Technical review and analysis of oceanographic information presented in Coastal Resources Limited's marine dumping consent application – EEZ100015

Technical Review

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1 Introduction

Coastal Resources Limited (CRL) has lodged an application for a 35 year marine dumping consent with the Environmental Protection Authority (EPA) to annually dump up to 250,000 m^3 of dredged material from source sites within Auckland and Waikato, at an existing dump site 25 km east of Great Barrier Island.

The EPA requires an experienced oceanographer to review the relevant information in the application documents that relate to work carried out at the Northern Disposal Area (NDA).

The review will provide advice to the Decision Making Committee on whether the information provided in the relevant documents adequately describes the existing oceanographic conditions at the Northern Disposal Area, for the following:

a) To assist in the identification of possible adverse effects, and
b) To enable a consideration of relevant decision-making matters under section 59 of the EEZ Act.

The present report constitutes Deliverable 1 as described in the RFQ /1/.

1.1 Scope of Review

The scope of the review was set out in the description of the work in the RFQ /1/.

Deliverable 1 shall include a review of the relevant documents and an analysis that:

a. Advises whether the best available information has been used to describe the oceanographic environment, noting that best available information means the best information that, in the particular circumstances, is available without unreasonable cost, effort, or time.
b. Advises whether the information on the oceanographic conditions is sufficiently adequate and certain to enable a consideration of the relevant decision-making matters under section 59 of the EEZ Act.
c. Comments on the accuracy of the descriptions of the dispersion / re-suspension environment and any significant limitations.
d. Comments on the robustness of the numerical modelling described in Chapter 5 of Flaim's 2012 thesis and the conclusions therein (Chapter 6) on dispersion.
e. Comments on whether any conclusions relating to the oceanographic environment of the Northern Disposal Area that are made in any of the relevant documents (including the impact assessment by CRL) accurately represent the descriptions of the oceanographic environment.

The report shall further provide recommendations for additional information or analysis, if any, and justification as to why the additional information is necessary to understand the oceanographic environment, and how it will assist with assessing the scale and significance of the dumping of dredged material at the Northern Disposal Area.

The base documents specified for review are:

- Beca's report – appendix 4 to the application, including Appendix B and D to the Beca report;
- Report 2, Report 3, and Report 6 of the Post-Disposal Monitoring of the Auckland Marine Disposal Ground Post (February 2011); and
- Relevant parts of Flaim's PhD thesis (2012).

This has subsequently been supplemented by:

- Evidence by Peter Longdill;
- Evidence by Connon Andrews, including Appendices A, B and C related to disposal of dredged material, near-field and far-field modelling; and
- NIWA Addendum to report.

For the Evidence by Connon Andrews, it has specifically been requested to assess whether:

a The chosen dispersal model(s) is suitable for predicting the fate of dredge material with regards to:
   i. The material proposed to be dumped, and
   ii. The proposed disposal site.

b The dispersal model set-up is in accordance with international best practice;

c The quality of input data or datasets used are adequate, including any modelled datasets;

d The input data has adequate resolution to allow for a reasonably accurate simulation of the fate of the material proposed to be dumped; and

e Reasonable effort has been made to accurately describe:
   i. The uncertainty of the model.
   ii. The uncertainty of the model set-up.
   iii. The uncertainties in the input data and databases used in the model.
   iv. The effect of these uncertainties.

1.2 Reviewer Qualifications and Experience

My full name is Claus Pedersen. I am a Regional Technical Director for Asia-Pacific, employed by DHI Water & Environment, Malaysia and based in Malaysia. I hold the qualifications of Master of Science and Ph.D. in Coastal Engineering from the Technical University of Denmark.

I have 25 years professional experience in the fields of coastal and marine engineering and environmental impact assessments. I have a strong background in development and application of numerical modelling as supporting tools for both engineering and environmental applications in the marine environment. I am a registered Environmental Consultant with the Department of Environment, Malaysia as well as with the Environment Protection Department of Sabah and the Natural Resources and Environment Board of Sarawak, and I have provided input to development of guidelines for numerical modelling and impact assessment in both Malaysia and Western Australia.

Over the past 20 years based in Asia, I have been heavily involved in both planning, assessing and managing large dredging and reclamation related projects in Malaysia, Singapore, Brunei and Australia. I was the DHI project manager on modelling and environmental assessment support provided to Chevron for the EIS and Environmental Management of dredging of 40 million m^3 for the Wheatstone LNG project in Western Australia. This involved predictions of dredge and disposal plume impacts for the EIS and daily forecast and hindcast modelling of all dredge and disposal activities over a 3 year period, supported by extensive monitoring. I am currently the technical advisor for large dredging projects in Brunei and Singapore with daily modelling, monitoring and reporting.

I have previous experience undertaking a review for EPA (STOS Māui Offshore Facilities Marine Consent Application Drill Cutting and Condensate Spill Modelling). As part of this review, an analysis of oceanographic information (measurements and model predictions) presented in the consent application was required. I understand the requirements and expectations with regards to reporting, caucusing and hearing attendance.

1.3 Code of Conduct

I confirm that I have read and agree to comply with the Code of Conduct for Expert Witnesses in the Environment Court of New Zealand Practice Note (2014).

2 Summary

The summary of the review focuses on the 5 key questions/items raised in the scope. Specific review comments to the individual documents are included in subsequent sections.

2.1 Question A

Whether the best available information has been used to describe the oceanographic environment, noting that best available information means the best information that, in the particular circumstances, is available without unreasonable cost, effort, or time.

I am not aware of other data sets or information that would add significant weight to the description of the oceanographic environment which have been left out.

Long term data from an oceanographic model such as HYCOM (data available for download) may supplement the 10 year ocean current hindcast data included in the Trajectory modelling of invasive species in the Hauraki Gulf (Appendix D to Appendix 4) as an additional source for comparison in assessing seasonal and inter-annual variability in oceanographic environment.

2.2 Question B

Whether the information on the oceanographic conditions is sufficiently adequate and certain to enable a consideration of the relevant decision-making matters under section 59 of the EEZ Act.

Whereas there will always be variability and statistical uncertainties related to climatic conditions, I feel that the information available from longer and short term monitoring (Flaim 2012) combined with information from the longer term ocean current hindcast provided in Appendix C to Evidence by Andrews, forms an adequate baseline for the oceanographic conditions for informed decision making.

