Appendix D
Hydrodynamic modelling scope

Final Scope of Work for a Hydrodynamic Modelling and Measurement Study of the Proposed Gunns Pulp Mill

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1 Background

In October 2007, the Federal Minister for the Environment released his decision to approve the construction and operation of a bleached Kraft pulp mill at Bell Bay, Tasmania by Gunns Limited under the EPBC Act of 1999. This was based on advice from the Commonwealth Chief Scientist who provided the Federal Minister with advice in relation to potential impacts of the proposed pulp mill on the Commonwealth marine environment.

The approval is subject to 48 Conditions, the second of which requires Gunns Limited to develop and submit an Environmental Impact Management Plan (EIMP). The objective of the EIMP is to ensure that no adverse impacts on matters of national environmental significance will occur as a result of the construction and operation of the mill.

Among the 48 conditions is a general condition (No. 3) that the EIMP must include trigger points and maximum limits in relation to effluent discharge and that an operational objective of the pulp mill shall be that these are not reached during the operation of the pulp mill. In relation to the wastewater effluent discharge, the contaminants of concern are stated in Condition 32 to be dioxins and furans, chlorate, total chloroacetic acids, total nitrogen, total phosphorous, total suspended solids (TSS) and biogeochemical oxygen demand (BOD). The studies described here, together with information about the composition and likely settling and flocculation properties of the fine organic materials in the effluent will provide predictions of the fate and likely concentration levels (above background) in both the receiving waters and the sediments.

1.1 The Proposed Outfall Site

The proposed pulp mill outfall is a diffuser pipe that will discharge some 64 megalitres/day (64 million litres/day) of treated effluent 2.7 km offshore from Five Mile Bluff to the east of Low Head on Tasmania’s north coast (Fig. 1). The proposed diffuser pipe will have some 20 ports spaced 10m apart and at its seaward end, will be in a water depth of about 26 m. The tidal range here varies between about 2 to 3 m.

1.2 Requirement for Hydrodynamic Modelling

Condition 38, states that additional modelling must be carried out in relation to the fate of effluent, prior to the commencement of commissioning of the mill, and the Commonwealth Department of Environment must approve the details of the modelling to be commissioned and the organisation responsible for performing the modelling. The Tasmanian authorities also require additional hydrodynamic modelling with details specified in Schedule EM1 of the Pulp Mill Permits.

Considerable hydrodynamic modelling has already been undertaken in relation to the fate and transport of the effluent (Gunns Pulp Mill IIS, Hydrodynamic Modelling, 2006). The hydrodynamic and water quality modelling had some deficiencies, according to the Chief Scientist. These were the inappropriate use of 2-D models, neglect of background stratification, insufficient vertical resolution, high horizontal eddy diffusion, omission of low frequency forcing, inadequate calibration and short run times. In view of these deficiencies the Chief Scientist stated that the effluent dilutions predicted by the model are open to question and that the modelling study may have over-estimated minimum dilution rates and under-estimated maximum tracer concentrations away from the outfall. The Chief Scientist concluded that there is sufficient uncertainty in the modelling carried out to date that it cannot be guaranteed that the proposed water quality objectives for contaminants such as chlorate and colour will be met at all times in Commonwealth waters.

Section MZ 4.1-4.4 of Schedule EM1 of the (Tasmanian) Pulp Mill Permits also pointed to a number weaknesses in the hydrodynamic modelling, most notably the lack of field data for model verification and calibration. A key outcome is the requirement for a revised definition of the mixing zone to ensure the State's water quality objectives are likely to be achieved.

1.3 Components of Additional Hydrodynamic Modelling

The Chief Scientist has recommended that improved hydrodynamic and sediment modelling of the fate and impact of effluent be undertaken that considers both dissolved and particulate contaminants. This will provide critical information on the expected concentration levels in the receiving waters and the sediments, and assist in the design of the monitoring program. Condition 38 of the Commonwealth approval requires the hydrodynamic modelling to include, but not be limited to:

