APPENDIX 1 – BITTERNS RESOURCE RECOVERY STRATEGY

1 Introduction

Straits Salt Pty Ltd (Straits) is proposing to construct and operate a nominal 10 million tonne per annum (Mtpa) solar saltfield on the eastern margin of the Exmouth Gulf in Western Australia. The Yannarie Solar project will meet the rapidly growing demand for salt from the Asia-Pacific region.

Conventional solar salt production involves natural evaporative processes to crystallize sodium chloride salt from seawater and does not involve any chemical processing or hazardous chemicals. The current practice in Western Australia is to discharge the concentrated seawater residue (called bitterns) after the initial process of removing about 75% of the sodium chloride salt.

The Yannarie Solar project will be significantly different from conventional salt production through a commitment to maximize resource recovery of the remaining salts and other naturally occurring compounds in the bitterns resource. An initial feasibility study by the CSIRO on the technical capacity for bitterns reuse and the potential value of bitterns products has identified significant long term opportunities with both economic and environmental benefits.

In order to maximize the potential benefits from the bitterns resource, the proponent is not seeking approval to discharge any bitterns and has instead embarked on a programme of cleaner production to simultaneously address environmental and economic objectives.

Within ten years from commissioning of the project, final assessment of the technical and market options of reusing all of the bitterns resource will be completed. Any new value adding processes will then be referred to the Environmental Protection Authority (EPA) for assessment. A separate referral to the EPA would also be made for the disposal of any bitterns residue not able to be practicably reused or contained.

The proponent is not seeking approval to discharge bitterns, but the work that has been done on three scenarios involving the discharge of pre-diluted bitterns are provided in this report. These scenarios each involve a new level of best practice for bitterns discharge in Western Australia and will provide a baseline impact against which further improvements in bitterns management can be measured.

The proponent will also undertake a contingency research program of continuous improvement for bitterns discharge, in consultation with the Department of Environment and Conservation (DEC). This programme will include investigation of different dispersion and dilution models as well as direct toxicity assessment to provide scientific rigour to any potential impacts.

The proponent has committed to undertaking a major environmental review of the project, to the satisfaction of the Minister for the Environment on advice from the EPA, prior to any commencement of stage 3 of the development. The results of the final assessment of bitterns reuse options as well as the contingency research into bitterns discharge will be included in this review.

1.1 Cleaner production and sustainability

Australia has recognised that resource efficiency and cleaner production are integral components of sustainable development. A strategy to increase adoption of cleaner production in Australia was developed in 1998 (ANZECC 1998).

The ANZECC 1998 strategy adopts the United Nations Environment Programme (UNEP) definition of cleaner production (UNEP 1994); “Cleaner production is the continuous application of an integrated preventative environmental strategy to increase eco-efficiency and reduce risks to humans and the environment. It can be applied to processes, products and services.

- For processes, Cleaner production includes conserving raw materials and energy, eliminating the use of toxic raw materials and reducing the quantity and toxicity of all emissions and wastes.”

The Yannarie Solar project is the first solar salt proposal in Western Australia that has been designed specifically to accommodate cleaner production and resource efficiency through the recovery of various residual salts and other value added compounds from bitterns. Recovery of resource values from bitterns will provide a number of significant economic and environmental benefits locally and regionally.

1.2 Existing Bitterns Management elsewhere in Western Australia

Currently in Western Australia solar salt production based on seawater evaporation involves discharging undiluted bitterns into tidal creeks and channels where passive mixing takes place before final discharge into the ocean.

In the case of the saltworks at Onslow, the undiluted bitterns is discharged into a tidal channel (SSJV pers comm. 2006) that flows into a coastal area designated as the Ashburton Nursery within the Onslow Prawn Managed Fishery (DoF State of the Fisheries Report 2001/2002).

The Department of Fisheries have recorded prawn yields from Onslow within the acceptable catch range from 2001 when salt export commenced (SSJV pers comm. 2006) to 2003 (limit of data available on website). (Department of Fisheries State of the Fisheries Report 2003/04). The prawn yield in 2003 was 193 tonnes which at that time was the highest catch on record, dominated by tiger prawns. The high tiger prawn abundance was thought to reflect very favourable environmental conditions (Department of Fisheries 2004).

At Dampier the saltworks discharges bitterns into Nickol Bay via a tidal channel. This channel discharges the bitterns into an excised area within the indicative boundary of the proposed Dampier Archipelago Marine Park. The discharge area is about 5kms from the proposed Nickol Bay Reef Flats special purpose (intertidal reef protection) zone. (CALM 2005). There is no evidence to indicate that the benthic habitat values have been significantly compromised by previous discharge of bitterns and consequently are still considered worthy of Special Purpose protection within the indicative Marine Park.

The receiving environment for the bitterns discharge in Nickol Bay is designated as the Nickol Bay Nursery within the Nickol Bay Prawn Managed Fishery (Department of Fisheries State of the Fisheries Report 2003/04).

The Nickol Bay prawn fishery operates predominately by specifically targeting schools of banana prawns. In 2003, only 5% of the total Nickol Bay prawn nursery was fished. However, the catch of banana prawns (165tonnes) was significantly higher than the projected catch range of 40 – 80t, but within the acceptable catch range of 40 – 220t. (DoF 2004).

The salt operation at Port Hedland discharges bitterns into the ocean via two tidal creeks (6 Mile Creek and Paradise Creek) at three locations (DoE 2004. Licence Number 7183/8).

2. Bitterns Resource Recovery Strategy

2.1 Potential resource recovery from bitterns

Australia has yet to take full advantage of the significant economic opportunities from processing salt field bitterns. Existing salt producers in Western Australia normally discharge their undiluted bitterns back into the sea after harvesting only some of the potential sodium chloride salt.

Only SunSalt in Victoria produces a by-product of saline waters, being Epsom salt (magnesium sulphate heptahydrate) (CSIRO 2004).

In the United States, Israel, China, India, France, Ireland, Jordan, Korea, Mexico, Netherlands, Ukraine and Chile there are significant value adding industries associated with bitterns and other concentrated brines. Russia, Italy and Japan also recover bromine from sea water. (CSIRO 2004).

