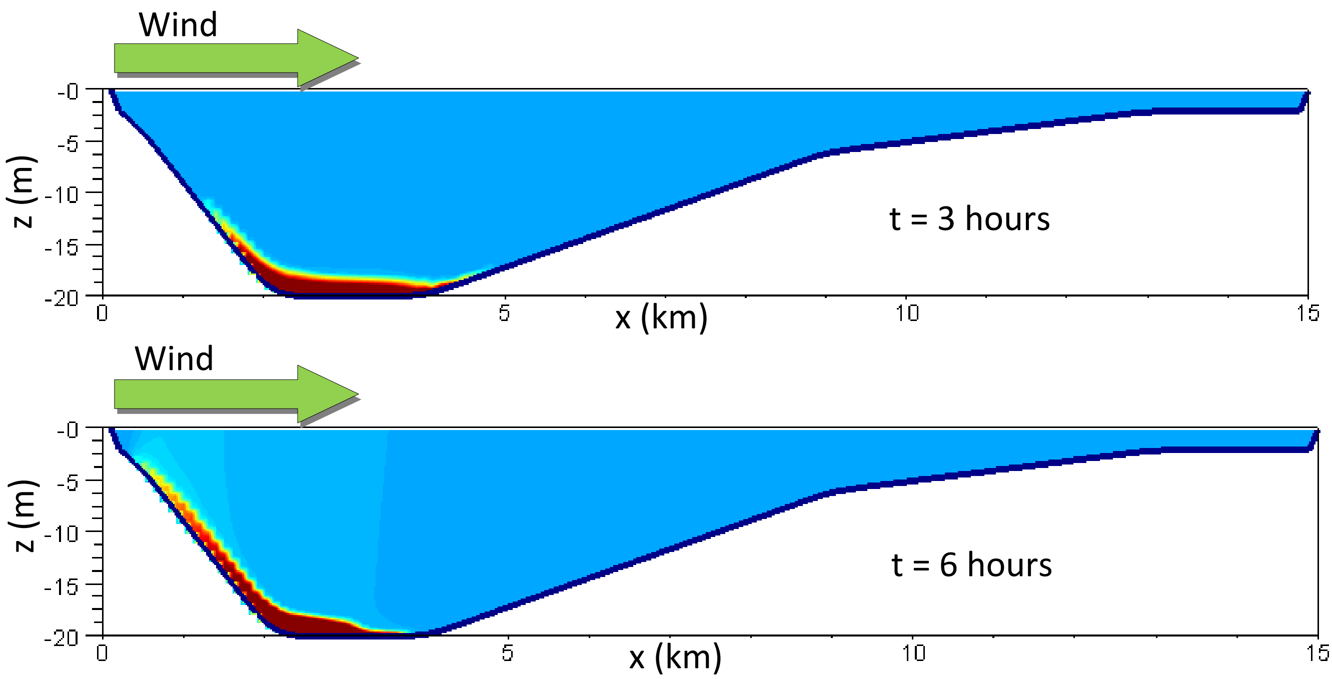

Figure 6: Simulation of direct wind-driven upwelling of toxic brine (red shading) into shallow waters. Red shading corresponds to salinity anomalies exceeding 1 g/kg.

Independent hydrodynamic studies reveal that toxic brine can upwell into shallower water within a few hours. This process, which is not addressed in the draft EIS, poses a severe threat to the cuttlefish breeding aggregation which is located in close vicinity of the proposed outfall.

The results (Figure 6) demonstrate that offshore winds at Point Lowly can trigger transient upwelling of toxic brine in a thin (~1m) bottom layer into the shallower cuttlefish aggregation sites and this on short time scales of only 6 hours. Salinity anomalies predicted for the model configuration used appear in shallower water (<10 m) with values in a range of 0.4 – 0.8 g/kg (Figure 7). This corresponds to dilutions between 100:1 and 50:1, with the lower value coming dangerously close to the safe dilution value of 45:1 stated in the Executive Summary. Numerical models are subject to artificial numerical diffusion (mixing). Therefore, it is likely that brine concentrations in the real situation exceed values predicted here.