Quantification of waves and currents is key in the assessment of likely dispersion (both during and following the disposal process, and as a result of potential re-suspension). Due to the large water depths and operational limitations, the effects of surface waves is insignificant. The currents have been resolved through short and medium term measurements combined with longer term hindcast. This should provide a good statistical basis, although documentation of model performance against the available data set would have been desirable.

Aspects where some uncertainties remain in my mind, include the presence and effects of stratification over the water column and the occurrence and potential for re-suspension associated with internal waves. Whereas these components can affect the dispersion of suspended material and the potential for re-suspension of deposited material, they are not anticipated to be dominant components of the environment.

There appears to be significant uncertainty related to ambient Suspended Sediment Concentrations (SSC) with a very large variability in the derived concentrations from water samples collected during the disposal plume monitoring campaign in 2010. For any evaluation or formulation of conditions relatively to background concentrations, it is important to have a clear understanding of levels and variability in SSC.

2.3 Question C

Comments on the accuracy of the descriptions of the dispersion / re-suspension environment and any significant limitations.

The phases and processes that lead to dispersion of sediments during the disposal are well described in Flaim 2012. The first two phases (convective descent of the bulk of the material to the bottom and the dynamic collapse as the plume impacts with the bottom) are as much dependent on parameters related to the material and the release as it is on the oceanographic environment. These phases are density driven, and the ambient density profile over the water column plays a role. Some stratification was observed during the 2010 monitoring of disposal events, and there is a data gap in the knowledge of the stratification at the area of interest.

For the assessment of the dispersion of the passive plume in phase 3 of the disposal process, the currents are considered key at the present site. Whereas it is useful for the understanding the predictions to separate the currents into different components (tidal, wind driven, East Auckland Current, etc) it is important to remember that it is the combined effects of these, that will disperse the sediment and also cause potential resuspension in extreme conditions. This is generally well described, though Flaim left an important component out in defining “strong” current conditions, and a validation against the available data set would have been very useful for the 10 year ocean current hindcast.

Whereas the ambient SSC has no significant effect on the dispersion or re-suspension of sediment, it is critical in terms of the ability to distinguish any plume derived from disposal from background, and would often also be a reference for impacts. Based on my review to date, I suspect that ambient concentrations are low (a few mg/l), but measurements of “ambient” concentrations during the surveys in 2010 showed high variability.

2.4 Question D

Comments on the robustness of the numerical modelling described in Chapter 5 of Flaim’s 2012 thesis and the conclusions therein (Chapter 6) on dispersion.

The modelling presented in Chapter 5 has its limitations which will be briefly outlined, grouped into three aspects:

1) Modelling strategy
2) Model setup
3) Model application and interpretation (choice of scenarios and presentation of results)

Modelling Strategy
Whereas the objective of the modelling was clearly set out to:

“*investigate the influence and effects of forcing mechanisms on dispersion at the AMDG that were not previously observed in the field campaigns through the modelling of a range of idealised scenarios representing potential conditions at the AMDG”*

the strategy to achieve this was not well defined. It is common best practice to model near-field (dynamic) and far-field processes separately. Whereas Flaim recognises this in the conclusion, an attempt was made to model both aspects in a single model, resulting in a setup that was not ideal for either component.

Model Setup
The model as set up cannot simulate the near-field dynamic processes, and any attempts to do so would have a high risk of being misleading rather than being informative.

For simulations of the far-field dispersion, the model setup has limitations in respect to:

- Limited coverage of 3D model – would lead to boundary effects for longer term simulations.
- Limited area of high resolution mesh would lead to high numerical dispersion along and immediately outside the boundaries of the NDA.
- Vertical resolution and model boundary forcing is not set up to simulate 3D water column effects. For instance it cannot resolve potential effects of the observed pycnocline.
- The source terms included in the model are considered likely to be conservative.
- The entire sediment source term is conservatively placed at the surface. A distribution over the water column to represent the passive plume would be considered more appropriate.

Model Application and Interpretation
The criteria for model interpretation are not established. The model simulations are stopped at times where suspended concentrations are still high, and well before the plume can reach the boundary for the prevailing currents. This may be defendable based on plume concentrations relative to background, but a clear case has not been stated for this (and there is not a clear assessment of what constitutes background).

The choice of modelled scenarios is considered non-conservative. The chosen "high current scenarios" have average currents speeds in the order of 6-7 cm/s, which is far lower than the currents observed during the disposal monitoring which reached up to 25 cm/s, and lower than the ~9 cm for mid depth estimated in the 10 year ocean current hindcast study. This leads to an obvious under estimation of the dispersion from the disposal site in the "longer" simulation. The model has only been run up to a few hours, but much of the passive plume will remain suspended for days.

In Chapter 6 under the heading of: **Objective 3 – Assess the potential for loss of disposed sediment from disposal site,** it is stated that:

1. *"In all instances, measured and predicted dispersion distances were found to be less than the radius of the AMDG (1500 m) for a representative time frame after disposal"*

and

2. *"Through completion of this objective, it became clear that the AMDG behaves as a retentive site; one where disposed material is retained within the boundary."*

For statement 1, a simple assessment of the prevailing net currents at the site combined with the low setting velocities of typical particles suspended in the passive plume leads to the conclusion that a proportion of the passive plume will be carried outside and settle outside the boundaries. It is quite possible that this is insignificant and does not pose an environmental risk, but the modelling is not utilised to support this assessment, and no attempt has been made to quantify the associated concentration and sedimentation rates outside the NDA.

For statement 2, the definition of retentive hinges on the deposited sediment not re-suspending once it has settled out. A qualitative assessment has been given in support of this based on both observations of the seabed, the limited effect of waves at the seabed in deep water, and the limited current speeds at the bottom. All observations seem to support the statement that the site is retentive. It does, however, not rule out that resuspension could take place under extreme conditions. This could be further supported by simulating the combined effects of currents and waves on the bottom shear stresses. Whereas I would not rule out that re-suspension could occur on rare events, I consider it unlikely that this would constitute a significant proportion of the material disposed (and resuspension would likely also occur in surrounding areas at the same time). In this basis I concur that the site can be classified as retentive.

2.5 Question E

Comments on whether any conclusions relating to the oceanographic environment of the Northern Disposal Area that are made in any of the relevant documents (including the impact assessment by CRL) accurately represent the descriptions of the oceanographic environment.