In 2004, CSIRO was commissioned to prepare a preliminary assessment of the technical and market options for resource recovery from bitterns. The objective was to identify potential commercial products that could be extracted from the bitterns. In particular the focus of the study was on the economic potential of high volume, high value products that could be extracted, particularly magnesium oxide.

Production of magnesium hydroxide and magnesium oxide from seawater and other brines has been undertaken around the world for decades and seawater is a universally preferred raw material due to its lower impurity levels compared to natural magnesite.

Magnesium oxide can be produced by thermal processing using rotary kilns or fluidized beds heated to 700°C. At these temperatures the bitterns decomposes to produce magnesium chloride ($MgCl$) and hydrogen chloride (HCl) gas. The impure $MgCl$ can then be washed to remove the water soluble impurities and the wash water evaporated in solar ponds to precipitate magnesium sulphate and potassium salts. These products can be further purified by dissolution and fractional crystallization.

The economics of thermal bittern processing will depend on a range of factors, including product integration and market opportunities for the HCl by-product. In order to increase the market potential for HCl, consideration would be given to concentrating the acid to about 36% w/w.

Hydrochloric acid has a range of potential markets and value adding opportunities, including production of high purity magnesium compounds for niche markets. This could be achieved by reacting impure magnesia with HCl from which magnesium hydroxide can be precipitated using ammonia. Ammonia is available from the Burrup Peninsula.

Hydrochloric acid is also a useful alternative to sulphuric acid for treatment of phosphate rock in the fertisliser industry. Phosphate deposits in the region include those at Mt Weld, Christmas Island and Murin Murin and low cost HCl might make some of the marginal phosphate operations economical.

Existing technologies can also be adopted to convert chlorine and hydrogen from any excess HCl. Chlorine can then be used as a commercially practiced method to extract bromine. Alternatively, chlorine may be used to make vinyl chloride monomer (VCM). This raw material for the plastics industry is currently imported from Persian Gulf countries.

In assessing the opportunities for individual bitterns products, consideration will also be given to the various combinations of integrated operations which could focus on a related range of products. Consequently, integrated magnesium oxide, potash and bromine production, as is commercially undertaken in Israel for example, would be investigated.

Additionally there is potential for Straits to integrate its operations to produce cross chemicals and fertilisers such as potassium nitrate, magnesium nitrate, ammonium magnesium phosphate and others. As part of the bitterns resource recovery assessments, integration with neighbouring industries will also be considered.

As an alternative to thermal processing, magnesia can also be produced by wet processing using lime to precipitate magnesium hydroxide from the bitterns.

Bitterns processing profitability is expected to be significantly improved by aiming to produce products for niche markets such as flame-retardant grade magnesium hydroxide, pure feedstock for production of magnesium hydroxide slurry and magnesium metal markets.

In summary, the CSIRO study identified a range of products and product combinations that can be marketed domestically and around the world, with opportunities such as:

1. Supply of potassium sulphate, potassium chloride and magnesium sulphate to fertilizer producers. Currently there is no potassium salt production in Australia, although this product is imported for agricultural and chemical industries.
2. Supply of magnesium oxide to refractory brick producers and cement industries.
3. Supply of flame-retardant grade magnesium hydroxide. Magnesium based flame retardant is used to replace halogenated and brominated flame retardants used in products such as electrical cables and computer casings. This ‘environmentally friendly’ flame retardant is a growing niche market with potential to encourage cleaner production across a range of industries.
4. Supply of feedstock to magnesium metal producers.
5. Supply of bromine salts. Currently no bromine salts are produced in Australia.
6. Supply of hydrochloric acid (a by-product of magnesium oxide production) to e.g fertilizer manufacturers, plastic producers, nickel ore processors.
7. Supply of chlorine and chlorine value added products such as vinyl chloride monomer

The Yannarie Solar project provides a significant opportunity for Western Australia to develop new industrial capacity, new markets and environmental best practice through a strong focus on cleaner production and eco-efficiency. The proximity of the project to gas supplies, Burrup industries, the Asian markets and the economies of scale which the Yannarie Solar proposal can harness, all provide a unique set of synergies for potential future value adding industries.

2.2 Resource Recovery process

The bitterns resource will be collected, concentrated and managed as an integral part of the salt production business for the Yannarie Solar project.

In the first stage of bitterns production, seawater will be pumped through a series of shallow ponds where solar evaporation concentrates the dissolved salts. In the final stage of this concentration, the brine becomes saturated with salt (sodium chloride) and is transferred to a series of smaller ponds where the salt crystallizes out of solution. The residual brine (called bitterns A), is continually discharged from the crystallisers at a specific gravity (SG) of 1.25 gm/ml resulting in 75% of the sodium chloride in the seawater being crystallized and harvested.

It is expected to take about 18 months after the start of construction of the Stage 1 Southfield that the first volume of bitterns A will need to be discharged from the Stage 1 crystalliser ponds. The salt crystallised in the ponds during this period will form part of the permanent pavement required to support the heavy harvesting equipment. The completion of the salt pavement build-up is expected to take about six months. Harvesting usually commences within six months of the completion of all pavement salt build-up and is therefore projected to occur between 24 – 30 months from the start of construction.

Construction of the Stage 2 Southfield crystallizer ponds will be undertaken progressively and completed in time to accept the bitterns A which will be discharged from the Stage 1 crystalliser ponds.

Salt pavement build-up will then commence in the Stage 2 crystalliser ponds using the salts precipitated between the densities of 1.25gm/ml (bitterns A feedstock) and 1.30gm/ml. Once the bitterns density of 1.30mg/ml is reached it is no longer suitable for pavement salt build-up. Of the 25% of sodium chloride remaining in the bitterns A at 1.25gm/ml density, a further 18% will have been precipitated by the time the density reaches 1.30 gm/ml.

Pavement build-up in Stage 2 crystalliser ponds will commence two years after the start of construction of Stage 1 and 18 months before the first salt is exported. As the volume of bitterns A now being used for pavement build-up is less than that used in the Stage 1 crystallisers, coupled with the higher density, the rate of pavement build-up will be slower. It has been assumed that commissioning of the Stage 2 Southfield will commence about 5 years after pavement build-up in the Stage 2 crystallisers commences.

