Centre for Marine Science and Technology, Curtin University, Assessment of:

A. Predicted underwater sound impacts on marine mammals in sand mining area and recommendations

B. Review of modelling of underwater noise from the proposed Trans-Tasman Resource Ltd (TTRL) iron sands extraction operation carried out by AECOM

CMST Project 1504, Report 2017-08, Date Prepared: 18-May-2017

Authors:
Alec Duncan (PhD), Robert McCauley (PhD), Christine Erbe (PhD)
Centre Marine Science and Technology, Curtin University, GPO Box U 1987 Perth 6845, Western Australia.

Contents

Summary

Our general assessment from the documentation provided is the underwater sound field predictions presented to support the underwater sand mining operations are inadequate and insufficient on which to base a rational biological risk assessment. As the underlying sound field predictions are inadequate there is little basis for criticising how the biological risk assessment has been made as it would be based on erroneous received levels.

With regards to the modelling work carried out by AECOM:

Crawler (SSED) source levels and source spectra appear to have been substantially underestimated by AECOM due to:

1. A labelling error on a plot in the original 1994 IMT report on measured noise levels from a De Beers Marine subsea mining operation that was the original source of data on which the source spectrum was based. This resulted in the lower of two curves being used, whereas a careful reading of the IMT report indicates the upper curve should have been used.
2. Errors in converting source spectral levels in 1 Hz bands to octave band source levels.
3. Errors in converting sound levels in air to sound levels with equivalent intensity in water (although the reviewer considers this a dubious thing to do in any event).

Estimates of the effects of correcting these errors together with a consideration of measured levels from dredging operations, indicate that the Crawler source levels are likely to be around 10 dB higher than the 171 dB re 1 μPa @ 1m estimated by AECOM, although this would include some contribution from the integrated mining vessel (IMV).

A comparison to measured underwater noise levels from floating production, storage and offloading vessels (FPSOs) used in the offshore oil and gas industry, which are in many ways similar to the proposed integrated mining vessel (IMV), indicate that median IMV source levels (those exceeded 50% of the time) are likely to be at least 10 dB higher than the 171 dB re 1 μPa @ 1m assumed by AECOM, and that the highest IMV source levels associated with the mining operation, which are likely to be associated with offloading operations, may exceed the median levels by 7 dB or more.

The acoustic propagation modelling carried out by AECOM assumes a softer, less reflective seabed than the seabed geology description for this area in Orpin (2013) would lead one to expect. This is likely to result in an over-prediction of transmission loss and hence an under-prediction of received levels by several dB.

Given all of these factors we expect that median received levels from the mining operation are likely to exceed those given in the AECOM report by at least 9 dB, and possibly higher. The reviewer therefore considers it highly unlikely that this operation will be able to meet the target level of 135 dB re 1 μPa at a range of 500 m, except perhaps for short periods of time when there is little activity.

Experience from measuring noise levels from FPSOs (e.g. Erbe et. al. 2013) indicates noise levels are likely to have large fluctuations depending on the activities being undertaken and so is important that target levels should be defined statistically, such as the median level, and that verification should be carried out over a long enough period of time to include all phases of the mining operation in a variety of weather conditions.

Our recommendations are: 1) the underwater noise modelling needs to be re-calculated using a best estimate source spectrum considering all potential noise sources summed incoherently at the

receiver to give typical and worst case sound fields in the vicinity of the mining operations out to median ambient noise conditions; 2) from these sound field estimates, zones of potential biological impact types are defined for major fauna types expected in the region; 3) the impact zones are overlain on marine mammal densities to give estimated risk assessments (probability and consequence of threat) for the major marine mammal groups; and 4) underwater mining operations are measured, and actual levels compared with estimated levels to confirm, or force a re-assessment of, biological risk. Verification measurements should be carried out over a long enough period of time to include all phases of the mining operation in a variety of weather conditions so that a proper statistical assessment of the noise levels can be made.

Personal Statements

Alexander J Duncan, Centre for Marine Science and Technology, Curtin University
18th May 2017

I, Dr Alexander (Alec) John Duncan, am an employee of Curtin University and work as a Senior Research Fellow at the university's Centre for Marine Science and Technology (CMST). CMST has been engaged by the Royal Forest and Bird Protection Society of New Zealand Inc. to provide a review of AECOM New Zealand Limited's modelling of underwater sound levels from the proposed Trans-Tasman Resource Limited (TTRL) iron sands extraction operation and to provide an overview of how this activity has been assessed in relation to potential impacts of underwater noise on marine mammals.

