BEFORE THE OTAGO REGIONAL COUNCIL

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of an application for resource consents for Project Next Generation
BY	**PORT OTAGO LIMITED**
	Applicant

STATEMENT OF EVIDENCE OF ROBERT GORDON BELL ON BEHALF OF PORT OTAGO LIMITED 6 April 2011

LEN ANDERSEN
Level 3, Westpac Building
106 George Street
P O Box 5117, Moray Place
DUNEDIN 9058
Tel 03 477 3488
Fax 03 474 0012
Counsel: L A Andersen

ANDERSON LLOYD
Level 10, Otago House
Cnr Moray & Princes Street,
Private Bag 1959,
DUNEDIN 9054
Tel 03 477 3973
Fax 03 477 3184
Solicitor: J E St John

INTRODUCTION, QUALIFICATIONS & EXPERIENCE

1. My full name is Robert Gordon Bell. I hold the degrees of Bachelor of Engineering (Civil) with First Class Honours and a PhD in Civil Engineering from the University of Canterbury. My PhD thesis examined the response of sediment transport to floods in gravel-bed rivers.

2. I have worked as a coastal scientist and environmental engineer, researching and advising on coastal processes, oceanography, wastewater discharges, dredging projects, sediment transport and natural hazards since 1980.

3. I currently hold the position of Principal Scientist – Coasts and Hazards with the National Institute of Water and Atmospheric Research (*NIWA*), by whom I have been employed for the last 18 years. Prior to that, I was employed in the Coastal Group in Hamilton as part of the Water & Soil Division of the Ministry of Works (1980-1989) and then DSIR Marine & Freshwater (1989-1992).

4. I am a certified Hearings Commissioner under the *Making Good Decisions* programme, a member of the Institution of Professional Engineers NZ (MIPENZ) and a Chartered Professional Engineer (CPEng) in the practice area of Environmental Engineering. I am on the Advisory Board for the Civil and Natural Resources Engineering Department at the University of Canterbury.

5. I am also a member of the NZ Coastal Society, the NZ Society for Risk Management (Inc.), and the Meteorological Society of NZ (Inc.).

6. Of particular relevance to Port Otago's Project Next Generation is my previous research on tidal and wind circulation in coastal and shelf areas, and dispersion and dilution processes associated with marine discharges. For the latter field, I have co-authored a book *Ocean Disposal of Wastewater* (Wood et al., 1993) and have undertaken dispersion or oceanographic studies for 26 of New Zealand's ocean outfalls.

7. I was part of the team at the DSIR Water Quality Centre that carried out the previous field and modelling study of Otago Harbour in 1987–88 for the then Otago Harbour Board in preparation for capital works dredging at that time. I have been involved in similar consultancy roles for dredging modelling studies for the Port of Tauranga over several years

from 1983 to 1994, the Port of Nelson in 1985-86 and the Port of Napier in 1988–89, which also included assessments of dredged-material disposal grounds.

8. I have also acted as a peer reviewer for harbour dredging or disposal studies for the Ministry of Transport (offshore disposal ground off Cuvier Island), Ports of Auckland in 1990 (Noises Island disposal ground) and the Port of Gisborne in 2000 (harbour modelling).

9. My evidence is given in support of applications for resource consents lodged with the Otago Regional Council (*ORC*) by Port Otago Ltd. (*POL*) in relation to Project Next Generation and publically notified on 21 June 2010.

10. I am familiar with most of the inshore area that the Project covers, and have visited Port Chalmers, Aramoana, Spit Beach, Spit Jetty, and The Mole.

11. I have read the Code of Conduct for Expert Witnesses as contained in the Environment Court Consolidated Practice Note (2006). My evidence has been prepared in compliance with that Code in the same way as I would if giving evidence in the Environment Court. In particular, unless I state otherwise, this evidence is within my sphere of expertise and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express.

BACKGROUND INFORMATION

12. I have been the Project Manager for the NIWA components of the Project since NIWA's first engagement with the Project in late 2007. NIWA's involvement with the Project has included deployment of current and wave meters, oceanographic analysis, hydrodynamic modelling of tides, winds and the Southland Current, supplying tidal currents to ship-handling and navigation channel design consultants, sediment dispersion modelling, long-term sand transport from the disposal site A0, and developing monitoring conditions. I also coordinated the inclusion of wave-modelling studies undertaken by MetOcean Solutions Ltd through their Manager Dr Peter McComb.

13. NIWA produced two early reports in the Project of which I was a co-author. One was an initial scoping study report in January 2008 that

included some preliminary hydrodynamic modelling results (Oldman et al., 2008), which is Technical Report 13 in the documents lodged with the *Next Generation* applications to ORC; the other a field data report in November 2008 based on extensive offshore field measurements (Bell & Hart, 2008), which is Technical Report 11 in the lodged documents.

14. In conjunction with other scientists from MetOcean and NIWA whom I supervised, I prepared the main computer modelling report entitled: Port of Otago Dredging Project: Harbour and Offshore Modelling (Bell et al., 2009), which is Technical Report 10 in the documents lodged with the *Next Generation* applications to ORC. I will alternatively refer to this as the 2009 Modelling Report. The report assesses the effects of the Project works on physical coastal processes and turbidity during the dredging phase, based on using a moderate-size trailing suction head dredger with a 10,800 m^3 hopper capacity, and on the hydrodynamics once the new deepened channel is completed. The other main authors of the Report were:

    14.1 Mr John Oldman, formerly a Coastal Modelling Scientist with NIWA, who carried out most of the Otago Harbour model simulations.