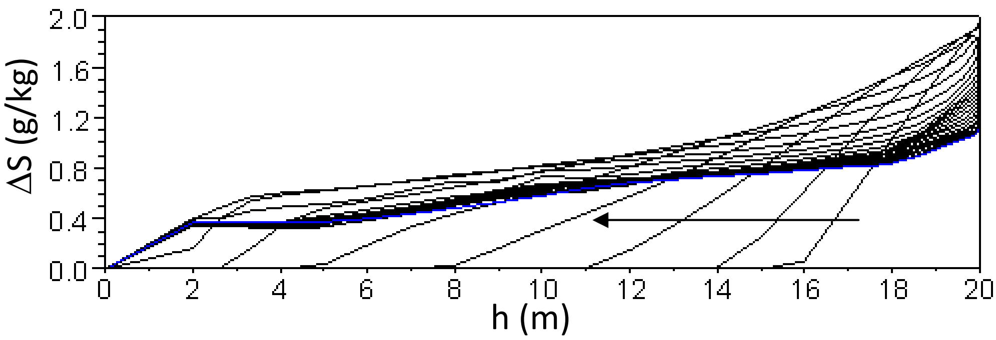

Figure 7: Salinity anomaly ΔS (above ambient) of near-bottom water plotted against local water depth (h).

This model application provides first evidence of the likelihood of upwelling of toxic brine into cuttlefish breeding aggregations in the Point Lowly region. This evidence contradicts BHP Billiton's claim that the mixing zone would never reach into water shallower than 10 metres. The possibility of such upwelling clearly demonstrated the inadequate choice of the outfall location.

5. Review of Ecotoxicological Methods

5.1. Choice of test species & tests employed

The initial choice of test species for the Draft EIS provided a representative sample of organisms across a selection of phyla, using the generic approach, as stated in Dr Warne's report (Appendix O10). At best, this provides an approximation of effects on species that are relevant to the immediate area, and at worst, may simply miss effects that are species specific.

The move to using endemic species (see again Dr Warne's report, Appendix O10) is a move that is likely to provide more relevant information, and if these tests are conducted on specific organisms that have important roles either in specific ecosystems, food chains, fisheries or other industries, then the information gained from these tests would provide a highly accurate picture of the impacts of the brine on the receiving waters.

Some of the selected endemic species fulfil one or more of these criteria (see Table 1 in Dr Warne's report). For example, the inclusion of Yellowtail Kingfish and Pacific Oysters provides information that is directly relevant to local industries, the inclusion of the macroalga *Hormosira bansksii* provides information relevant to the ecosystem, and the inclusion of *Sepia apama* provides extremely useful information for the tourism industry centred around this species.

In order for the choice of species to be used to their fullest extent, comparable tests are required on all of the selected species. This requires that all tested species have similar life stages compared, that they are tested for similar lengths of time, and that they are tested in conditions that best represent those which they may be expected to be exposed in the event of this development going ahead.

It is apparent from the data presented that none of these criteria have been fulfilled. The only organism tested extensively was the Giant cuttlefish, *S. apama*. For this species, several tests were done, covering embryo development, days to hatch, length, weight & width at hatch, length, weight & width post hatch and post-hatch survival. Even so, these tests only cover the early life stages of this organism. In order for this data to be truly comprehensive, data on adult growth, reproduction and immune status is required. For this species, data is clearly available that shows a dilution factor of 103 is required for a 99% level of protection. <u>This is well beyond the safe dilution value of 45:1 stated in the Executive Summary</u>.

Selected life stages of test species are not comparable as they are not done at the same stage, for the same duration, or in the same conditions.

In order for the choice of tests to provide accurate information useful to the assessment of risk to species from the discharge of brine, a suite of studies are required. As an example, the test of larval survival for Yellowtail Kingfish needs to be complemented by fertilisation success, hatch rates, juvenile and adult survival, growth and immune status, and adult reproductive impacts.

Without this additional information, the most that can be said from the data collected for the Draft EIS is that the brine will have an impact on the tested stage of the test organism, and no further conclusions can be made. More comprehensive testing is needed if the environmental impacts of this development are to be accurately assessed.

In fairness to the proponents, several of the test organisms are pelagic, and as such, they have the capacity to actively evade unfavourable conditions. This may be why the early life stages of the Giant cuttlefish were the only ones tested, but the adults are also likely to encounter the effluent in their movements towards their breeding grounds. It is possible that if this organism detects unfavourable conditions, then alternative breeding grounds may be sought, but this is not something that can be known with any degree of certainty before effluent discharge commences.

For other benthic species that do not have the ability to move, for example bivalve or gastropod molluscs, they will be subjected to the "*higher salinity water* (which) *is heavier than normal seawater and would therefore fall towards the seafloor"*, as correctly stated in the Draft EIS. Prawns are also partly dependent on the benthos, as they like to burrow into the sediment. This places them at higher risk of encountering the effluent stream when conditions for mixing are less favourable.

