APPLICATION OF VENTURI DIFFUSER DESIGN FOR HYPERSALINE WASTEWATER DISCHARGE INTO THE MARINE ENIVRONMENT

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INTRODUCTION

The discharge of hypersaline wastewater into the marine environment can be a challenging problem with respect to balancing the minimisation of environmental impacts and maximising cost efficiency across the lifetime of a project. When the density gradient between the discharge water and the receiving water is large, this gradient can dominate the nearfield mixing regime and result in a high-density, hypersaline layer at the seabed forming in the nearfield, and extending into the farfield, mixing zone. This layer can remain virtually undiluted once it extends past the zone of turbulent mixing in the nearfield region. This problem can be enhanced at sites with variable seabed bathymetry, including where dredged navigation channels may be present, resulting in a seabed layer that maintains high salinity over large spatial and temporal scales.

The analyses and diffuser design presented in the following sections are based on a project site located in the coastal waters off the Pilbara coastline in northwest Australia. The project is a greenfields high-quality salt and potash project that will generate a significant volume of bitterns wastewater with a salinity of 300 ppt (approximately). Over several years, numerical modelling studies have been completed to examine hydrodynamic and transport-dispersion processes related to the requirement to release bitterns by-product to be created by the project each year, via the use of a bitterns outfall. The numerical models used in the study were calibrated and validated to measured water level, current and wave data from key locations in the project region. For modelling of the dilution and mixing of the bitterns wastewater, analysis was undertaken using the CORMIX [1] nearfield model [1], and a high-resolution Delft3D [2] model using the Z-layer schematization option to define the vertical grid layers. A larger scale farfield Delft3D model with sigma-vertical layers was also applied to examine salinity changes over distances of up to 40 km from the project site.

This paper presents case study based practical insights into the hydrodynamics and transport-dispersion of hypersaline discharge in a shallow-water environment, along with the design of a venturi type diffuser to enhance the environmental performance in a shallow, coastal location.

CONVENTIONAL DIFFUSER DESIGN

The project design in the environmental approvals phase included a conventional multi-port diffuser to discharge the bitterns wastewater to the coastal receiving environment. It was a requirement that the diffuser be located within 250 m of the dredged navigation area boundary. Water depths surrounding the navigation area are shallow, at only 2 to 4 m, whereas the water depths in the navigation area are on average between 6.5 to 8.5 m. An initial assessment indicated that it was not practical to discharge the volume of wastewater in the shallower natural seabed areas, with the diffuser then specified to be located within the dredged area while considering the constraints of navigation and marine structures.

The conventional diffuser design was developed from nearfield modelling completed using the CORMIX model system. This model was applied with simplified assumptions regarding seabed bathymetry and ambient current flows to model mixing up to 250 m from the diffuser site. The environmental approvals criteria required that the wastewater achieve a 200-fold dilution at the boundary of the dredged navigation area, and a 300-fold dilution within 250 m of the dredged area.

The parameters of the conventional diffuser which achieved this nearfield environmental criteria included:

- 20 ports directed into the dredged basin along a 200 m diffuser line.
- Pre-mixing of bitterns wastewater with 5 parts marine water and 1 part bitterns to achieve discharge salinity of approximately 81.6 ppt.
- Port diameter of 0.155 m to achieve a discharge velocity of 2.5 m/s.

FARFIELD ENVIRONMENTAL MODELLING

Assessment of the dilution and dispersion of the pre-mixed bitterns product within the navigation channel, where the wastewater diffuser needed to be located to achieve environmental criteria, required that salinity, density, and the potential for vertical stratification be assessed via high-resolution modelling of the diluted bitterns wastewater along the length of the channel. A high-resolution Delft3D-Zlayer model that featured 8 m horizontal, and 1 m vertical (z-layer) grid resolution was developed, covering the length of the navigation channel and the potential spatial extents of any stratified flow conditions that may develop. Figure 1 presents a plan view of the model extent and bathymetry. The 200 m long diffuser was positioned along the eastern batter slope of the dredged basin, immediately east of the Berth Pocket location (see Figure 1).

The boundary conditions for the Delft3D-Zlayer model were obtained from a regional scale hydrodynamic model that had been calibrated and validated to measured water level, current and wave data collected in the study area. The boundary conditions from the regional model consisted of spatial water level boundaries along the western, northern, and eastern boundaries, with a spatial velocity boundary proscribed along the southern boundary.