A conclusion by Flaim, which is sited in several documents, is that the suspended concentrations will be indistinguishable from background within 1 - 2 hours. This was concluded mainly from surface visual observations, and does not take account of potential higher concentration plumes deeper down in the water column. After the initial convective settling of the bulk of the material to the bottom, a plume of material that has been stripped off the main descending plume will remain suspended over the water column (process well described in Flaim 2012). The plume is likely to contain a range of particle sizes from clay to fine sand. Even fine sand with a diameter of 100 microns will take about 5 hours to settle from the surface to the bottom, and most of the particles are likely to take longer (in the order of days and up to weeks). After 1 – 2 hours, only a fraction of the passive plume would have settled out, but the combination of settlement below the surface and mixing/dispersion which will tend to reduce surface concentrations and reduce sharp concentrations gradients will make the plume less distinguishable at the surface.

Based on the conclusion that plumes have blended into ambient concentrations within 1-2 hours after disposal, it is also concluded that “dispersion distances” are less than the radius of the disposal site. This would be the case for the bulk of the material that settles to the bottom in a convective flow, but for the passive plume, which to a large degree consists of fine particles with low settling velocities distributed over the water column, it takes less than 5 hours for a particle to travel the 1500m distance to the border of the NDA for a net current speed of 9 cm/s (estimated mean current speed mid-depth). Based on the combination of ambient currents and low settling velocities, it is considered that most of the sediment in the passive plume is likely to leave the NDA. The sediment plume model should be able to assist in quantifying this.

2.6 Additional Information

The report shall further provide recommendations for additional information or analysis, if any, and justification as to why the additional information is necessary to understand the oceanographic environment, and how it will assist with assessing the scale and significance of the dumping of dredged material at the Northern Disposal Area.

It is recommended to establish a better baseline for suspended sediment concentrations (SSC), including variations in time and space. Without specific threshold limits on SSC and/or sedimentation related to tolerance limits of environmental receptors, it is often used to evaluate excess concentrations against ambient concentrations. If any quantitative monitoring of SSC or turbidity is required, it would preferably require a good understanding of baseline.

It is suggested to produce additional output from the plume model to illustrate and quantify the fate of the passive plume. In the present representation of model results from the far-field model, the results are averaged over a month, which leads to extremely low average concentrations. Most of the monthly averaged concentrations outside the 1000 m radius have dropped below the threshold value for plotting, which gives the impression that plumes do not occur here. The plotting should in principle be guided by requirements to make an assessment of the risk of impacts to the environment. This could for instance include:

- Representative 2D “snapshots” of depth-averaged and/or maximum over depths plume concentrations to illustrate the development of the plume in time and space. A few series for different ambient current conditions would be helpful.

- Statistical plots of exceedance frequencies of given threshold limits (e.g. 5 mg/l, 10 mg/l, 25 mg/l). This will assist in better understanding the Intensity-Duration relationship rather than just a monthly averaged value.
- Sedimentation plots with a lower threshold value for plotting to show the sedimentation patterns.

3 Review Comments for Individual Reports

3.1 Flaim 2013

Overall, Flaim's thesis contains a thorough description and documentation of both the historical context in the Auckland area, the physics of the processes involved, a comprehensive data collection campaign and numerical modelling carried out with the intent to further improve the understanding of the likely dispersion at the Auckland Marine Disposal Ground.

The present review has, in accordance with the prescribed scope, focussed on an assessment of the robustness of the numerical modelling described in Chapter 5 and the conclusions (Chapter 6) on dispersion.

3.1.1 Section 5 – Numerical Modelling Exercises for Improved Understanding of Dispersion at the Auckland Marine Disposal Ground

Modelling Strategy

Modelling of sediment plumes and sedimentation generated from disposal is commonly separated into considerations of near-field and far-field effects, where the near-field effects are dominated by the density and turbulent driven effects during the initial descent and subsequent dynamic collapse of the "bulk" of the sediment (processes well described in Chapter 2 of the thesis), and the far-field processes focus on the dispersion, sedimentation and potential resuspension of the passive plume distributed over the water column.

Modelling of these two components requires consideration of different scales (both spatial and temporal) and processes, and the norm is to separate them into different models, although there are attempts to link them.

In Flaim's thesis, there is an attempt to get a single model to simulate both near-field and far-field processes. This has limited success for the near-field processes in particular due to the limitations of the model setup, which is also acknowledged by Flaim.

Some specific review notes are included below for the hydrodynamic and sediment model setup and applications.

Hydrodynamics

A far-field 2D tidal model was attempted, but abandoned due to lack of performance believed to be associated with the limited number of tidal constituents included in the deep water tidal boundaries. Focus was then directed to a "local" 3D hydrodynamic model, which was set up to reproduce the measured/estimated tidal and non-tidal currents during the 4 monitored disposal events.

Some specific comments to the limitations of the 3D model setup in terms of being able to simulate relevant processes includes:

- The mesh coverage is up to 5 km from the centre of the disposal site. In a 25 cm ambient net current, particles with a diameter finer than about 100 microns can travel this distance before reaching the bottom. The model coverage is far too small for longer term simulations with the intent to determine the fate of all released sediment (this was not attempted by Flaim)

- The mesh resolution drops dramatically outside a 2 by 2 km quadrant. This would lead to severe numerical dispersion outside this quadrant (including parts along the edges of the NDA)
- The “fine” mesh resolution is in the order of 50 m, which is considered ok if the model is set up with the intent to simulate far-field dispersion of sediment.
- The mesh has been established with 4 layers over the depth. This is much too coarse if the intent were to resolve stratification or any water column hydrodynamics (Flaim has clearly stated that the model has been set up in barotropic mode due to limitations in available boundary forcing data). The model is thus not set up to simulate any effects along the observed pycnocline.
- If the model was intended to simulate the density driven near-field effect or the momentum from the sediment release, it would require a far finer grid resolution both horizontally and vertically.

Sediment Transport

The sediment transport model applied by Flaim to simulate the plume dispersion is widely applied for far-field modelling of sediment plumes derived from a variety of sources. In its standard application, it is NOT coupled with the hydrodynamics (i.e. there is no feedback to the HD model on e.g. densities). For far-field applications, the resolution at the source will normally be limited, and it is standard to apply source terms that are representative of the passive plume(s) in the water column. For disposal as the present case, this would typically mean a representation of the passive plume left in the water column after the dynamic processes have taken place.