5.2. Acute and chronic toxicological studies

The studies conducted by Geotechnical Services are very well done. In comparison, the approach used Hydrobiology has a basic flaw, which is also noted in some of the comments within the Geotechnical Services reports. To understand this flaw, some background information is required.

Acute toxicity tests are used for one reason, and that is to determine a concentration which causes death to a certain proportion of a test population over a set period of time (Lethal Concentration, or LC), or alternatively, the period of time at which a certain proportion of the test population dies at a set concentration (Lethal Time, or LT).

These tests give a result in terms of mortality. In comparison, chronic tests give results in terms of effects that also cause death, over longer periods, but the deaths caused in chronic deaths often have very different underlying physiological factors contributing to death. In addition, chronic studies can be used to examine whole organisms' responses in terms of growth or performance.

Chronic studies provide useful information from an ecological point of view, as impacts on populations can then be modelled and used to generate measures of impact, such as Effective Concentration (EC), which estimate the level at which a certain proportion of a population is expected to demonstrate the modelled effect.

When the test organism in chronic exposure tests shows a response, in terms of, for example, growth, it is actually the gross manifestation of many physiological changes in the organism. When considering salinity as the toxicant, these changes can include cellular changes in the gills and kidneys as the organisms adapt to pumping more ions out of their bodies, which have secondary impacts as well.

Any organism has a set energy budget, which represents the partitioning of energy. Normally, a set amount is directed towards obtaining food, basic metabolic needs, growth, reproduction, and immunocompetence.

When an additional stressor is placed on an organism, this partitioning changes, which effectively diverts energy away from some of these processes into dealing with the new stressor. This is then observed on a gross level as decreased in growth, reproduction or the ability to fight disease. These processes are very different to those that produce short term death, which, if again using salinity as the example, may include cellular disruption and necrosis, or organ failure.

The use of correction factors to extrapolate long term effects from short term experiments is a fundamental flaw in the scientific process.

In the historical development of ecotoxicology and the use of such tests in environmental impact assessment, an arbitrary connection was made between acute and chronic tests, which did not recognise the basic differences in physiological and physical responses to acute and chronic toxicant exposure. This connection was developed into an 'application factor' or 'correction factor', which was a method developed to extrapolate chronic effects from acute studies.

Acute studies are relatively quick to perform, so any way of connecting the two types of studies to generate twice the data had advantages. Although this approach saw its use become widespread for many years, the flaws in this approach have long been recognised.

The reports by Geotechnical Services clearly state that, "The use of sub-lethal testing is recommended to remove the correction factors that are required when using LC data." In comparison, the report by Hydrobiology states that *"Safe" dilutions of the discharge were determined by combining acute data (after application of an acute to chronic ratio) and chronic data in a species sensitivity distribution.*

It is the opinion of the authors of this review that any data treated in this way is erroneous, as it does not provide accurate information on which to base further estimates for sensitivity, impacts or suitability of a particular environment for the receiving of brine effluent.

5.3. Relevance of test concentrations

The issue of the acclimation period is raised by Dr Warne in his report (Appendix O10). This is a crucial factor when setting up toxicology studies. Unless this period (of at least several days) is respected, then it cannot be confidently said that the results of the toxicology studies are due to the tested factors alone.

It is not clear from the consultants' reports how long any acclimation period actually was. In addition, it is not clear how the organisms were exposed to the test concentrations when the experiments started. When starting exposure, there are several factors to consider. First of all is whether a rapid, or instantaneous, change from the acclimation conditions to the test conditions will cause additional effects that might otherwise be dealt with by the test organism if conditions changed more slowly. Secondly is whether the test organisms are likely to actually be exposed to dramatic changes in their environment, as represented by a dramatic change from acclimation conditions to test conditions. This is the issue of environmental relevance, and is very important to designing studies that actually represent real world conditions. Designing studies to match how exposure will occur in real situations may also have drawbacks in that the starting point of exposure may become obscured. Whichever choice was made for the tests detailed in Appendix O10 is difficult to assess, as this information is not included.

All of the toxicology tests presented in Appendix O10 were done as static, or static with renewal tests. This involves the exposure of test organisms to the test water for a set period, after which all or part of it is replaced. During this time, metabolites from the test organisms can accumulate up to the point of water exchange, when conditions are returned back to start values.

