BEFORE THE ENVIRONMENTAL PROTECTION AUTHORITY
AT WELLINGTON

IN THE MATTER of the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012

AND

IN THE MATTER of a decision-making committee appointed to hear a marine consent application by Trans Tasman Resources Limited to undertake iron ore extraction and processing operations offshore in the South Taranaki Bight

EXPERT EVIDENCE OF MICHAEL DEARNALEY ON BEHALF OF TRANS TASMAN RESOURCES LIMITED

15 DECEMBER 2016
Contents

EXECUTIVE SUMMARY .................................................................3
INTRODUCTION ...........................................................................5
Qualifications and experience ...................................................... 5
Code of conduct ........................................................................ 5
SCOPE OF EVIDENCE .................................................................5
BACKGROUND ..............................................................................6
SOURCE TERMS AND SEDIMENT PROPERTIES ..............................10
Other sources of fine material from the mining operations ..............22
Requirement for numerical modelling .........................................25
NUMERICAL MODELLING OF HYDRODYNAMICS AND SEDIMENT TRANSPORT .................................................................25
SEDIMENT PLUME MODELLING ..................................................32
SUMMARY OF PREDICTED LEVEL OF EFFECTS ..............................40
PROPOSED MONITORING AND MANAGEMENT PROGRAMMES ........40
RESPONSE TO SUBMISSIONS .......................................................41
CONCLUSIONS ............................................................................47
APPENDIX 1 – RELEVANT PROJECT EXPERIENCE .............................50
APPENDIX 2 – TIME SERIES OF PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS .................................................................................................................56
EXECUTIVE SUMMARY

1. My evidence relates to the fine sediment plume that will be generated by the mining activity. In order to assess the impacts of this plume it is first necessary to consider how the plume will be generated and what amounts of material will be forming the plume. It is then necessary to understand the physical properties of the material that will form the plume so that the behaviour of this material in the longer term and within the wider environment can be adequately assessed. The results of processing trials by Trans-Tasman Resources Limited (TTR) and laboratory testing undertaken at HR Wallingford of the materials arising from these tests have provided this information.

2. In order to assess the consequences of the mining operation over time and in the wider environment of the South Taranaki Bight (STB) it is necessary to establish a robust numerical model that properly represents the important aspects of the hydrodynamic regime of the area. Such a model has been developed by the National Institute of Water and Atmospheric Research (NIWA). I have worked closely with the NIWA modelling team, providing updated source terms and reviewing the results and the report during preparation. I am fully confident that the model applied is a reliable tool with which to predict sediment transport in the STB and in particular the dispersion of the plume of fine sediment that will arise from the mining works.

3. The analysis of source terms shows that for every 50 million tonnes (MT) of sand mined from the seabed about 0.7 MT of fine sediment will be released from the mining area to be transported by the tides and currents through STB and eastward through Cook Strait. Dispersion of the plume to levels indistinguishable from background is predicted to
occur within STB with transit times through STB being 1-2 months.

4. The results of the plume modelling have been used to inform the environmental assessment which concludes that the effects of the plume will be moderate within 20km in the principle direction of the plume dispersion and within 3km otherwise. Closer to the coast (within 5km) the effect of project derived sediment will be insignificant as project derived sediment levels are not discernible relative to the naturally occurring background levels in the high energy coastal environment. The time varying nature of background sediment levels is significant. Over most of the area that can be influenced by the plume the occasional increases associated with the plume are within the envelope of naturally occurring sediment levels.

5. Programmes of baseline and operational monitoring have been proposed so that the sediment transport model can be refined and used during operations as part of the environmental management of the mining.
INTRODUCTION

Qualifications and experience

1. My name is Michael Dearnaley. I am the Chief Technical Director at HR Wallingford (HRW) in the United Kingdom (UK). I hold the degrees of Bachelor of Science (Geophysical Sciences) and Doctor of Philosophy (Oceanography) from the University of Southampton in the UK.

2. Over the course of my time at HR Wallingford (some 27 years) I have led pioneering research associated with field and laboratory measurement and numerical modelling of the properties of cohesive material (mud) and the release of fine material from different types of dredging and disposal activity.

3. I have provided advice to developers and regulators on dredging including the mining of gravels and sands from the sea, the disposal of dredged material to sea and the beneficial use of dredged material including reclamation.

4. Attached as Appendix 1 is a list of relevant projects that I have been involved in.

Code of conduct

5. I confirm that I have read the Code of Conduct for Expert Witnesses as contained in the Environment Court Practice Note dated 1 December 2014. I agree to comply with this Code. This evidence is within my area of expertise, except where I state that I am relying upon the specified evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

SCOPE OF EVIDENCE

6. In my evidence I address:
(a) Background to the project as it relates to matters associated with the fine sediment plume;

(b) Source terms and sediment properties associated with the fine material that will create the sediment plume;

(c) Numerical modelling of hydrodynamics and sediment transport;

(d) Sediment plume modelling;

(e) The predicted level of effects;

(f) Proposed monitoring and management programmes associated with the sediment plume; and

(g) Conclusions associated with the sediment plume.

7. I also consider matters raised in submissions.

BACKGROUND

8. Trans-Tasman Resources Limited (TTR) proposes to extract up to 50 million tonnes (MT) of seabed material per year, targeting the recovery of iron sand deposits. The project area is located between 22 and 36km off the coastline of South Taranaki in waters between 20 and 42m deep and extends over an area of approximately 65.76 km² (see Figure 1 below). The mining is anticipated to be undertaken to an average depth of about 5m. On average each year about 5km² of the seabed will be mined.
The extraction will be undertaken continuously from a large (335m in length) Integrated Mining Vessel (IMV) deployed continuously in the resource area. The mining will be undertaken by a remote controlled submersible connected to the IMV by umbilical and pipeline that will discharge the extracted material with seawater onto the IMV for processing into iron ore concentrate for export. The processing on board the IMV will remove approximately 10\% by volume of the material, the remaining de-ored sediments, approximately 45 MT per year will be returned back to the seabed within the previously excavated area via a controlled discharge system. The IMV is designed to extract and process seabed material at 8,000 tonnes per hour for an average of 6,200 hours per year.

The IMV will transfer the processed sea bed material by hydraulic discharge to a Floating Storage and Offloading Vessel (FSO). The transfer will use desalinated water which will serve to wash the chlorides from the ore during transfer from the IMV to the FSO. The desalination plant will operate
onboard the IMV using seawater drawn from the surface waters at the mining location. Up to 30,000 m³ of desalinated water will be required to be produced on a daily basis with an annual requirement of about 5 MT. On board the FSO the iron ore concentrate will be de-watered to a moisture content of 10% using hyperbaric disk filtration.

11. It is important to note that the mining process will remove and return material back to the seabed. There will not be large areas of the seabed left as holes or pits after completion of the extraction. There will however, be an area of elevated seabed created at the south western edge of each mining area as the extraction process commences and a depression at the north eastern edge where the pit is not completely backfilled. In his evidence Dr Iain MacDonald indicates that the mounds may be up to 10 m in height and the depressions up to 10 m in depth. This would occur if the mining process were to excavate to about 11m depth below the seabed surface.

12. The scale of the extraction and return of de-ored sediment makes the proposed project similar to other large scale dredging projects around the world. Most dredging projects involving this mass of material being removed from the seabed would be more complex, involving several large pieces of dredging plant working simultaneously and typically with the dredgers participating in a cycle of loading, transporting and discharging the material. Such projects might typically last for one to three years and be associated with a construction project. The scale and impact of such large scale projects and approaches to management of the works are well understood. The TTR project is different in that the activity is planned to take place over many years. The IMV is able to continuously operate on site with excavation and discharge of sediment happening in close proximity. This means that there is, at any
time, a clearly identifiable location from where fine sediment from the activities is being released. Compared to other large scale dredging activities this facilitates impact assessment and operational monitoring and control.

13. My evidence considers the impacts associated with the release of fine sediment from the mining activities. By fine sediment I mean material with particle size less than 38 microns. The consideration of fine sediment is most important because it is this fraction of material that settles most slowly and can therefore be transported the greatest distances from the project site.

14. Because the amount of fine sediment present in the seabed sediments to be mined is small (on average about 2.0% is less than 38 microns in size) the impact assessment can, in simple terms, be considered as what happens to the 1.0 MT of fine material that is removed and returned to the seabed in the project area on an annual basis. The sand will be returning to a sandy environment and will remain local to the mining area.