The norm is to include the sediment into the model as a “spill source term”, with the spill defined through source terms that may vary in time, space and mass. Each source will have a representative distribution of material on a “settling curve” represented by a number of fractions. The source terms may either be released through a source in the hydrodynamic model (a water source specified by rate and velocity) with an associated concentration, or as a “passive” source with no momentum effects in the HD model.

Some specific comments to the model setup by Flaim (as it is understood) are provided below:

- It is not entirely clear to me whether a hydrodynamic source term was included in the model. In any case, the mesh resolution used would not allow the resolution of any momentum effects of a release “jet” as stated under the hydrodynamics.
- The entire barge load has been included in the source term, released over a 5 second period at the surface. This may represent the actual release process well, but does not necessarily lead to a good representation of the passive plume as noted below:
  - The density driven descent of the “bulk” of the material has been emulated by including two sediment fractions with high settling velocities representative of the observed settling velocities of the bulk of the material during the initial convective phase. If the intent is to get this included in the local sedimentation footprint, this is considered a reasonable approach. It should, however, be kept in mind that the model has not been set up to include density effects, so the added dispersion at the bottom caused by the momentum and subsequent density currents are not included in the model. The model will only represent the effects of ambient currents and dispersion during the settling to the bottom.
  - Three additional sediment fractions are defined with representative settling velocities corresponding to clay, silt and fine sand, based on the observed distribution in the dredged material. These are meant to represent the passive plume dispersed in the water column during the dynamic phase. The entire source term for these components is also included in the surface layer over the 5 second release period. This does not take the gradual stripping of the sediment along the edges of the descending “jet”. A better representation could easily be achieved by including these components in a number of sources distributed over the water column.

- The relative distribution between the sediment fractions has 30% of the total on the 3 fractions representing the spill at the surface. Based on literature and experience, this sounds relatively high and is likely conservative (Flaim has references to the proportion lost as 1 – 5% of the disposed material).

Model Applications and Interpretation

For the application of Flaim, which focusses on the dispersion of sediments from the centre of the fine mesh within the first hour after release, the model can reasonably simulate the dispersion of the passive plume, excluding any density effect over the water column.

The model was further applied by Flaim to extend the assessment to a wider range of climatic scenarios beyond what was encountered during the monitoring campaign. The simulation times were extended to 4 hours, but as the so-called "high current cases" only included average current speeds up to 6-7 cm/s, the plumes still remained within 1000 m from the source. It is notable that the so-called "high current cases" resulted in net current speeds that were far less than those observed during the field campaigns (up to 25 cm/s). If the intent is to consider the potential for dispersion of the plume outside the boundaries of the disposal ground, the choice of scenarios are highly non-conservative.

The simulations did not include the effects of other non-tidal forcing such as the East Auckland Current (EAUC), which could significantly increase the net currents and transport the plumes beyond the limits of the disposal site. The model mesh would not be suitable to handle such simulations. Flaim has acknowledged that*:*

"It would be beneficial to simulate the effect of the EAUC in combination with winds and tides. This is an area of research that deserves further examination, but requires more data than that obtained during the field programme for this study."

As measurements have clearly indicated the presence of stronger net currents up to at least 25 cm/s, it would have been desirable to see such cases tested in longer model simulations. The 2-month record of measured currents should provide a good starting point for this, and the available data has certainly indicated that the currents applied in the slightly longer simulations (4 hours) are not conservative. Longer simulations of net currents would have required an amendment to the mesh to avoid boundary effects and too high numerical dispersion.

There are no clear criteria set for model run times and presentation of results. With the entire source term (conservatively) placed at the surface, all the sediment introduced in the three fractions representing the passive plume will still remain suspended in the model after 1 hour (also confirmed by Figure 5.28), and only the fine sand fraction would have settled out after 4 hours. A criterion on maximum concentration or other relevant threshold would normally be applied to select the minimum time simulated.

3.1.2 Section 6 – Summary and Conclusions: Dispersion Potential at the Auckland Marine Disposal Ground

The description of the currents seems to have contradictory statements in respect to the influence of wind on currents where one statement describes the wind during the 2010 surveys, when stronger currents were experienced, to be the predominant forcing mechanism, while another statement describes the wind-driven currents as weak compared to tidal currents under conditions where it would be possible to undertake disposal operations.

Under Objective 3 – Assess the potential for loss of disposed sediment from disposal site, it is stated that

"In all instances, measured and predicted dispersion distances were found to be less than the radius of the AMDG (1500 m) for a representative time frame after disposal".

This finding hinges on the “representative time frame”. The ADCP monitoring was stopped about 1 hour after disposal on the basis that the residual plume was barely visible above background at the surface. This does, however, not mean that there is not a significant plume remaining further down in the water column that will continue to and across the boundary. After 1 hour, most of the sediment in the passive plume would remain in suspension (it takes fine sand about 5 hours to settle 150 m, and medium silt more than 2 days).

For the plume to travel the 1500 m to the boundary within 1 hour would require an average speed in excess of 40 cm/s, which was not experienced. For the simulations that were extended to 4 hours, the average current speeds were low, and therefore the plumes did not extend beyond 1000 m from the source.

With the net currents experienced at the site (measured up to 25 cm/s during disposal 3), and using representative settling velocities of “individual” particles in the passive plume, it is clear that a proportion of the sediment in the passive plume at times will cross the boundary and eventually settle outside the boundaries of the disposal area. The model can assist in estimating relevant parameters to assess whether this is a potential threat. The model can, for instance, assist in estimating the proportion of the material that settles outside the boundaries; the frequencies and durations of the plumes outside the boundaries; where and at what rates the sediment eventually deposits. It is further stated that:

“The findings revealed some specific conditions that were observed or simulated that may result in dispersion beyond the boundary of the site, but in general, those cases are few and are not likely to occur during disposal at the site”

Based on simple calculations I do not concur with this statement. I find it likely that some fines will settle outside the boundaries for most if not all disposals. The key question is whether this is significant and leads to any risks of impacts, which may very well not be the case due to limited volumes and/or absence of sensitive receptors, but this is beyond the scope of my review.