Water quality factors such as ammonia, carbon dioxide and subsequently pH, can all deviate from those at the beginning of the test, and unless measured at both the point of water introduction and the point before water is exchanged, cannot be accurately assessed as either being confounding factors or as having no influence on the experiment.

Although these static tests are accepted as performing well enough for toxicological tests, without actually having additional water quality measurements over the water exchange cycle there is doubt as to whether the observed effects are solely due to the toxicant of interest. The best approach is to have a continuous replacement of the water in a flow through system, so that no build up of metabolites can occur, and so that no further confounding effects due to the act of replacing the water (stress on the test organisms) can occur.

To further pursue this point, CSIRO data presented on page 69 of Appendix O10 show pH values of 7.4-7.7 for test solutions. These are values never likely to be encountered in marine conditions, unless significant effluent from acid-sulphate soils or acid mine leachate is present. The reporting of dissolved oxygen (DO) as mg/L is also not as useful as it could be, as the most useful units for describing the physical availability of DO to aquatic organisms is in terms of % saturation.

5.4. Choice of recommendations for toxicology estimates

There is an excellent discussion of the procedures for selecting the recommended toxicological estimates contained in Geotechnical Services' report in Appendix O10. The procedure recommended when there are several different endpoints is to use the endpoint with the lowest geometric mean. This should be extended to the suite of studied species, so that the species most intolerant of the tested conditions be considered as the one for which the dilution levels be aimed.

If the information presented in the Draft EIS is the only information available, then the most sensitive life history aspect of the most sensitive species should be the value from which dilution estimates need to be generated. This is the value for post-hatch survival of the Giant cuttlefish, which requires a minimum dilution level of 103. This is well beyond that advocated in the Executive Summary, where levels of either 45 for a 99% protection level, or a level of 85 for a 100% protection level are recommended.

5.5. Impact of toxicological estimates

The implications of both the toxicological estimations and the dilution modelling data can be extended to provide economic impact estimations. The Upper Spencer Gulf has industries that produce aquaculture Yellowtail Kingfish, fisheries that produce prawns, abalone, Blue Swimmer crabs, rock lobsters and sardines, and a tourism centred around the Giant cuttlefish.

If the less conservative PC99 value is used, then a 3% reduction in post-hatch survival of the Giant cuttlefish would produce a minimal reduction in the numbers of the animals. However, if Assoc. Prof. Kaempf's estimations of peak dilution values are correct, then exposure to dilutions as low as 10:1 would produce significant impacts on all economic species, even if this exposure is only for a short period.

The most recent values for Western King Prawn production from the Spencer Gulf and West Coast is $34 million for 2005/2006 (EconSearch 2007). Assuming that a proportion of the fishery is directly caught from stock spawned in the Upper Spencer Gulf (eg 40%), then a reduction of productivity by 10% (Using EC10 values) would produce a direct $1.36 million shortfall.

Aquaculture production of Yellowtail Kingfish is currently at approximately 2 500 tonnes, and is predicted to reach 10 000 tonnes by 2010 (FRDC 2008). Much of the production of this species is within Spencer Gulf. Although the toxicological estimates for Yellowtail kingfish provide an EC10 at 11% brine dilution, the potential for the uneven spread of the discharged brine brings additional risks to the culture of this species. Whereas wild fish will have the capacity to evade brine discharge, any effluent not diluted to a sufficient level during conditions of adverse wind direction and/or dodge tides will cause problems for the cultured Yellowtail kingfish which are confined within net pens.

6. Other Important Aspects

6.1. Formation of brine underflows

The Draft EIS clearly underestimates the severe risk of the formation of brine underflows in which toxic brine covers vast areas of the seafloor becoming subject to oxygen depletion. Probably the best example of such underflows is observational evidence in vicinity of the desalination outfall in Cockburn Sound, Western Australia by Okely et al. (2007) (Figure 8).

