Assessment of sediment deposition and re-suspension behaviour of tailings

Trans Tasman Resources Limited
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APPENDIX A: MEMO PHASE 1 RESULTS NEAR FIELD DISPERSION TAILINGS PLUME, SVASEK HYDRAULICS. .... 15
1 Introduction

Trans Tasman Resources Limited (TTRL) has requested IHC Mining Advisory Services (IMAS) to give specialist advice on the behaviour of sediment tailings arising from the South Taranaki Bight Iron Sands Mining project in New Zealand (ref. scoping document 20130429 Sediment Behaviour scope V4). IMAS has requested MTI Holland and Svasek Hydraulics to perform the preliminary study requested by TTRL. For this task, IMAS submitted a proposal to TTRL on 14 May 2013 (ref. M10002.0001).

The scope of this task includes two stages:

- Part 1: Analysis of tailings concept and evaluation of model capabilities (MTI Holland Memo M013-153 and current report)
- Part 2: Estimation of sediment source from tailings and advice on effects of mining and discharge methods.
2 Approach

The objective of the task ‘assessment of sediment deposition and re-suspension behaviour of tailings’ is twofold:

1) To gain more insight on the backfilling process of the tailings in the mined out area and possible effects on the proposed mining method, i.e. the crawler operation.
2) To make a first order estimate on the deposition of the tailings and re-suspension of the fine sediment as the primary sediment source to be used in an environmental assessment.

The behaviour of the tailings plume in the near-field zone from the tailings pipe is studied by a detailed 3D CFD (Computational Fluid Dynamics) Navier Stokes solver, turbulence is included by the LES (Large Eddy Simulation) technique using the WALE subgrid-scale model. The model includes variable density, hindered settling for cohesive fractions and interaction with seabed by erosion and deposition of both cohesive and non-cohesive sediment fractions. The 3D CFD solver is validated against experimental data and reference simulations for a wide range of hydraulic applications, including suspended sediment, deposition, jet and plume in cross flow.

For further description of the model set up see Appendix A: MEMO Phase 1 results near field dispersion tailings plume by L. de Wít, Svasek Hydraulics.
3 Near field model input

TTRL provided IMAS with initial input for setting up the Near field 3D CFD model. The complete input data is presented in Appendix A. Specific assumptions on the input data are:

**Ambient conditions:**
- Ambient current is assumed constant over the vertical, no log-profile. This velocity corresponds to the maximum near seabed current velocity, given by TTRL and reported in Oceanographic measurements data report (NIWA, August, 2012).
- Ambient viscosity \( \nu = 1.6 \times 10^{-6} \text{ m}^2/\text{s} \) (given water temperature at the sea bottom was 5˚C). This temperature value is not reported in NIWA (2012)\(^1\).

**Tailings release**
- Release pipe inner diameter \( D = 1100 \text{ mm} \)
- Average specific gravity tailings \( 3.0 \text{ t/m}^3 \)
- Mass concentration 70% (equivalent to volume concentration 44.5%). Therefore, mixture density is calculated as 1907 \( \text{kg/m}^3 \).
- Slurry flow is calculated as \( 1.4464 \text{ m}^3/\text{s} \)
- Pipe outflow calculated velocity \( W = 1.522 \text{ m/s} \)
- Fines content in tailings sediment mixture (\(<63 \mu m\)) was estimated as 4.55\%, based on the passing percentage given by TTRL on May 14, 2013. For the current simulations, the distribution over the fractions of the finest sediments (\(<38 \mu m\)) is not included as information on this was not available.
- Four fractions are determined, based on the PSD provided by TTRL:

<table>
<thead>
<tr>
<th>Flux</th>
<th>Particle size</th>
<th>( d_{50} ) (( \mu m ))</th>
<th>Cum %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0&lt;d&lt;38µm</td>
<td>19</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>38µm&lt;d&lt;63µm</td>
<td>50</td>
<td>4.55</td>
</tr>
<tr>
<td>3</td>
<td>63µm&lt;d&lt;283µm</td>
<td>218</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>283µm&lt;d&lt;2.8mm</td>
<td>384</td>
<td>100</td>
</tr>
</tbody>
</table>

**Interaction sediment with bed**
- For deposited material, erosion of the fine cohesive sediment is dependent on the assumed erosion constant and critical bed shear stress. The constants used (erosion constant \( M = 5 \times 10^{-4} \text{ kg/sm}^2 \), and the critical bed shear stress constant \( \tau_c = 0.15 \text{ N/m}^2 \)) account for large resuspension and therefore resulting in an upper bund estimate of the SSC in the tailings plume.
- The model does not include update in bed level. The short simulation times for the model, however, allow for an accurate result on the deposition and resuspension of sediment.
- The model includes resuspension of fine cohesive sediments already deposited.