A final statement that I will briefly comment on reads:

“Through completion of this objective, it became clear that the AMDG behaves as a retentive site; one where disposed material is retained within the boundary.”

There are two key questions to consider:

1) Whether the disposed material settles within the disposal site
2) Whether disposed material remains within the site once settled or may re-suspend and be transported out of the site.

The second question is key to the assessment whether a site is retentive. It has been assessed that waves large enough to generate sufficiently high orbital velocities at the bottom to re-suspend material are unlikely. The likelihood of extreme currents and/or combined currents and waves has not been addressed.

3.2 BECA Report: Northern Disposal Area – Physical Oceanography Assessment, Dredged Material Disposal Options and International Deep Water Disposal Sites

The scope of Beca’s report is listed as:

- A desktop review of existing monitoring and research at the NDA as well as international literature on deep-water disposal.
- A summary of the historical context of regional disposal and commentary on dredged material disposal options.

- A summary of details of deep-water disposal locations.
- Review of the 2016 and previous bathymetric surveys and sediment core monitoring to identify trends in the disposal mound over time.
- Estimation of the future disposal mound envelope.

As outlined in the scope, the Beca report is primarily a review of existing documents and data sets, and it leans heavily on the studies and findings of Flaim.

Evaluation of Potential Oceanographic Effects

Beca has included a discussion on the short and long term physical impacts of increasing the deposited volume, where short term impacts are related to mainly turbidity generation during the disposal process until the disposed material has settled while long term impacts are related to material mound erosion, re-suspension and settlement.

Key conclusions include:

- Each future individual disposal operation is expected to be similar in terms of material composition, volume and physical disposal.
- The turbidity generated by each individual disposal is thus expected to be similar to past monitored events, which indicated that the disposal plume takes in the order of 1-2 hours to disperse.
- Whereas the overall time with elevated turbidity will increase proportionally to the increase in disposal volume (factor of 5 in terms of proposed permitting), it is argued that the area impacted does not increase

Review Comments

The assumption of the disposal plume dispersing in 1-2 hours is critical. As explained under the review of Flaim 2012, the passive plume will take much longer to fully settle out. This leads to a risk of cumulative effects where plumes from two or more subsequent disposal events mix. This is best evaluated in sediment plume model where the effects of subsequent disposals can be tested for different climatic scenarios.

To determine risk of impacts, it is normally required to identify any receptors at risk, establish a set of tolerance or threshold limits for these and evaluate the risk of these thresholds to be exceeded – often using a numerical tool. Threshold limits are often established as Intensity-Duration-Frequency (IDF) relations for a given stressor, for instance SSC or sedimentation. In an IDF framework, even if there is no plume overlap leading to higher concentrations, two equal events within a given timeframe compared to one will increase the risk expressed through the duration/frequency. Although the turbidity effects of each individual disposal event may be identical, the area where a given threshold is exceeded (call it a zone of impact) will typically increase when the frequency of operations is increased.

To evaluate the risk of cumulative impacts, each event needs to be assessed until the passive plume has settled out.

Resuspension/Erosion

Individual current components generated by waves and non-tidal currents were evaluated and compared to threshold limits.

Review Comments

Whereas I concur that resuspension is likely to be rare and minimal in terms of loss of material from the site, I note that to properly evaluate the risk, the combined effects of waves and total currents on the bottom shear stresses should be considered. In a re-suspension event it is considered that the surrounding areas are also likely to experience re-suspension, and the impacts from any resuspension plumes from the NDA may in this context not be significant.

3.3 NIWA Review of Report 2 – Multibeam Echosounder: Seafloor Geomorphology

NIWA states that comparative surveys are the main tool used to determine the bathymetric impact on spoil dumping on the seafloor. They go on to describe the multiple error sources and provide a sample error budget for different water depths which illustrates the increasing total standard errors with increasing depths.

NIWA emphasizes the requirement for a consistent and carefully thought out work programme and project methodology to minimise all measurable errors. They specifically recommend:

- Applying a patch test of the system prior to the start of surveying.
- Obtaining a sound velocity profile prior to start.
- Monitor surface sound speed during surveying.
- Use of the same equipment, platform and good work practices for all surveys.
- Ensuring sufficient overlap between survey lines.
- Survey on relatively calm days only.
- Obtain tidal record to remove tidal effects.

Review Comments

Whereas it is recognised that the absolute and relative errors will increase with increasing depths, I agree that multi beam bathymetry data likely provides the best means of getting a full 3D picture of the larger scale changes in bathymetry. Other “point” measurements, such as, drop cores will not be able to provide the same spatial overview. The measures recommended by NIWA to minimise the errors are sound best practice, and with the bathymetry in the area being described as largely flat and featureless, it should be possible to remove systemic errors to achieve a better relative comparison within the areas affected by the disposal.

Even with this, the bathymetry measurements cannot be expected to resolve the minimal changes expected along the boundaries of the NDA, but it should be able to support an assessment of the general trend of the larger scale changes and also be useful to ensure that disposal is taking place within the dedicated area and not encroaching on the boundaries.

3.4 Auckland Marine Disposal Ground Monitoring Series, Report 3 – Plume Monitoring

Report 3 presents a fairly comprehensive field campaign set up to monitor disposal plumes in fulfilment of the consent conditions. The main objectives defined in the report were to determine the dispersion potential of the suspended sediment and whether or not it would disperse beyond the established boundary of the site (1500 m radius form the centre of the site). A secondary objective was to test the methodology used for monitoring the disposal plume to determine what was practical, in order to make recommendations for future monitoring.

Multiple sensors were deployed, but all faced challenges related to the rapid development and transient nature of the plume, which makes capturing and quantifying it through fixed and/or mobile stations a challenge.

Most of these challenges are identified and described in the report, with the overall conclusion that the ADCP transect measurements provide the most informative data set to track the plume development and dispersion.

In terms of fulfilling the main objective, the report states that the monitoring has indicated that:

- The main component of the disposed material deposits within seconds and within 250m of the release point.
- Turbidity arising from the dispersed fines was only significant within a 500-600 m radius of the disposal location

Based on these results, and the assumption that disposal will be of similar volume and due to the operational limitations of the equipment will take place under similar "calm" conditions, it is concluded that it is reasonable to assume that a plume arising from dredged material disposed at the centre of the proposed site will not be dispersed at detectable levels beyond the established boundary.