    14.2 Dr Brett Beamsley, Oceanographer with MetOcean Solutions Ltd. who carried out the wave modelling.

    14.3 Dr Mark Pritchard, Oceanographer with NIWA who undertook the offshore hydrodynamic modelling.

    14.4 Dr Malcolm Green, Principal Scientist with NIWA, who provided the analysis of the long-term fate of sands at the offshore A0 disposal area.

15. The 2009 Modelling Report was peer-reviewed by Dr Mark Hadfield (Scientist, Marine Physics Group, NIWA), Dr David Roper (Regional Manager, NIWA, Hamilton) and was externally peer-reviewed by Dr Alastair Senior (Tonkin & Taylor) and independently reviewed for ORC by Dr Ross Vennell (Marine Science Department, University of Otago).

16. The 2009 Modelling Report was informed by, or relies upon, or supports other technical reports lodged with the ORC in support of the Project, those reports being primarily.

16.1 James, M. et al. (2009). Biological resources of Otago Harbour and offshore: assessment of effects of proposed dredging and disposal by Port Otago Ltd., which is Technical Report 1 of the lodged documents.

16.2 Single, M. et al. (2010). Physical coastal environment of Otago Harbour and offshore: assessment of effects of proposed dredging by Port Otago Ltd., which is Technical Report 9 of the lodged documents.

16.3 Pullar, A. & Hughes, S. (2009). Project Next Generation dredging methodology and disposal alternatives, which is Technical Report 18 of the lodged documents.

16.4 Opus Consultants (2008). Factual report of geotechnical investigations, which is Technical Report 16 of the lodged documents.

17. Post lodgement, POL engaged NIWA to prepare a supplementary report (Bell & Reeve, 2010) entitled: Sediment plume dispersion modelling: Comparison of a larger dredger and the *New Era*. I will refer to this as the 2010 Modelling Report. This Report compares sediment plume simulations for Otago Harbour (*Harbour*) and the offshore disposal area between using a moderate-size Trailing Suction Head Dredge (*TSHD*), as adopted in the 2009 Report, and using the much smaller *New Era* owned and operated by POL. *New Era* has a hopper capacity of only 600 m^3. I carried out the additional offshore plume model simulations while my colleague, Mr Glen Reeve undertook the extra harbour simulations under my supervision.

18. My evidence sets out the results of assessments for both Major Capital Dredging, which is mostly covered in the 2009 Modelling Report, and Incremental Capital Dredging using *New Era* (or similar size TSHD), which is covered by the 2010 Modelling Report.

SCOPE OF EVIDENCE

19. I have been asked by Port Otago Limited (POL) to prepare evidence on the hydrodynamic and physical suspended-sediment effects of the Project for both Major Capital Dredging, using a moderate-size TSHD,

and Incremental Capital Dredging, using *New Era* (or similar-sized TSHD). In my evidence I discuss:

19.1 The effect of the completed capital dredging works on tides and currents in the Harbour.

19.2 Sediment plume dispersion from dredging activities inside the Harbour.

19.3 The short-term plume dispersal and long-term fate of dredged sediments from the offshore disposal site at A0.

19.4 Effects of the disposal at A0 on wave heights offshore.

19.5 Monitoring conditions related to sediment plumes and hydrodynamic effects.

19.6 Specific issues raised by submitters on harbour or coastal physical processes or hydrodynamics.

19.7 Specific issues raised by the Reporting Officer's report.

EXECUTIVE SUMMARY

20. My evidence covers the dispersion and deposition of sediment discharges from dredging activities and assesses the hydrodynamic effects of an altered seabed bathymetry arising from the Project on two different marine environments.

21. First, I cover effects of the Project within Otago Harbour, where the capital dredging will take place, eventually achieving a widened and deeper shipping channel, as discussed by Mr Coe in his statement of evidence. The main tools used in the assessment were past and new field measurements of currents in the Harbour and numerical modelling based on a calibrated depth-averaged (2D) hydrodynamic model.

22. Secondly, I outline the findings of my assessment for the offshore disposal area. Initially I will describe my input to the disposal site selection process of three alternative offshore sites (A1, A2 and A0). I then discuss in more detail my assessment of sediment plume and seabed transport from the proposed disposal site at A0. My assessments are underpinned by results from a 3D offshore hydrodynamic model and a separate wave model of the Otago

continental shelf, which were calibrated by field measurements of currents and waves respectively.

23. In both the Harbour and offshore environments, I consider the effects on sediment plumes and seabed deposition of using a moderate-size TSHD for Major Capital dredging and Incremental Capital dredging using the small capacity *New Era* (or similar-sized TSHD).

24. The effects of the final deepened 15-m channel on the hydrodynamics of the Harbour will be minor or in some cases negligible. This includes changes to the tide range, timing of the tide, tidal currents and the ebb and flood tide flows through the Harbour entrance. In particular:

 24.1 Changes in tide ranges for an average tide will be negligible around the Harbour Entrance (up to 4 mm), and over most of the rest of the Harbour, no more than 6–8 mm higher, which is no more than 0.6% of the average 1.6-m tide range.