Once the pavement salt build-up in the Stage 2 crystalliser ponds has been completed the bitterns A resource will then be transferred to additional crystalliser ponds for recovery of the residual sodium chloride available between densities of 1.25 and 1.30.

Once the bitterns reaches a density of 1.30mg/ml the residual sodium chloride salt is now accompanied by increasing percentages of other ions present in seawater, particularly potassium, magnesium and associated sulphate. At this point the remaining bitterns (bitterns B) is transferred to additional crystalliser ponds for further processing.

Between the densities of 1.30 and 1.35 g/ml, complex salts (principally potassium) now precipitate out of solution. The nature of these complex salts changes substantially over the range of weather conditions experienced at saltfields around the world. Research at saltfields where conditions are similar to those expected at the Yannarie Solar project indicate that economic recovery of these potassium salts is anticipated when Stage 1 of the project is fully operational. Site specific research work will be required to confirm the technical and market options for this stage of the bitterns resource recovery.

The ponds used to concentrate the bitterns B from 1.30 to 1.35g/ml density will comprise two series. The first set of ponds will focus on those salts precipitated while the bitterns is close to 1.30g/ml density. The second series will focus on the salts precipitated as the bitterns resource approaches 1.35g/ml density.

Once the bitterns has reached a density of 1.35g/ml it is transferred to a final pond for further processing. This bitterns product (called bitterns C) has a very distinctive magnesium chloride composition. At this stage the bitterns C has a volume of only about 20% of the volume of the bitterns A.

Recovery of the magnesium values that remain in the bitterns C will result in full resource recovery, but this requires further evaluation of the various technical and market opportunities available.

Any new value adding processes arising from the final assessment of bitterns resource recovery will be referred to the EPA for consideration under Part IV of the Environmental Protection Act 1986.

3. Best Practice bitterns management options

3.1 Previous work on the discharge of bitterns

This section provides an outline of work carried out to date.

An outline of the policy context for discharge is also presented to provide an indication of the potential regulatory environment for any such discharge.

3.1.2 Context for potential bitterns discharge

- **National Water Quality Management Strategy Australian and New Zealand Guidelines for Fresh and Marine Water Quality.**

The Australian and New Zealand Environment Conservation Council (ANZECC) together with the Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) released a set of water quality guidelines for the protection of marine and freshwater ecosystems (ANZECC/ARMCANZ 2000).

The framework for applying the guidelines involves the following:

1. Define primary management aims which may be a statement of environmental values (particular uses or values of the environment) and level of protection (water quality necessary to protect values) to maintain these values;
2. Determine appropriate water quality guidelines (concentration of substances) tailored to local conditions;
3. Define water quality objectives to indicate the water quality to be achieved and may be concentrations of substances or a descriptive statement;
4. Monitoring and assessment program to determine whether water quality objectives are being achieved; and
5. Management response to attain or maintain water quality objectives.

The guidelines recognise a number of environmental values and assign "trigger values" for each value for substances that may impair water quality. If a trigger is exceeded or predicted to be exceeded, further investigation or a management response may be initiated.

Two levels of guideline trigger values were recommended:

1. Low risk guidelines below which there is a low risk that adverse biological effects will occur.
2. High risk guidelines above which there is a significant risk that adverse biological effects will occur.

The guidelines provide a comprehensive list of recommended low trigger values for physical and chemical stressors broken down into five geographical regions across Australia and New Zealand

Mixing Zones

The guidelines indicate that it is accepted practice to apply the concept of a mixing zone around an effluent discharge point. A mixing zone is defined as an area around the discharge point where certain environmental values are not protected.

If a mixing zone is to be applied, the management of the mixing zone should ensure that the area for mixing is as small as practicable and the designated values of the broader ecosystem must not be compromised.

Before a mixing zone is permitted, every effort should be made to reduce the amount and concentration of the discharge by applying the waste hierarchy: avoid, reduce, reuse, recycle, treat and dispose (ANZECC/ARMCANZ, 2000). Straits is committed to a project based on cleaner production and eco-efficiency in order to maximise economic and environmental benefits.

It was assumed in previous work that the constructed barge harbour would be the designated mixing zone. Contact recreation and fishing within the barge harbour will not be permitted, even if bitterns is not being discharged, due to the manouvering of barges and associated safety concerns. In addition the barge harbour is not a pre-existing marine habitat and hence no existing marine values will be compromised within this mixing zone.

State Water Quality Management Framework

The EPA has developed an Environmental Quality Management Framework (EQMF) for marine waters which involves the development of the following hierarchy and has applied this to the Exmouth Gulf (Department of Environment 2006):

1. Environmental Values (EVs) using the five environmental values prescribed by the national guidelines relevant to Exmouth Gulf – ecosystem health, recreation and aesthetics, cultural and spiritual, fishing and aquaculture and industrial water supply;
2. Environmental quality objectives (EQOs) are the outcomes required – equivalent to the management goals in ANZECC/ARMCANZ 2000);
3. Level of ecological protection (LEP) – maximum, high, moderate or low (relevant to ecosystem health value only); and
4. Environmental quality criteria (EQC) are concentrations of substances.

Interim EPA Water quality framework for Exmouth Gulf

The EPA has adopted interim EVs, EQOs and LEPs for the Exmouth Gulf since the referral and scoping of the environmental assessment of this proposal to the EPA (Figure 6.1, Vol 1).

The interim EQO (management goal) for the identified EV of ecosystem health for the east coast of the Gulf in proximity to the project area is defined as follows:

"Maintain Ecosystem Integrity – This means maintaining the structure (e.g. the variety and quantity of life forms) and functions (e.g. the food chains and nutrient cycles) of marine ecosystems."

The maximum level of ecosystem protection has been assigned for this EQO on the east coast of the Gulf adjoining the project area. This level of protection (which recognises conservation as a pre-eminent value of the area) does not either explicitly permit or disallow industry from the area, but will significantly constrain discharge and disturbance from commercial and land use activities. (Department of Environment 2006).

The interim framework has proposed low protection levels adjacent to large existing activities and population centres. Consequently the bitterns discharge into the excised area of the indicative Dampier Archipelago Marine Park is nominated as "Moderate/low LEP boundaries to be determined."