- The inclusion of a sediment transport component.
- The use of three-dimensional models for all levels of spatial resolution.
- Increased vertical resolution for the high-resolution model used in the water quality analysis.
- Forcing from all mechanisms that may potentially influence residual or diurnal dynamics, including background sea level gradients, low frequency sea level oscillations, surface heat flux, sea level, temperature and salinity open boundary and initial conditions which capture mesoscale variability and wave enhanced bottom friction.
- The execution of long term simulations that capture seasonal variability, and evidence of the model achieving pseudo-steady state in the regional (Bass Strait) field.
- The calibration of model tracers (e.g. temperature or salinity) and velocity to data derived from moored instruments (for temporal comparisons) and measured vertical profiles over the period the model is simulated. This will involve a supplementary field program designed specifically for model calibration (ie. implemented over an annual cycle). Detailed evidence of satisfactory calibration must be supplied, including correlation between phase and amplitude of calibration variables.
- Sensitivity analysis for key model parameters, particularly horizontal diffusion.
- The use of sufficiently long simulation periods for generating plume statistics.
- The use of data (modelled or measured) that captures the three-dimensional nature of the water column and seasonal variability for use in the near-field model.

2 Scope of Work

Modelling the hydrodynamics of an effluent continuously discharging into the marine environment involves mixing and transport processes occurring in two separate regions, the "near-field" and the "far field". The "near-field" is the region near the outfall where the initial dilution of effluent occurs, while the "far-field" is the region where effluent is transported by ocean currents and further diluted through a combination of diffusive and mixing processes. The fine particulate material in the effluent will be subject to continuously varying ocean currents and waves causing intermittent events of deposition to the bottom sediments and resuspension. To provide a robust system of accurately predicting the transport, dilution and accumulation of effluent requires the application of a series of appropriately calibrated and validated models. Accordingly, the scope of work has been broken up into the following five major components:

- Far-field Hydrodynamic Modelling
- Near-Field Modelling
- Sediment Transport Modelling
- Wave Modelling
- Field Measurement Program

The following specific outputs are expected from the modelling:

- Predictions of the maximum concentrations above ambient of the key effluent substances in the water (TSS, BOD_5, COD, AOX, Colour and Chlorate) for a range of forcing scenarios likely to occur over any one year period in Bass Strait.
- Based on the relevant Water Quality Objectives (WQO's), exceedance statistics for all of the above substances. This can be done using only one model run by assuming a unit input of tracer and then scaling the results to represent the actual effluent input of each individual component tracer. Results would be presented in terms of the scaled concentrations for each component.
- Predictions of the concentration of dioxins and furans in the sediments of Bass Strait to establish whether there are any long-term accumulation zones and to inform the choice of monitoring sites.

2.1 Far-Field Hydrodynamic Modelling

The model will be a state-of-the-art 3-D hydrodynamic model capable of simulating ocean currents driven by the range of forcing mechanisms prevailing in Bass Strait. The model's horizontal and vertical resolution will be sufficient to allow changes in the concentration of passive tracers to be resolved to a degree where the effluent plume is clearly mapped. It is recommended that a model employing a variable horizontal grid resolution, such as an orthogonal curvilinear grid, be used. This will enable fine scale resolution (~50m) around the outfall site and in the Tamar estuary, and coarser resolution far from the outfall so that the number of grid points in the model are not excessive (ensuring model run times are not excessive).

The model will also be capable of coupling with sediment transport and wave models that simulate the processes causing sediment dispersion, deposition and resuspension. The model will also be capable of interfacing with a near-field model using an appropriate loading pattern.

2.1.1 Model Specifications

2.1.1.a Type of Model

Essential:

- Primitive equation model based on Navier Stokes equations
- Three dimensional including effects of density stratification
- Numerically accurate and efficient

    - Choice of advection schemes (eg. ULTIMATE QUICKEST, MPDATA)
    - Alternative turbulence closure schemes (Mellor Yamada, k-ε, k-ω)
    - Alternative open boundary conditions
    - Spatially and temporally varying horizontal diffusion (eg. Smagorinsky)
    - Free surface
    - Capable of coupling with near-field, sediment transport and wave models

- Demonstrated track record
- Ability to add passive tracers to determine water quality
- Ability to include point sources and sinks of volume and tracers
- Horizontal orthogonal curvilinear grid capability
- Nested grid capability

Desirable:

- Multi-processing capability (multi-threading, parallel or vector processing)
- Vertical coordinate that resolves tidal variability (eg wetting and drying z, z*,σ)
- Transport model capability to simulate plume transport over long (~decadal) time scales (ie advecting tracers using offline velocity and mixing data)

2.1.1.b Domain Configuration

Essential:

- An orthogonal curvilinear grid model with a fine resolution in the order of 50m surrounding the outfall, and extending from the coast into Commonwealth waters and sufficiently large to resolve the expected size of the mixing zone
- It is expected that the curvilinear grid region would be nested within a large scale model of Bass Strait with a resolution in the order of 2.5km to simulate long-term build up of effluent
- Three levels of nesting may be required with an intermediate resolution grid between the large scale model and high resolution curvilinear model

- All models should be 3-D
- Vertical resolution should be sufficient to resolve surface and bottom boundary layers and surface stratification/convective mixing due to surface heat-flux input. It is recommended that the surface layer thickness is <0.5 m
- Reasonable run-time ratios through the use of threaded processing or parallel processing

2.1.1.c Model Forcing

Essential:

All forcing mechanisms that may potentially influence currents at time scales ranging from hours (tides and wave-induced) to weeks (low frequency sea-level variations). These include:

- Wind and atmospheric pressure forcing with adequate temporal and spatial resolution (eg. Bureau of Meteorology MesoLAPS)
- Surface heat flux including diurnal variations (eg. MesoLAPS)
- Open-Boundary forcing from

    - Barotropic tides
    - Low frequency sea-level (eddy resolving global models or products – eg. BRAN2.1or synTS - CSIRO)
    - Background mean sea-level changes (eg long term mean from CSIRO)
    - Temperature and Salinity along open boundaries (eg. synTS)
    - Wave-enhanced bottom friction for resuspension of sediments (eg. WaveWatch III)
    - Initial conditions on temperature, salinity and sea-level that contain meso-scale variability (eg tides + BlueLink)

2.1.1.d Modelling Transport of Passive Tracers

To model the water quality, a passive tracer of unit concentration and volume rate corresponding to the known effluent discharge rate (64 million litres per day) should be released in the cells surrounding the outfall diffuser in a distribution obtained from the near-field modelling. The initial dilution of effluent in the far-field model will be obtained from the near-field model, but should be representative of the diffuser’s expected initial dilution.

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2.1.1.e Parameterisation

A number of parameters are required to be assign by the model user and these should be chosen on the basis of typical values from the literature combined with adjustments made in the calibration of the model (discussed below). These include:

- Horizontal diffusion and viscosity
- Background vertical diffusion and viscosity
- Surface roughness (in the k-ω turbulence closure scheme)
- Bottom roughness and drag
- Wind-stress drag coefficients
- Surface heat-flux parameterisations
- Open boundary conditions

Of these parameters the most critical is the horizontal diffusion coefficient which is the parameter that determines the degree of spreading of effluent due to oceanic turbulence. The actual values for the ocean have been estimated using a number of different techniques including dye tracking and drifter studies, and are in the range 0.01 to 0.5 m^2s^{-1}. However, the values used in models may be quite different because turbulent eddies responsible for diffusion are not properly resolved as the grid resolution increases. This means that larger horizontal diffusion coefficients are required as the grid resolution increases.

For models with variable horizontal grid resolution, such as models employing orthogonal curvilinear coordinates, the horizontal diffusion coefficient must be allowed to vary and this can be done by using a Smagorinsky formulation. In this formulation the horizontal diffusion coefficient is proportional to the velocity shear at each grid point, scaled by an empirical constant which usually has a value in the range 0.1-0.2.

The sensitivity of the modelling results to variations in the value of this constant should be investigated.

If either of the two-equation turbulence closure models are used, sensitivity of the model results to the specification of the minimum TKE (k-ε, k-ω) and surface roughness (k-ω) values should be performed. The precise formulation of the turbulence closure scheme used should be stated including the details of the stability functions.

Any significant sensitivities should be highlighted, perhaps in tabular form.

2.1.1.f Calibration and Validation

A high level of model calibration and validation against relevant reliable historical and new field data must be undertaken using appropriate statistical measures. The model should be calibrated to sea-level, temperature, salinity and current velocities. At a minimum the model should reproduce tidal sea-level amplitudes with an accuracy of <5% rms error and tidal velocity amplitudes with an accuracy of <10% rms error. Errors in phases may be a little larger. Similar errors are expected for temperature and salinity, but higher errors are expected for residual currents and sea-levels (~20-30%).
Based on known historical data, the level of calibration described above will require a supplementary field program described in Section 2.5 below. The calibration and validation should include events occurring at seasonal time scales, and this will require a measurement program extending over a minimum period of 12 months.