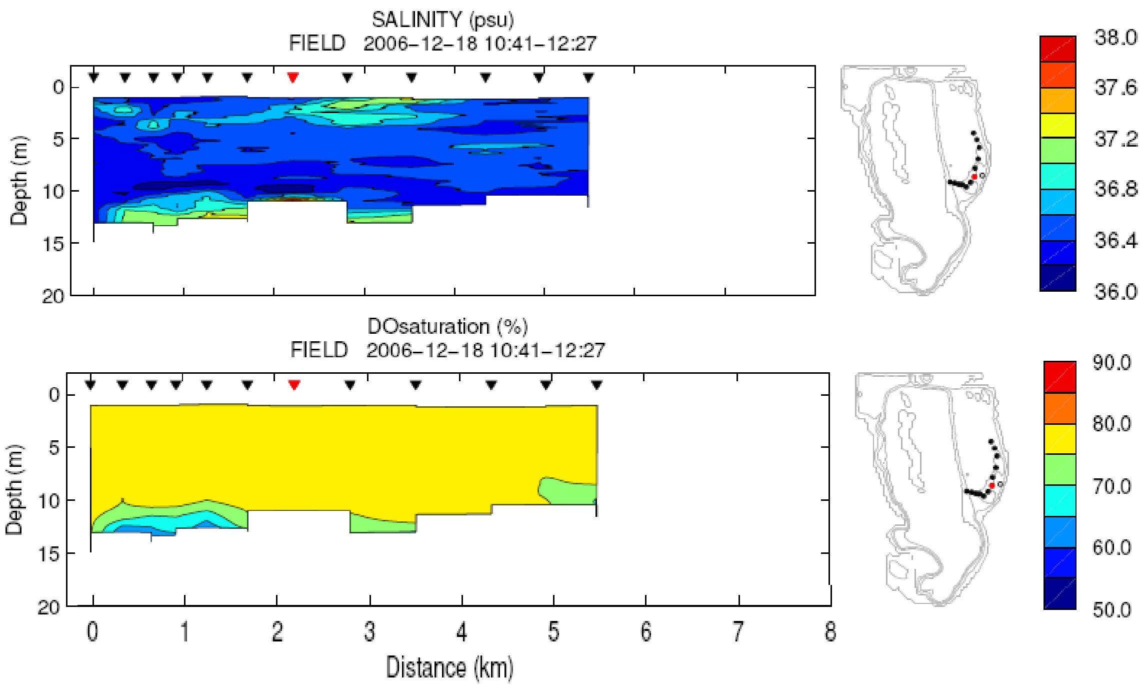

Figure 8: Transects of salinity and dissolved oxygen saturation along a transect in Cockburn Sound. From Okely et al. (2007).

These measurements reveal the existence of a brine underflow of decreased dissolved oxygen saturation to 60%. The salinity data correspond to relatively low dilution values of 24:1 in the brine underflow spreading over a distance of 2 km from the outfall. These measurements were the reason for a lowering of the dilution target of initially 45:1 to 20:1. Such modifications of license conditions are certainly not in favour of conservation of marine resources of this region, knowing that Cockburn Sound had already suffered from a severe loss of most of its seagrass meadows in the past (Lemmens *et al.*, 1996).

Observations in Cockburn Sound, Western Australia, revealed the formation of brine underflows of dangerously low dissolved oxygen levels which is the reason why the Perth desalination plant had to be shut off twice in 2008.

It is also interesting to note that operators of the Perth desalination plant have been seeking for more than a year to have the set of dissolved oxygen trigger levels (set to a bottom level of 60%), which caused the plant to be shut down twice in the early months of 2008, removed as a condition of the plant being closed. Fortunately, this request, which would remove one of the environmentally most relevant conditions from the operational licence, has not been granted so far. From the viewpoint of marine conservation and given previous observational evidence of brine underflows, the Perth desalination plant can certainly not be classified as cutting-edge technology, and South Australia should avoid making similar mistakes.

6.2. Dissolved oxygen depletion

Given the existence of calm periods during neap/dodge tides and the severe risk of formation of brine underflows, too little research presented in the Draft EIS has focussed on this risk and consequences for the marine environment.

Although suitable numerical tools are available at the Centre for Water Research in Western Australia, modelling of dissolved oxygen was not attempted here. The dissolved oxygen issue is discussed in Section 16.6.9 of the Main Report (pages 535-536). Here we can read that:

> *The risk of significant deoxygenation occurring during fortnightly two-day periods of low water movement (when stratification might occur) is minimal because the sediment oxygen demand is too low. Assuming that the sediment oxygen demand off Point Lowly is 0.33-0.82 g/m^2/d (Lauer, 2005), and the ambient dissolved oxygen level is 5.5 g/L (the lowest level in the return water), it would take 6-15 days to draw the dissolved oxygen level (in the bottom 2 m layer of water) down to a threshold of 3 mg/L below which ecological effects could occur (Diaz and Rosenberg, 1995).*

This statement is not convincing given the clear lack of in-situ observations of near-bottom flows (which could be too weak to destroy brine-related stratification on periods longer than 2 days), existence of “shallow regions” in which tidal flows are markedly reduced (see tidal animation available at BHP Billiton Olympic Dam Expansion Website), and observational

The occurrence of a single event of dissolved oxygen depletion in Upper Spencer Gulf can lead to widespread and severe damage to the fragile marine ecosystem of this region.

evidence of low dissolved oxygen levels caused by brine discharge in Cockburn Sound. To this end, the Draft EIS does not compellingly convince the authors that deoxygenated brine underflows cannot exist in Upper Spencer Gulf.