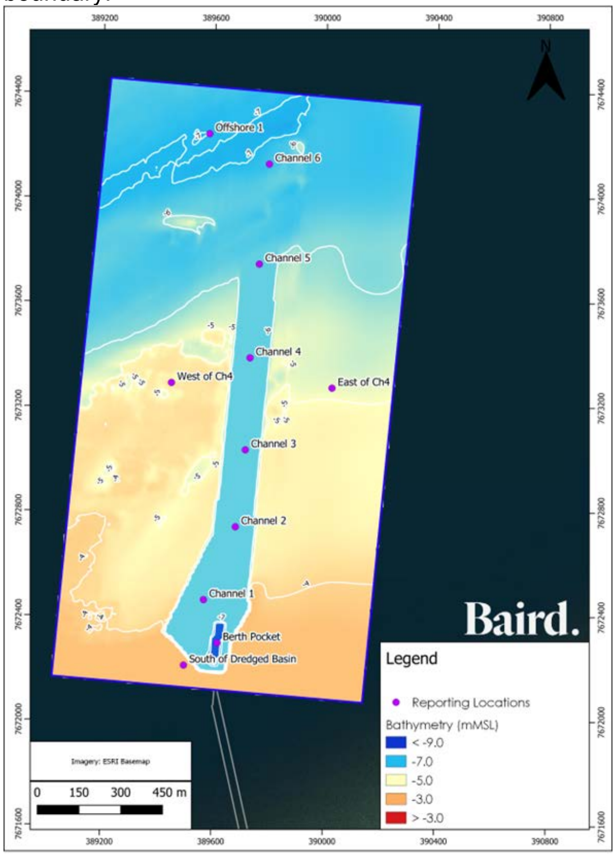

Figure 1 - Model extent and bathymetry for the Delft3D-Zlayer model.

The model adopted a constant horizontal eddy viscosity and diffusivity coefficient, and a k-ε vertical turbulence closure model. The effect of wave enhanced vertical mixing was evaluated using a combination of measured and hindcast wave data, and the wave enhanced vertical mixing model described in [3]. A constant vertical eddy viscosity and diffusivity coefficient of 5 x 10^{-5} m^2/s was adopted to represent typical ambient wave conditions at the site. This additional vertical mixing had relatively small impact on the transport and dispersion of higher-density residual bitterns at the seabed, in the lower levels of the water column.

Delft3D allows an alternative vertical turbulence scheme to be proscribed that includes calculation of the Ozmidov Length Scale. This Ozmidov Length Scale results in a horizontally and vertically varying enhanced vertical diffusivity term within the Delft3D model, according to Equation 1. The vertical density gradient is computed in each vertical layer and grid point of the model, for every time step.

- $$D_{3D} = \max\left(D_{3Dc},\ 0.2{L_{oz}}^2\sqrt{-\frac{g\delta\rho}{\rho\delta z}}\right) \quad (1)$$

where, D_{3D} is the is vertical eddy diffusivity coefficient, D_{3Dc} is the constant background value proscribed for background wave enhanced mixing, L_{oz} is the specified Ozmidov Length Scale, g is acceleration due to gravity, ρ is the water density and $\frac{\delta\rho}{\delta z}$ is the vertical density gradient calculated at the interface between each vertical layer in the model. The Ozmidov Length Scale was defined based on [4] which provided measured data on the length scales of internal wave enhanced mixing from an estuarine site where a salt wedge penetrates into the estuary, travelling close to the seabed. Based on [4], the Ozmidov Length Scale under moderate current forcing with a very stratified seabed salinity layer was measured at between 0.05 m and 0.1 m. A value of 0.075 m was adopted in this modelling.

The Z-layer model was applied to examine the transport of the high-density residual bitterns wastewater along the navigation channel and into the surrounding marine environment for a range of tide and seasonal conditions. The model results indicated that in spring tides, where tide range can exceed 4 m, the bitterns was well mixed, and a dense seabed layer did not develop beyond the immediate vicinity of the diffuser, as shown in Figure 2. During neap tides, a dense seabed layer flowed along the length of the navigation channel, but with complete mixing occurring within a short distance of the transition to the deeper (un-dredged) waters north of the dredged channel, as shown in Figure 3.

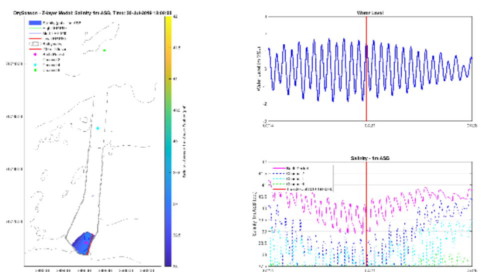

Figure 2 – Example of the spatial seabed salinity distribution under constant bitterns discharge during spring tides.