Application of EPA interim levels of protection

The EPA has set, for the interim, a maximum level of protection for the east coast of the Exmouth Gulf. This maximum level of protection corresponds to the following prescribed levels of change:

- No contaminants – pristine (assumed to be no detection of contaminant concentrations)
- No detectable change from natural variation for biological indicators.

According to ANZECC/ARMCANZ (2000), for High ecosystem protection toxicants should not exceed the 20^{th} and 80^{th} percentiles from a suitable reference site.

The only differentiation between Maximum and High levels of ecosystem protection is in the ability to detect change in water or sediment quality but both LEPs have the same level of change or impact on the biological environment (no detectable change from natural variation). Because bitterns and seawater are chemically similar, particularly after significant pre-dilution and tidal mixing, the ability to trace and/or differentiate the two solutions is problematic.

Even before the bitterns resource has been reduced in volume through the further extraction of the remaining sodium chloride and other salts, it was found that monitoring, through close investigation of the magnesium content, for example, would need to detect a 1.6% change in the average magnesium concentration given background inshore waters with a salinity of 39ppt. Statistically such detection would be highly unlikely (PB 2006). Furthermore, it was noted that the salinity of the inshore waters also has some variability, having been measured in the vicinity of Hope Point at 42.3ppt and that this also resulted in variation of magnesium content (PB 2006).

Consequently it is proposed that using a no-effects concentration for bitterns derived from a Direct Toxicity Assessment using locally endemic species would provide a more reliable indicator of potential impacts on the marine ecosystem than the use of the 20th and 80th percentile of natural water quality variability.

Direct Toxicity Assessment

Work undertaken on direct toxicity assessment of an initial discharge scenario (Scenario A) has been completed and the work presented to the Stakeholder Reference Group. This first stage work was based on a discharge scenario involving no resource recovery from the bitterns. However, sufficient quantities of the bitterns relevant to this scenario was available to conduct some detailed ecological assessment. This scenario represents a *worse than worst case* outcome as Straits will be recovering further salts from the bitterns resource. This scenario is provided to a benchmark which will only be significantly improved upon according to preliminary assessment of scenarios B and C.

The potential for additive ecotoxicological effects arising from the complex composition of bitterns and the possibility of physiochemical stressors (for example, osmotic stressors) results in the need to undertake a Level 3 Ecological Risk Assessment (direct toxicity assessment). Accordingly, a program of acute and chronic ecotoxicological testing was undertaken using 5 ecologically and/or commercially important species resident to the Gulf to derive site specific trigger values for bitterns discharged to the Exmouth Gulf.

The species used during the study were analogues of currently used test organisms and procedures used for toxicity assessment elsewhere in Australia (ANZECC/ARMCANZ, 2000). Testing involved 5 species from 4 taxonomic groups including:

- Mangrove Jack (*Lutjanus argentimaculatus*);
- Tiger Prawn (*Penaeus monodon*);
- Pearl Oyster (*Pinctata albina*);
- Brine Shrimp (*Artemia franciscana*); and
- Green Algae (*Tetraselmis* sp.).

A summary of the rationale for the selection of the test species is as follows:

- Mangrove Jack - endemic to the Gulf and the nearshore environment (juvenile stage);
- *Tetraselmis* sp was selected following discussions with CSIRO as the strain used for testing (CS-352) is known to be endemic to the Dampier area (strain provided by CSIRO Marine Research Laboratory, Hobart);
- Pearl Oysters - important for spat and pearl production in the Gulf. Also, the proximity of the bitterns discharge to aquaculture leases (potentially sensitive receptors);
- Tiger Prawn – commercially important and endemic to the Gulf and nearshore environment (juvenile stage)
- Brine shrimp - euryhaline species endemic to the Gulf ecosystem (most likely a sub genus of *Artemia franciscana,* Fisheries WA pers. com.).

Rigorous peer reviewed laboratory quality assurance / quality control (QA/QC) measures were monitored for water quality and test animal health according to international and Australian protocols for toxicity testing. Concurrent reference copper testing was also completed alongside the bitterns toxicity tests as a measure of test species sensitivity and acceptability.

No effects concentration (NOEC) values for the 5 species was used to calculate the site specific trigger values for bitterns using the Species Sensitivity Distribution (SSD) method (ANZECC/ARMCANZ 2000).

Derivation of trigger values for bitterns A

Site specific trigger values were calculated for bitterns A according to the methodology contained within the Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000) for Mixing Zones (80% of species protected), Low (90% of species protected), Moderate (95% of species protected) and High (99% of species protected) levels of ecosystem protection and are presented in Table 1

Table 1: Trigger Values for Bitterns A for Mixing Zones, Low, Moderate and High Levels of Marine Ecosystem Protection

Level of Ecosystem Protection	% of Species Protected	Trigger Value (% bitterns in marine water, by volume)	Estimated equivalent salinity* (ppt)
Mixing Zone	80%	0.91	42.1
Low	90%	0.73	41.5
Moderate	95%	0.63	41.1
High	99%	0.49	40.7

Note: *equivalent salinity is based upon the dilution of raw bitterns using ambient seawater (38ppt) at the intake south of Hope Point

Source: PB, 2005h.

The above trigger values for bitterns accord well with previous studies using shrimps, amphipods and mussels which reported no acute (LC10) or chronic (NOEC) impacts at <1% bitterns in seawater by volume (Hansen and Associates 1994).

3.1.3 Potential Sensitive receptors for bitterns residue

All potential scenarios for discharge involve firstly the pre-dilution and mixing of the bitterns before controlled release into the Hope Point barge harbour, followed by tidal flushing of the harbour to Exmouth Gulf.

The barge harbour is not a pre-existing marine habitat and is to be used for secondary dilution and mixing of bitterns.

Potentially sensitive receptors in the vicinity of the barge harbour include:

1. Exmouth Gulf ecosystem.
2. The Exmouth Gulf Prawn Managed Fishery.

3. The Exmouth Gulf Beach Seine Fishery. This fishery is operated from the western side of the Exmouth Gulf and will not be affected by any discharge at Hope Point because of distance and waters on the east coast of the Gulf tend to migrate to the north away from these areas;
4. Recreational fisheries.
5. Aquaculture – There are currently 21 aquaculture licences and 8 pearl farm lease sites located within Exmouth Gulf, however, only one of these is active and located in the vicinity of Hope Point.
6. EPBC Act Protected Species – Exmouth Gulf supports a number of threatened or endangered species identified under the EPBC Act 1999, including the Humpback Whale (*Megaptera novaeangliae*) and Dugongs (*Dugong dugon*). Exmouth Gulf is classified as critical habitat for these species based on their requirements of the Gulf, at a population sustaining level, for resting and feeding. Humpback Whale cow/calf pods rest in the Gulf in large numbers during their southern migration (Jenner *et al*. 2001) and Dugongs feed there (possibly year round).