Detailed evidence of satisfactory validation should be supplied. This should include evidence of correlations between temporal and spatial variability of T/S, sea-level and velocity and information regarding the errors in amplitude and phase of calibration/validation variables. Calibration and validation should be performed over the full period of the model simulations (See 2.1.1.g below: Either one year or monthly periods representative of each season).

2.1.1.g Model Runs

Model runs simulating a period of at least 12 months should be performed using the orthogonal curvilinear grid model to capture season variability. Evidence that the model achieves a pseudo-steady state should be provided. The possibility of increasing trends of effluent concentrations resulting in long-term build up of effluent in the waters and sediments of Bass Strait must be investigated. This will require longer simulations of the model, perhaps of at least several years, using recycled forcing conditions relevant to the first year of simulation. Decadal simulations of the effluent plume could be performed using offline data.

It would be acceptable to identify shorter periods (depending on the model results and measured data, but perhaps monthly) representative of each season in the simulation for which to run the model (owing to the likely small run-time ratio due to the ~50 m fine grid resolution).

Plots describing the mixing zone in a statistical sense (e.g. 95 percentile plots for toxicants and median distributions for physiochemical variables) will be provided describing the concentrations of TSS, AOX and chlorate and colour in appropriate model layers (e.g. surface, bottom and layers of maximum concentration). The plume statistics will be generated for periods during which oceanic conditions are both predominantly calm and energetic..

2.2 Near-Field Modelling

In the “near-field” region, the mixing behaviour of a discharge effluent plume is governed by the interaction of ambient conditions and effluent discharge properties. Ambient conditions include bathymetry around the outfall, ambient waves and currents, temperature and density distribution and background concentrations of effluent substances. Discharge properties include outfall configuration and design (eg. depth, number and size of diffuser ports, discharge rate).

2.2.1 Model Specifications

The model must be capable of simulating a multiport diffuser from which the initial effluent jet trajectory and entrainment, is governed by the momentum flux, buoyancy flux, ambient conditions and outfall geometry. This region encompasses the jet sub-surface flow and any surface or bottom interaction, and in the case of density stratification, terminal layer interaction. In this region, outfall design can usually affect the initial mixing characteristics through appropriate manipulation of engineering design variables of the diffuser pipe and water depth. The model will:

- Be capable of simulating a range of discharge geometries including submerged multiport diffusers
- Be applicable to buoyant and non-buoyant discharges
- Include 3-D effects
- Be applicable to stratified receiving environments
- Include discharge and ambient flow induced mixing (including ambient flows that vary vertically obtained from either measurements or far-field model)
- Include horizontal and vertical dispersion
- Include surface and bottom interaction
- Include background concentrations of pollutants
- Be capable of coupling with the far-field model using known and tested approaches

Given a discharge rate, diffuser design and ambient conditions, outputs of the near-field model are effluent plume characteristics in terms of dilution, concentration, rise height, thickness and size of the mixing zone.

The near-field modelling should address seasonal variability such as those associated with stratified conditions in summer and well-mixed conditions in winter. These conditions may be obtained from the high-resolution far field model or the permanent mooring at the outfall site (see below).

2.2.2 Dioxins

Dioxins are of particular concern because they are highly hydrophobic (water-insoluble) and partition strongly to fine organic particulates in the discharge or in the bottom sediments. The key issue with respect to dioxins is knowing where the particulate material settles and this will depend on the prevailing ambient conditions. Particulate material containing dioxins is unlikely to accumulate near the outfall because the site is subject to frequent storm events, which will cause resuspension and transport away from the outfall.

A critical part of the near-field calculation will be the assumed concentration of AOX in the treated effluent discharge, which will not be known until the mill is operational. Accordingly the worst case scenario should be chosen which will be based on a discharge limit on AOX of 8.7 mg/L***** based on the maximum emission limit on AOX. (Note that this limit is different from the limits placed on the individual components of AOX by Tasmania’s RPDC, notably 2,3,7,8-TCCD (30 pg/L) and 2,3,7,8-TCDF (13pg/L, and later revised down by the Commonwealth to 2.0 pg/L monthly mean and 3.4 pg/L maximum TEQ).

* This figure is calculated using the following data:
Maximum monthly average discharge limit on AOX of 0.2kg/ADt
Annual production of pulp of 1 million ADt (Air Dried tonnes)
Discharge volume of 64 million litres per day.