I have a PhD in physics (marine acoustics) from Curtin University, Perth, Western Australia, a Master of Applied Science (Applied Physics) from Curtin University and a Bachelor of Applied Science (Applied Physics) from the Royal Melbourne Institute of Technology. I have been carrying out research and consulting in marine acoustics since 1980 and have extensive experience in the prediction of underwater sound levels from human activities. I have also supervised a number of PhD students carrying out research in this field and have an extensive list of scientific publications.

I confirm that I have read the Code of Conduct for Expert Witnesses that form part of Environment Court of New Zealand Practice Note 2014 and that I agree to abide by it.

18/5/2017

Dr Alexander John Duncan

Robert D McCauley, Centre for Marine Science and Technology, Curtin University
18th May 2017

I, Dr. Robert (Rob) Donald McCauley, am an employee of Curtin University and work as a Senior Research Fellow at the university's Centre for Marine Science and Technology (CMST). CMST has been engaged by the Royal Forest and Bird Protection Society of New Zealand Inc. to provide a review of AECOM New Zealand Limited's modelling of underwater sound levels from the proposed Trans-Tasman Resource Limited (TTRL) iron sands extraction operation and to provide an overview of how this activity has been assessed in relation to potential impacts of underwater noise on marine mammals.

I have a PhD in Science (marine biological acoustics) from James Cook University (North Queensland and a Bachelor of Science degree with majors in Zoology and Marine Biology also from James Cook University. I have been carrying out research and consulting in marine acoustics since 1987. I confirm that I have read the Code of Conduct for Expert Witnesses that form part of Environment Court of New Zealand Practice Note 2014 and that I agree to abide by it.

Dr Robert Donald McCauley, 18/5/2017

……………………………………………………………………………………………..

Christine Erbe, Centre for Marine Science and Technology, Curtin University
18th May 2017

I, Dr. Christine Erbe, am an employee of Curtin University, Associate Professor in Applied Physics and Director of the Centre for Marine Science and Technology (CMST). CMST has been engaged by the Royal Forest and Bird Protection Society of New Zealand Inc. to provide a review of AECOM New Zealand Ltd.'s modelling of underwater sound levels from the proposed Trans-Tasman Resource Limited (TTRL) iron sands extraction operation and to provide an overview of how this activity has been assessed in relation to potential impacts of underwater noise on marine mammals.

I have a PhD in Geophysics from the University of British Columbia, Canada. I have been carrying out research and consulting in marine acoustics since 1994. I confirm that I have read the Code of Conduct for Expert Witnesses that form part of Environment Court of New Zealand Practice Note 2014 and that I agree to abide by it.

Dr Christine Erbe, 19/5/2017

A. Predicted underwater sound impacts on marine mammals in sand mining area and recommendations

Authors: Robert McCauley and Christine Erbe

To accurately estimate impacts on marine fauna requires accurate estimates of the intensity, frequency content and type of noise (i.e., impulsive, continuous, stationary, moving etc.) produced by the operation in question. As estimates of noise intensities produced by the proposed sand mining operations have not been defined adequately (see section B. below), the assessment of biological impacts provided is erroneous irrespective of if the method of biological risk assessment is appropriate or not. This is because the biological risk assessment is based on erroneous received levels. Given this we have presented below general comments on the documentation of biological risk assessment provided, then present recommendations on how we would ask for a scientifically defensible biological risk assessment. As the underlying noise field estimates are considered to not be adequate in the first instance we have not given specific comments or criticisms on the biological assessment results provided.

A.1 General comments:

1. The "mining area" discussed by the proponents is not defined. The areas, or zones, for various impact types on marine mammals and other fauna produced by noise from the mining operation are not defined correctly. The potential densities of marine mammals in the noise-impacted area are vaguely defined. It is probable that zones of impact for behavioural changes and masking in marine mammals will be much greater than the 'mining area', and larger again for audibility. Thus the continual referral within the documentation to marine mammal impacts in the 'mining area' is misleading and not correct, given that different impact types have different associated ranges. These different ranges will lead to some impact types having significantly larger areas than 'the mining area', and so these impact types may apply to a wider portion of the Taranaki Bight than as alluded to in the documentation. The documentation should define what densities of marine mammals lie in each of the estimated zones of underwater noise impact, avoid using subjective language as it currently does, and provide a biological risk assessment based on estimate of actual numbers of species likely to be present in each noise-impact zone per unit of time (perhaps in seasonal blocks).