15. The environmental risks associated with the fine sediment released by the mining activity need to be considered against the context of the quantities of fine sediment naturally available for resuspension by waves and currents in the top few centimetres of the South Taranaki Bight, estimated to be about 20 MT, and the fine sediments discharged from the main rivers into the South Taranaki Bight, estimated to be about 12 MT per year (Hadfield and Macdonald, 2015)\(^1\). Given these magnitudes of fine material within and annually being fed into the environment, the sources from the mining activity are likely to only influence

---

\(^1\) Hadfield and Macdonald, 2015. Sediment Plume Modelling, NIWA, October 2015.
the offshore area, nearshore supply from the land will dominate the inshore fine sediment regime.

16. I led a review by HR Wallingford, commissioned by TTR in July 2014, that covered the following:
   - The source terms for the sediment transport model;
   - The near bed processes associated with the release of sediment;
   - The integrity of the flow model used to drive the sediment transport modelling; and
   - Sediment properties and associated assumptions used within the sediment transport modelling.

17. As a result of this review HR Wallingford were commissioned in September 2014 to undertake laboratory work and some detailed modelling of the near-field sediment transport processes, commissioned in November 2014. I was responsible for this work at HR Wallingford.

18. The work culminated in new source terms and parameterization of sediment properties for use in the NIWA sediment transport model (HR Wallingford, 2015). I have discussed the model and source terms extensively with NIWA over the period of our investigations and was able to have detailed discussion with NIWA staff during a visit to Wellington in September 2015. I reviewed and commented upon early drafts of Hadfield and Macdonald (2015).

**SOURCE TERMS AND SEDIMENT PROPERTIES**

19. In order to assess the impact of fine material being released from a dredging or disposal activity it is necessary to quantify the scale of the activity, in terms of the rates at which material is being disturbed or released into the environment.

---

2 HR Wallingford, 2015, Support to Trans-Tasman Resources – Source terms and sediment properties for plume dispersion modelling, October 2015.
Combining this with a knowledge of the environment within which the activity is proposed in terms of water movements (wind, waves and tide) and the natural sediment regime, it is then possible to establish the requirements for investigation to support the dredging design and impact assessment and ultimately dredging plans and associated monitoring.

20. In the case of the TTR mining proposal much of this work had been undertaken and had been subject to examination in the Hearing that took place earlier in 2014, before my involvement. My approach to advising TTR with respect to the refinement of their studies to support the new application has been to build upon the comprehensive investigation already undertaken by TTR in terms of the operational processing of the seabed material and through discussion with NIWA to refine some of the inputs used in their modelling and to recommend formats for presenting some of the results rather than fundamentally changing the assessment approach. An important consideration was to present results in such a manner that they could be readily compared with those presented in the previous application.

21. The main assessment tool used for considering the scale of impact of fine sediment released by the mining activity is the ROMS sediment transport model set up by NIWA (Hadfield and Macdonald, 2015) and I consider this to be an entirely suitable model to support the investigations. This model requires source terms which describe the release of material from the mining activity into the model at the location of the mining. The ROMS model is set up to cover a large area compared to the area where the mining will take place. Given this, it is necessary to consider in some detail how the source of material to be released from the mining operations can best be represented in the ROMS model so as to predict mid and far-field effects.
22. Firstly, there is a need to quantify the rate at which material will be introduced back into the water column after removal from the seabed; and secondly, there is a requirement to consider how physical processes associated with the rate of reintroduction and the actual seabed morphology arising from the mining activity will influence the source term and where in the water column it should be represented.

23. The mining activity is planned such that it will annually remove 50 MT of material from the seabed using a crawler equipped with suction head and water jets. The material will be hydraulically pumped to the IMV with seawater where it will be subjected to processing.

24. The processing will involve separation of the ore from the seabed material and seawater. This process results in the bulk of the de-ored sandy material (coarse sediment) arising with low water content, a discharge of 1.4m³/s with a total sediment discharge of 1,863kg/s. The fine sediment discharge will occur as a discharge of 8.8m³/s with a total sediment discharge of 86kg/s from the hydro-cyclone operation.

25. TTR have undertaken a comprehensive survey of the mining resource to establish an average in-situ size grading for the material to be mined (see Section 2.2 of Impact Assessment)\(^3\). This is shown in the second column of Table 1. Based upon their investigations into the separation of the ore from the mined material TTR have estimated particle size distributions for the coarse and fine fractions of material. These are shown in the third and fourth columns of Table 1 below. The fifth column in Table 1 shows the weighted combination of these different sizes of material for the combined discharge.

\(^3\) TTR (2016). South Taranaki Bight Offshore Ironsand extraction and processing project, Impact Assessment, August 2016
Table 1: Size gradings of in-situ material to be mined and de-ored sediment to be discharged from the IMV

<table>
<thead>
<tr>
<th>Particle size (μm)</th>
<th>PSD of sediment (cumulative, %)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>In-situ sediment, to be mined</td>
</tr>
<tr>
<td>&lt; 8</td>
<td>0.8</td>
</tr>
<tr>
<td>8–16</td>
<td>1.3</td>
</tr>
<tr>
<td>16–38</td>
<td>2.0</td>
</tr>
<tr>
<td>38–90</td>
<td>3.0</td>
</tr>
<tr>
<td>90–125</td>
<td>5.1</td>
</tr>
<tr>
<td>125–150</td>
<td>9.0</td>
</tr>
<tr>
<td>150–212</td>
<td>26.9</td>
</tr>
<tr>
<td>212–250</td>
<td>40.5</td>
</tr>
<tr>
<td>250–355</td>
<td>69.8</td>
</tr>
<tr>
<td>355–500</td>
<td>86.6</td>
</tr>
<tr>
<td>500–710</td>
<td>93.9</td>
</tr>
<tr>
<td>710–2000</td>
<td>99.1</td>
</tr>
<tr>
<td>&gt; 2000</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The size distribution of these two classes of material is conservative in terms of fines content. The analysis by TTR includes fines that may be released if mining were to also include removal of layers of more silty and clayey material that were encountered during the site investigations. One of the purposes of the grade control drilling programme is to enable optimisation of the mining activity to avoid such layers where practical. The result of encountering a silty clayey layer for any significant period would be a reduction in the rate of recovery of ore because the ore content of such layers is reduced. There is no incentive for TTR to mine in such areas as they are less economic.

Even with this conservative assumption regarding the fines content of the material to be dredged from the seabed, it
can be seen that most of the material returned from the IMV will be sandy material. The significant matter for the impact assessment is to quantify the amount of fine, slowly settling material that is released from the IMV and is then able to migrate away from the mining area within a plume. It is this source that is required as input to the ROMS sediment transport model.

28. The on-board processing operation has been carefully designed by TTR. It can process material at a maximum rate of 8,000 tonnes per hour. To maintain a consistent (optimum) rate of production the output from the crawler may at times vary but any increase will be stored in and released from built-in process “buffers” on-board the IMV, maintaining a consistent feed into the processing system. The combined discharge of the coarse and fine sediment discharges (see paragraph 24) is 10.2m$^3$/s with a sediment discharge of 1,949kg/s. This scale of sediment release is comparable to the discharge of sediment from the overflow of a large trailer suction hopper. I have been involved in projects monitoring such scales of release from mobile dredgers and this work informs how I expect the discharge to behave in the mining area.

29. As a result of our investigations I have recommended to TTR that these two discharges are to be re-introduced to the water column together with the point of release located near to the seabed. By releasing the discharge as a high density near bed discharge much of the material released will simply remain on the seabed as a result of the density differences between the overlying water and the water/solids mixture being discharged. By discharging the fine fraction with the coarse fraction the potential for the finer fractions to be buried within the pores between the sand grains as the sand settles onto the seabed is also increased. Both of these design elements; based on simple
physical processes, reduce the proportion of fines that may be released into the water column and therefore limit potential transport of fines away from the mining site into the wider marine environment.

30. It is noted that whilst the main source for release of fines into the water column is the return of de-ored material into the water column from the IMV, there are other additional sources, which include: the desalination process on board the IMV, the de-watering on-board the FSO, operation of the crawler; the regular re-location of the anchors of the IMV; the operation of the grade control drilling and disturbance of the seabed by regular benthic sampling as part of the monitoring programme. These potential sources would have been considered too small to be of significance previously (in the first application) but for completeness I consider them briefly in a later section of my evidence. A schematic sketch of the layout of a pit is shown in Figure 2. The mining unit will dredge a lane 24 m in width, an average of 5 m in depth, but potentially up to 11m in depth, moving along one edge of the pit at an average speed of around 35 to 70 m/hour. The IMV will move in tandem with the crawler unit, at the same speed controlled by winches on cables anchored to the sea bed. At the leading (north east) edge of the pit the mining unit will be removing sediment while at the south west edge the IMV will be placing de-ored sediments back into the pit. Thus the pit will “move” steadily in a north east direction during the operations. The pit is orientated in this manner so that the IMV is aligned into the main direction of waves. This maximises the operational window for the mining and enables mining to take place in most sea states.
31. It is expected that during most of the mining cycle the pit will have a length of 300 m which will be constantly maintained (though at the start of each pit mining operation, the pit will increase in length to 300 m). This 300 m constant distance is the approximate distance between the position of the seabed crawler unit and the point of de-ored sediment discharge from the IMV. During the initial construction of the pit, de-ored sediment will be placed back onto the seabed rather than into the pit being worked at the time. Once the pit is about 300m in length the de-ored sediment will begin to be discharged back onto the bed of the excavated pit rather than onto the existing seabed.