**Simulation time**
- The results of the model are given in a 2 minute time average. A new average result is obtained every 8-10 minutes.

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4 Near field model scenarios

Three scenarios are used to study the dispersion and deposition behaviour of the sediment plumes from the tailings in the near field of the pipe outflow. Additionally, the results of all the scenarios, at x=200 m from the pipe outflow, are used for the schematisation of the sediment source for the far field modelling.

The scenarios vary on a) water depth, b) flat bed or representation the slope of the mining pit, and c) distance between tailings outflow and seabed level. The following scenarios are carried out:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Water depth (m)</th>
<th>Seabed topography</th>
<th>Distance (vertical) pipe outflow</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>Flat seabed</td>
<td>4 m from seabed</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>Pit slope (35°), 5 m deep (30 m downstream)</td>
<td>4 m from seabed</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>Pit slope (35°), 5 m deep (30 m downstream)</td>
<td>9 m from seabed</td>
</tr>
</tbody>
</table>

Scenario 1, with a flat seabed and 4 m vertical distance to the discharge, represents a discharge location more than 200 m from the edge of the pit or discharge at an already filled pit.

Scenario 2 and scenario 3, with a pit slope and variable vertical distance to the pipe outflow, represent the discharge in an empty pit near its edge. The objective of these two scenarios is to gain insight on how the seabed features of the pit and the vertical distance of the pipe outflow could affect governing processes in the near field plume dispersion (e.g. effect on the density driven mixture flow by vertical mixing or water entrainment).
5 Near field deposition and dispersion of tailings plume

Three output locations (cross sections) on the horizontal distance from the pipe outflow were selected:

a) $x=10 \text{ m}$, this location is suitable to assess the immediate deposition and stirring processes within a few meters from the outflow pipe;
b) $x=50 \text{ m}$, this location is used to assess deposition, mainly from the coarser sediment fractions and to determine to what extent they could interfere with the crawler operation;
c) $x=200 \text{ m}$, this output location is suitable to assess technical implications of the tailings for the operation of the crawler as well as to determine the sediment source for the mid- and/or far-field modelling.

The preliminary results are assessed in terms of Suspended Sediment Concentrations (SSC), in mg/l and deposition rate ($D$) in mm/min.

5.1 Scenario 1

The time averaged results simulated for scenario 1 (Appendix A, Figure 4.1) show that initial deposition occurs around the pipe. The high density mixture discharge induces plume radial dispersion around the outflow of the tailings pipe, but the axial dispersion upstream is limited by the direction of the ambient current. Vortex shedding occurs immediately downstream of the pipe stirring up sediment up to 10 meters above the seabed. In the first 10 m downstream of the pipe outflow (Appendix A, Figure 4.2), nearly 45\% of the total tailings flux would deposit. Sediment in suspension can be found up to 10 m above the seabed with concentrations of 25-50 mg/l. High SSC (1000 mg/l) can be found at around 5 m above the seabed.

In the first 50 m downstream of the pipe outflow (Appendix A, Figure 4.3), nearly 95\% of the total tailings flux would deposit. This deposition accounts for nearly 100\% deposition of flux 4 and flux 3 and 55\% of flux 2. Nearly 95\% of flux 1 and 50\% of flux 2 stay in suspension, causing SSC of 25-100 mg/l between 10 m and 15 m above the seabed.

At location $x=200 \text{ m}$ (Appendix A, Figure 4.4), nearly 98\% of the total flux would deposit. It could be inferred that the maximum expected SSC around 5 m above the seabed is 25-50 mg/l. At this location, maximum deposition (finest fraction) is 0.04 mm/min, 0.03 mm/min for the finest fraction.

Figure 1 shows the average deposition rate in the near field for scenario 1. Lateral deposition (in the first 50 m downstream of the pipe outflow) is limited by the boundaries of the computational area and therefore boundary areas should not be used for drawing conclusions. For the fine fractions ($d_{50}=19 \mu m$ and $50 \mu m$) deposition rates are homogenous within the first 100 m from the pipe outflow ($0.1-0.5 \text{ mm/min}$) and between $x=100 \text{ m}$ and $x=150 \text{ m}$ ($0.05-0.1 \text{ mm/min}$). The deposition rate for the coarser fractions ($d_{50}=218 \mu m$ and $384 \mu m$) are well differentiated as the flow advances. In the first 50 m from the pipe outflow the deposition rates varies from $>100 \text{ mm/min}$ to $1 \text{ mm/min}$. From $x=50 \text{ m}$ to $x=100 \text{ m}$ the deposition rate of the coarse fractions is similar to the deposition rate of the fine fractions ($0.1-0.5 \text{ mm/min}$). From this figure it can be inferred that the vortex shedding behind the vertical pipe has influence in the dispersion of fines and that reduced flow velocity ($<0.5 \text{ m/s}$) behind the pipe has influence in the settlement of the coarse fractions (see Appendix A, figures 4.2-4.4: horizontal velocity).
5.2 Scenario 2
The time averaged results simulated for scenario 2 (Appendix A, Figure 4.6) show that more stirring of sediment occurs downstream of the pipe than compared with scenario 1, possibly due to the interaction with the seabed and the pit slope.