2. The calculation of underwater noise produced by the underwater mining operations is discussed at length below in section B. The documentation provided states that three vessels will be on site plus the undersea mining vehicle, the 'crawler'. The two larger vessels, an FPSO and FSO will presumably be anchored most of the time (although this is not explicitly stated in the documentation provided). These anchored ships will radiate broadband noise and tones which is considered in the underwater noise calculations and discussed in B. below. The third vessel is a "tug" used for various purposes. The tug will be required to operate in DP, or 'dynamic positioning' mode where the tug uses multiple propellers spread around the vessel to move or hold it in any required direction or orientation, respectively. The document states that DP mode will be used by the tug for 10% of the time but no definition of where this 10% value comes from is given and DP noise has not been considered in the noise modelling supplied. Vessels operating in DP mode are notoriously noisy underwater, likely considerably more so than as for the mining operations. When operating in DP mode large amounts of cavitation on the propellers is produced, which generates noise. This is as the propellers are of a compromised design with regards to their direction of thrust and as they are generally used at high thrust loads. Given the probable moderate to high wind and current speeds in the area (no meteorology or current predictions are given in the documentation provided) it is likely the tug will be required to operate in DP

mode for considerable periods of time, possibly even when simply holding station nearby so that the vessel is free to respond if required. As the noise produced by DP operations may be of similar or higher source level than that produced by underwater mining operations it needs to be included in underwater noise estimates and a defined estimate of the expected periods of time DP will be used, provided.

3. The applicants seem to have somewhat arbitrarily imposed noise limits upon themselves, which has created a situation where the noise modelling and source levels used appear to be adjusted to meet the imposed noise limits. This seems an odd and circular approach and will be at times incorrect as it is probable that the major noise producing sources will at some points be considerably spatially separated (for example, when the tug operates in 'heavy' DP mode, perhaps while lifting an anchor, it may be several km from the mining operations). It would be far better if accurate modelling was carried out combining all potential sources in several operational scenarios and this used to define estimated zones of noise impact. This approach is discussed below in the Recommendations.

A.2 Recommendations

4. The underwater noise modelling needs to be calculated using better defined and more realistic source spectra, including: the underwater mining operations; surface vessels at anchor; surface vessels underway; and high levels of dynamic positioning vessel noise from a tug sized vessel. The modelling should incorporate the seabed type as discussed below. The estimated noise fields from independent noise sources should then be combined spatially assuming incoherent sound fields using various source operational states and spatial locations, to give a typical and worst case sound field about the mining area for all mining associated vessels. This type of modelling using multiple sources has been carried out many times before and should be done by a recognised specialist underwater acoustics group.

5. Based on the estimated sound fields calculated which combine all mining vessels, predicted zones of impact for different fauna can then be created for typical and worst case operational scenarios. This can be overlaid with estimated marine fauna densities in the area, possibly with time (season) factored in, to provide a risk assessment (likelihood and consequence of threats) for the major species groupings expected to occur in the impacted region. This then becomes the agreed, estimated underwater noise risk assessment.

6. Various unknown or unforeseen factors may change the actual mining underwater sound fields from those modelled. A simple way to account for this is to measure the underwater sound field using fully calibrated hardware, from mining operations at several locations over a period long enough to obtain statistics of the actual noise generated by the mining operations – a six-week minimum period is suggested. At the conclusion of this period the actual levels of mining noise are derived and compared with those estimated and on which the biological risk assessment had been calculated. If the measured mining underwater noise is statistically similar to or less than the estimated underwater mining noise, then the biological risk assessment is accepted. If the measured mining underwater noise is statistically greater than the estimated underwater mining noise, then the biological risk assessment is altered according to the measurements and the risk is re-evaluated by all. This type of underwater noise assessment has been carried out twice by this author (McCauley) in large-scale industrial operations (major port expansion and seismic survey) with the measured noise levels falling within the estimated level statistical bounds on each occasion.

B. Review of modelling of underwater noise from the proposed Trans-Tasman Resource Limited (TTRL) iron sands extraction operation carried out by AECOM

Authors Alec Duncan & Christine Erbe

B.1 Introduction

CMST has been asked to review an assessment of likely underwater noise levels from the proposed Trans-Tasman Resource Limited (TTRL) iron sands extraction operation carried out by AECOM New Zealand Limited. It should be noted that this review has not involved any repeat modelling and is therefore restricted to a consideration of the modelling inputs used by AECOM and the interpretation of the outputs produced, as described in Childerhouse_Response_to_DMC_Questions_Appendix_3_and_4.pdf. Within the terms of this review it has not been possible to verify the accuracy of the numerical model itself except by some simple tests for reasonableness.