32. Whilst the length of the mining pit is fixed at about 300 m by the dimension of the IMV and relative position of the crawler, the width of the pit in the south east-north west direction may vary. The greater this dimension the less turning of the crawler unit at either side of the pit and the more efficient
the overall operation. It is assumed by TTR that the width of the pit will be 900 m on average.

33. During the mining operations de-ored sediment would be returned to the sea bed via the discharge pipe. The introduction of this sediment, which can have significant initial momentum, into the water column results in a body of water and sediment (plume), denser than the surrounding water that descends rapidly towards the seabed. This plume is referred to as the dynamic plume.

34. The dynamic plume collapses onto the bed to form a density current which will not initially mix with the overlying waters because of the density difference between this layer and the ambient concentrations of suspended sediment in the water column. Consequently the density current will spread radially outwards from the point it impinges on the seabed. The sediment in the density current will be in the form of individual grains and aggregates of finer grains referred to as flocs. The overall concentrations of sediment in the spreading density current will reduce the rate of settling of individual particles and flocs present ("hindered settling") because the sediment particles start to interact with the upward moving water associated with individual particles settling.

35. As the density current expands and sediment eventually settles out of this layer to the bed and the concentration of the layer is reduced, mixing occurs and the sediment left in the density current may be entrained into the waters above to form a suspension of sediment. This is the material that forms the so-called passive plume. By passive plume I mean the suspended sediment that is able to move and disperse in accordance with the motion of the water body. It is the physical processes associated with this passive plume that
the ROMS sediment plume model simulates (Hadfield and Macdonald, 2015).

36. As the IMV moves so slowly (up to 70 m per hour) across the pit, and as the pipe discharge is so close to the bed, the discharge from the pipes will, almost immediately upon release, create a density current which is a few metres thick. As a result the discharge is likely to spread over much of the pit, with the finest material spreading near bed as a suspension under the influence of the prevailing current (see Figure 6.2 of HR Wallingford, 2015). The sandy material will settle out closest to the point of discharge.

37. The settling of the slower settling fines fractions to the bed within the pit will be limited by the action of naturally occurring currents which will move sediment which has not settled within a certain time frame out of the pit. The finer sediment is also prevented from settling within the pit by wave action, although, at times, the presence of significant amounts of mud will change the frictional properties of the bed of the pit, creating smooth turbulent, rather than rough turbulent conditions and a near bed high concentration sediment layer (both of which act to damp turbulence), mitigating the stress from currents and waves within the pit reducing the amount of fines lost from the pit.

38. A series of laboratory experiments were undertaken by HR Wallingford using samples of material provided by TTR (Appendix A of HR Wallingford, 2015) to investigate how the fine material would behave in terms of its settling and resuspension properties. The locations where the samples were obtained are shown in Figure 3. The settling tests showed, as would be expected, that the finest fraction of the material did not simply settle as individual particles at very low speeds. Instead these fines are subject to significant flocculation, which combines the particles into larger settler
aggregates and results in a significant proportion of the mass of finer particles settling at speeds greater than would be attributed to the constituent particles in the floc. This is a natural physical process requiring no addition of chemicals.

Figure 3: Locations of samples supplied to HR Wallingford by TTR

39. Suspensions of material were investigated with concentrations of 10 mg/l and 100 mg/l in an annular flume. These concentrations were considered representative of the range of concentrations that might be expected in the near to mid field associated with fines released by the mining activity. A video image analysis system, LABSFLOC, was used to record the settling behaviour of flocs with a size in excess of 30 microns (Appendices A10 and A11 of HR Wallingford, 2015). Mean settling velocities for the floc populations were in the range 6 to 10mm/s, orders of magnitude higher than the settling rates of constituent fine particles.

40. Not all the mass of fines settled as flocs in the experiments and a small percentage of the material was found to settle very slowly. Around 4% settled with fall speeds less than 0.02mm/s and around 0.5% with fall speeds less than 0.005mm/s. It was however found that such slow settling material appeared to be readily combined into flocs if
additional fines were introduced into the settling chambers. The expectation is thus that most of the finest fraction will flocculate and settle more rapidly shortly after release into the marine environment and any fine material not initially flocculating may reasonably be expected to subsequently flocculate on encountering other fine material or organics. Professor Lawrence Cahoon makes an important point in his evidence that the additional effects of biological material are likely to further enhance the formation of flocs and thereby increase the proportions of the mass of fine sediment that settles to the seabed. This process is not something that has been included for in the modelling I describe.

41. I supervised another modelling team based in Wallingford who undertook detailed 3D and 1DV modelling of the fine sediment transport processes within the mining pit to examine the fate of material with different settling velocities (see Section 6 of HR Wallingford, 2015). The pit simulated was 300m in length and had a width of either 300m or 900m. The modelling showed that very little of a sediment fraction with a settling velocity of 0.01mm/s would be trapped in the pit (5% would be trapped). With this low rate of settling the material simply did not settle to the bed before being carried out of the pit by the ambient currents. For material settling at 0.1mm/s it was predicted that on average 25% of this fraction would be trapped if the pit were 300m wide and on average 50% if the pit were 900m wide. It was further established that virtually all of the fine material settling at 10mm/s would be trapped in the pit. Based on the modelled results it was assessed that for material settling with a velocity of 1mm/s about 90% would be trapped within the pit. With the starting assumption that there was 3.4% fines in the material being mined (equivalent to 1.7 MT/year). This source term analysis shows that more than half of these fines are trapped in the mining pit as it is refilled.
42. As a result of the settling tests and numerical modelling it was decided that for the purposes of the passive plume dispersion modelling in the ROMS model the fines mass could be represented as settling with velocities of 0.01mm/s, 0.1mm/s, 1.0mm/s with mass proportioned 30%, 63% and 7% respectively (see Table 7.3 of HR Wallingford, 2015). All of the fine material settling with velocities of 10.0mm/s was predicted to be trapped within the mining pit.

43. Annular flume experiments were also used to look at the resuspension properties of the fine material after it settled (see Appendix 12 of HR Wallingford, 2015). In these tests a circular flume was used with a rotating lid to create the effect of an infinitely long flume. The rotation speed of the flume was increased in steps to observe the current velocity, and therefore stress exerted on the deposited material in the flume, that was required to resuspend fine material from a settled bed. These tests established that for material deposited for between 45 to 48 hours (i.e. material that was able to undergo some consolidation and establishment of strength after settling) resuspension occurred with a bed shear stress of between 0.2 to 0.3N/m². For the purposes of the ROMS modelling the lower value was used to represent the stress required to resuspend all fine material, whether introduced by mining, discharged from the rivers or naturally within the offshore seabed.

44. The source terms used for the ROMS plume modelling are provided in Table 2.

Table 2: Source terms for sediment fractions used in the ROMS model
<table>
<thead>
<tr>
<th>Class</th>
<th>Source</th>
<th>Settling velocity (mm/s)</th>
<th>Critical stress (Pa)</th>
<th>Discharge rate (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>sand_08</td>
<td>Overflow</td>
<td>1.0</td>
<td>0.200</td>
<td>1.45</td>
</tr>
<tr>
<td>sand_09</td>
<td>Overflow</td>
<td>0.10</td>
<td>0.200</td>
<td>12.55</td>
</tr>
<tr>
<td>sand_10</td>
<td>Overflow</td>
<td>0.01</td>
<td>0.200</td>
<td>6.00</td>
</tr>
<tr>
<td>sand_11</td>
<td>Underflow</td>
<td>1.0</td>
<td>0.200</td>
<td>0.25</td>
</tr>
<tr>
<td>sand_12</td>
<td>Underflow</td>
<td>0.10</td>
<td>0.200</td>
<td>1.80</td>
</tr>
<tr>
<td>sand_13</td>
<td>Underflow</td>
<td>0.01</td>
<td>0.200</td>
<td>0.85</td>
</tr>
</tbody>
</table>

45. The average rate at which fines are introduced into the sediment transport model to represent the passive plume at the mining area during operations is the sum of the fifth column of Table 2, namely 22.9kg/s (equivalent to about 0.7 Million Tonnes per year). This contrasts with the mean inputs of fines from the riverine discharges of 373kg/s used in the model (which are equivalent to about 12 Million Tonnes per year - see Table 2.1 of Hadfield and Macdonald, 2015). Additionally already present on the seabed of the sediment transport model in the top 0.05m of the bed is a mass of about 20 Million Tonnes of fines some of which will be mobilised during periods of higher wave activity.