In the first 10 m downstream of the pipe outflow (Appendix A, Figure 4.7), nearly 55% of the total tailings flux would deposit. Sediment is brought into suspension up to 5 m above the seabed with concentrations of 25 mg/l. High SSC (1000 mg/l) can be found in the first couple of meters above the seabed.

In the first 50 m downstream of the pipe outflow (Appendix A, Figure 4.8), nearly 95% of the total tailings flux would deposit. Similar to scenario 1, this deposition accounts for nearly 100% of flux 4 and flux 3. Nearly 45% of flux 2 and 10% of flux 1 would deposit. More dispersion occurs than for scenario 1, hence higher SSC concentrations (2500 mg/l) are encountered at around 5 m above the seabed.

At location x=200 m (Appendix A, Figure 4.9) Nearly 100% of the total flux would deposit. Maximum SSC around 5 from the seabed is expected to be 250 mg/l, minimal lateral dispersion occurs (30 m around the pipe) compared to the 60 m dispersion around pipe for scenario 1. At this location, maximum deposition is 0.04 mm/min, 0.018 mm/min for the finest fraction.

Figure 2 shows the average deposition rate in the near field for scenario 2. Lateral deposition (in the first 50 m downstream of the pipe outflow) is limited by the boundaries of the computational area. The fine fractions (d50=19µm and 50µm) deposition rates are homogenous within the first 50 m from the pipe outflow (0.1-0.5 mm/min), it varies between 0.05-0.5 mm/min between x=50 m and x=100 m and it is homogeneous again between x=100 m and x=150 m. The deposition rate in the first 50 from the pipe outflow for the coarse fractions (d50=218µm and 384µm) are well differentiated as the flow advances, similar than for scenario 1. The deposition rates varies >100 mm/min to 1 mm/min. From x=50m to x=100 coarse sediments continue depositing at a rate of 0.1-0.5 mm/min. From x=100m to x=150m the deposition rate of the coarse fractions is similar to the fine fractions (0.05-0.1 mm-min). It can be inferred that the vortex shading behind the vertical pipe has influence on the dispersion of fines. Higher flow velocity than in scenario 1 (see Appendix A, figures 4.7-4.9, horizontal velocity), may cause an increase the extension of the deposition area.
5.3 Scenario 3
The main difference of scenario 3 is the higher location of the pipe outflow above the seabed, i.e. 9 m. (Appendix A, Figure 4,11) Larger dispersion occurs downstream of the tailings pipe. It is expected that more water entrainment and vertical mixing will occur, reducing the density of the sediment plume.

In the first 10 m downstream (Appendix A, Figure 4,12), nearly 40% of the total flux would deposit, in contrast to the nearly 55% of scenarios 2 and 3. Nearly 50% of flux 4 would deposit compared to 70% of scenarios 1 and 2. And, from flux 3, 30% would settle in contrast to 40% of scenarios 1 and 2. More lateral dispersion is observed compared with scenarios 1 and 2.

In the first 50 m downstream from the pipe outflow (Appendix A, Figure 4,13), nearly 90% of the total tailings flux would deposit. Nearly 100% of flux 4 and 80% of flux 3 would deposit. Similar SSC are observed at 5-10 m above the seabed (1000-2500 mg/l) than in scenario 2, but much higher than in scenario 1.

At location x=200 m (Appendix A, Figure 4,14) Nearly 98% of the total flux would deposit. Maximum SSC around 10 from the seabed is expected to be 100 mg/l. Lateral dispersion occurs around the pipe (40 m) compared to 60 m for scenario 1 and 30 m for scenario 2. At this location, maximum deposition is 0.09 mm/min, 0.01 mm/min for the finest fraction.