Modelling received underwater sound levels requires the following steps:
1. Estimating the source levels and spectra of the sound sources.
2. Using a numerical model run at multiple frequencies to predict the transmission of sound in different directions from the source location(s). This is quantified by a quantity called transmission loss (TL) which is measured in dB.
3. Combining the source spectrum and the transmission loss results in order to calculate the received spectrum at each location of interest.
4. In most cases some form of integration over frequency is then carried out in order to produce a single received level for each location of interest.

In the following sections we consider the reasonableness of AECOM's approach to each of these steps
.

B.2 Source levels and source spectra

AECOM consider three potential noise sources:

1. The crawler unit (Subsea Sediment Extraction Device, or SSED) that operates on the seafloor.
2. The integrated mining vessel (IMV). This appears to be the vessel referred to as the FPSO in the original assessment of noise effects (Hegley, 2015).
3. Other vessels associated with the operation. These include a floating storage and offloading vessel (FSO) and anchor handling tugs.

Crawler unit

The information used by AECOM for modelling the crawler unit appears to be the same as that used in the original noise assessment (Hegley 2015), although AECOM appear to reduce this source level from 172 dB re 1 µPa @ 1m to 171 dB re 1 µPa @ 1m for reasons that are not particularly clear. The Hegley result itself appears to be based on sound level measurements made on components of a cutter-suction dredge operating in air and then translated to an 'equivalent' sound power level in water. The manner in which this conversion from air to water has been done is not specified, which is important, because depending on the assumptions made the results can differ widely. On p. 13 of Hegley (2015) it is stated that these components have "a combined sound power level of 117dB re 20µPa", which is dimensionally inconsistent because dB re 20 µPa is a measure of sound pressure level, not of sound power which should be in units of dB re 1 pW. Assuming that 117 dB re 20µPa was actually the measured source level in air (possibly deduced from a sound power measurement), and further assuming that the source radiates the same total acoustic power into water as it did into air, then the reviewer's calculation indicates the equivalent source level in water would be 179 dB re 1 μPa @ 1m. This estimate should, however, be treated with considerable caution as it is very sensitive to the 'equal power' assumption.

AECOM refer to two reports containing measured data from a De Beers Marine subsea mining operation using equipment similar to that proposed for the TTRL operation (see IMT 1994 and IMT 1995). The first of these reports provides the measurements of crawler noise plotted in Fig. 1 (Figure 3 in that report) from which a source level can be estimated.