**Other sources of fine material from the mining operations**

46. The desalination plant on board the IMV will be producing up to 30,000 m$^3$ of water per day. This will require an intake of some 35,000 m$^3$ per day (equivalent to 0.4m$^3$/s, or 4% of the discharge rate from the IMV). This seawater is drawn in from the surface waters adjacent to the IMV. The typical suspended solids content of the water will be less than 1 mg/l and the fines associated with daily production less than 35kg per day. The fines will be contained on-board the IMV but if they were released at the same rate as they were extracted the source term would be less than 0.001 kg/s, which is negligible compared to the source term from the discharge from the IMV.
47. The iron ore concentrate will be slurried with desalinated water and pumped from the IMV to the FSO. This will reduce the chloride content of the ore. The iron ore concentrate will be dewatered on board the FSO. No chemicals or fines will be released from the FSO but the filtered transport water will be discharged back to the sea.

48. Experience during grade control drilling operations has shown that losses of fines during placement and operation of the rig and pumping of samples to the vessel are minimal. The footprint of seabed affected by the drill is reported as being about 4 m$^2$ and the volume of material removed by the 100 mm diameter drill up to 0.086 m$^3$. Up to 12 drill samples may be undertaken in a 24 hour period. If the seabed were impacted to a depth of 0.1 m over the drill footprint and all the fines therein released (approximately 20 kg) and all the fines in the drill volume sample were lost from the vessel during sample handling (approximately 4 kg), the maximum loss per sample could be about 25 kg, equivalent to up to 300 kg/day or 0.0035 kg/s (up to about 0.015% of the fines release from the mining and discharge operations, see Table 2).

49. The seabed crawler will be operating in the mining area. It is my view that once the discharge from the IMV is being directed back into the mined area much of the lowered bed in the mined area will be covered by a near bed suspension of very slowly settling fine material (see Figure 6.2 of HR Wallingford, 2015) that will eventually disperse from the pit forming part of the source of the fine sediment plume. If some of this suspension is pumped back to the IMV as part of the transport water for the mining operation and then returned back with the discharge it will not affect the overall source of fine material.
50. In addition to the recirculation of fines with the transport water, the crawler will be moving across the seabed over a lane width of about 24 m width at an average speed of 35 to 70 m/hour. If the seabed is on average disturbed to a depth of 0.1 m, over 2.6 m of this width by the tracks of the crawler and all the fines in the seabed (2.5%) are released into suspension within the mining pit the additional contribution of fines will be up to about 0.25 kg/s, which is about 1% of the fine sediment discharge from the IMV.

51. The release of disturbed seabed material (sediments) as a result of the relocation of anchors for control of the IMV will happen during and following installation of the anchors. The anchors are to be relocated approximately every 10 days. The IMV will operate using four anchors. If repositioning of each anchor can result in the disturbance of up to about 500 m$^3$ of seabed and all the fines in this material are released into near bed suspension on each occasion (approximately 25 tonnes per anchor) then the effect of repositioning the four anchors every ten days would be equivalent to an additional source term of up to about 0.1 kg/s in the vicinity of the mining area (equivalent to about 0.5% of the source term given in Table 2).

52. The release of seabed material (sediments) as a result of taking of sediment and benthic samples associated with environmental monitoring will be occurring over a large area, episodically at very low rates. Given the typical low fines content of the seabed it is unlikely that each sample would release more than 1 kg of fines during capture and retrieval. Assuming up to 50 benthic samples are obtained a day then this contribution to the source term is negligible (less than 0.001 kg/s).

53. It can be seen that consideration of additional sources of fine sediment releases from the operations confirms that
these sources are insignificant compared to the fine sediment discharge from the IMV.

Requirement for numerical modelling

54. On first inspection it is to be expected that plumes are likely to only be of significance local to the mining area. Inshore the natural suspended sediment concentration (SSC) and turbidity associated with the river discharge will dominate. However, without the aid of a numerical model, quantification of effect and consideration of spatial and temporal, including timescales of storms and seasonal sensitivities is not practical.

NUMERICAL MODELLING OF HYDRODYNAMICS AND SEDIMENT TRANSPORT

55. Numerical modelling of sediment transport in the marine environment requires appropriate representation of the hydrodynamic conditions over the study area. My review of the NIWA models in 2014 and subsequent discussions with the NIWA team in 2015 over the application of their models as described in Hadfield and Macdonald (2015) has given me confidence that the representation of hydrodynamic conditions over the 2 year assessment period used in the models is comprehensive and entirely adequate for the purposes of this impact assessment. I have been able to work with the NIWA team as they ran their model and processed the results and prepared reports in a similar way to how I work with project staff at HR Wallingford. I have given direction regarding presentation and matters for discussion in the report. However, one important aspect of the new modelling work was to present it in a format that enabled ready comparison with the results of the previous modelling.

56. NIWA have used the ROMS modelling suite for the studies. The flow model (Cook Strait model) covers a larger area...
than the sediment transport model in order to adequately define the time varying hydrodynamic conditions around the boundary of the sediment transport model. The model areas are shown in Figure 4. The sea area covered by the sediment transport model has been termed the Sediment Model Domain (SMD). The area of the SMD is approximately 13,000 km².

57. The horizontal resolution of the Cook Strait model is 2 km and that of the SMD model is 1 km. Sensitivity tests were undertaken for a sub area of the SMD model with a model with a 500 m grid. The models have 20 layers in the vertical which are distributed proportionately through the water column with respect to the total water column depth (see Appendix A of Hadfield and Macdonald, 2015). The layers are distributed so as to have greatest resolution near surface and bed.

Figure 4: ROMS model domains: Outer, Cook Strait, (flows only) and Inner (flows, waves and sediment)
58. The simulation period for the hydrodynamic modelling is 1,000 days in duration and the results of the simulation over the last 730 days (which correspond to 21 March 2011 to 20 March 2013) are used for assessment. The first 270 days of the simulation are used for the hydrodynamic conditions and also the background sediment transport to become established. The hydrodynamic modelling includes for time varying river discharges over the simulation period. The mean discharge of the combined rivers into the model was 593 m$^3$/s.

59. The ROMS hydrodynamic model has been calibrated and validated against a variety of data collected by NIWA. Comparisons of the numerical model against the measured data are provided in Chapter 3 and Appendix B of Hadfield and MacDonald (2015).

60. The long term residual flows are shown in Figures 5 and 6 and these show a well-defined north eastward moving residual flow pattern across the Taranaki Bight passing to the south of the proposed mining site and eastward and then southward flow around the eastern part of the SMD.

Figure 5: Residual flow pattern in the Cook Strait model
Figure 6: Residual flow pattern in the Sediment Model Domain (SMD)

61. The short term flow patterns within the SMD are less well defined over periods of a few days and can be influenced by wind driven fluctuations in the currents. This can result in short term residual currents over the resource area being landward or stationary, all of which can then influence fine sediment plume behavior.

62. The sediment transport model of background conditions includes time varying sediment inputs from the rivers with a mean of 373 kg/s (equivalent to about 12 MT/year). This river derived sediment was represented as being coarse silt and fine silt/clay characterized with settling velocities of 0.63 and 0.01 mm/s respectively. The critical shear stress for resuspension of fine material was set to 0.2 N/m², consistent with the results of HRW flume testing. The material initially distributed over the seabed of the model domain was a mixture of five sediment classes including the two classes introduced from the rivers. 2% of the seabed was represented as fine material similar to the riverine derived sediment. The remainder was fine, medium and coarse sand with settling velocities of 6.3 mm/s, 38 mm/s and 103 mm/s and proportions on the sea bed respectively of 6%, 72% and 20%. This distribution of sediment on the seabed was fine
tuned to improve baseline predictions of near surface suspended sediment concentrations in the nearshore area.

The important point about the different sediment fractions is that the fastest settling fractions require a greater force from the combined effects of currents and waves to be mobilized and also when in suspension, remain closer to the seabed. The finest, most slowly settling fractions can become well mixed throughout the water column and can therefore travel further after being resuspended from the seabed with only a small proportion of the mass of the most slowly settling material contained in the water column being able to settle onto the bed during periods of reduced flow.