Figure 3 shows the average deposition rate in the near field for scenario 3. Lateral deposition (in the first 100 m downstream of the pipe outflow) is limited by the boundaries of the computational area. The fine fractions (d50=19µm and 50µm) deposition rates are homogenous within the first 50 m from the pipe outflow (0.1-0.5 mm/min). From location x= 50 m to x=100 m downstream, the average deposition varies from 0.05-0.1 mm/min. For the coarse fractions (d50=218µm and 384µm), the average deposition rate in the first 50 from the pipe outflow is much higher than for scenarios 1 and 2. From x=50m to x=100 coarse sediments continue depositing at a rate of 0.5-1 mm/min. From x=100m to x=150m the deposition rate of the coarse fractions is similar to the fine fractions (0.1-0.5 mm/min). Settlement of coarse sediments continue up to x=200m. For this scenario there is a significant influence of the lateral boundaries on the results, influencing the estimation of
fines deposition. Higher flow velocity than in scenario 1 (see Appendix A, figures 4.12-4.14, horizontal velocity), may cause an increase the extension of the deposition area.

![Deposition diagrams](image)

**Figure 3** Scenario 3: average deposition [mm/min] (2-minute simulation time)

**Left:** Fine fractions, flux 1 and 2. **Right:** Coarse fraction, flux 3 and 4

### 5.4 Implications for proposed block mining method

It is of interest to TTRL to assess the deposition of the tailings arising from the current mining plan and to study the implications for the proposed block mining as shown in Figure 4. The scope of this plume modelling study does not include assessment of the tidal variability, magnitude and direction of currents. Interpretation of results are subject to further analysis of the South Taranaki Bight flow field and of the project area. The results are representative for a one-direction maximum current velocity of 0.5 m/s.

For all of the three simulated scenarios, the maximum dispersion of both coarse and fine fractions occurs within 200 m downstream from the pipe outflow. The minimal distance between the crawler operation and the tailings release is estimated to be more than 250 m. Therefore it is expected that the dispersion of the coarse fractions will not interfere with the proposed mining method directly. However, as a result of the daily tidal currents the proposed direction of extracting the mining blocks should be from North East towards South West. This leaves a mined out area always NE of the mining blocks in which the tailings will be dispersed as shown in Figure 4.

It should be noted however that the maximum extension of this dispersion may be influenced by the tidal current velocity and direction as well as by meteorological conditions.
Swell $H_s$: 2-3 m

Tidal current $V_{max} = 0.5 \text{ m/s}$

Mined out pit (0)

Mining pit (1)

Mining pit (2)

Swell $H_s: >4 \text{ m}$ (4% of the time)

Figure 4 Scheme, block mining-discharge method
6 Source term for far field modelling

The 3D CFD model is used to determine the sediment source term for further far-field modelling and for environmental assessment of the proposed mining operation. Due to the numerical schematisation of the tailings pipe the tailings flux in the near field CFD model is 2.8% larger than in reality. Therefore all the fluxes computed are scaled back 2.8% to account for real fluxes. See Appendix A, section 5: Source term for far field modelling based on near field dispersion of tailings plume.

The source term is the fine sediment that is available for dispersion by local currents and flows. The source terms are used for mid- or far-field model computations in order to assess the dispersion of sediment plumes (mainly composed of fine fractions) and the effects that those could have in sensitive receptors.

To determine the source terms for NIWA’s far field model, two separate fluxes are calculated at 200 m downstream from the pipe outflow:

1) Sediment in suspension: this flux is calculated from the plume of the tailings discharge and the resuspension of fine cohesive sediments already deposited on the seabed (very small contribution). For this source term, the vertical distribution is given in Appendix A, figures 5.1-5.3.

2) Sediment deposited at the seabed: this flux accounts for the total deposition of the different fractions on the seabed and therefore cannot be considered yet as a source term for the mid- or far-field modelling. It is necessary to determine a mixing depth above the deposited sediment for determining the potential layer to be worked by local resuspension processes, especially for the fine fractions.

For the three scenarios, the following source terms are calculated:

6.1 Scenario 1
This scenario has the largest suspended flux for \(d_{50} = 19\mu m\). This is probably due to resuspension caused by the large near bed velocity in the density current (see Appendix A, figures 4.2-4.4)

<table>
<thead>
<tr>
<th>Particle size</th>
<th>(d_{50}) (µm)</th>
<th>Flux at x=200m in suspension (kg/s)</th>
<th>Flux at x=200m already deposited (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&lt;d&lt;38µm</td>
<td>19 µm</td>
<td>32 kg/s</td>
<td>26 kg/s</td>
</tr>
<tr>
<td>38µm&lt;d&lt;63µm</td>
<td>50 µm</td>
<td>0.85 kg/s</td>
<td>29 kg/s</td>
</tr>
<tr>
<td>63µm&lt;d&lt;283µm</td>
<td>218 µm</td>
<td>0.07 kg/s</td>
<td>878 kg/s</td>
</tr>
<tr>
<td>283µm&lt;d&lt;2.8mm</td>
<td>384 µm</td>
<td>0 kg/s</td>
<td>966 kg/s</td>
</tr>
</tbody>
</table>

6.2 Scenario 2
This scenario has higher suspended flux for sediments \(d_{50}=19\mu m\) and \(d_{50}=50\mu m\) than scenario 1. This is caused by the increased mixing induced by the pit edge.