 24.2 Timing of high and low tides will advance, ranging from less than a minute around Harington Bend and the Entrance to no more than 3 to 4 minutes for the upper Harbour.

 24.3 Outside the new widened and deeper channel, mean-tide current velocities will not change by much more than ±0.02 to ±0.05 m/s (±0.04 to ±0.1 knots), which compares with the accuracy limit of modern current meters of 0.01–0.03 m/s.

 24.4 Similar differences for high-water timing, tide ranges and velocities were obtained for strong 20-knot south-west and north-east winds, as discussed by Oldman et al. (2008).

 24.5 Tidal volumes passing through the Entrance Channel at the Spit Jetty will change by less than 1.3%.

 24.6 The deepening will have a negligible effect on extreme storm-tide and wave overtopping events around the Harbour coastline. Apart from a slight increase in high tide level (up to 4–5 mm), the wave fetch lengths at the critical high tide period will remain unchanged and the extensive shallow intertidal areas will still be present, limiting the wave heights.

25. Sediment plumes generated during Major Capital Dredging within the Lower Harbour are predicted to reach 2-week average suspended-

sediment concentrations of 100-500 mg/L in the main fairway, connecting side channels and intertidal banks adjacent to the fairway, with small patches from 500–1000 mg/L in the vicinity of the dredge. Elsewhere in the Harbour, the concentration would be in the range 0-100 mg/L above background levels.[1]

26. Sediment plumes generated by *New Era* (or similar-sized TSHD) within the Lower Harbour are predicted to reach 2-week average suspended-sediment concentrations of 20–50 mg/L in the main channels, with smaller patches from 50–100 mg/L in the vicinity of the dredge, after allowing for reasonable mixing. On the central intertidal areas, mostly the average concentrations will reach no more than 20 mg/L above background concentrations. Elsewhere in the Harbour, the concentration would be in the range 0–10 mg/L above background levels. Although the numerical values for the *New Era* scenario are approximately tenfold lower than those for the moderate-size TSHD, this low level of extra turbidity extends over a longer period of time due to the duration of lower intensity works.

27. Excluding the main channels, the central intertidal flats in the lower Harbour are predicted to accumulate silt material on the seabed from Major Capital Dredging at typical rates of around 0.1–0.3 mm/day, with no more than 1 mm/day on the intertidal bank opposite Port Chalmers. Under Incremental Capital Dredging, sedimentation rates will be around 0.01–0.03 mm/day using *New Era*, with no more than 0.1 mm/day on the intertidal bank opposite Port Chalmers. There would be negligible direct deposition in most of the eastern parts of the Lower and Upper Harbour for both forms of dredging activity.

28. In the longer-term, silts deposited initially in exposed locations, including the shallow or intertidal banks in the middle of the Harbour and Aramoana, will be resuspended by subsequent wave activity and dispersed more widely and thinly throughout the Harbour. Silts will ultimately settle in more quiescent areas of the Harbour that naturally accumulate finer sediments from catchment runoff.

[1] In dredging modelling studies, the “extra turbidity” or “extra deposition” due to dredging is isolated to determine its magnitude, and hence its direct effect, over and above the background levels of turbidity and deposition. Background levels of both can vary markedly depending on weather, wave, river flow conditions and for deposition, catchment land-use.

29. For the moderate-size TSHD, considering all silt-size classes in the vicinity of A0, moderate (14 m/s) WSW winds will generate the most adverse conditions for sediment concentrations in the bottom layer. For a predominantly-silt hopper load, maximum suspended-sediment concentrations may reach around 900 mg/L above background levels just “downstream” of the disposal area. For an average sand/silt hopper load, the maximum concentration for all silt size classes would be about 30% less at around 620 mg/L. The highest surface-layer concentrations of silt-sizes will occur during light (3 m/s) NNE winds with a maximum surface-layer concentration of around 270 mg/L above background, with about 30% less at 185 mg/L for an average sand/silt hopper load.

30. In the vicinity of the A0 disposal area, maximum suspended-sediment concentrations for predominantly-silt loads from *New Era* are predicted to be no more than 7–11 mg/L and 47–57 mg/L above background levels, in the near-surface and bottom ocean layers respectively. For an average sand/silt hopper load, peak concentrations would be similarly between 23–33% less than for predominantly-silt hopper loads.

31. Further afield, the fringes of sediment plumes generated during disposal may sometimes, in theory at least, reach the coastline north of Karitane and Cornish Head, but in practice the suspended-sediment concentrations of silts will be very small—no higher than 0.9 mg/L for a mid-size TSHD and 0.05 mg/L for *New Era* above background levels for the six different wind simulations undertaken. These values are so small as to be virtually undetectable in the field, and in effect, are an artefact from modelling a continuum down to infinitesimally small concentrations. Under light NNE winds, the fringes of sediment plumes may also reach Otago Heads, in theory, where the concentrations for silts will be no more than 2–3 mg/L for a mid-size TSHD and 0.6 mg/L for *New Era* above background levels. Again these are essentially modelling artefacts.

32. Due to the predominant northerly or easterly residual current at A0, deposition of sands and silts from plumes generated directly from disposal operations at A0 will occur mainly to the north or north-east of A0, thinning out to a “direct” deposition rate of no more than 0.4 mm/day for a mid-size TSHD and 0.04 mm/day for *New Era* at 9 km north of A0. Swell wave activity will regularly re-suspend the silt material that initially settles on the seabed surface, further dispersing it over the continental

shelf. Fine sediments will not be transported and deposited to nearshore/beach areas due to the predominant residual currents to the north or north-east and the presence of vigorous turbulence from shoaling and breaking waves, which precludes any settling of silts in the nearshore zone for most of the time.