Figure 7: Comparison of baseline suspended sediment model results with observations derived from turbidity measurements at nearshore site 13 (Waitotara River)

The sediment transport model is firstly applied to predict baseline conditions. This allows comparison against measured data. Section 4.1 of Hadfield and Macdonald (2015) presents the comparisons. The first comparison is made with near shore surface turbidity data measured with turbidity monitors (30 minute sample intervals) which is converted to a time series of suspended sediment concentrations (mg/l). The model (12 hour average)
compares well (generally within a factor of two – which is considered good for a sediment transport model) and reproduces the influences of river discharge and periods of wave action. See for example Figure 7 which is a comparison of a time series of observations (blue) against a time series of model predictions (red). Offshore the model predictions of SSC are in the range 0.001 mg/l to 0.01 mg/l which is effectively zero and there are no comparable turbidity measurements or water samples against which to compare the model.

65. The model predictions of surface suspended sediment concentrations have also been compared with a remote-sensed product called Total Suspended Solids (TSS), which was derived from satellite estimates of backscatter at 488 nm (Pinkerton and Gall, 2015). TSS includes the inorganic suspended sediment modelled here, but also phytoplankton and suspended organic matter. Offshore, TSS is expected to exceed SSC, but near the shore the two quantities should be approximately equal as inorganic sediment dominates. The statistical comparisons presented in Section 4.2 of Hadfield and Macdonald (2015) show that at the coast the model predictions of SSC compare well with remotely sensed measures of TSS over the range of comparisons (2-60mg/l).

66. Offshore (outside the 22.2 km territorial limit) the model prediction of SSC is effectively zero and remotely sensed TSS is in the range 0.1mg/l to 1.0 mg/l. The sediment transport model does not include organic components so would, in any case, be expected to under predict TSS. Also the sediment transport model includes no influxes of sediment

---

4 Pinkerton and Gall (2015) Optical effects of proposed iron-sand mining in the South Taranaki Bight region, NIWA, September 2015. Where backscatter was derived from the NASA ocean colour satellite sensor, MODIS-Aqua, using measurements between 2002 and 2008. Data were processed using the Quasi-Analytical Algorithm with local modification for the SMD derived from in situ bio-optical measurements.
through any of the offshore boundaries, only sediment inputs from the rivers and mobilisation from the seabed within the model domain so the model will tend to under predict baseline fine sediment concentrations in the offshore waters.

67. The model was also compared against short periods of measurements of near bed sediment concentrations on Patea Shoals (see Section 4.3 of Hadfield and Macdonald (2015)). The measurements were made with Acoustic Backscatter Sensors (ABS) and it was identified that there was considerable variation in measured data from one site to another under similar hydrodynamic forcing. The data was characterised by short periods of resuspension, the timing of which was reproduced by the model. However, the observed bursts of SSC were not consistent. This may be linked to variability in bed form and associated near bed friction and turbulence which are not spatially varying in the model.

68. Overall when simulating background conditions the model provides a good basis for characterizing the well-mixed distribution and variability of the finest sediment fractions in the inshore waters. This is the area most influenced by the plume generated by the mining and here the predicted SSC in the plume can be considered against the predicted natural variability in SSC. In the offshore area where observations of suspended sediment concentrations are very low (typically less than 1 mg/l) the model background predictions are effectively zero. The plume does not often extend into these offshore areas and here the predicted SSC in the plumes can be considered against a background of effectively zero SSC.

69. However, it should be borne in mind that commonly the SSC results from models of this kind are presented with a lowest contour interval of 2mg/l to 5mg/l. This being reasonable
accuracy with which routine water sampling techniques might be expected to determine SSC. Because of the linkage to optical properties and the potential effect that small changes in very low SSC values can make on optical properties the model results are presented with a much lower contour interval than normal of 0.1mg/l.

SEDIMENT PLUME MODELLING

70. The ROMS SDM model is primarily set up to predict the effects of continuous mining activity. The fact that the model is well able to represent the natural variability in fine suspended sediment concentrations in the inshore areas gives confidence in the use of the model to predict the effect of fines released from the mining site in the mid and far-fields.

71. The ROMS model was run to represent the effects of the mining activity. The mining sources were introduced over the last 800 days of the 1,000 day simulation with 20% downtime for the mining operation included over the 800 day period. The results are presented in Section 5 of Hadfield and Macdonald (2015). The cases presented in Section 5.1.1 of Hadfield and Macdonald (2015) help illustrate the variety of short term distributions the plume can take up depending upon wind driven fluctuations in the currents.
Figure 8: Predictions of median SSC from the NIWA plume model: top – baseline, middle – mining only and bottom, mining + baseline combined.

Figure 8 presents the results of the sediment transport modelling for median near surface SSC with mining at Site A on the inshore edge of the mining area. The top figure shows the baseline predictions with less than 0.5 mg/l (light blue contour) predicted as background levels over the inshore part of the mining area. The middle figure shows the mining derived SSC, which has values of up to 1.0 mg/l (light purple contour) in the mining area. The bottom figure shows the predicted concentrations for the combined mining and background scenario. This indicates predicted concentrations in the colour contour band of up to 2 mg/l (light green contour) over the northern part of the mining area.
Figure 9: Predictions of 99th percentile SSC from the NIWA plume model: top – baseline, middle – mining only and bottom, mining + baseline combined.

Figure 9 presents the results of the sediment transport modelling for 99th percentile over the two year period (i.e. concentrations exceeded on about 7 days over the two year period) for near surface SSC with mining at Site A on the inshore edge of the mining area. The top figure again shows the baseline predictions with up to 10 mg/l (dark blue contour) predicted as background levels at the inshore edge of the mining area. The middle figure shows the mining derived SSC, which has values of up to 5 mg/l (dark green
contour) in the mining area. The bottom figure shows the predicted concentrations for the combined mining and background scenario. This indicates predicted concentrations in the colour contour band of up to 10 mg/l (dark blue contour) over the northern part of the mining area. The time series in Appendix 2 provide greater detail of the 95th percentile, 99th percentile and maximum values at six locations inshore and to the east of the mining area.

74. The model report includes presentation of the median and 99th percentile near bed SSC. Since the baseline near bed SSC are much larger than the near surface SSC the significance of the plume on near bed SSC is less than that for the surface SSC.

75. The model report also presents the results analysed for summer and winter seasons. This shows that in winter the naturally driven background concentrations in the nearshore area are higher, as a consequence of river discharge and resuspension by wave action, and as a result the plume is more conspicuous above the background levels in summer local to the mining area.

76. In addition to presenting a statistical analysis of the median and 99% SSC it is possible to present a time series of predicted concentrations at a particular location. Time series of SSC have been produced for the locations shown in Figure 10. An example of the time series output for location 1, Rolling Grounds is provided in Figure 11. For completeness time series data for all six locations are provided in Appendix 2.
Figure 10: Locations at which time series of suspended sediment concentration have been predicted
Figure 11 Time series of suspended sediment concentrations predicted at Rolling Grounds, 1km from edge of mining area. top – baseline, middle – mining only and bottom, mining + baseline combined. Note use of different vertical scale on middle figure.

Figure 11 shows for a site on the Rolling Grounds (site 1 on Figure 10) predictions of SSC for baseline, mining only and mining plus baseline. For baseline conditions the median SSC
is 0.1 mg/l, 99% is 3.1 mg/l and maximum concentration is 7.8 mg/l. For the mining only plume the median SSC is 0.0 mg/l, 99% is 0.4 mg/l and maximum concentration is 0.8 mg/l. For the mining plus baseline the median SSC is 0.1 mg/l, 99% is 3.0 mg/l and maximum concentration is 7.9 mg/l. At the Rolling Grounds the time series of baseline conditions is dominated by a few storm related events. Peaks associated with the mining activity are not necessarily coincident with these storm related peaks and the incremental effect of the mining does not give rise to a simple additive effect on peak background levels. Professor Lawrence Cahoon and Dr Mark James also present and discuss these results in their evidence.

78. The model also predicts the deposition arising from the background and plume scenarios. The effect of deposition from the plume is indistinguishable from deposition from background SSC except within a few kilometres of the mining activity. The ROMS model assumes a bulk dry density for deposition of 1,860 kg/m$^3$, which is appropriate for the in-situ sandy material with low fines content. Note again that the contour intervals used to illustrate the thickness of deposits from the plume have been selected to illustrate the existence of plume deposits. With a lowest threshold of 10 microns it is physically unrealistic to consider such a deposit uniformly distributed over a 1 km grid of the model domain.

79. When considering deposition of fines from the plume only, in close proximity (up to 3km) to the mining operation, I would suggest scaling the plume only deposition plots by a factor of five to give an upper bound of the thickness of the veneer of fine sediment that could be deposited at times. This is because the bulk dry density for fines assumed in the ROMS model is too high for a veneer of recently deposited cohesive material, which might have a bulk dry density in the range of 300 to 500 kg/m$^3$. Hence the maximum five day
deposition for the deposition within a few kilometres of the mining area might be closer to 3mm rather than the 0.6mm quoted in Section 4.4.2.4 of the Impact Assessment. However, the further away from the mining area the deposit from the plume occurs the more interaction there will have been between the plume deposit and the sandy seabed and it becomes appropriate to use the density assumed in the ROMS model to assess the thickness of the deposited material. Where fine sediment from the plume is settling onto an organism rather than the seabed it is prudent to consider the thickness of accumulation with the lower density.