<table>
<thead>
<tr>
<th>Particle size</th>
<th>(d_{50}) (µm)</th>
<th>Flux at x=200m in suspension (kg/s)</th>
<th>Flux at x=200m already deposited (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&lt;d&lt;38µm</td>
<td>19 µm</td>
<td>23 kg/s</td>
<td>35 kg/s</td>
</tr>
<tr>
<td>38µm&lt;d&lt;63µm</td>
<td>50 µm</td>
<td>3 kg/s</td>
<td>27 kg/s</td>
</tr>
<tr>
<td>63µm&lt;d&lt;283µm</td>
<td>218 µm</td>
<td>0.75 kg/s</td>
<td>877 kg/s</td>
</tr>
<tr>
<td>283µm&lt;d&lt;2.8mm</td>
<td>384 µm</td>
<td>0.01 kg/s</td>
<td>965 kg/s</td>
</tr>
</tbody>
</table>
6.3 Scenario 3
This scenario has higher suspended flux for sediments $d_{50}=19\,\mu m$ and $d_{50}=50\,\mu m$ than scenario 1. This is caused by the increased mixing induced by the pit edge.

<table>
<thead>
<tr>
<th>Particle size</th>
<th>$d_{50}$</th>
<th>Flux at x=200m in suspension</th>
<th>Flux at x=200m already deposited</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&lt;d&lt;38µm</td>
<td>19 µm</td>
<td>24 kg/s</td>
<td>34 kg/s</td>
</tr>
<tr>
<td>38µm&lt;d&lt;63µm</td>
<td>50 µm</td>
<td>4.0 kg/s</td>
<td>26 kg/s</td>
</tr>
<tr>
<td>63µm&lt;d&lt;283µm</td>
<td>218 µm</td>
<td>2.2 kg/s</td>
<td>875 kg/s</td>
</tr>
<tr>
<td>283µm&lt;d&lt;2.8mm</td>
<td>384 µm</td>
<td>0.01 kg/s</td>
<td>965 kg/s</td>
</tr>
</tbody>
</table>
7 Conclusions and recommendations

Model input

- The scenarios in this report present the results for the latest update of the PSD provided by TTRL in which the fine fraction content (<63µm) is assumed as 4.55%. In Memo M013-153, MTI Holland reported preliminary results for a different PSD accounting for fine fraction content as 14%. It can be concluded that due to the reduced amount of the fine fractions compared to the results of the prior Memo, reduced SSC is expected higher in the water column.

- The current results only account for the study of the deposition and resuspension of the fine fractions as described in PSD (<63µm: 4.55%). However, the sediment source arising for the cyclone post treatment on board and any other sources are not taken into account in this study. It is recommended to TTRL to revise the PSD for the fine fractions and to provide MTI Holland-Svasek Hydraulics with this information for detailed analysis.

- In Memo M013-153, the tailings discharge velocity was assumed as 1.28 m/s and in the current results this velocity was calculated as 1.52 m/s (downwards). This results in a higher slurry flux that influences the sedimentation and dispersion of the tailings flow in the near field of the outflow pipe.

Mining method

- As it was described in Section 5.4, current modelling results for the large sediment fractions indicate that no mayor influence is expected on the crawler operation. Further analysis on the flow field of the South Taranaki Bight flow field and of the project area (30-40 m depth) is recommended for a better assessment of current results.

Schematisation of sediment source

- The results presented in this report, Section 6, provide TTRL and NIWA with a preliminary source term to be used in mid- or far-field modelling. However, the following considerations must be taken into account:

  Source term a) Sediment in suspension: this source term is given at 200 m downstream of the outflow pipe; the vertical distribution profile is given and could be used for setting of mid- far-field model set up; the distribution over the fractions for sediment <63µm is currently not specified.

  Source term b) Deposited sediment: the fluxes provided in this report are not to be used as a source term for dispersion and erosion models without a prior analysis of the surface layer to be reworked by local flows. It is recommended to TTRL to assess the mixing layer depth for a proper estimation of the source term due to erosion at the seabed.
Appendix A: Memo phase 1 results near field dispersion tailings plume, Svasek Hydraulics