33. The fine sands and entrapped silt material will settle to the seabed in or around the A0 disposal area much more quickly than the dispersed silts, forming a progressive mound with a bias towards the north and north-east from the prevailing currents. Long-term sand transport from A0 will continue to be towards the north or north-east as evidenced by the existence and orientation of the offshore submergent Peninsula Spit on which A0 is located.

34. For a moderate-size TSHD, the resulting sediment mound at A0 of up to 1.7 m in height from Major Capital dredging, could take decades to diminish and blend in more with the local topography. With the Incremental Capital dredging programme using *New Era*, the net mound height would only grow gradually or incrementally in steps for each dredging season for several up to 15 years. Further, taking into account ongoing sediment transport on the mound throughout the lengthy Incremental Capital dredging programme, and alternative disposal of non-silt material on inshore disposal areas, the final mound height at A0 will be somewhat less than that for a Major Capital dredging programme. For Major Capital Dredging, the maximum mound level may reach 25.3 m below Chart Datum, so the 25 m Chart Datum minimum depth/maximum height suggested by the Reporting Officer in Condition 4 of the proposed Coastal Permit 2010.198 is sufficient.

35. Swell wave activity, sufficient to mobilize fine sands on the sea bed at the typical 28 metre water depth at A0, will occur approximately 40% of the time on average per year, rising to around 50% in the more active winter season. However, net sand transport only occurs in the direction of the prevailing current, with no net transport under waves alone, as the to and fro sediment motion under the wave crest and trough cancel out. Consequently, waves and swell at A0 will not by themselves cause dredged sediments to be transported to the coastline.

36. The physical presence of the final mound at disposal site A0 will have no discernable effect on wave patterns for mean wave heights, but for

maximum significant wave heights of around 6 m, there may be small localised changes of no more than 0.05 m in wave height.

37. Monitoring conditions in the draft Environment Management Plan (*EMP*) are proposed to measure and document, for any type of dredger, in-situ sediment plume turbidity behind the dredger using mobile sensors. This would be backed up by two sets of 1-month fixed turbidity buoy monitoring for a moderate-sized TSHD (if used) in order to confirm that the model predictions for suspended-sediment concentrations are matched or are conservative. For the *New Era*, these fixed-site buoys should only be deployed if the mobile monitoring shows suspended-sediment concentrations in the top 5 m of the water column exceed something like 50 mg/L (or equivalent in calibrated NTU) after allowing for reasonable mixing e.g., 300–500 m downstream of *New Era*.

38. Conditions on in-situ monitoring of turbidity at key habitats and the associated management response levels are discussed by Dr James in his statement of evidence. I support other draft conditions that are intended to document changes to bathymetry in the harbour and offshore A0 disposal area [Conditions 2010.193(20) and 2010.198(10)] and to document any changes to the tidal regime in the Harbour [Condition 2010.193(12)].

39. I respond to key or repeated concerns that are raised by submitters that are not covered specifically in the main body of my evidence or alternatively I will reiterate some statements. In particular, key areas of concern from the submissions that I address specifically are the veracity of the Harbour and offshore modelling, wave resuspension of previously-settled sediments, sediment plumes potentially reaching the coast and the need for monitoring conditions in the Harbour and offshore waters. I also briefly comment on a few aspects of the Reporting Officer's report.

THE PROPOSAL

40. My evidence relates only to the following specific activities to be undertaken as part of Project Next Generation (*"the Project"*) to:

    a To disturb and remove dredge material from the foreshore and seabed to deepen and widen the Lower Harbour shipping channel and approach channel and the swinging basins and berths at Port Chalmers by either Incremental Capital or Major Capital dredging or a sequence of both [Proposed Consent 2010.193];

b To discharge dredging decant water/sediment material during dredging operations to deepen and widen the Lower Harbour [Proposed Consent 2010.195];

c To deposit dredged material at sea at the offshore disposal site A0, 4 nautical miles north-east of The Mole, sourced from the Otago Harbour for the purposes of widening and deepening the main channel [Proposed Consent 2010.198].

THE PHYSICAL ENVIRONMENT

Otago Harbour

41. Otago Harbour covers 46 million square metres and stretches 21 km along a south-west/north-east orientation, which aligns with the prevailing winds. Port Chalmers is located at the northern head of the Lower Harbour, while Dunedin Wharves are located at the head of the Upper Harbour. The Upper and Lower Harbours are partially separated at the mid-section by both Quarantine and Goat Islands and the prominent Portobello Peninsula as shown in Figure 1.

42. Winds measured at Otago Heads exhibit a bi-modal distribution, with winds mainly from the west to south-west, which produce the strongest wind speeds of 24 m/s or from the north to north-east 16 m/s, based on 99 percentile of each sector.