80. Model predictions of SSC for mining at Site B have also been undertaken and these are presented in Section 5.2 of Hadfield and Macdonald (2015).

81. Consideration has also been given to the mobility of the material placed back onto the sea bed in the mining area (see Section 5.3 of Hadfield and Macdonald, 2015). The initial sea bed is assumed to have 2% fines present throughout (see Table 2.5 of Hadfield and Macdonald, 2015). The redeposited material in the mining area has a higher fines content than the adjacent seabed, partly because of the removal of the ore but also because of the conservative assumptions made about the fines content of the material to be extracted (assumed to be 3.7% fines). The simulation of resuspension from the redeposited material is shown to be unlikely to create a plume comparable to those produced by the suspended sources created during the mining activity. This is because the fine material in the patch is distributed over the depth of the mining pit and is released only slowly into suspension as the seabed in the patch is overturned or eroded by the combined effects of waves and currents.
SUMMARY OF PREDICTED LEVEL OF EFFECTS

82. Based on the modelled outputs of suspended sediment concentrations from the project it is concluded in the environmental impact assessment that the effects of the sediment plume near the project will be moderate. I would suggest that within 3km is an appropriate distance to apply here. Note that this is really 3km from the mining operation rather than from the mining area because the simulations assume the plume source is fixed over time. It should also be noted that the sediment plume is predicted to move around in response to the wind driven currents so when there are elevated concentrations associated with the plume near the project these effects are not continuous. Closer to the coast the effect of project derived sediment will be insignificant as project derived sediment levels are not discernible relative to the naturally occurring background levels in the high energy coastal environment.

83. Potential effects of the sediment plume on water quality, ecology and fauna is described in the expert reports of Professor Lawrence Cahoon and Dr Mark James.

PROPOSED MONITORING AND MANAGEMENT PROGRAMMES

84. The proposed conditions require an extensive programme of baseline monitoring over a two year period prior to commencement of mining operations (Draft TTR BEMP, 2016).

85. The baseline monitoring will include measurement of currents and waves, temperature, conductivity, turbidity with moored sensors and vertical profiling, water sampling, gross sedimentation with settlement tubes and particle size and settling velocity of suspended sediment. These measurements will all feed into an improved validation of the baseline sediment transport modelling.
86. An operational hydrodynamic and sediment transport model is proposed to be used throughout the mining operations. The model will enable the influence of the mining plume to be identified compared to background levels.

87. During operations a similar programme of measurements to that undertaken over the two year baseline monitoring programme will be made to inform the validation and refinement of the operational sediment plume model (described in Draft TTR EMMP, 2016). These measurements will themselves serve to demonstrate that SSC arising from the operations are within compliance limits and not causing an adverse effect.

88. This combination of monitoring and model refinement and application with which to manage the mining operations represents the application of international best practice for a dredging project.

89. Given the timescale for the operational phase of the project I consider that it is important to learn lessons from the monitoring as it progresses and to take time to review and refine monitoring and modelling so that the operational management remains effective. The conditions provide appropriately for this to occur.

RESPONSE TO SUBMISSIONS

90. The submission of Mr Douglas raises the issue, (also raised by GHD), that the dry bulk density of the deposited material may have been over-estimated. I have considered this in paragraph 79 of my evidence.

91. Mr Douglas also raises the issue of particle size distribution of the de-ored sediment. The laboratory tests I describe in paragraphs 38 to 40 and 43 of my evidence utilised representative fine material from the proposed processing operations and the settling velocity distribution for the fines
fraction of material was derived from these results. Laboratory testing was also undertaken to determine the thresholds for resuspension of recently deposited fine material.

92. Potential sedimentation rates close to the mining area in the path of the plume have been assessed. I have noted above in paragraph 79 that close to the mining area it is prudent to consider multiplying the predicted deposition rates from the plume only by a factor of five to acknowledge the potential for low density deposits of fine sediment to arise up to about 3mm in thickness.

93. Mr Douglas raises the issue of the precision with which the model predictions are presented. As noted in paragraph 69 above this precision has been included for suspended sediment concentration because of the need to subsequently consider the optical effect of the plume.

94. A number of submissions have been made that raise sediment plume issues (including that from Ms Pratt) and many use the material prepared by Kiwis Against Seabed Mining (KASM). Plume impacts are a concern of KASM and I have summarised the physical processes involved in plume formation and the quantification of physical effects of the plume in my evidence above.

95. I note that KASM and others have misunderstood the natural process of flocculation. Flocculation is not a mitigation measure that TTR are proposing to implement by including some sort of treatment with chemical agents. Flocculation is simply an important characteristic of how fine particles naturally behave in suspension. As a result of the flocculation process there will be less mass available in suspension as very slow settling individual particles. Ms Malpas raises the concern that the minerology of the de-ored sediment is such that it should not flocculate. The
evidence from the laboratory trials in both fresh and salt water showed clearly that relatively large flocs readily formed from this material. Ms Ellet considers that the flocculation tests should be repeated by an independent specialist. Mr Grant raised an issue of where the samples for the tests had been taken. I have included Figure 3 to clarify this point. I consider that the testing by HR Wallingford is independent and the results presented in a manner suitable for expert scrutiny. These reports have been independently reviewed by the specialists appointed by EPA.

96. In his submission Mr Grant also pointed out that in-situ, non-heat treated, sediment could have been used for the laboratory tests. I agree with this point and this is certainly something that could be undertaken during the baseline monitoring period.

97. The submission of Mr Olson rightly points out that the mining operation will mobilise sediment that would otherwise remain undisturbed. The consideration of river inputs and the potential to mobilise material from the sea bed contained in paragraphs 14 and 15 is to provide context against which to consider the significance of mobilising this additional material.

98. In his submission Mr Appleyard raises concerns over the ability to predict the sediment plume direction accurately. The ROMS model has been run for extended periods of time so as to capture the range of currents and weather patterns that occur at this site and part of the challenge is finding ways in which to convey this information to stakeholders. Mr Smith draws attention to a natural plume formed at Farewell Spit in his submission. As I note in paragraph 71 I recommend that the cases in Section 5.1.1 of Hadfield and Macdonald (2015) are viewed to appreciate the variation in plume
direction and extent that can occur as a result of these environmental factors.

99. Mr Appleyard and Mr Edgar reiterate the point raised by GHD regarding the accuracy and reliability of predictions being dependent on the predicted discharges from the IMV. I have addressed this point in paragraph 28. The key point being that the maximum production that can be achieved by the processing system on board the IMV is 8,000 tonnes per hour. It is in TTR’s interest to maintain production at this level and this is facilitated by buffering of mined material on board the IMV to maintain a steady rate of supply to the processing unit. The impact assessment has been undertaken on the basis of this processing rate. Whilst the production from the crawler may vary over time, being buffered on board the IMV, the processing which leads to the generation of the discharge and the creation of the fine sediment plume is wholly dependent on the feed through the processing unit where every endeavour will be made to maintain this optimally at 8,000 tonnes per hour.

100. In his submission Mr Appleyard raises concern over the longer term fate of fines released by the mining in the inshore waters of the STB. Here it is important to consider the fate of fines that have been released over the years from the rivers and to consider the additional material from the mining operation against this context. The long term process is that the fines released from North Island are flushed from the STB through Cook Strait by the residual currents (see Figure 4). The residence time for fines released from the mining operation in the SMD is in the region of 1-2 months. The predictions of sedimentation in the SMD over the full simulation period do not show a significant accumulation of mass, either as a result of river inputs or from the mining. If fine sediment could be accumulating in the nearshore waters of the SMD it would have been happening for
thousands of years as a result of the river inputs. If that has not been happening the relatively small additional inputs from the mining operation will not significantly alter the nearshore regime.

101. In his submission Mr Anderson indicates that sediment plumes are created at the time of mining and when the unwanted sand is discharged through the de-ored sediment pipe back down on the seafloor. It is important to note (see paragraphs 46 to 53) that the only significant source for plume generation is the discharge from the processing of the mined sediment on board the IMV.

102. In his submission Mr Grant raises a concern that reef ecosystems will be substantially damaged by sediment deposition over the operational period of 35 years. I note that the modelling of plume effects makes necessary assumptions about the general nature of the seabed. This means that the precise morphological detail of the small scale features of a reef system cannot be represented in the model. Accordingly the predictions of sedimentation in these areas are averaged across space. Because the predicted increases in suspended sediment concentration at sensitive receptors are within the range of natural variability then the expected sedimentation will also be within the range of natural variability experienced.