The consultant is to advise the basis for the selection of the range of particle size fall velocities to be adopted for the particulate material.

2.3 Sediment Transport Modelling

Condition 38 specifically mentions the need for a sediment transport model arising from the fact that dioxins partition strongly to particulate organic material in the sediments. A model is required that simulates the frequent resuspension of sediments, due to storm events, transport with ocean currents and subsequent re-deposition in zones with low bottom stress (deposition zones), either in deeper water further offshore or in sheltered bays and the Tamar River estuary.

This model will require baseline studies characterising sediment composition around the diffuser and other sites (see section 2.5.4), and the specification of properties of the

particulate matter in the effluent such as settling rates, flocculation rates and critical shear stresses for deposition and resuspension. However this information won't be available until the mill is operating, and data will need to be obtained from similar pulp mill effluents produced by overseas mills.
Efforts to calibrate the model should be made if the baseline studies provide information on natural sources of sedimentation. The model should be used to inform the design of long-term monitoring programs for dioxin and other long-lived hydrophobic contaminants.

2.3.1 Model Specifications

The sediment transport model must be capable of simulating the transport of particulate, dissolved and sediment-bound tracers in the water column and in the sediment bed. It will be based on the following:

- An advection –diffusion equation for mass conservation of suspended and bottom sediments
- Turbulent mixing in the water column and horizontal advection driven by the far field hydrodynamic model
- Effects of suspended sediment on density stratification may be neglected
- Displacement of particles in the sediment bed is included through bioturbation, flocculation, swelling and consolidation
- Flocculation represented as a two-step process; transport and attachment
- Bioturbation represented by local diffusion
- Cohesive sediments are eroded or deposited depending on bottom shear stresses and critical shear stresses
- Non-cohesive sediments are eroded or deposited according to a parameterised equilibrium sediment distribution
- Bottom friction dependent on waves and bottom currents (eg Grant and Madsen formulation)
- Physical roughness dependent on whether sediment bed is cohesive (constant) or non-cohesive (skin friction at bed and form drag over ripples).
- Bottom changes related to the rate of deposition and resuspension (probably insignificant)

Initial bottom sediment distributions would be required and these could come from data already collected by Gunns' Ecological Monitoring Program and appropriate historical data obtained from organisations such as Geoscience Australia. The data would be presented as particle size distributions (psd's) ranging from the very fine clay (~8 phi) to very fine gravel (~ -1 phi) in about eight categories. In addition to the existing data it is recommended that new sediment data is collected using latest sediment measurement technology. This is described below.

The model should be applied to investigate the potential for long-term build up of effluent contaminants in the sediments (particularly AOX) by producing spatial distributions of sea-bed deposits of these contaminants.

2.4 Wave Modelling

The inclusion of wave modelling is necessary because the primary mechanism causing the mobilisation of sediments is the changes in bottom shear stress arising from the interaction of near-bottom orbital velocities caused by waves with the mean wind-driven and tidal currents over a rough bottom.

The expectation is that one of the state-of-the-art public domain models such as WaveWatchIII would be used to provide the wave information over the regional, intermediate and high-resolution domains. This is a 3rd generation wave model developed by NOAA. It simulates wind-generated waves that grow and decay due to the changes in the wind-field, non-linear resonant interaction, dissipation and bottom friction. The model includes the mechanisms of refraction and straining due to changes in water depth. The model is applicable in deep to shallow water environments and includes the mechanism of depth-induced wave breaking.

Model outputs are time dependent gridded fields of significant wave height, wave directions and wave periods, and spectral information that describe the wave energy at the different wavelengths. These outputs allow the calculation of on-bottom parameters such as the wave-induced bottom shear stress responsible for the wave-induced component of sediment suspension.

2.5 Field Measurement Program

A number of measurement programs have been undertaken over the past 10 to 15 years that would provide relevant data, mostly in the form of ocean current time-series. The most recent of these were designed specifically to support previous hydrodynamic modelling studies for the pulp mill, but in the Commonwealth view these were inadequate for model calibration.