This statement also ignores the physiological importance of dissolved oxygen levels. Oxygen is required at a sufficient level of availability (saturation) for maximal metabolic function. Any reduction in oxygen availability below a level of critical oxygen dependence (Pc) reduces the capacity for aerobic metabolism (Fry 1971). For many fish species, this level lies close to 80% of saturation, whereas some species have demonstrated a very high Pc level (eg Greenlip abalone at 96% and 77% of saturation for EC5 and EC50, respectively (Harris et al. 1999).

Several species of prawns have been assessed for their Pc values, and these have the potential to be affected by the plume from the brine, as their Pc values are 2-5 mg/L for similar species (Seidman & Lawrence 1985; Liao & Chien 1994; Rosas et al. 1999). No data are available for the Western King prawn. Ecological effects will be occurring well above the threshold level of 3mg/L stated in Section 16.6.9 of the Main Report (pages 535-536), which represents 40% of saturation at 18°C.

6.3 Risks involved with operation of a landing facility

Operation of a landing facility in Upper Spencer Gulf implies increased risks of marine pollution associated with construction, increased ship traffic and potential oil spills, which can cause dramatic environmental disasters. Given the high ecological significance of Upper Spencer Gulf, BHP Billiton's proposals to build a landing facility in this fragile environment should be declined.

7. Possible Impacts on Fisheries

The section BHP Billiton's Draft EIS on commercial fisheries in the area (Main Report, Vol. 1, pg. 497) is too brief. In fact, it only consists of 3 paragraphs and refers to Appendix O6, which in itself is very brief, totalling 6 pages of which only 2.5 pages are of relevant text material. Some relevant information, however, is clearly stated in the documents, briefly replicated in the following.

Deepwater channels, <29m deep, south of Point Lowly are the most extensive marine habitat in Upper Spencer Gulf. These areas are dominated by filter feeders such as Razorfish, Soft Corals, Stalked Ascidians and Sea Pens. This habitat also supports *detritivores* such as Western King Prawns which has an annual harvest of 2000t, worth $40M.

Western King Prawns feed on polychaetes, foraminifera, micro-molluscs and micro-crustaceans that live in the deep waters off Pt. Lowly (PIRSA, 2003, pp. 22-23). Western King Prawns spawn twice a year around November and March in deeper waters between 15-50m in Spencer Gulf. Similar to the Australian Giant Cuttlefish, this species a relatively short lived animal of only 3-4yrs (PIRSA, 2003, pp. 22-23), which makes its survival sensitive to extensive marine pollution. Clearly, this species would be potentially affected by increasing salinities in the "zone of ecological impact" and even more drastically in case of the occurrence of a deoxygenated brine underflow.

The proposed outfall location overlaps with existing fishing zones of Western King Prawns, Blue Crabs and Marine Scalefish (see Figure 16.9, Main Report, Vol. 1), noting that even short-lived anoxic events can cause the mass mortality of fish and benthic organisms. The associated high risk of such environmental disasters for the Upper Spencer Gulf fishery industries is undeniable. Risks could be substantially lowered by choice of a different outfall location.

8. General Monitoring Requirements

In the unlikely case that constructions of the seawater desalination plant and a landing facility in Upper Spencer Gulf be approved by the authorities, adequate, strict and transparent monitoring requirements have to be put in place. Important conditions for the monitoring program should be:

- free site access for independent scientists to conduct measurements in close vicinity of the outfall (and the intake)
- regular (at least every neap tide) measurements of important parameters (salinity, dissolved oxygen levels, etc.) within a reasonable distance from the outfall
- public release (preferably via the Internet) of all data acquired
- use of adequate and state-of-the-art marine instruments
- regular ecologic field surveys

We are convinced that there is more than enough striking evidence that justifies decline of the proposal for Upper Spencer Gulf in full, but we propose the above general monitoring requirements as a template for other developments.

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