43. The tide range in the Harbour varies from 1.2 m on a neap tide to 2.0 m on a spring tide at Port Chalmers, with an additional 0.1 m in spring-tide range at Dunedin. Currents in the Harbour are dominated by the tides, with some variability due to winds. Channel currents in Harington Bend area reach 0.8 to 1.3 m/s (1.5–2.5 knots) on a spring tide, and similarly peak at 1.0 to 1.1 m/s (2.0–2.2 knots) off Port Chalmers. The highest currents occur at the Entrance opposite Spit Jetty, where currents reach 1.55 m/s (3.0 knots) at the peak of the flood tide.

44. Waves in the Harbour are fetch-limited[2], especially as intertidal banks emerge at lower tide levels. Significant wave heights could reach 1.2 m high in the Lower Harbour. Wave periods are generally in the range 2 to 5 seconds.

Continental shelf

45. The inner shelf of interest extends from Cape Saunders in the south to Cornish Head (shown in Figure 2) and further beyond to the north.

46. The key sand bodies are the ebb-tide sand bar on the eastern side of the approach channel off Taiaroa Head and a northerly-aligned submergent sand spit offshore in 27–30 m water depth that swings out from Cape Saunders with its terminus 11 km due east of Karitane Point. The offshore underwater sand spit is fed by sands emanating from the Clutha and Taieri Rivers, whereas silt from these rivers is dispersed widely along the coast and over the shelf. The proposed disposal area of 2 km diameter centred on A0 has been positioned to be on the offshore submergent spit which is subject to a net northerly transport regime.

47. Later I will describe my input, based on the modelling, to the disposal site selection out of three alternative offshore sites (A1, A2 and A0). Two of these sites A0 and A1, shown in Figure 3, were also sites where field measurements of currents were undertaken by NIWA at A1 from March to August 2008 (Bell & Hart, 2008) and recently at A0 by MetOcean from October to December 2010 (MetOcean Solutions Ltd., 2011). Waves were also measured at A1.

48. Offshore, the tidal influence falls off quickly outside the influence of the ebb-tide jet emanating from the Harbour Entrance. At A0 and A1 (Figure 3), the average tidal current speed is only around 0.05–0.06 m/s (0.1–0.12 knots). The relatively small tidal current offshore at A0 and A1, accounting for only 14-15% of the total energy in the north-south component of currents, means that residual (non-tidal) currents dominate on the shelf, being the north-going Southland Current together with some influence from regional-scale winds.

---

[2] The height that waves can build up to in a harbour is limited by the length of open water or fetch that the wind blows over.

Offshore residual currents

49. Because of issues raised by many of the submitters on the absence of measurements at A0 and the veracity of the modelling of current velocities, and hence sediment plume movements, I will now describe in detail the complex pattern of residual currents on the shelf at the proposed disposal site A0 and also the so-called Blueskin Bay eddy. Firstly I present some background to the 2009 modelling study (Technical Report 10 of the lodged documents) and the subsequent peer reviews.

50. NIWA has provided what I consider to be fit-for-purpose modelling results to POL to underpin the AEE for the Project. Offshore modelling of currents was undertaken in late 2008 using a 3-dimensional (3-layer) finite-element model (DHI MIKE-3 FM) of the Otago Shelf, that was driven on the offshore boundaries by tides, winds (taken from Taiaroa Head) and a mean velocity for the Southland Current over the 2008 field programme, which was extracted from another larger-domain ocean model developed by a NIWA colleague Dr Mark Hadfield. The latter was applied with different spatial distributions of input flow discharge along the southern boundary of the offshore model, concentrated more at the main shelf break, until a good match was obtained with residual (net) currents over 2.5 months from ADCP[3] measurements at site A1, which is 3 km WSW from A0 (Figure 3). The details can be found in Chapters 10 & 11 in the 2009 Modelling Report (Technical Report 10 of the lodged documents).

51. POL engaged Tonkin & Taylor (T & T) to carry out an independent peer review of the NIWA/MetOcean modelling technical report. The review is contained in a T & T letter to POL dated 3 August 2010. The modelling was assessed as being robust and fit-for-purpose, with no further or more detailed studies being necessary. Although the T&T peer review suggested that alternative models and methodologies could have been used, they also state that the final conclusions are likely to be similar to those given in the NIWA/MetOcean modeling report. Finally, T & T

[3] Acronym for acoustic Doppler current profiler, a current meter that sends out acoustic signals through the water column and determines the current velocity from the Doppler shift in the return signal.

appraised the modelling results and conclusions drawn from them to be sound.

52. A further independent peer review of the 2009 modelling report was undertaken by Dr Ross Vennell of the Department of Marine Sciences, Otago University at the request of the Otago Regional Council. The review is contained in a PDF document dated 16 August 2010. In terms of the offshore hydrodynamic modelling, Dr Vennell noted the following main points:

52.1 The 3-D modelling did not include the effects of water density, but he concluded that ignoring water density at the depths involved, e.g., 30 m depth, was reasonable.

52.2 The Southland Current was kept constant in the 3-D offshore model. Dr Vennell questioned what effects a variable current would have and whether the chosen value is a true average or a conservatively high value.

52.3 The offshore model didn't explicitly include Otago Harbour – rather it was substituted in the offshore model as a tidal flow boundary condition at the Harbour Entrance. Dr Vennell comments that this is a reasonable approach.

52.4 Dr Vennell commented on the very good comparison of modelled currents and field measurements at site A1.

52.5 He also noted that no current measurements were undertaken at the proposed disposal area A0 and suggested that direct measurements at A0 would increase the confidence in the model, particularly as the Southland Current is variable.

