FRIEDA RIVER

Frieda River Limited
Sepik Development Project
Environmental Impact Statement

Appendix 12b – Diffuser Modelling near Vanimo Harbour for the Sepik Development Project

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To:	Travis Wood	**Date:**	August 27, 2018
c:		**Memo No.:**	01_v2
From:	Alex Huang and Aurelien Hospital	**File:**	TRN.WTRM03106
Subject:	Diffuser Modelling near Vanimo Harbour for the Sepik Development Project		

1.0 INTRODUCTION

Coffey is preparing an Environmental Impact Statement (EIS) for the Sepik Development Project, which includes infrastructure and activities in Vanimo Harbour in Papua New Guinea (PNG).

Concentrate slurry will be transported 325 km by pipeline from a process plant at the Frieda River mine site to the Vanimo Ocean Port in Dakriro Bay, PNG. The slurry will be thickened and filtered at the port to produce the concentrate for export. Overflow water from the thickener will be used for washdown with the excess being treated for discharge to the environment in Dakriro Bay. Figure 1.1 shows Dakriro Bay, the Vanimo Ocean Port and the approximate location of the discharge point. This memorandum outlines a study that modelled the dispersion of the concentrate thickener overflow discharge into Dakriro Bay. This work was conducted by Tetra Tech for Coffey in support of the EIS.

This report assumes the discharge is via a multi-port diffuser. The suitability of the system will be assessed through meeting PNG ambient marine water quality standards. In this study, the horizontal distance from the discharge point at which the PNG ambient marine water quality standards will be met for two discharge scenarios is determined. The two scenarios and dilutions required to meet the PNG ambient marine water quality standards are as follows:

- Scenario 1: This scenario involves mechanical treatment to remove any solids to less than 50 mg/L. The discharge of this effluent requires a 55:1 dilution (i.e., 54 parts sea water to 1 part discharge) to meet PNG ambient water quality standards (based on dissolved copper).
- Scenario 2: This scenario involves mechanical treatment to remove any solids to less than 50 mg/L and chemical treatment to reduce metals concentrations to meet IFC mining effluent criteria (IFC, 2007). The discharge of a treated effluent requires a 10:1 dilution (i.e., 9 parts sea water to 1 part discharge) to meet PNG ambient water quality standards (based on dissolved copper).

To conduct this study, the US-EPA Visual Plumes model was used. The model is capable of simulating discharge from single and multi-port outfalls. The model is described in more detail in Section 2.