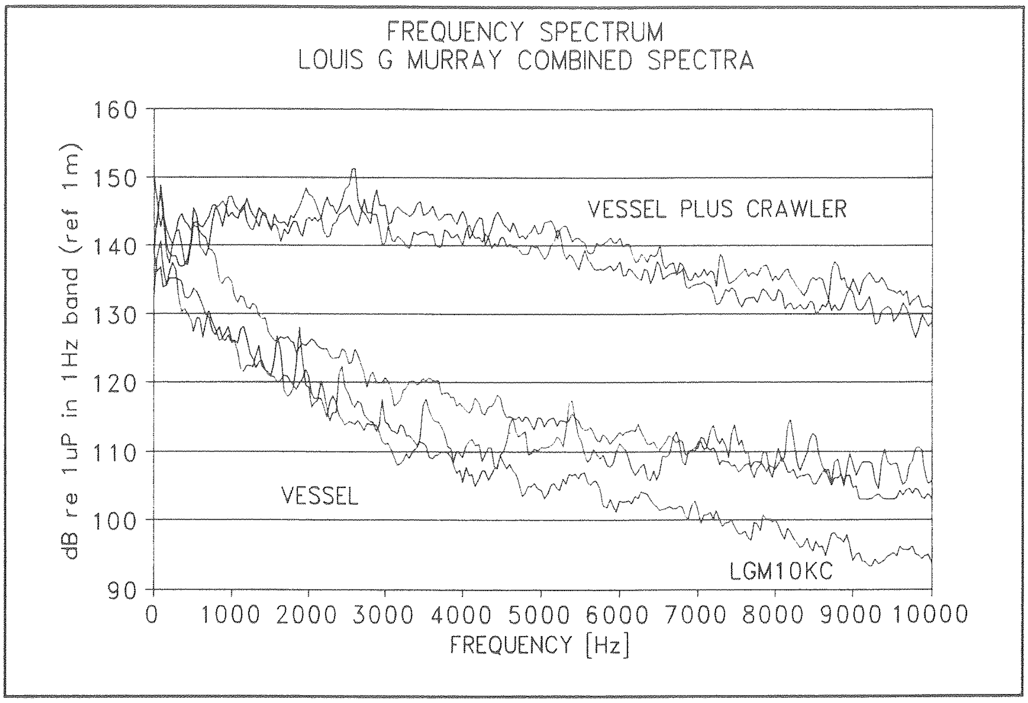

Fig.1. IMT 1994, Fig. 3

Estimating the dominant part of the crawler noise spectrum as having an average source spectral level of about 145 dB re 1 μPa in 1 Hz bands, and a 3 dB bandwidth extending from about 500 Hz to 4500 Hz, or a bandwidth of 4000 Hz, results in a source level of:
$SL = 145 + 10\log 4000$ =181 dB re 1 μPa @ 1m.
Note that the vessel itself may be generating higher noise levels when the crawler is in operation and it is not possible to separate their individual contributions from these measurements.

A comparison of figures 3, 4, 7, and 8 in IMT 1994 with Figure 9 in the same report (reproduced in Fig. 2 below) indicates that the labels of the GB+DRILL and LGM+CRAWLER curves in Figure 9 have been swapped. It is therefore likely that the upper curve, rather than the second highest curve, corresponds to the crawler data. This is important as this plot, with the same labels, but with some minor differences at low frequencies and a change from a linear to a logarithmic frequency axis has carried through to IMT 1995, Fig. 6, which appears as Fig. 1 in the AECOM report.