Bitterns Discharge Modelling

A hydrodynamic model was developed to appraise dispersal associated with the discharge of bitterns to the Gulf via the barge harbour and shallow barge channel at Hope Point (APASA, 2006).

Using the tidal and creek boundary conditions from the EFDC model (WorleyParsons, 2005b), the bitterns hydrodynamic model was used to evaluate the dispersion of raw bitterns at a constant discharge rate. The model simulation was run under constantly changing wind and tide conditions based on 30 day simulations. Initial salinity and temperature values for the receiving Gulf waters were set at 37ppt and 25^{o}C based on measurements taken immediately adjacent to Hope Point.

The models were initially validated by comparing the results with measured elevation data made available by the Australian Institute of Marine Science (AIMS) for four locations within Exmouth Gulf: Point Murat, Giralia Bay, Point Lefroy and Fly Island (2 months of data at each station). Data from a tidal gauge installed at Hope Point for the purpose of controlling the vertical datum on bathymetric soundings were also available (1 month of data). Further detailed information relating to this modelling is provided in APASA (2006), available in Technical Volume 2.

Transient Exposure (TE)

The hydrodynamic mixing model demonstrated that the extent and intensity of bitterns within the receiving marine environment could be expected to fluctuate about the barge harbour outlet depending upon wind, wave and tide conditions (much like a flame fluctuates around a candle wick with changes in the breeze).

Transient exposure can be thought of as the percent exceedence of the stated trigger value for bitterns in either surface or bottom waters. Thus a transient exposure of 95% means that for 95% of the time the area so identified experiences bitterns concentrations (expressed as salinity) greater than the stated level of marine ecosystem protection (trigger value).

The hydrodynamic dispersion model indicated that due to the diurnal tidal dominance at the barge harbour, transient exposure could be expected to be in the order of 50% and that receptors within the area predicted to be touched by the discharge plume would only be exposed to the bitterns plume for 50% of the time. (RPS Bowman Bishaw Gorham 2006)

A conservative approach has been adopted and a nominal value of 95% transient exposure was selected, meaning mapping of those areas exposed to the bitterns for 95% of the time.

3.1.4 Contingency Discharge Scenarios

While the proponent is not seeking approval to discharge the bitterns resource, three discharge scenarios are presented to provide information on the range of possible outcomes.

The characteristics of the three potential scenarios are presented in Table 3

Table 2: Discharge settings for 3 pre-dilution scenarios

Parameter	**Scenario A: Bitterns A**	**Scenario B: Bitterns B**	**Scenario C: Bitterns C**
Specific gravity	1.25	1.3	1.35
Bitterns volume flow rate	19.8 Mil m^3/year	12.2 Mil m^3 /year	4.2 Mil m^3 /year
Bitterns salinity	286 g/L	316 g/L	362 g/L
Dilution volume flow rate	100.13 Mil m^3/year	100.13 Mil m^3/year	100.13 Mil m^3/year
Dilution water salinity	38 g/L	38 g/L	38 g/L
Dilution ratio approx	1:5	1:8	1:24

Source: RPS Bowman Bishaw Gorham 2006

Introduction

Scenario A

Scenario A represents a '*worse than possible worst case*'. This involves the discharge of bitterns after only about 75% of sodium chloride has been crystallized from solution. This 'Bitterns A' is what is currently being discharged undiluted from WA saltfields.

Scenario A also involves pre-dilution and mixing of the bitterns at 1 part bitterns to 5 parts seawater before controlled discharge into the barge harbour where further dilution by tidal and wave action takes place. Pre-dilution of the bitterns at 1:5 prior to discharge represents a new level of best practice for bitterns discharge in Western Australia.

This scenario has been included because there were sufficient examples of this bitterns product to conduct further ecological testing to show the possible level of environmental impact. However, the proponent will be removing most of the remaining sodium chloride and other salts to significantly reduce the volume of the bitterns and allow for a much greater level of pre-dilution. Hence Scenario A is worse than the possible worst case, but still provides a general understanding of how any potential impact will be reduced by further reuse of the bitterns resource.

Scenario B

The proponent will be reusing the Bitterns A resource by removing most of the remaining sodium chloride. This will provide 'Bitterns B' which has been modelled and mapped.

Scenario B represents the '*worst case*' scenario, if further processing of the bitterns resource is unexpectedly not practicable.

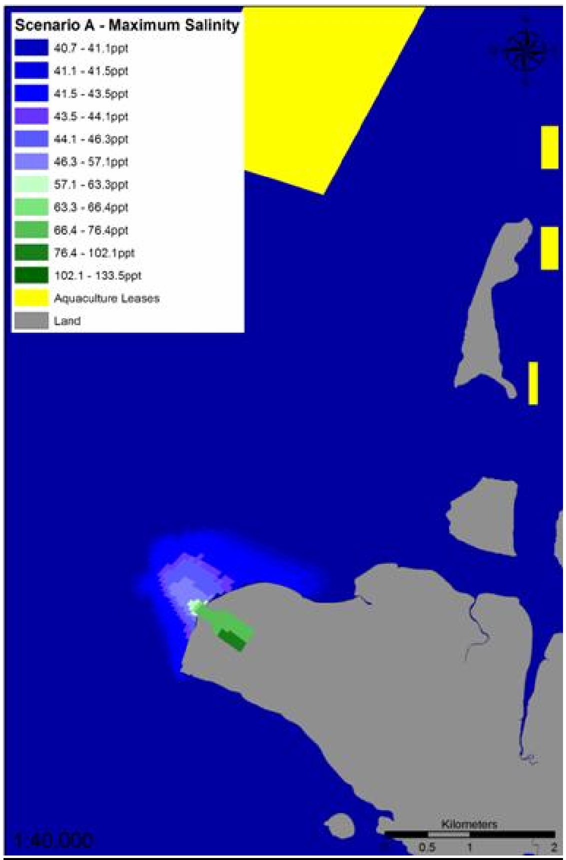
While the modeling results of Scenario B have been provided as a comparison of salinity contours with Scenario A, there has been no ecotoxicity testing for bitterns B. Therefore the assessment of potential impacts is indicative only and additional ecotoxicity testing will be required. In addition, a Tier III Ecological Risk Assessment is required to substantiate the results in accordance with the requirements of the Guidelines (ANZECC/ARMCANZ 2000). The bitterns research programme will address these requirements for any relevant discharge scenarios.