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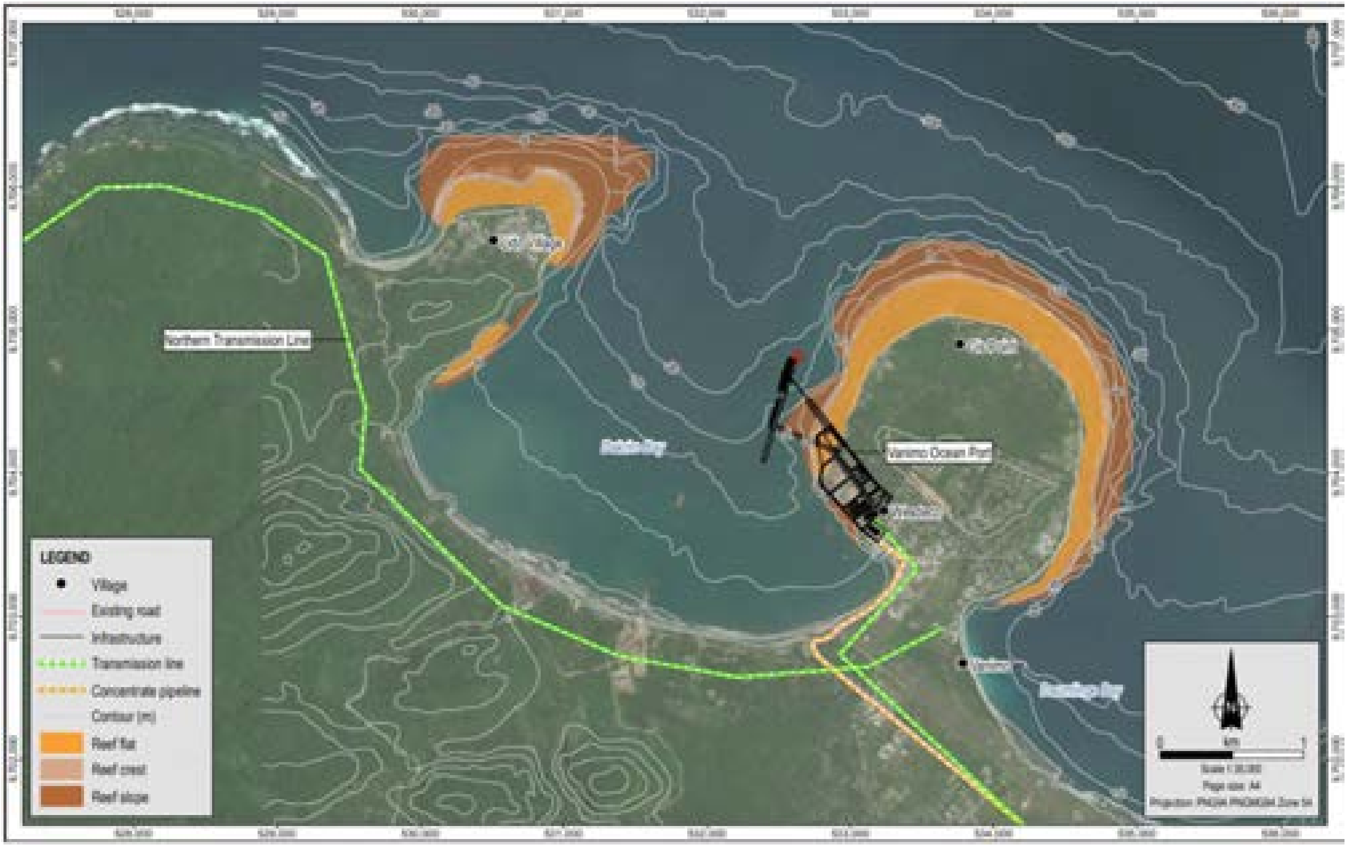

Figure 1.1 Location of discharge point (red circle) in Dakriro Bay (provided by Coffey)

2.0 METHODOLOGY

2.1 US-EPA Visual Plumes Model

Visual Plumes is a Windows-based model developed by the US-EPA for simulating surface water jets and plumes with the capability for mixing zone analysis. The model simulates single and merging submerged plumes in arbitrarily stratified ambient flow. The model outputs include dilution, rise, diameter, plume tracing, and other parameters. The model produces both textural outputs and graphical outputs.

The Visual Plumes user interface features five tabs: Diffuser, Ambient, Special Settings, Text Output, and Graphics. The Diffuser and Ambient tabs are used primarily to input project specific information. The Diffuser tab features several inputs for the discharge information as seen in Figure 2.1. The Ambient tab allows inputs to define the ambient conditions at the discharge location as seen in Figure 2.2.

Diffuser, Flow, Mixing Zone Inputs

Port diameter	n/r	Port elevation	Vertical angle	Hor angle	Num of ports	Port spacing	n/r	n/r	n/r	Acute mix zone	Chronic mix zone	Port depth	Effluent flow	Effluent salinity(*)	Effluent temp	Effluent conc
m	m	m	deg	deg		m	s	s	s	m	m	m	m3/s	psu	C	kg/kg
0.05		1	45	0	5	2				10	100	13	0.055	0	30	100

Figure 2.1 Diffuser information inputs for Visual Plumes

Ambient Inputs

Measurement depth or height	Current speed	Current direction	Ambient salinity(*)	Ambient temperature	Background concentration	Pollutant decay rate(*)	n/r	n/r	Far-field diffusion coeff
	depth	depth	depth	depth	depth	depth	depth	depth	depth
	constant	constant	constant	constant	constant	constant	constant	constant	constant
	constant	constant	constant	constant	constant	constant	constant	constant	constant
m	m/s	deg	psu	C	kg/kg	s-1	m/s	deg	m0.67/s2
0	0.309	180	30	30	0	0			0.0003
13	0.309	180	30	30	0	0			0.0003