103. In his submission Mr Smith provide a graphic of the tidal flows in and out of Cook Strait. The NIWA modelling fully represents these important exchange processes and demonstrates that the plume is predicted to disperse to background levels within the STB. His concerns about potential contaminants are addressed in the evidence of Dr Mark James.

104. In his submission Mr Smith makes the important point that models are only as good as the information fed into them
and that he constantly sees models produced to give the outcome that the modellers wish to portray. I would concur with the first point and observe that the role that I have performed on behalf of TTR is to ensure that the models that are being used to predict the sediment plume created by the mining activity are based on the best available information. Regarding his second point, Mr Smith should be assured that the model results in this case have been widely reviewed by experienced independent specialists capable of challenging, as necessary; the outputs of modelling that have been presented.

105. In his submission Mr Edgar notes that not all of the sediment discharges have been considered in the modelling. In paragraphs 46 to 53 I have summarised this position and demonstrated that the most important discharges have been considered. Mr Edgar also states that we need more research to understand the impact of sediment in deep-sea environments as the effects in shallow waters cannot be extrapolated to deep-sea waters. Mr Edgar should be aware that the depth of the proposed mining and the seabed levels in the areas influenced by the plume are not considered deep-sea and are representative of locations around the world where mining and dredging have taken place and there is a robust evidence base of physical effects.

106. In his submission Mr McDougall raises a concern over the removal of broken shells lying on the surface of the mining area. In the mining area, these broken shells will be collected by the mining process, along with the other seabed material, but during early processing these broken shells are likely to be screened out. It is not expected that these fragments will be ground up during the processing. They will however be returned to the seabed in a such a manner that their initial distribution will be well mixed through
the depth of backfilling. Mr McDougall also gives the impression that the material returned to the seabed from the IMV will only be a very fine silt. As I have explained in paragraphs 24 and 25 and summarised in Table 1 this is incorrect. The bulk of the material being discharged is sandy and the material backfilled into the mining pits will be sandy with similar properties to the in-situ material. The modelling of the “patch” of material returned to the seabed (see paragraph 81) addresses Mr McDougall’s concerns about high currents eroding any silt left in the tailing piles.

107. In her submission Ms Coughlan notes that the EPA Key Issues Report (2016) raises several concerns related to the sediment plume. I have addressed these points above.

108. In her submission (Figure 3) Ms Hammonds indicates that there are more reef areas inshore of the mining area. The nearest of these areas is under 5km from the mining area. I have shown through the plume model results that whilst any reefs close to the mining area may be subject to occasional short lived increases in sediment levels. These levels are likely to be well within the range of natural variability experienced at that site.

CONCLUSIONS

109. Comprehensive investigations of the properties of the fine sediment that will be released from the mining activity have been undertaken. These show that the fine sediment will naturally flocculate and will therefore settle through the water column faster than if it remained as individual particles. The resuspension properties of the fine material after it has been deposited have also been established through laboratory tests.

110. Consideration of the physical processes associated with the discharge of the de-ored material back to the seabed has
identified that combining the coarse and fine fractions arising from the processing and discharging them near bed is the preferred design for minimising release of fine material into the wider environment. It is assessed that more than half of the fines fraction will remain in the mining pit, the remainder disperses through South Taranaki Bight and makes its way eastward through Cook Strait over a 1-2 month period. Where it will be undetectable from naturally varying levels.

111. Based on the application of numerical modelling of the detail of the release of sediment in the mining area, source terms for use in the NIWA sediment transport model have been refined. The NIWA sediment transport model has been reapplied to predict the impact of the proposed mining operations on suspended sediment concentrations and deposition. Model results have been presented as statistical levels, median and 99th percentile across the model domain and also time series have been generated from the model results at six key locations. The time series data clearly illustrates the extent of natural variability in background suspended sediment concentrations.

112. From the model results arising it is concluded in the environmental impact assessment that the effects within 3km of the project will be moderate. Closer to the coast the effect of project derived sediment will be insignificant as project derived sediment levels are not discernible relative to the naturally occurring background levels in the high energy coastal environment. For the reefs that occur in the offshore area the elevations in suspended sediment concentrations associated with the plume are generally insignificant because the reefs are typically more than 5 km from the perimeter of the mining area and therefore at least this distance from the mining operation.
113. Programmes of baseline and operational monitoring have been proposed in the conditions so that the sediment transport model can be refined and used during operations as part of the environmental management of the mining. I consider these programmes to be appropriate and in accordance with international best practice.

Michael Dearnaley

15 December 2016
## APPENDIX 1 – RELEVANT PROJECT EXPERIENCE

<table>
<thead>
<tr>
<th>Project</th>
<th>Commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Icthys LNG, Darwin Australia</strong></td>
<td>Responsible Director (2009-present) for dredging and environmental support studies undertaken by HR Wallingford during the planning, procurement and construction of Icthys LNG. The studies included review of third party studies and recommendations for the way forward. HR Wallingford was then commissioned to undertake numerical modelling of sediment transport and plume dispersion for the project to inform the EIA and permit application. Subsequently the modelling tool was used to assist the evaluation of dredging tenders and then to assist in developing the dredge management plan. The capital dredging has now been completed for this project. The modelling tools are being used for planning the maintenance dredging.</td>
</tr>
<tr>
<td><strong>Wheatstone LNG, Onslow, Australia</strong></td>
<td>Technical Director (2009-2015), responsible for dredging and sedimentation studies within Front End Engineering Design (FEED). Development of dredging plan and costs, preliminary impact analysis, development of monitoring and management strategy and liaison with the Environmental Assessment Team. Contract document preparation, tender evaluation and support to Project Management Contractor (PMC) during delivery of the project. This support has included review of third party reports and participation in liaison with Project Owner and regulators.</td>
</tr>
<tr>
<td><strong>Ports of Harwich and Felixstowe, UK</strong></td>
<td>Responsible for all hydraulic studies (1994 to present) for Ports of Harwich and Felixstowe, the UK’s largest container port. Hydraulic studies (1997-1998) to support the environmental assessment of proposed deepening of the approach channel to Felixstowe. The studies included prediction of increases in the requirement for maintenance dredging, the impact on the Stour and Orwell estuaries and the options for disposal of capital and maintenance dredged material. The project was consented and channel deepening</td>
</tr>
</tbody>
</table>
(~15 Mm³) took place between 1998 and 2000. During the deepening a programme of monitoring of suspended sediment concentrations was undertaken. Dr Dearnaley now attends the annual regulators meeting, reporting on progress on the maintenance dredging, offshore disposal and recycling of sediment into the estuaries along with the results of ongoing monitoring activities associated with the scheme and the evolution of the morphology of the Stour and Orwell Estuaries in response to port operations. Hydraulic studies, including plume dispersion studies for the development of new offshore disposal sites at Inner Gabbard (1999-2000); inner Gabbard East (2004) and a new inshore maintenance disposal site (2013-present). Hydraulic studies carried out (2000 to 2002) proposed to extend the existing Trinity Terminal at Felixstowe upstream into the Orwell Estuary. An assessment of the impact of the scheme on hydrodynamics, sediment transport, maintenance requirement and estuary wide morphology. A mitigation scheme involving beneficial use of clay, silts and gravels was proposed. Dr Dearnaley appeared as an expert witness on behalf of HP (UK) at the Public Inquiry into the proposals in May 2002. The project was consented in 2003 and is now operational. Hydraulic studies carried out to support redevelopment of existing berths in the southern part of Felixstowe to create three new deep water container berths. As part of the investigations associated with the EIA for the scheme HR Wallingford were commissioned to provide an assessment of the impact of the scheme on hydrodynamics, sediment transport, maintenance requirement and estuary wide morphology. Dr Dearnaley appeared as an expert witness on behalf of HP (UK) in October 2004. The project received consent in February 2006 and is now operational. Hydraulic studies carried out to create three new deepwater container berths at Parkeston near