For the secondary objective, it is recommended to focus on ADCP transects, but stated that a calibration is not necessary as ADCP backscatter is sufficient to provide the necessary information (relative to background). It is recommended to set up a fixed, pre-assigned grid and run transects here for at least one hour.

Review Comments

Whereas the conclusion that

"it is reasonable to assume that a plume arising from dredged material disposed at the centre of the proposed site will not be dispersed at detectable levels beyond the established boundary"

may be reasonable based on the presented data from the monitoring campaign, it does raise two key questions:

1. What is the detectable limit – can it be quantified?
2. Does the "*detectable limit"* constitute an accepted lower limit below which dispersion beyond the NDA boundaries is accepted?

For the first question, this will both depend on the equipment, the presentation of the data and the level and variability of the ambient concentrations. With the requirement to penetrate to deep water, some resolution may be lost on the "accuracy" in concentrations derived from backscatter, and the presentation of the data (in terms of colour bins, etc) is obviously also important. In Figure 3.80 of the report, an "indicative range" of background is given as 60 - 82 dB, which on the parallel scale in the figure is correlated to 0 - 40 mg/L, which sounds like a high range. If there are ambient concentrations this high, it also raises the question where it comes from, which in turn could raise the question of re-suspension and whether the site really is retentive?

It is recommended that a better determination of the background TSS is carried out.

For question 2, whether potential "sub-detectable plumes" outside the NDA are of concern is beyond the scope of my review and is better addressed by a biologist. From experience, environmental threshold limits are often expressed relative to ambient concentrations, in particular in the absence of defined receptor tolerance limits. If non-detectable in this context means that the excess concentration is only a small value compared to ambient, then it may well be acceptable. But this ties back to how well the concentrations can be resolved and distinguished from ambient.

Based on the correlation scale between SSC and backscatter provided in Figure 3.8, there is inconsistency between the background values measured by ADCP (generally in the ranges of 12-27 and 27-40) and the SSC derived from water samples, which for a large part are below 10 mg/l. This points towards a potentially flawed calibration. The report states that due to the transient nature of the plumes, it was not feasible to collect enough water samples to accurately correlate backscatter levels to SSC. In particular with the limited time available and difficulties in collecting water samples at depth, this is a recognised challenge. If the purpose is only to track the plume relative to background to establish how far from the source the plume is distinguishable above background, this may not be an issue, but if a quantification of sediment fluxes through the transects or a comparison to absolute values is required, a correlation would have to be established.

Whereas it is recognised that the presentation of large data sets to produce a clear overview and understanding is not straight forward, the presentation of results in Report 3 could be improved through a better selection of scales. Given the identified issues with the current data sets, it would likely not add much value in the present case, but data should as far as possible be clearly presented. Examples include:

- The use of a log scale for suspended sediment concentrations makes detailed interpretation of the graphs impossible.
- The BIO-FISH overview maps only show the general area of survey. A larger overview map with the location of the disposal marked, and sequentially numbered transects with clear indications in the time series plot where these fit, would benefit the interpretation.

For the secondary objective of providing guidance on potential future monitoring campaigns, I concur that the ADCP transects are the better tool to provide overview and quantify the sediment dispersion. ADCP transect surveys are used extensively (on a daily/weekly basis) as a powerful tool on Environmental Monitoring and Management Programmes (EMMP) in Singapore, Brunei and Malaysia.

I would recommend that particular attention is given to the relative accuracy and resolution of the measurements and presentation to ensure that it is set up to capture as small differences relative to background as possible.

There are many ways of designing the survey. The main advantage with ADCP transects is that it is highly flexible, and setting up a limited fixed grid as recommended in the document will not take advantage of this flexibility to best track the plume. One approach that we have good experience with in capturing the plume excursion is to:

- Determine current direction prior to disposal (should come directly from ADCP if set up to measure currents).
- Prepare transects perpendicular to the current direction.
- Immediately after dumping, start to sail transects through the plume – (make sure the transects extend fully out of the plume at both ends).
- Gradually shift the transects down-current as the plume is convected downstream.
- This can be continued until no plume is distinguishable from background along any of the transects.
- By including currents and bottom tracking, sediment fluxes transported through the transect can be derived.

3.5 NIWA Review of Auckland Marine Disposal Ground Monitoring Series, Report 3 – Plume Monitoring

NIWA points out the lack of correlation between SSC derived from turbidity sensors and water samples and concurs with the report that the method is impractical.

Concern was also raised in respect to the water samples collected as the SSC values derived from the water samples generally are low and do not correlate well with the ADCP transect data. NIWA recommends that calibration of the ADCP backscatter should be incorporated into future plume monitoring.

NIWA recommends that transects must be sufficiently long to capture the full spatial extent of the plume (as several transects are stopped within the high concentration plume)

Review Comments

NIWA raises some of the same concerns that I have raised in my review. NIWA specifies that a correlation to TSS should be carried out. I concur that this is preferable, but also acknowledge that it may be very challenging with the large water depths and incoherent plume to collect the samples and achieve a good correlation.

3.6 Evidence by Peter Clifford Longdill

The evidence focused on 4 main components (of which I have comments for 2 components):

1. Dredging Method.
2. Seabed Monitoring Station Alignment.
3. Cumulative Water Column Suspended Sediment and Turbidity Effects.
4. Other Amendment to the Proposed Conditions of Consent in the Evidence of Hay.

3.6.1 Dredging Method

Peter Longdill draws attention to the fact that the method of dredging will affect the particle size distribution and properties of the material to be disposed, which in turn is likely to affect the dispersion of fines during the disposal process. Relative to mechanical dredging (which is understood to have been a consent condition for previous disposal), hydraulic dredging has the potential to increase the fines content in the material through particle attrition, thus resulting in an expected increase in water column turbidity and dispersion of material during disposal. Peter Longdill proposes to firm up the wording in the consent to disallow disposal of material that has been hydraulically dredged.

Review Comments

I concur with the physical description of the dredging processes provided by Peter Longdill as well as the likely effects in terms of increased turbidity generation during disposal. Whether the likely increase in turbidity at the disposal site is significant in terms of increased risks of impacts has not been ascertained, but based on the principle of minimising the risks, it is agreed that limiting the dredging to mechanical means is reasonable, unless there are specific and valid reasons that this is not practical or economical for a given case.