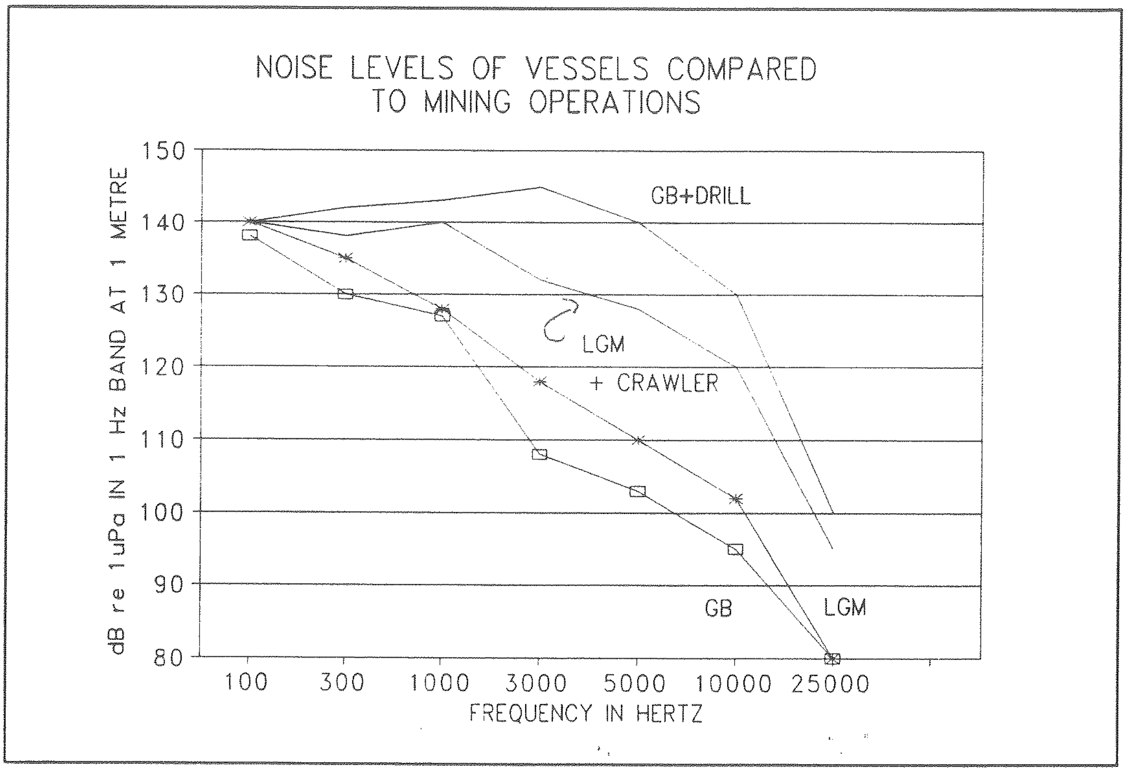

Fig. 2, IMT 1994, Fig. 9

It is implied in the AECOM report that this figure is the source of the TTR crawler source spectral data given in Table 1, however the reviewer has been unable to reconcile the two. Conversion of 1 Hz spectral levels (as in the IMT report) to octave band levels (as in Table 1 of the AECOM report) requires adding a bandwidth correction equal to $10\log(w)$ where w is the bandwidth of the octave band being converted (Hz). Reading the spectral levels by eye from AECOM Fig 1, and applying the calculated bandwidth corrections results in the gray and orange curves in Fig. 3 below, corresponding to the upper and lower curves in AECOM Fig. 1 respectively. These can be seen to bear little resemblance to the AECOM Table 1 octave band levels (yellow curve). What appears to be an error in AECOM's calculation of the octave band source spectrum for the crawler invalidates the results of the modelling that was then based on this source spectrum because, in these relatively shallow water depths, sound at frequencies between 1000 Hz and 10000 Hz, where the AECOM source spectrum appears to be up to 30 dB lower than it should be, would be expected to propagate more efficiently than sound at lower frequencies, at least out to ranges of a few tens of kilometres.

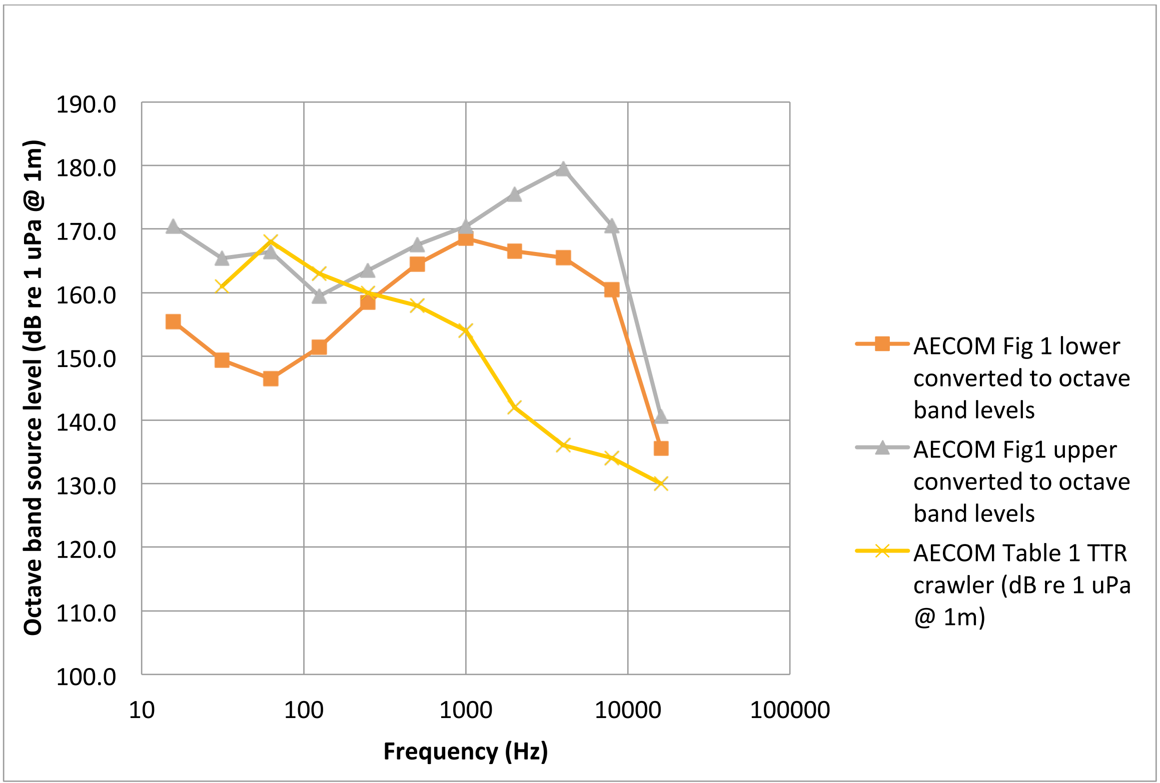

Fig. 3. A comparison between octave band source levels calculated by the reviewer based on the lower and upper curves in AECOM Fig. 1 and those given in AECOM Table 1.