53. As a result of the last suggestion by Dr Vennell, Port Otago Ltd. contracted MetOcean Solutions Ltd. to deploy a current meter later in 2010 at site A0 (within 50 m of the disposal area centroid 45.7358°S and 170.799°E). A 47-day deployment of a single-point InterOcean S4 current-meter was undertaken from 19 October to 5 December 2010, set at approximately 4 m above the seabed. The results are documented in a report by MetOcean Solutions Ltd. (2011).

54. The main results from the deployment near the seabed at A0 are:

54.1 the mean current speed was 0.14 m/s, with a maximum of 0.5 m/s, which are only slightly higher than equivalent values at A1 (mean of 0.09–0.13 m/s and a maximum of 0.44 m/s).

54.2 strongest currents were to the NNE and SSE sectors.

54.3 the overall residual (net) current for the entire period was to the east.

54.4 the directional distribution of currents for this period does not necessarily reflect the long-term distribution, and it is notable that the strongest currents were directed towards SSE and SE coinciding with persistent strong northeasterly winds.

55. The MetOcean Solutions (2011) report concludes that "the current regime at A0 appears to be predominantly influenced by regional-scale wind-driven flows. However, it is likely that the combined effects of bathymetric steering and the impingement of oceanic-scale flows will also be influential at this location."

56. By combining this information, a more complete picture emerges of the variability of currents out at the proposed disposal site A0. I will now provide that synthesis, noting that nothing in this further evaluation fundamentally alters the conclusions I have drawn in the 2009 and 2010 modelling reports.

57. The oceanography of the Otago Shelf is complex with the oceanic Southland Current, which does meander in its pathway, interacting with both regional and local winds and to a much lesser degree, tides. With very limited past measurements of currents on the Otago Shelf, it was quite a challenge to model all these processes operating together, besides including natural day-to-day variability.

58. Under my direction, my NIWA colleagues modelled the offshore area based on a 0.15 m/s velocity for the Southland Current, which was the mean velocity computed by NIWA's larger ocean model of the wider Otago Shelf and abyss over the mid-March to May 2008 period, coinciding with ADCP field measurements at site A1. The variability in the Southland Current velocity simulated in the larger ocean model from regional wind forcing over this period ranged from 0.075 m/s up to 0.33 m/s to the NNE at a location 31 km due south of Cape Saunders in ~130 m water depth. This range is within the 0 to 50 cm/s range cited by

Dr Vennell in his peer-review, based on current measurements by Chiswell (1996) off Nugget Point in 108 m water depth and a mean of 0.238 m/s.

59. Therefore the mean Southland Current of 0.15 m/s used for the A0 plume modelling is towards the lower end of the Southland Current speed range. Use of the 0.15 m/s as the basis for developing an inflow boundary for the Otago shelf model produces a net residual current to the NNE at A0, which matches with the pattern of seabed deposition shown in Fig 11.22 of the 2009 modelling report. The same model simulation shows a south-east residual current at site A1, which closely matched extensive current-meter measurements (Figure 10.3 of the 2009 modelling report).

60. Further modelling diagnostics recently carried out by my colleague with different Southland Current inflows on the southern boundary of the MIKE3 FM model show that increasing the Current beyond 0.15 m/s would orient the net current at A0 more offshore to the NE and persistently so. Therefore, using higher Southland Current flows would tend to under-predict impingement of the edge of diluted sediment plumes on the Otago coastline and so use of the lower velocities is conservative. Also, a simulation was undertaken for the same mid-March to May 2008 period with no Southland Current (i.e., only winds and tides), which produced a much smaller net residual current (about 10% of that for the simulation used), which was to the north for the bottom and middle layers while the surface-layer residual current was to the NNE. However, there were periods in this additional simulation when the current drift was to the SE or East, particularly in the surface layer (sometimes from strong SW wind periods), but seldom onshore and even then only for short periods due to local winds, which are already included in the reported plume simulations.

61. Therefore, in summary, the lower mean velocity used for the Southland Current will tend to overestimate any coastline effects and hence is conservative. As far as simulating the effect of varying the strength of this current for plume simulations, it would have compounded the number of model combinations. It was deemed more important in terms of local variability to focus more on wind variability for the plume modelling rather than increasing and decreasing the Southland Current strength, which only makes slight differences in net residual current

direction. The focus on building winds into the simulations used in the 2009 and 2010 Modelling Reports, taking into account their frequency of occurrence, is backed up by the recent measurements.

62. Figure 4 shows the overall residual current pattern for the bottom layer (akin to the deployment depth for the recent current-meter) from the long simulation used in the 2009 Modelling Report. The centroid of the A0 area (shown by cross-hairs) is at the landward edge of the influence of the Southland Current offshore, which has its strongest expression further offshore at the main shelf break in depths of 100–500 m. Given its location in this east-west transition zone, the A0 site will experience variations in currents that over the long-term are dominated by the NNE flow at the edge of the Southland Current influence, but there will also be periods when it is more influenced by the East to ESE flow arising from the outer extension of the Blueskin Bay eddy (Figure 4) and/or regional/local wind effects. This variability is also confirmed from larger-domain ocean model simulations by NIWA oceanographers that show meanders (in-and-out movements) of the landward edge of Southland Current flowstream in the vicinity of A0 at periods of days subject to regional wind patterns.