What the Chief Scientist requires is a measurement study over a sufficiently long period dedicated to produce concurrent data for model calibration and validation, and for inputs such as surface winds, bottom sediment characterisation and ambient temperature and salinity (T/S) distributions. The measurements must cover an entire year and include permanently tethered moorings with a range of instrumentation that measure sea-level and profiles of currents, temperature and salinity (ADCPs, fixed current meters, Sea-Bird Microcats, etc). At least one of the tethered moorings should be adjacent to the outfall site to provide data that will assist with the near-field modelling. Seasonal surveys of T/S distributions should also be undertaken to determine the degree of stratification and its horizontal variability

At this stage it is envisaged that measurements would be required for a period of at least 12 months at 3 sites representing the outfall site, a site near the mouth of the Tamar River and one deep water (~40-50m) relocatable site whose position changes during service visits (2-3 months). All sites including the relocatable positions would be chosen in consultation with the State and Federal agencies.

2.5.1 Major Objectives of Measurement Program

Data collected over a 12-month period is required for the following purposes:

- To represent the seasonal variability in conditions at near-shore, offshore and outfall sites, hence 3 moorings;
- To determine the appropriate value of horizontal diffusion;
- To provide characterisation of the receiving environment (T/S, sediments).
- To validate and calibrate hydrodynamic models (sea-level, currents, temperature and salinity, waves and sediment transport) over the range of conditions typically experienced in any one year;
- To provide surface wind, atmospheric pressure and heat flux data for calibration of modelled data from, for example, MesoLAPS or NCEP; and
- To provide background levels of key contaminants of concern (AOX, DO, BOD_5, COD and Chlorate) in water and sediments.

2.5.2 Ocean Currents and Waves

It is recommended that ocean currents at each location be measured using bottom mounted broadband (600 kHz) Nortek Acoustic Wave And Current (AWAC) profilers, and one fixed current meter near the surface to provide redundancy and validation of the AWAC data. The AWACs have the capability to measure current speed and direction, and sea-level (tides), wave height and direction.

The AWAC is designed as a coastal monitoring system. It is small, rugged, and suitable for multi-year operation in tough environments. It can be operated online or in stand-alone mode with an internal recorder and batteries. The 600 kHz version will sample currents to depths of 50 meters and waves to 60 meters.

The instruments would need to be serviced at least every three months, which means at least 5 field visits (deployment, 3 service visits and recovery). More frequent service visits may be required if previous measurement studies by Gunns and others suggest that marine growth would make this is necessary.

2.5.3 Temperature and Salinity (T/S)

In order to determine the level of stratification, temperature and salinity profile data will need to be collected at the three sites. It is a requirement that the three sites will record continuous measurements of vertical profiles of T/S using appropriate instrumentation, such as CT (Conductivity/Temperature) loggers attached to the moorings. The data would be used to ensure that the vertical density distribution used in the model is correct, and as a tracer for the calibration of modelled tracer distributions. These data, together with current data, will provide the basis for estimating the horizontal diffusion coefficient. Satellite imagery of SST may also be used to provide both input and calibration data.

2.5.4 Sediments

Knowledge of the sediment characteristics together with the wave and current information around the outfall site is important to understanding the near-field sediment dynamics. For this reason measurements of particle size distribution, turbidity and settling velocity distribution will be required at the outfall site for the near-field modelling and at the other two sites for input to the far-field sediment modelling. A comparison of these data with existing historical data (held by Gunns and Geoscience Australia for example) should be made to assess the accuracy of the historical data for input to the sediment modelling. Further measurements may be required at other sites to obtain a better representation of the sediment characteristics.

It is expected that state-of-the-art sediment sampling instrumentation will be used.

2.5.5 Water Quality

Background levels of certain water quality parameters should be known in the receiving waters at the outfall site and the other sites. Parameters include turbidity (TSS), DO, BOD_5, COD, AOX, Colour and Chlorate. Also background levels of 2,3,7,8-TCDD and 2,3,7,8-TCDF should be known in the sediments at the three sites. This information may already exist from measurement programs conducted by Gunns, but if not, new measurements will be required.

2.5.6 Meteorological Measurements

The hydrodynamic modelling requires the specification of surface winds and heat flux across the entire modelled domain. It has been suggested that the Bureau of Meteorology’s MesoLAPS forecasting system could provide these forcing fields. Other possibilities include NOAA’s NCEP wind and heat flux data and satellite derived QUIKSCAT wind data. An evaluation of the accuracy of these data should be made using suitable measured data if they exist. If not, a meteorological station should be established at a site that is representative of marine conditions, which could be at the coast or offshore. An offshore station is preferable but would be a more expensive option if no suitable coastal site were available. Parameters to be measured include wind speed and direction, barometric pressure, air and sea temperature, wet bulb temperature, dew point, relative humidity, and solar radiation.