3.6.2 Cumulative Water Column Suspended Sediment and Turbidity Effects

I concur with the overall evaluation for this component, however have the following comments.

- For item 39, my interpretation of the 0.03 mg/l of suspended sediment at the boundary of the NDA is that this is averaged over a month. It does not inform on neither intensity, duration nor frequency. It could represent a 100 mg/l plume that passes the NDA boundary over a period of 13 minutes, or a general elevation of just 0.03 mg/l the turbidity throughout the period. I recommend additional presentation of the model results to provide more clarity.
- For item 44, I suggest that a better understanding of the background SSC levels should be established and the results from the sediment plume model be further interrogated and presented in a way that allows a better understanding of the predicted concentrations and frequencies.
- For Item 45, I consider that a 0.2 mg/l relative to background is impossible to measure and differentiate from background.

4 Evidence by Connon James Andrews

In support of his Evidence, Connon James Andrews presents two modelling exercises covering the near-field and the far-field processes. For the evidence related to the modelling, it has specifically been requested to assess whether:

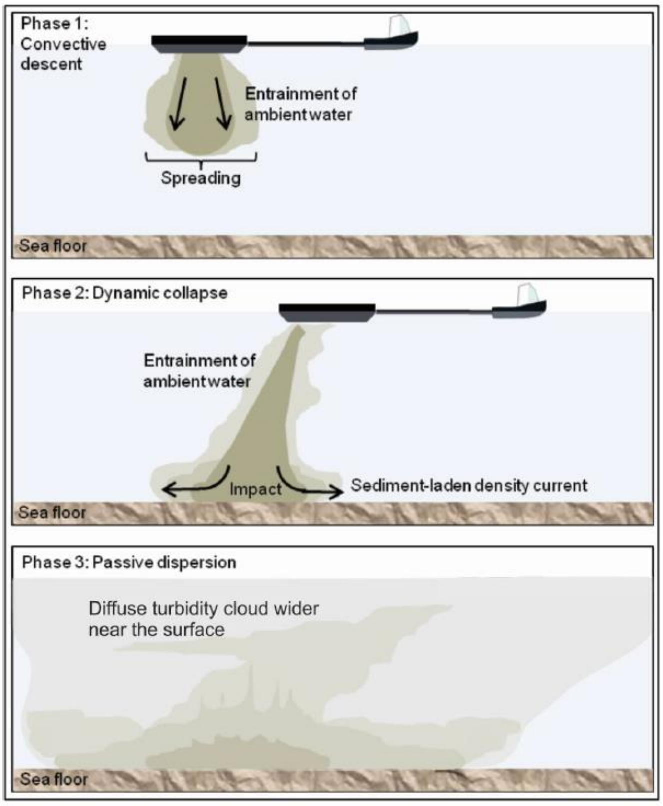
a. The chosen dispersal model(s) is suitable for predicting the fate of dredge material with regards to:
    i. The material proposed to be dumped, and
    ii. The proposed disposal site.
b. The dispersal model set-up is in accordance with international best practice;
c. The quality of input data or datasets used are adequate, including any modelled datasets;
d. The input data has adequate resolution to allow for a reasonably accurate simulation of the fate of the material proposed to be dumped; and
e. Reasonable effort has been made to accurately describe:
    i. The uncertainty of the model.
    ii. The uncertainty of the model set-up.
    iii. The uncertainties in the input data and databases used in the model.
    iv. The effect of these uncertainties.

The assessment has been carried out separately for the two modelling exercises as the models are vastly different and undertaken by separate teams.

4.1 Modelling Overview

A suite of models have been established to evaluate the dispersion of sediments associated with the disposal operations. From a modelling perspective, it is common best practice, to model the sediment dispersion separately in the near-field and far-field regions. This is because the fate of the sediment plume in each of these areas is driven by different processes and occurs at different temporal and spatial scales as described below with reference to figure by Flaim. This was recognised by Flaim, and it was recommended to establish a separate model for the near-field area.

- Near-field region: When the sediment is discharged from the barge, mixing occurs as the ambient receiving water is entrained by the sediments. The behaviour of the disposed material can be divided into phases:
    - Initial acceleration upon release of the sediment.
    - Convective descent, during which the sediment is driven by gravity. This is where the greatest sediment losses, or sediment stripping, occurs.
    - Dispersive phase, or dynamic collapse, is when the cloud or jet impacts with the bottom or arrives at a level of neutral buoyancy.
- Far-field region: Here mixing is governed by the ambient hydrodynamic conditions with subsequent advection and dispersion, induced by the ambient currents. Input to this modelling exercise includes the sediment losses calculated through the near-field region modelling work.



Sketch of 3 phases of disposal process (Flaim 2012)

4.2 Near-Field modelling

The near-field modelling study has been carried out by Beca Ltd. In response to questions raised by the EPA in relation to the amount of material that can deposit outside the NDA. The objectives of the modelling works have been defined to:

- Quantitatively assess the amount of material that is stripped from the descending plume within the near-field and definition of likely deposition footprint for individual discharges
- Quantitatively assess the far-field fate of stripped sediment and to assess the effects from seasonal changes in metocean conditions.

4.2.1 Model Suitability/Best Practice

The near-field modelling was performed with the numerical model STFATE (**S**hort-**T**erm **Fate**). STFATE is a parametric numerical model developed by the US Army Corps of Engineer that computes the water column concentrations and bottom deposition resulting from a dredged material disposal operation. A detailed description of STFATE, and its verification against laboratory disposal tests, are presented in /2/.

STFATE is a model designed to describe the near-field, short-term fate of dredged material disposal in open waters and is used extensively in the dredging industry /2/. It provides a good estimation of the deposition volume and area, the plume frontal velocity, and the stripped material, at specific depths. The STFATE model is parametric, based on a number of assumptions, and its accuracy is largely dependent on the definition, or choice, of a number of input parameters and coefficients. The establishment of these is defined based on the environmental conditions of the area, the sediment properties, and sediment dumping operational methods and procedures.

It is it not designed to describe the details of the complex transient 3D mixing mechanism occurring during the plume descent and collapse, however in the opinion of the reviewer these processes are not required for this study, as this project focusses primarily on sediment deposition and calculation of the sediment to remain in the water column to be dispersed by the current.