63. Consequently, the recent 2010 current-meter measurements at the centroid of A0, with an overall residual current to the East for the 47-day deployment, confirms that this area is indeed a variable transition zone between regional/local wind effects and the influence of a varying Southland Current flowstream. Mostly currents were either to the N, NE, or SE (particularly during two persistent NE wind periods). It is not known what the strength and variability of the Southland Current at offshore locations was during this field deployment, although it is not necessary to know this in the context of A0 currents to be able draw firm conclusions relevant to the potential for sediment plumes to encroach on the coastline.

64. Taken together, with the modelling, the key points that arise out of these investigations with respect to the A0 disposal area are:

    64.1 Based on the 2010 measurements by MetOcean plus additional shelf model simulations with a zero Southland Current, the current at A0 is very seldom directed onshore. For the two short periods when the current was directed towards the shore, it appeared to coincide with light NE winds (2–10 m/s). However several other occurrences of light to moderate NE winds coincided with currents directed offshore or to the south-east. Plume modelling results I will summarise later indicate that if the dilute edge of the plume does reach the coast, the concentrations, while very low, are highest for light NNE wind conditions, which indicates that plume model is responding to these onshore wind conditions.

64.2 While it has been confirmed there will be periods of days and weeks when the residual current is more directed to the east (including brief periods of 1-3 days when the current is more to the SE), these residual currents will transport sediment plumes offshore, where after a short travel distance (particularly if the current is to the SE) they will quickly encounter the Southland Current and be transported in a general NNE or NE direction, depending on the strength of the Southland Current at the time.

64.3 The hydrodynamic model simulations in the 2009 and 2010 modelling reports do not include this eastwards (offshore-directed) residual at A0, so these model results tend to show the plume closer to the coast and are therefore more conservative for the Otago coastline, than if an easterly (offshore-directed) residual had been included.

64.4 At the very long timescales, the offshore submergent spit on which A0 has been placed shows a strikingly consistent North to NNE orientation. This will enhance topographic steering of currents to some degree, particularly on the offshore side of the spit, but is also indicative of a long-term net residual current to the NNE that has shaped this large sedimentary body.

65. Inshore, a weak anti-clockwise eddy occurs most of the time in inner Blueskin Bay, with a southwards, then south-east net flow out of the southern Bay as shown in Figures 3 and 4. However, this flow pattern can be temporarily reversed by south to south-east winds, as demonstrated by current-meter measurements undertaken in the centre of Blueskin Bay and off Heyward Point (Bell & Hart, 2008). This eddy is included in the plume modelling, contrary to many submissions stating it

was not included, as shown by the resulting residual flow pattern extracted from the model in Figures 3 and 4.

66. A smaller clockwise eddy occurs off Taiaroa Head, causing a predominant net current to the south-east at A1 (Figure 3 and also Figure 6), which was confirmed by a 4-month current-meter deployment undertaken at A1 in 2008 (Bell & Hart, 2008). The implication, I discuss later, is that any material discharged at A1 will be caught up in this clockwise circulation and preferentially carried towards the Otago Heads shoreline.

Offshore wave climate

67. Based on a 10-year wave hindcast from 1998 to 2007 undertaken by MetOcean Solutions (2009 modelling report), the average significant wave height[4] offshore in 30 m water depth is 1.1 m, rising seasonally to 1.2 m in winter months. For waves less than 1 m high, a wide range of wave periods occurs from 3 to 15 seconds, exhibiting local sea or swell or a combination. Wave heights over 2 m are generally swell from the south-east quadrant with periods of 9 to 15 seconds.

68. Based on the same hindcast, waves are capable of mobilising fine sands of 0.1 mm diameter at the disposal site A0 for 55% of the time on an annual basis. Mostly, this is achieved by waves from the easterly and south-south-east directions. Seasonally, winter swells and sea produce the most active mobilisation at 68% of the time, reducing to 42% in summer months.

69. To and fro wave orbital velocities at the seabed in such deep water are usually symmetric in magnitude in the horizontal direction under the crest and trough of the waves, or vertically up on the rising wave front, so they seldom induce any net transport of sediments at the seabed. Their function is to mobilise and/or resuspend sediment into the water column momentarily, but transport in any given direction only occurs under the influence of a current flowing over the seabed at the time. At the disposal site A0, net transport of sediments winnowed from the seabed will predominantly move to the north, north-east or east until

---

[4] The "significant wave height" is a precise term used in wave applications to define the average of the highest 1/3 waves over a measurement period.

sediment particles settle again. Given the low occurrence of onshore-directed currents, there is no effective mechanism present for onshore movement of re-suspended sediments, as onshore-directed waves and swell alone will not result in any net shorewards sediment transport in deeper water.

SELECTION OF A0 DISPOSAL AREA: HYDRODYNAMIC FACTORS

70. In the process outlined by Mr Coe in his evidence, A1 was selected as an initial option for a disposal area. However, after undertaking field measurements and some preliminary plume-model simulations, it became clear that sediment plumes could regularly encroach on the coastline of Otago Heads.

71. The reason is the persistence of the smaller clockwise eddy off Taiaroa Head, which affects currents at A1, with a net south-easterly followed by a south-westerly flow. This onshore movement towards Otago Heads rendered this site as unsuitable for dredged-material disposal.