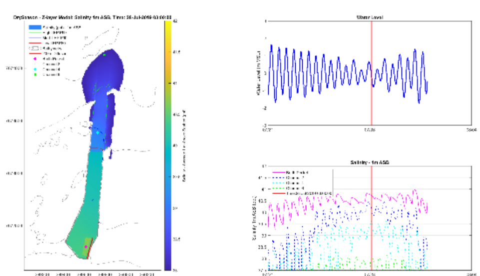

Figure 3 – Example of the spatial seabed salinity distribution under constant bitterns discharge during neap tides.

The Z-layer model results indicated that the diffuser design could achieve the farfield environmental criteria and was the key model used in reporting submitted to achieve environmental approvals by the Western Australia Environment Protection Authority (EPA) for the bitterns discharge.

VENTURI DIFFUSER DESIGN OPTION

The diffuser design which achieved environmental approval has significant capital and operating costs and large electrical power requirements associated with the need to pre-dilute the bitterns at a ratio of 5:1 with ambient seawater. A design optimisation study was subsequently completed for an outfall using a venturi brine diffuser design by ECOStec to improve the efficiency of the diffuser design by reducing pre-mixing requirements and improving the reliability of nearfield mixing during periods of low current flows and water levels. Modelling of the venturi diffuser option was completed using the methods described and validated in [5] and [6]. The venturi brine diffuser, consisting of a diffuser nozzle feeding into a diffuser head that increases the dilution rate within the diffuser via entrainment of ambient seawater (known as the venturi effect) produced by ECOStec's novel design, ensues a better mixing of the incoming brine with the ambient seawater than using a conventional diffuser, as shown in Figure 4.

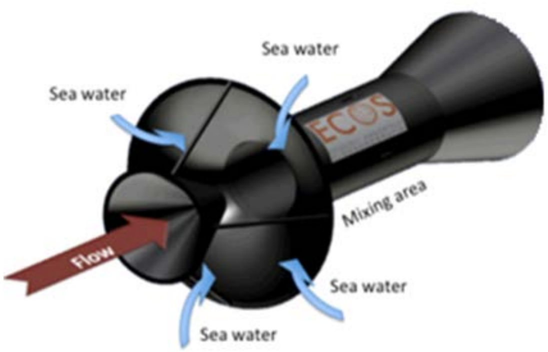

Figure 4 – Venturi Brine Diffuser - Sketch

As a result, a more diluted brine exits the diffuser head, having a lower impact in the marine ecosystem than a conventional diffuser port. An initial venturi diffuser design requiring 3 to 1 pre-mixing with ambient marine water via 6 venturi diffuser ports was identified as suitable for the site.

Following this initial investigation, the desire to achieve the same level of nearfield dilution and mixing with lower ambient pre-mixing requirements was identified. Further modelling and design refinement to increase the number of ports to 10 resulted in the required level of initial mixing being reduced to 2:1 ambient marine water to bitterns product. The horizontal and vertical characteristics of the bitterns plume in the receiving water were evaluated as shown in Figure 5 using results from the models proscribed in [5] and [6].

The final venturi concept design details were significantly more efficient than the conventional diffuser. The diffuser parameters which achieved the nearfield environmental criteria via use of venturi diffusers included:

- 10 ports directed into the dredged basin along a 74 m diffuser line.
- Pre-mixing of bitterns wastewater with 2 parts marine water and 1 part bitterns to achieve discharge salinity of approximately 125 ppt.
- Port diameter of 0.077 m to achieve a discharge velocity of 10.2 m/s.

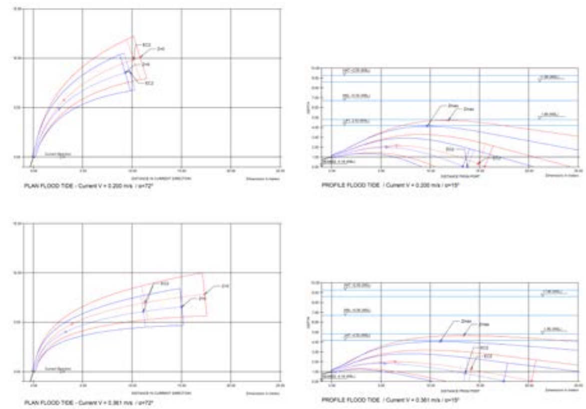

Figure 5 – Example of Hypersaline Plumes plan and profile per Diffuser Port.

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