<table>
<thead>
<tr>
<th>Project</th>
<th>Commentary</th>
</tr>
</thead>
<tbody>
<tr>
<td>(~15 Mm³) took place between 1998 and 2000. During the deepening a programme of monitoring of suspended sediment concentrations was undertaken. Dr Dearnaley now attends the annual regulators meeting, reporting on progress on the maintenance dredging, offshore disposal and recycling of sediment into the estuaries along with the results of ongoing monitoring activities associated with the scheme and the evolution of the morphology of the Stour and Orwell Estuaries in response to port operations. Hydraulic studies, including plume dispersion studies for the development of new offshore disposal sites at Inner Gabbard (1999-2000); inner Gabbard East (2004) and a new inshore maintenance disposal site (2013-present). Hydraulic studies carried out (2000 to 2002) proposed to extend the existing Trinity Terminal at Felixstowe upstream into the Orwell Estuary. An assessment of the impact of the scheme on hydrodynamics, sediment transport, maintenance requirement and estuary wide morphology. A mitigation scheme involving beneficial use of clay, silts and gravels was proposed. Dr Dearnaley appeared as an expert witness on behalf of HP (UK) at the Public Inquiry into the proposals in May 2002. The project was consented in 2003 and is now operational. Hydraulic studies carried out to support redevelopment of existing berths in the southern part of Felixstowe to create three new deep water container berths. As part of the investigations associated with the EIA for the scheme HR Wallingford were commissioned to provide an assessment of the impact of the scheme on hydrodynamics, sediment transport, maintenance requirement and estuary wide morphology. Dr Dearnaley appeared as an expert witness on behalf of HP (UK) in October 2004. The project received consent in February 2006 and is now operational. Hydraulic studies carried out to create three new deepwater container berths at Parkeston near</td>
<td></td>
</tr>
<tr>
<td>Project</td>
<td>Commentary</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>Harwich by reclaiming Bathside Bay. As part of the investigations associated with the EIA for the scheme HR Wallingford were commissioned to provide an assessment of the impact of the scheme on hydrodynamics, sediment transport, maintenance requirement and estuary wide morphology. The work comprised of three phases: the first provided an initial assessment of impact based on current knowledge to allow informed consultation by interested parties and regulators; the second involved field measurements of flow and suspended sediment concentrations; and the third involved the further development of 2D and 3D hydrodynamic, sediment transport and morphological models based on the results of the field surveys. Mitigation measures in the form of beneficial use of dredged material and compensation measures in the form of managed realignment were proposed. Dr Dearnaley appeared as an expert witness on behalf of HP (UK) at the Public Inquiry into the proposals in June 2004. The project received full consent in March 2006.</td>
<td></td>
</tr>
<tr>
<td><strong>London Gateway Port, UK</strong></td>
<td>Responsible for all hydraulic studies (2001 to present) associated with the planning, design, construction monitoring and operational support for the new London Gateway Port a major new container terminal at the old oil refinery site at Shellhaven on the Thames Estuary. Compensatory measures in the form of two managed realignment sites were part of the proposals. Assessment of dredging source terms and simulation of sediment plumes formed a key part of the assessment and design of the monitoring protocols for the project. Dr Dearnaley appeared as an expert witness on behalf of P&amp;O at the Public Inquiry into the proposals in May 2003. The project received consent in June 2007. Dredging (~ 30 Mm³) took place between 2010 and 2013 making this the largest UK dredging project. Since consent was achieved Dr Dearnaley has been Responsible Director for on-going technical advice on hydraulic, dredging and environmental monitoring studies to DP World regarding the</td>
</tr>
<tr>
<td>Project</td>
<td>Commentary</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>Project Commentary</td>
<td>development of the container terminal. Dr Dearnaley is a member of DP World’s Environmental Assurance Team for the works. During the construction an extensive monitoring programme was instigated to enable adaptive management of the dredging to take place. The monitoring included fixed installation at numerous locations around the dredging works and measurement of sediment plumes generated by different dredging plant and reclamation activities to confirm source terms used in the original EIA studies.</td>
</tr>
<tr>
<td>Maintenance Dredging on the Thames Estuary, UK</td>
<td>Project Manager (2001) for the field monitoring taking place during and following the capital dredging of the approach channel to Medway Port. This monitoring was required as part of the consent for the deepening and involved long-term silt monitoring and measurement of the impact of the beneficial placement of dredged material within the estuary system. A programme of monitoring and plume dispersion modelling (2002-2008) was undertaken on behalf of the Port of London Authority to assist them in developing plans for use of water injection dredging as a sustainable means of maintaining riverside berths on the Thames Estuary.</td>
</tr>
<tr>
<td>Port of Bristol, Severn Estuary, UK</td>
<td>Project Director for hydraulic studies (2005-present) to investigate the feasibility, design and environmental assessment of a deep water container terminal development on the Severn estuary at the Port of Bristol. The scheme was subject to detailed sediment transport and plume modelling and navigation assessment to support the EIA, which also included the requirements for a new disposal site for dredged material and the outline concept for a realignment site as a compensatory measure. Through participation in consultation with key marine stakeholders the need for Public Inquiry was avoided and the project was consented in March 2010.</td>
</tr>
<tr>
<td>Aggregate Dredging in Eastern English</td>
<td>Hydraulic studies to consider effects of sediment plumes generated from aggregate dredging in the Eastern English Channel (1999-2009).</td>
</tr>
<tr>
<td>Project</td>
<td>Commentary</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>Channel, UK</strong></td>
<td>Studies culminated in consent of largest UK aggregate resource for decades with an agreed programme for monitoring. Project Director for monitoring and analysis studies (2008-2009) to determine the rates of release of fine sediment from marine aggregate dredging in the Eastern English Channel and the evolution and decay of plumes generated by the dredging. Monitoring involved sampling on board dredgers to assess source terms and plume monitoring to examine the fate of fine sediments in the plumes. ADCP and Multi-Beam used for acoustic detection of plume.</td>
</tr>
<tr>
<td><strong>Aggregate Dredging in UK</strong></td>
<td>Technical Director at HR Wallingford for supporting studies (2001-2006) to Centre for Environment, Fisheries &amp; Aquaculture Science (Cefas) considering hydrodynamic indices which may be applicable to aid in defining the timescales for recovery of the seabed following aggregate extraction. As part of the studies Cefas are undertaking an extensive programme of benthic sampling and physical characterisation of sites around the UK where aggregate extraction has recently ceased. Project Manager for research (1996-1998) in conjunction with UK aggregate dredging contractors. Research was undertaken to examine the initial dispersion of material from spillways and screening. Analysis of the settling velocity of re-suspended material and the distribution of fines material was carried out. This research was funded by DOE and the Dredging Industry. Research (1993-1995) into the comparison of turbidity produced by dredging operations carried out using standard monitoring methods (water sampling, silt monitoring) and acoustic (ADCP) techniques. The project was undertaken with close co-operation from dredging contractors and consultants. This work was funded by DOE and the Dredging Industry.</td>
</tr>
<tr>
<td><strong>Sediment Plume Monitoring, Shoreham, UK</strong></td>
<td>A monitoring programme (1994) using ADCP, water sampling and optical silt monitoring was established to determine the fluxes of sediment released into the water column during a trenching operation involving</td>
</tr>
<tr>
<td>Project</td>
<td>Commentary</td>
</tr>
<tr>
<td>---------</td>
<td>------------</td>
</tr>
<tr>
<td>Cutter suction dredger and spreader pontoon. ADCP and water sampling techniques were applied.</td>
<td></td>
</tr>
<tr>
<td><strong>Sediment Plume Monitoring, Londonderry, UK</strong></td>
<td>A silt monitoring programme (1992-1993) was instigated in the Lough, before, during and after capital dredging of the navigation channel. The VMADCP technique was used to look at short term dispersion of material from different dredging plant (TSHD and BHD).</td>
</tr>
<tr>
<td><strong>Research into properties of Dredged Material</strong></td>
<td>Project Manager for research undertaken (1995-1998) to examine the erosion threshold of material placed at offshore disposal sites in the UK. The research was undertaken in conjunction with Ministry of Agriculture, Fisheries and Forestry and bed frames from MAFF were installed in the vicinity of disposal sites during winter periods. The HR instrument for insitu measurement of shear stress was used on undisturbed samples obtained from a 30cm diameter corer.</td>
</tr>
<tr>
<td><strong>Research into settling properties of Cohesive Material</strong></td>
<td>Application of the video image analysis technique for determining settling velocity and floc size during an international inter-comparison on the Elbe Estuary in Germany (1993). The video image analysis technique was compared directly with standard Owen Tube gravimetric analysis during the exercise. Research was carried out (1989-1993) into the settling velocities of cohesive sediment in the field and laboratory and a new video image analysis technique was developed. This work was funded by the DoE and EC.</td>
</tr>
</tbody>
</table>
APPENDIX 2 – TIME SERIES OF PREDICTED SUSPENDED SEDIMENT CONCENTRATIONS

Figure 1 Locations where time series of suspended sediment concentration (SSC) have been produced. Note that two sites have been illustrated at the Traps.
Figure 2. Surface SSC time series at key sites from mining source A. Top, middle and lower panels are for background, mining and background plus mining respectively. See Figure 1 for locations. Sites are:

A. Patea River Mouth customary fishing area
B. South Traps
C. North Traps
D. Rolling Grounds
E. Graham Bank
F. 20 km from the ISR site