Calculating the corresponding source levels by summing the equivalent mean square pressures in each band over frequency and then converting back to dB gives the results shown in Table 1. Note that the source level of 181 dB re 1 µPa @ 1m estimated above using IMT 1994 Fig. 3 is within the estimation uncertainty of the result in Table 1 based on the upper curve of AECOM Fig. 1.

Table 1. Broad-band source levels corresponding to the source spectra shown in Fig. 3.

	Source level (dB re 1 µPa @ 1m)
Reviewer's calculation based on lower curve in AECOM Fig. 1.	173.1
Reviewer's calculation based on upper curve in AECOM Fig. 1.	182.4
AECOM Table 1	171 (170.6 by reviewer's calculation)

Contrary to the statement on p. 13 of Hegley (2015), a number of measurements of dredging noise have been reported in both publicly available technical reports and refereed journals in recent years. See the introduction of Reine and Clarke (2014) for a useful summary of reported source levels, which have a large range, varying between 155 and 186 dB re 1 µPa @ 1m, with the highest levels being associated with vessels dredging gravelly sands. Note that in all these cases the reported levels include the combined effects of both the vessel and the dredging mechanism, which would overestimate the noise levels generated by the dredging mechanism alone, but would give a starting point for estimating the likely combined noise from both the crawler and the IMV.

IMV (FPSO) noise

The AECOM report discusses potential sources of noise from the IMV including machinery noise and thruster noise, but considers only machinery noise when estimating a source level of 171 dB re 1 µPa @ 1m. A 6 dB allowance for thruster noise is included in a "sensitivity analysis", but with caveats that the thrusters are only expected to operate for a small proportion of the time. These levels seem very low when compared to measurements of underwater sound levels from the FPSOs used in the offshore oil and gas industry. These are similar size vessels to the IMV that are anchored by means of a connection to a turret around which they are free to rotate, and are also fitted with thrusters which are used to maintain a desired heading in adverse sea conditions. The machinery fit-out is different to that of the IMV but the vessels are similar in most other respects. Erbe et al. (2013) report measurements of underwater sound radiated by six different FPSOs operating off the northwest coast of Australia. The 5th, 50th (median) and 95th percentile source levels (all vessels combined) were 188, 181, and 173 dB re 1 µPa @ 1m respectively. (This means that a source level of 188 dB re 1 µPa @ 1m was exceeded 5% of the time, 181 dB re 1 µPa @ 1m was exceeded 50% of the time etc.) The highest levels were associated with offloading operations, presumably due to the thruster use required at that time and the presence of other vessels. Mean source levels for the individual vessels varied from 174 to 183 dB re 1 µPa @ 1m. AECOM refer to this paper for information on thruster noise but do not mention these source level results, which the reviewer considers to be highly relevant.

A rough estimate of the combined effect of the crawler and IMV can be made by summing their source intensities, which for the equal source levels of 171 dB re 1 µPa @ 1m assumed by AECOM would give a 3 dB increase to an equivalent source level of 174 dB re 1 µPa @ 1m. (A more accurate approach is to model the sources separately and then sum their intensities at the receiver.) However, the discussion in the previous paragraph, together with that in the previous section indicates that the median combined source level is more likely to be at least 181 dB re 1 µPa @ 1m, and could be several dB higher. The FPSO data in Erbe et al. (2013) indicate that it is likely that the median source level will be exceeded by 7 dB or more at least 5% of the time.

The information in the AECOM report is insufficient to allow the reviewer to check the source spectrum values given in AECOM Table 1, except to say that they do not conform to either of the vessel-only noise spectra given in IMT 1994 Fig. 9.

The 5 m source depth assumed for the IMV noise is reasonable for mechanical noise but a deeper source depth may be appropriate for thruster noise, depending on the type of thrusters fitted to the vessel. Received levels are likely to increase with increasing source depth, but the dependence is weak, so the +/- 2dB variation stated in the AECOM report seems reasonable.

Noise from other vessels

The AECOM report discusses the additional noise that would be radiated by the other vessels involved in offloading operations but does not include them in any of the modelling on the grounds that such operations are intermittent. To the reviewer, effectively ignoring this noise seems to be a strange approach, given that offloading operations are an essential component of a subsea mining operation and that each such operation may take a considerable time to complete. Once again the measured FPSO data in Erbe et al. (2013) would be a very useful guide in this respect as noise from offloading operations is inherent in the statistics of these measurements.