Scenario C

Scenario C involves the removal of additional salts and other compounds and results in a bitterns residue with a distinctive magnesium chloride composition and further reduced volume. This 'Bitterns C' has been modeled and mapped to provide a general comparison of salinity contours with the other scenarios.

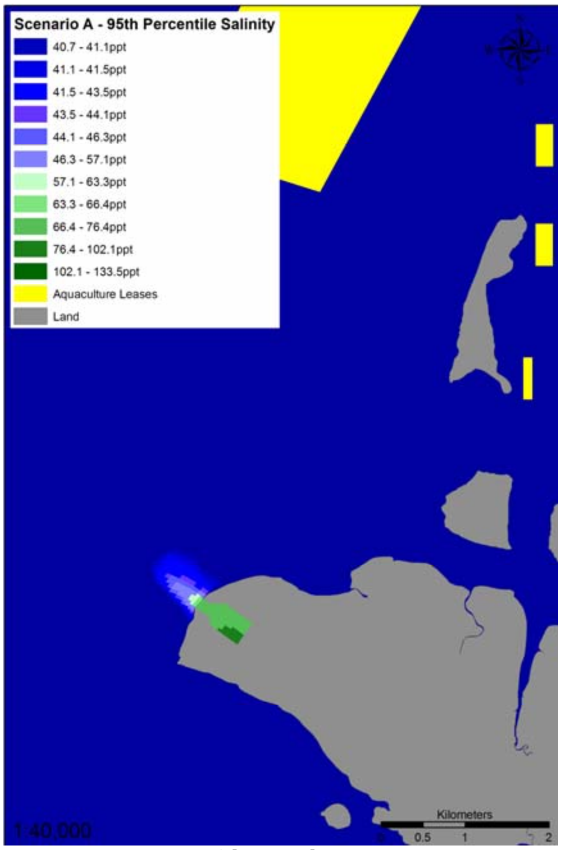
As with the Bitterns B scenario, there has been no ecotoxicity testing for bitterns C. Therefore the assessment of potential impacts is indicative only and additional ecotoxicity testing will be required. In addition, a Tier III Ecological Risk Assessment is required to substantiate the results in accordance with the requirements of the Guidelines (ANZECC/ARMCANZ 2000). The bitterns research programme will address these requirements for any relevant discharge scenarios.

Figure 1: Scenario A, maximum exposure



Source: RPS Bowman Bishaw Gorham 2006

Figure 2: Scenario A, 95% Transient Exposure



Source: RPS Bowman Bishaw Gorham 2006

Application of the nominal levels of ecosystem protection – Scenario A

In accordance with the Pilbara Coastal Water Quality Consultation Outcomes (DoE 2006) the EPA has endorsed on an interim basis the proposal that the east coast of Exmouth Gulf be nominally afforded a 'maximum' level of ecosystem protection (for ecological integrity). According to the draft policy the fundamental difference between 'Maximum' and 'High' levels of ecosystem protection is not based upon marine effects per se, but rather the ability to detect contaminants above ambient concentrations

Table 3: Nominal levels of ecosystem protection and the associated level of change that might be experienced

Level of Protection	Environmental Consequence	
	Water and Sediment	Ecosystem
Maximum	No contaminants – pristine	No effects on marine life
High	very low levels of contaminants detected	No effects on marine life
Moderate	Elevated levels of contaminated	Some effects on marine life
Low	High levels of contaminants	Significant effects on marine life

Source: DoE, 2004

According to ANZECC/ARMCANZ (2000), for High ecosystem protection toxicants should not exceed the 20^{th} and 80^{th} percentiles from a suitable reference site.

A site survey was conducted and salinity profiles established for the different sections of Exmouth Gulf. The measured salinities and observed gradient of salinity increasing from west to east are consistent with those reported by Ayukai and Miller (1998) and McKinnon and Ayukai (1996).

A summary of salinity data for the eastern Gulf is provided in Table 4.

Table 4: Summary of salinity data from east coast of Exmouth Gulf,

Source Oceanica 2006a

Location	Salinity (ppt)			
	Median	80th Percentile	20th Percentile	Number of Samples
Upper Creek	43.8	55.61	38.59	17
Mid-Creek	44.4	46.29	37.56	3
Mouth of Creek	41.5	43.49	37.79	14
Combined Creek data	42.6	46.64	38.15	34
Nearshore (off Hope Point)	37.9	41.13	35.89	7

The upper 80th percentile for salinity in the nearshore waters off Hope Point was found to be 41.13 ppt (n=7). This value is less stringent than the trigger value for bitterns for high ecosystem protection (40.7 ppt) derived from the direct toxicity assessment. It was therefore considered appropriate to use the more conservative bitterns dispersal modelling/direct toxicity assessment approach for assessing the environmental impacts of bitterns dispersal. Although this approach provided for the same level of ecosystem protection, it nevertheless afforded a greater area of protection (albiet not reliant upon 'detectable change' in ambient marine water quality *per se*).

In short, it is unlikely that given the composition of bitterns, the salinity of the Hope Point seawater intake (39 ppt) and the ambient salinity in the vicinity of Hope Point that chemical signatures within the bitterns could be used for the purposes of reliably detecting or tracking bitterns dispersion. The only differentiation between Maximum and High levels of ecosystem protection is in the ability to detect change in water or sediment quality. Both LEPs afford the same level of protection for marine life. The issue therefore is the extent to which such changes may be detected. Because bitterns and seawater are chemically similar, the ability to trace and/or differentiate the two solutions following significant dilution and mixing is problematic.