The US Army Corps of Engineers has verified the STFATE model against large scale laboratory experiments. These comparisons, together with model theory, are presented in /2/. However it should be noted that all comparisons were carried out for different disposal cases in water depths shallower than 100 m. The conclusion of the STFATE report verification presented in /2/ can be summarised as: "*Results from the simulations have substantiated that STFATE can be used to accurately simulate the fate of material during disposal operations. Descent and bottom surge speeds, stripping, rates of dilution, total depositional areas and suspended sediment concentrations in the bottom surge are all reasonably reproduced."*

The type of material disposed in the present study is in line with common practice. Although past validation of the model has been in sites shallower than 100 m, it is considered that for the present disposal rates, the bulk of the material continues to the bottom in the convective descent phase.

Based on the above it is considered by the reviewer that STFATE will provide best practice results, if properly set-up and verified to the present conditions.

4.2.2 Model Setup & Input Data

The model has been set up for two cases with different volumes of 700 m^3 and 1200 m^3. The model has been run for 3 representative current speeds for each barge size, as well as 3 different locations for the disposal relative to the NDA boundary to test worst case scenarios.

Model input is based on detailed information on the sediment, the equipment and oceanographic conditions of the receiving environment. Based on information on sediments from the likely dredge site, the sediment has been defined with a single fraction.

The model was set-up with default coefficients as recommended in the STFATE user's guide, however no discussion on the applicability of these default values to the present study were provided.

It is broadly stated that:

"It is noted that a sensitivity assessment has been completed on the various parameters – assumptions and it was concluded that the parameters are the best estimate for stripping percentage and mound characteristics."

Whereas the sensitivity assessment has not been presented, it is noted that the overall results related to stripping rates are in line with expectations and the mounds appear to be in line with field observations.

Although results from the sensitivity assessment to various model parameters could have provided valuable information on the uncertainties related to the modelling, it is considered that the model has been set up based on the site data to provide best estimates of the stripping and dispersion of material.

The uncertainties and the potential effects of these are not described.

4.3 Far-Field Modelling

The far-field modelling of the sediment barge discharges was carried out by MetOcean Solutions, and a report is included as Appendix C of the evidence.

The far-field modelling focuses on two key components:

1. Establishing a statistical basis through a 10-year ocean current hindcast; and
2. Modelling of the dispersal of disposal plumes (although the report states dredging plume).

The three dimensional (3D) far-field modelling was performed with the Regional Ocean Modelling System (ROMS) to reproduce the dynamical flow fields over the study area.

An in-house trajectory model was applied to model the sediment dispersion.

4.3.1 Model Suitability/Best Practice

ROMS is a widely accepted ocean/coastal model, it is a free-surface and hydrostatic model, it was based on the S-coordinate Rutgers University Model that can describe oceanographic flows that are relevant for this study.

Details on the particle model in terms of how particles are removed and whether it can emulate re-suspension is not provided. It is not expected that the model includes potential re-suspension.

4.3.2 Model Setup

The model has been established for a large area to capture regional flows with a 2-level nesting approach. The input data is derived from global model and data sets.

Overall the model setup and application of data sets appears to be in line with international best practice.

Tidal forcing was implemented through the Princeton Ocean Model (POM) driven by the TPXO7.2 tidal elevations and currents at the open boundaries.

The passive plume is included in the model with different masses in 7 layers derived from the near-field model. The sediment is represented by a single settling velocity of 1 m/hour.

4.3.3 Uncertainty

It is briefly stated that:

"T*he MSL-POM current model has been validated at various coastal and open ocean locations around New Zealand, including Otago, Taranaki, Western Cook Strait, Hawke Bay and Bay of Plenty."*

There is no documentation of calibration or validation, despite the presence of a longer term dataset from the site. It is therefore not possible to evaluate the model performance.

There is no discussion provided on uncertainties in the model and the possible effects of these uncertainties on the results.

4.4 Review of Modelling Results

4.4.1 Near-Field

The results presented in the report generally appear to be sound, and the overall stripping rate is in line with literature and expectations at around 5% for the 700 m^3 barge and slightly smaller for the 1200 m^3 barge.

4.4.2 Far-Field

The far-field results are presented as monthly average concentrations – covering the 10 year simulation period, as well as annual and monthly averaged sedimentation rates.

The choice of long term averaging (over a month) of very intermittent discharges (2 per 24 hours), combined with the choice of threshold in the scale for plotting, means that essentially nothing is seen outside of the area where the plume is released in the model.

As the objective of the far-field model should be to simulate the far-field processes and illustrate the fate of the material stripped off during the convective descent phase, which were specifically included in the far-field model, the output should be tailored to show this. Some suggestions to include as additional output items include:

- Representative 2D "snapshots" of instantaneous depth-averaged and/or maximum over depths plume concentrations to illustrate the development of the plume in time and space. A few series for different ambient current conditions would be helpful.
- A 2D plot of predicted maximum concentrations over a given period.
- Statistical plots of exceedance frequencies of given threshold limits (e.g. 5 mg/l, 10 mg/l, 25 mg/l). These can also be on a monthly basis. This will assist in better understanding the Intensity-Duration relationship rather than just a monthly averaged value.
- Sedimentation plots with lower threshold values for plotting to show the sedimentation patterns

With the limited volumes released into the far-field combined with the small settling velocity applied, it is likely that exceedance frequencies and sedimentation rates will be very small, but scales should be adopted to show the patterns.

Although the model cannot simulate the near-field effects, the deposition of the bottom of the bulk of material that is transported to the bottom through the convective jet has been "placed" in the model. As the model cannot simulate the near-field processes, and a near-field model was set up to simulate this, it would have been more informative to not include the bulk of the material in the simulation and only simulate the fate of the 5% of the material in the passive plume.

In essence, the sedimentation plots just illustrate that the stripped material (in the order of 5%) when settling out over a very large area leads to sedimentation rates that are negligible compared to the bulk of the material (95%) placed on the bottom in a limited area.

5 References

/1/ Request for quotation, Environmental Protection Authority. Technical review and analysis of oceanographic information presented in Coastal Resources Limited's marine dumping consent application (EEZ 100015)

/2/ Development and verification of numerical models for predicting the initial fate of dredged material disposed in open water. B. Johnston and M. T. Fong, Dredging Research Program Technical Report DRP-93-1 US Army Corps of Engineers, 1995.