B.3 Transmission Loss Modelling

AECOM carried out transmission loss modelling using the dBSea underwater acoustic modelling package. The reviewer does not have first-hand experience with this package but is familiar with the pros and cons of the various underlying calculation methods described in the AECOM report. The choice of the normal mode method for this work seems appropriate, providing it properly deals with the range dependent bathymetry, a normal mode model would be very computationally intensive at the highest frequencies listed in Table 1. (The upper frequency actually modelled is not specified in the report.)

The accuracy of this type of modelling is usually limited by the accuracy of the input environmental parameters, with the seabed properties being particularly important in shallow water such as this. The description of the assumed seabed properties given in the AECOM report is fairly vague "Assume seabed sand to a depth of 15 m", with a previous mention of silty sands as the predominant seafloor type in South Taranaki Bight. From the description of dBSea's normal mode solver provided in the report it would appear that an artificial attenuating layer would be included 15 m below the seafloor, in which case no sound would be reflected back into the water column from deeper in the seabed. The acoustic reflectivity of sand varies widely depending on its mean grain size, with coarse sands being more reflective than fine sand. Orpin (2013) provides a description of the sedimentary geology of the South Taranaki Bight and was prepared specifically for TTRL. From Section 4.3 of this report it appears that the seabed in and around the operational area is likely to consist of gravel, in places overlain by finer muddy deposits, the thickness of which increases with increasing water depth, particularly for water depths greater than 50 m. The gravel would result in a more reflective seabed than that provided by the uniform sand layer assumed by AECOM, whether or not it was overlain by a fine muddy layer, which would be virtually transparent to sound. It is therefore likely that the transmission loss will increase less rapidly with range in practice than the modelling carried out by AECOM would suggest, resulting in higher received levels than those estimated in the AECOM report. Without re-running the modelling with a more appropriate seabed model it is difficult to quantify the effect this would have on the calculated transmission loss, however the reviewer's expectation is that it would result in a reduction in transmission loss of several dB at 500 m range.

B.4 Received spectrum and level calculation

The remaining steps in calculating the received levels, i.e. combining the source spectra with the transmission loss results to obtain received spectra and then integrating these over frequency to obtained received levels, were also carried out by AECOM using dBSea. There is some mention of this calculation including separately modelling the received sound levels due to the crawler and the IMV and combining these at the receiver, although this is not explicitly stated, and it is unclear whether the 171 dB re 1 µPa @ 1m source level given in Table 2 includes both of these sources or only one. As mentioned above, if both sources are included, this is roughly equivalent to assuming a combined source level of 174 dB re 1 µPa @ 1m.

It appears that AECOM computed received levels for 500 m range at a single depth of 10 m. Received levels will vary with depth and it would therefore be prudent to calculate the received level at a range of depths spanning the water column and use the highest in the impact assessment.

It is apparent from the discussions in the preceding sections that the source levels given in the AECOM report have been underestimated, and the transmission loss values have been overestimated, both of which would result in an under-prediction of received levels. Considering both effects, and comparing the AECOM effective combined source level of 174 dB re 1 µPa @ 1m to the reviewer's estimate of 181 dB re 1 µPa @ 1m it seems likely that that median received levels will exceed those predicted in the AECOM report by at least 9 dB, and could be higher. There will be some range dependence but that cannot be quantified without repeating the numerical modelling.

B.5 References

Erbe, C., McCauley, R., McPherson, C., Gavrilov, A., (2013) "Underwater noise from offshore oil production vessels", JASA Express Letters, http://dx.doi.org/1.4802183

IMT (1994), "Institute for Maritime Technology, Environmental Impact Study, Underwater Radiated noise", TV0010-000003-730, 8 July 1994

IMT (1995) "Institute for Maritime Technology, Environmental Impact Study, Underwater Radiated noise II", TV0010-950048-730, 23 March 1995

Hegley, N. (2015), "Trans Tasman Resources Ltd, Offshore iron Sand Extraction and Processing, Assessment of Noise Effects." Hegley Acoustics Consultants, Report 9101, November 2015.

Orpin, A. R., (2013), "Geological Desktop Summary Active Permit areas 50753 (55581), 54068 and 54272, South Taranaki Bight", NIWA client report WLG2013-44, August 2013.

Reine, K. J., Clarke, D. (2014), "Characterization of underwater sounds produced by hydraulic and mechanical dredging operations", J. Acoust. Soc. Am. 135(6), June 2014, pp. 3280 - 3294.