Figure 2.2 Ambient inputs for Visual Plumes

Background theory on the model can be found in Muellenhoff et al., 1985, *Initial mixing characteristics of municipal ocean discharges. EPA/600/3- 85/073a and b*, as well as in Davis, 1999, *Fundamentals of environmental discharge modeling.*

2.2 Model Inputs and Assumptions

A multi-port diffuser offers the best potential for mixing, compared to a single port outfall such as a pipe. Based on Tetra Tech's past experience with similar systems, the follow parameters were selected for the diffuser configuration in order to maximize rapid dilution of contaminants after discharge:

- Five ports spaced 2 m apart
- Each port being 5 cm in diameter
- Angled at 45 degrees vertically, which should result in a higher dilution than a fully vertical diffuser, where the discharge effluent rises to the surface quickly.
- Diffuser is oriented in an approximate east-west orientation (horizontal angle of 0 degree in Visual Plumes), enhancing mixing with current directions likely oriented north-south, i.e. angled at 90° to the system.
- The depth of the diffuser is assumed to be at 13 m. This depth was selected based on the bathymetry as well as being at a depth below vessel draft but high enough above the seabed to limit scour of the seabed.
- The effluent flow is set to 55 L/s. This is the peak expected rate and was provided by Frieda River Limited (FRL).
- The effluent salinity is assumed to be 0 psu (as it is a freshwater discharge) and the temperature of the effluent is assumed to be 30°C.

For ambient conditions, 30 psu and 30°C are assumed to be the respective salinity and temperature in Dakriro Bay. Effluent accumulation was not considered, and background contaminant concentrations are assumed to be zero.

2.3 Sensitivity Analysis

There is limited information on the physical oceanographic conditions in Dakriro Bay. The most relevant source of information for this modelling study was the Sepik Development Project Vanimo Ocean Port Marine Ecology Baseline Report (BMT, 2018). This report provided information on wind statistics and water column profiles.

This section outlines the various sensitivity analyses used in the modelling, which cover a range of environmental conditions.

Since the study area, i.e., Dakriro Bay, is a relatively small bay, about 3km x 2km, with only one opening on the north, a series of simulations were undertaken in order to address the uncertainties associated with the environmental conditions of the bay and cover the potential range of currents that would influence the dispersion of the discharge. Several simulations were performed for two current types: wind-driven currents and tide-driven currents.

Wind-driven currents were based on the wind rose provided by the Sepik Development Project Vanimo Ocean Port Marine Ecology Baseline Report (BMT, 2018), itself provided by the NOAA CFSR modelled hindcast conditions at Vanimo Harbour.

Sensitivity Analysis 1 investigated the effect of a typical 3% wind speed applied to the surface layer, with a returning current in the opposite direction applied to the bottom layer of the water column. For this sensitivity analysis, the water column was divided into 5 equal-sized bins. The current speed for the top two bins are respectively 3% and 1% of the maximum wind speed. The middle bin was considered with no current, while the bottom two bins have a current speed of 1% and 2% of the maximum wind speed but in the opposite direction, hence creating a return current.

Sensitivity Analysis 2 investigated a case with no current. Due to a 0 m/s current, there was no need to consider different current directions.

Sensitivity Analysis 3 simulates the case of an equal wind forcing applied to the whole water column, considered to be 3% of the maximum wind speed. This case is very conservative, as the wind stress itself would not have the ability to move the entire water column.

Lastly, a simulation was conducted with a lower wind speed, to account for existing but weak currents.

Three directions for the currents were considered: 0º, aligned with the diffuser; 90º, aligned perpendicular to the diffuser; and 180º, aligned with the diffuser, but in the opposite direction to the first case. Due to the orientation of the ports (45º to the vertical), the 180º current direction results in currents being opposite to the direction of the discharge effluent. Table 3.1 summarizes the results for the wind-driven cases.

To assess currents generated by the tide, an estimation of the speed required to generate an approximate average tide of 0.7 m (from *Mobile Geographics*), was calculated at the northern boundary of the domain. This current speed was determined to be about 0.013 m/s. To account for approximation in this calculation, but also to provide an upper bound, a current of 0.026 m/s (i.e., double the speed required to generate a 0.7m tide) was also considered. The current is assumed to be constant through the water column. The results are presented in Table 3.2 for the tidal cases.