The results and findings of the site specific direct toxicity assessment demonstrate that the 99% level of ecosystem protection derived for bitterns (40.7 ppt equivalent) was more stringent than the maximum level designated by the 80th percentile (41.13 ppt). Accordingly, the use of the High level of ecosystem protection was considered to be an appropriately conservative approach to protecting the marine species of the Exmouth Gulf and that this should be determined using the dispersal model in combination with the results of the direct toxicity assessment.

Furthermore, the no-effects concentrations (NOECs) data for bitterns derived during the direct toxicity assessment (PB, 2005h) provides a more reliable and direct means of assessing the potential adverse impacts on key indicator species for the Exmouth Gulf than the above use of the 20th and 80th percentile of natural water quality variability.

Consideration of Potential Impacts – Scenario A

Benthic Primary Producer Habitat (BPPH)

Direct toxicity testing of bitterns on seagrasses was not possible due to the remoteness of the site and problems with translocating seagrasses and replicating similar turbidity and light conditions within the laboratory. However, in-situ trials were undertaken by placing mesocosm domes over seagrasses and measuring photosynthetic production when exposed to various concentrations of bitterns (Actis, 2005—available as an Appendix to Parsons Brinckerhoff 2005h in Technical Volume 2 Part C).

The findings of this work suggested no acute or chronic impacts to seagrass from bitterns when diluted 1:5 with seawater (equivalent to a salinity of 42 ppt). This concurs with the results from the direct toxicity assessment which identified bitterns trigger values for High ecosystem protection of 40.7 ppt. That is to say, that seagrass is well known to be resilient to salinity and appears to not be overly sensitive to bitterns. Notwithstanding, the importance of seagrass to the ecosystem processes of the Gulf and for prawn and fish habitat and Dungong foraging and the need to minimise such impacts is fully recognized.

The 42 ppt value was selected based on *in situ* benthic chamber testing of the effects of bitterns on seagrass to derive estimates of concentrations likely to have effects on seagrass and macroalgae (Actis, 2005). This value is likely to be extremely conservative given the salinity tolerances of seagrasses in the area, as reported by Oceanica (2006):

"Salinity tolerances are such that seagrass growth is not affected by slightly elevated salinities on the east coast (published tolerances: 64 ppt H. uninervis (Walker 1989); 50 ppt C. angustata (Walker 1989); 45 ppt H. ovalis (Hillman et al*. 1989), 75 ppt H. uninervis (Hillman* et al*. 1989))."*

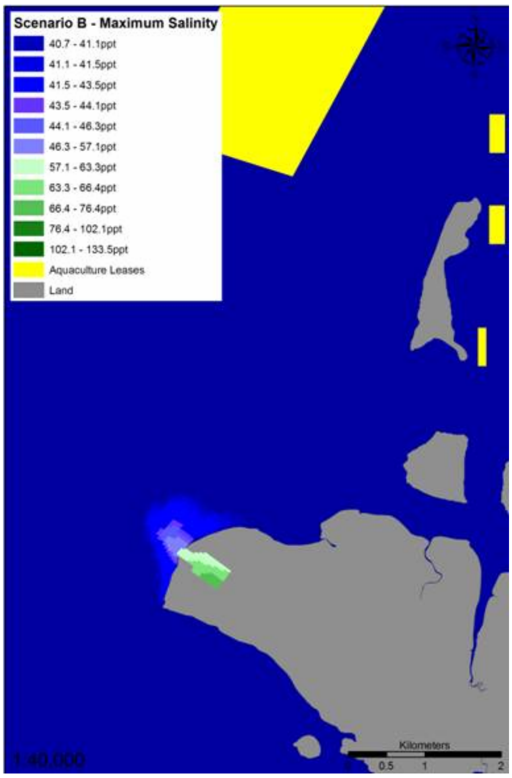
It is reasonable to expect that the area of BPPH to be affected will be less than the area which will not attain a High (99%) level of ecosystem protection as a result of bitterns discharge. That is, the depth limitation and resilience of seagrasses to bitterns is such that the area of BPPH impact is likely to be a subset of the ecosystem level impact. Accordingly, the areas of BPPH and marine ecosystem predicted to be affected by bitterns are different.

Notwithstanding, the density and actual extent of BPPH within the area potentially affected by bitterns is considered low based upon field observations and turbidity, further mitigating these impacts.

Aquaculture

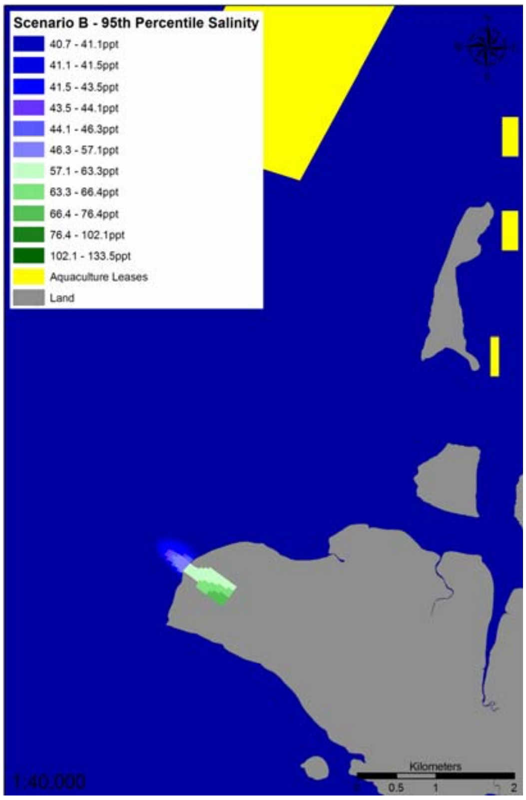
The hydrodynamic modeling predicts that there will be no exposure of aquaculture leases within the Gulf to bitterns from Scenario A and consequently there are no anticipated impacts on aquaculture from this scenario or the subsequently smaller areas of impact from the remaining discharge scenarios B and C.