It is very important that the station is located at a site that is representative of marine weather conditions, so, for example stations located in the Tamar Valley would not be suitable because of land influences.

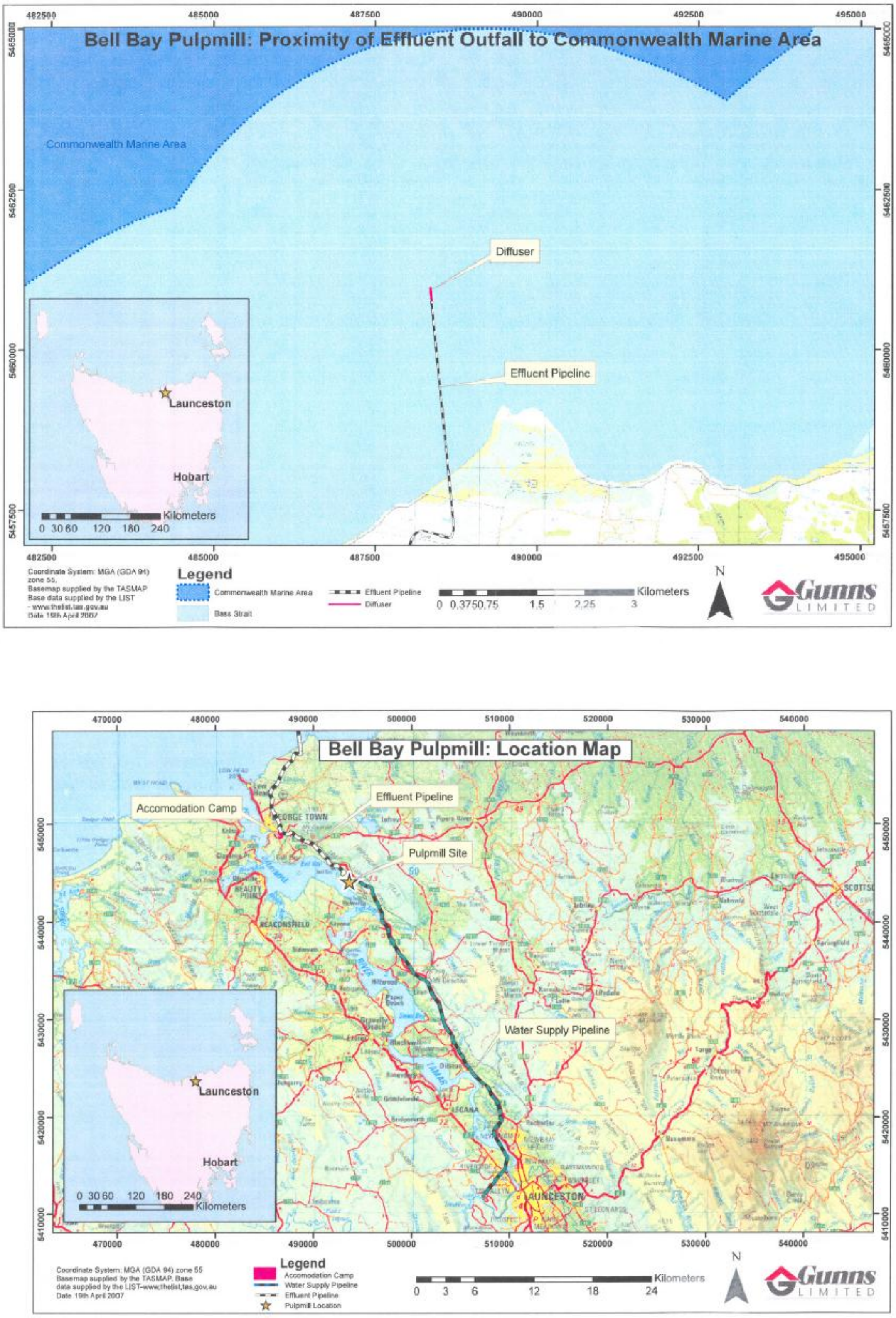

Figure 1: Location of the Pulp Mill (marked by the star) and the effluent outfall pipe.