3.0 RESULTS

The results for each sensitivity analysis mentioned in section 2.3 are tabulated and summarized in Tables 3.1 and 3.2. The horizontal distance required to reach the 10:1 and 55:1 dilution is indicated in each column. The largest distances to reach the 10:1 and 55:1 dilutions are 2 m and 8.8 m respectively and are observed in Sensitivity Analysis 3, where 3% of the maximum wind speed is applied to the entire water column (see red text in Table 3.1).

Table 3.1: Modelling Results for Wind-Driven Current Sensitivity Analyses

	Wind-Driven Current Forcing			
Direction of current compared to diffuser orientation (degrees):	**Sensitivity Analysis 1: Current Speed: 0.309 m/s (3% of max wind applied on the water surface)**	**Sensitivity Analysis 2: Current Speed: 0 m/s**	**Sensitivity Analysis 3: Current Speed: 0.309 m/s (3% of max wind applied to the entire column)**	**Sensitivity Analysis 4: Current Speed: 0.001 m/s (weak current)**
0	10:1 at 0.6 m from source; 55:1 at 0.6 m from source; *Plume surfaces 2 m from source*	10:1 at 1.5 m from source; 55:1 at 5.3 m from source; *Plume surfaces 6 m from source*	**10:1 at 2 m from source**; **55:1 at 8.8 m from source**; *Plume surfaces 43 m from source*	10:1 at 1.7 m from source; 55:1 at 5.2 m from source; *Plume surfaces 6 m from source*
90	10:1 at 1 m from source; 55:1 at 5.5 m from source; *Plume surfaces 11 m from source*	N/A	10:1 at 1 m from source; 55:1 at 6 m from source; *Plume surfaces 21 m from source*	10:1 at 1.7 m from source; 55:1 at 5.2 m from source; *Plume surfaces 6 m from source*
180	10:1 at 1.7 m from source; 55:1 at 6.5 m from source; *Plume surfaces 14 m from source*	N/A	10:1 at 0.5 m from source; 55:1 at 5 m from source; *Plume surfaces 35 m from source*	10:1 at 1.7 m from source; 55:1 at 5.2 m from source; *Plume surfaces 6 m from source*

N/A denotes 'not applicable' because with zero current there is no need to consider different current directions

Table 4.2 Modelling Results for Tidal-Driven Current Sensitivity Analyses

	Tidal Current Forcing	
Direction of current compared to diffuser orientation (degrees):	**Sensitivity Analysis 5: Current Speed: 0.026 m/s (constant current through entire column)**	**Sensitivity Analysis 6: Current Speed: 0.013 m/s (constant current through entire column)**
0	10:1 at 1.7 m from source; 55:1 at 6 m from source; *Plume surfaces 8 m from source*	10:1 at 1.5 m from source; 55:1 at 5.6 m from source; *Plume surfaces 7 m from source*
90	10:1 at 1.5 m from source; 55:1 at 4.5 m from source; *Plume surfaces 6 m from source*	10:1 at 1.5 m from source; 55:1 at 4.9 m from source; *Plume surfaces 6 m from source*
180	10:1 at 1.7 m from source; 55:1 at 3.8 m from source; *Plume surfaces 5 m from source*	10:1 at 1.5 m from source; 55:1 at 4.5 m from source; *Plume surfaces 5 m from source*

Note that the distances listed in the tables are horizontal distances, not absolute distances.

Two limitations are associated with this modelling approach. First, the US-EPA Visual Plumes software does not account for accumulation over time. This means that, if the natural flushing of Dakriro Bay by wind and tide forces did not occur on a regular basis, hence resulting in stagnant areas, these stagnant areas could see accumulation of effluent, resulting in concentrations greater than calculated in this study. The second limitation is related to waves. Wave conditions are significant in Dakriro Bay, with an average of about 0.6 m during the May-September period, while during the surf season (November-March), wave height reaches about 1.2 m in average. However, wave conditions cannot be incorporated in the model. In other words, the mixing energy generated by waves is considered as nonexistent in the model. Since the mixing generated by waves would enhance the dilutions during most of the year, the modelling study presents conservative results.

Based on this study, the selection of a 10 m radius from diffuser as the mixing zone would be a conservative choice in order to meet PNG ambient marine water quality standards.

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5.0 REFERENCES

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6.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

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