Figure 3: Scenario B, maximum exposure



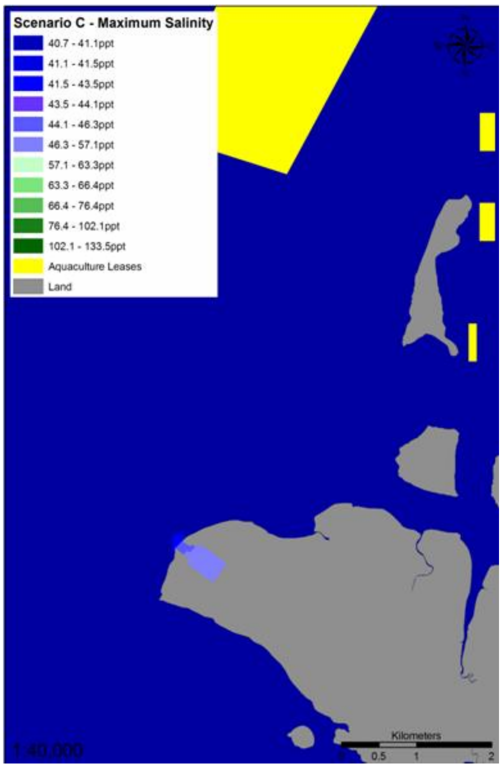
Source: RPS Bowman Bishaw Gorham 2006

Figure 4: Scenario B, 95% transient exposure



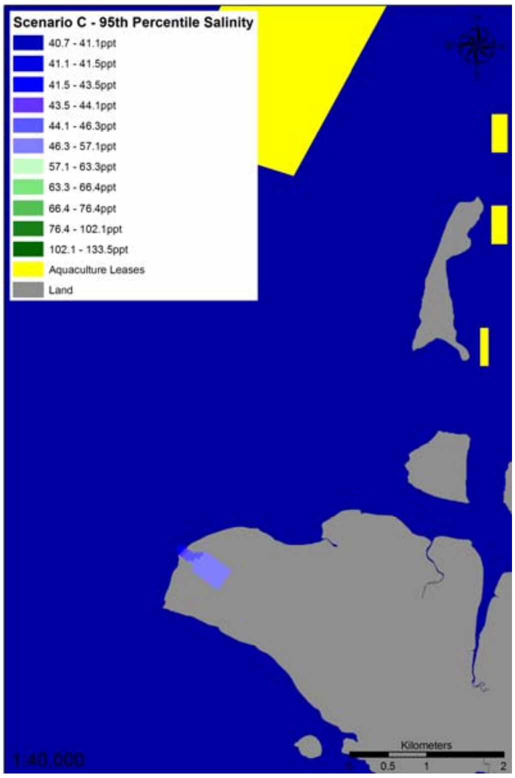
Source: RPS Bowman Bishaw Gorham 2006

Figure 5: Scenario C, maximum exposure



Source: RPS Bowman Bishaw Gorham 2006

Figure 6: Scenario C, 95% transient exposure



Source: RPS Bowman Bishaw Gorham 2006

Continuous improvement bitterns research

Due to the incomplete nature of the ecotoxicity testing of the different bitterns products, the findings of this assessment are to be used as a guide for further investigations. Each bitterns product will require full ecotoxicity assessment prior to the completion of a Tier III Ecological Risk Assessment in accordance with ANZECC/ARMCANZ requirements. Investigations will also be undertaken to compare the potential environmental impacts resulting from continuous bitterns discharge versus a pulsed discharge to allow for ecosystem recovery.

Table 5: Predicted footprints from discharge scenarios

Hydrodynamic Dispersion Model Parameter	Scenario A: Bitterns predicted footprint, Km^2	Scenario B: Bitterns predicted footprint Km^2	Scenario C: Bitterns predicted Footprint Km^2
99% Ecosystem Protection No transient impacts	1.699	0.825	0.187
99% Ecosystem Protection With transient impacts (95%)	0.485	0.302	0.167

Source: RPS Bowman Bishaw Gorham 2006

Potential management of bitterns discharge

Any possible bitterns discharge scenario would have to address the following:

1. Referral to the EPA
2. Preparation and implementation of a Bitterns Impact Assessment and Management Plan for EPA consideration.
3. Any channel used to convey the bitterns from the bitterns management area to the harbour would be specifically engineered to enable the introduction of the required inflow of seawater to achieve the nominated level of pre-dilution of the bitterns.
4. Pre-diluted bitterns before being discharged into the barge harbour for further mixing prior to entry to the open waters of the Exmouth Gulf. In the event of pump failure preventing a sufficient quantity of seawater intake to achieve the required pre-dilution, the following steps will be implemented immediately:

    - Bitterns discharge outlet valve at the bitterns management area will be closed (i.e. cessation of bitterns release into the bitterns flume)
    - Pre-diluted bitterns discharge from the dilution point to the barge harbour will be stopped (i.e. cessation of discharge into the barge harbour)
    - The quantity of undiluted bitterns collected in between the two points will be retained within the discharge flume until repairs to the seawater intake pump are completed.

Monitoring and Assessment of Performance

Any bitterns discharge proposal would include:

- A sampling and analysis plan would be prepared for bitterns which will outline a program of preconstruction baseline monitoring and effluent, sediment and biota sampling at key reference sites across the area to enable the assessment of whether the designated levels of ecosystem protection are being attained.
- A programme of sentinel mussels and sediment quality at appropriate reference sites to determine baseline information on bioaccumulation and whether any bioaccumulation occurs subsequent to any discharge of bitterns.

Proponents Commitments

- ***Continuous improvement***
  A contingency research programme involving field trials, ecotoxicological testing and investigating additional dispersion and mixing options will be implemented as part of a process of 'continuous improvement' for bitterns disposal, if required. The research will take place concurrently with the final assessments for re-use of the bitterns resource. The bitterns disposal research will be conducted in consultation with the EPA to ensure a bitterns management system that has the most minimal impact possible.

- ***Major Environmental Review***

  The proponent is seeking as a condition of approval to conduct a major environmental review of the project before commencing stages Three and Four. This review will consider all environmental impacts and how they are being managed as well as a review of any social issues associated with the project. The scoping for this review will be determined in consultation with the EPA and the review submitted to the Minister for the Environment. The EPA would assess the review and provide advice to the Minister on any new or amended environmental conditions needed to ensure the project continues to proceed in an environmentally acceptable manner.

  This major environmental review will include the outcomes of the final assessment of bitterns reuse options and the contingency research on bitterns disposal.