72. Modelled currents at site A2, 1.8 nautical miles north of A0 (shown in Figure 3), which was a third option for a disposal site, were similar to those at A0. Preliminary plume-model simulations for disposal at A2 resulted in no contact with the coastline around Otago Heads, but increased suspended-sediment concentrations somewhat more along the coastal zone north of Cornish Head.

73. A few plume simulations were undertaken also for sites further offshore at 2 km directly east of A2 and A0. These results provided only small improvements on the respective A2 and A0 simulations in terms of nearshore suspended-sediment concentrations on the northern coastal zone. This arises because dispersive (spreading) processes at ever-increasing length scales, from turbulent mixing and current-velocity shear from winds and the Southland Current, dominate the distribution of fine-silt transport on this area of the shelf. The plume transport characteristics would only become more dominated by advection, with less lateral spreading, if the disposal area was well into the main body of the Southland Current.

74. For the proposed site A0, plume simulations show that the very-dilute edge of the plume produces somewhat lower concentrations along the

northern coastline than those for site A2, but also for some wind conditions I will discuss later, the edge of the plume may also reach the coastline of Otago Heads, with a similar range of low concentrations.

75. In terms of hydrodynamic and plume dispersion process, A0 is an optimal disposal location for the disposal sites investigated, leaving aside other constraints discussed by Mr Coe in his evidence.

ASSESSMENT OF EFFECTS

Effects of the completed capital dredging on Harbour tides, currents and waves

76. Deepening and widening the channel in the manner described by Mr Coe will only have a minor (< 1%) effect on the tidal volume flowing in and out of Otago Harbour, as most of the volume change in the Harbour from dredging will occur below the low water mark i.e. the residual volume left at low tide.

77. A deeper channel will only have a slight effect on the tidal range because there will be slightly reduced friction exerted by the deeper seabed along the main navigation channel in the Lower Harbour.[5] Changes to the tidal range after capital dredging is complete will be negligible at the Harbour Entrance and only minor elsewhere with increases of no more than 6–8 mm for an average tide. These changes would be barely discernible, being just above the accuracy range of conventional tide gauges.

78. Mean high-water phase (timing), for the final deepened channel configuration, would advance from 0 minutes earlier compared to the present situation in the Entrance, increasing gradually to a 3-minute advance at Harington Bend, 6 to 8 minutes earlier at Port Chalmers and 5 to 6 minutes earlier in the shallower Upper Harbour. This will occur as the tide wave travels faster in deeper water, and then tails off as it propagates up the Victoria Channel of the Upper Harbour which is not being dredged as part of the Project. Similar, but slightly smaller

---

[5] Explained in Section 2.1 of the 2009 Modelling Report, *Technical Report 10* of supporting application documents.

advances in the timing of low water will also occur. The total period of the tide between successive high tides at any location will not change.

79. Overall there will be only minor changes of generally less than 0.1 m/s (0.2 knot) in the speeds of tidal currents following capital dredging—mainly reductions rather than increases in speed, and largely within the Lower Harbour. The largest absolute changes in the average-tide peak current would be localised increases of up to 0.1 m/s off the groyne at Beacon No. 10 on south side of Harington Bend and decreases in peak current by up to 0.10 to 0.13 m/s in patches along the flanks of the shipping channel (Port Chalmers area and Harington Bend) where more substantial dredging is required. Much of the main shipping channel will experience slightly reduced peak velocities. Away from the shipping channel, smaller changes generally less than ±0.06 m/s (0.12 knot) will occur in peak velocities in the side channel north of Quarantine Island (an increase of 0.02–0.05 m/s), with decreases of 0.02 to 0.05 m/s generally over the eastern side of the Lower Harbour between Harwood and Ohinetu Point, reducing locally at Ohinetu Point by up to 0.065 m/s. Most of the predicted changes in current speed outside the shipping channel would be close to or below the accuracy that can be achieved by conventional moored current meters of between 0.01 to 0.03 m/s and are of no practical significance.

80. With respect to storm-tides[6] in the Harbour, a key determinant is the wind set-up component from offshore winds and within-harbour winds. Modelling was undertaken early in the Project (Oldman et al., 2008) using strong south-west and north-east winds of 20 knots in the Harbour. The results showed that the differences between the deepened and present channels were similar to those using calm conditions i.e., the main difference stems from the tide, which dominates the hydrodynamics of the Harbour.

81. The largest waves within the Harbour are generated by either south-west or north-east winds that blow down the longest wind fetch of the Harbour. The maximum height of waves in Otago Harbour is limited by the fetch distance across or along the Harbour (which is governed also by the tide state) and are depth-limited by the shallow intertidal areas in

[6] Relates to elevated water levels produced when high tides combine with storm surges produced by low pressure systems and adverse winds

the middle of both the Lower and Upper Harbour. Consequently, the channel widening and deepening will have no discernable effect on the wave climate.

82. With respect to extreme coastal inundation, the deepening will only have a negligible effect on the exposure to extreme storm-tide and wave overtopping events around the Harbour coastline. Apart from a slight increase in high tide level (up to 5 mm on spring tides), the wave fetch lengths at the critical high tide period will remain unchanged and the extensive shallow intertidal areas will still be present, limiting the wave heights.

Sediment plume dispersion from dredging activities inside the Harbour

83. Dredging causes “extra turbidity” in the waters in which the dredge operates arising from seabed disturbance from the suction head and from near-surface discharges once the hopper overflows. The sediment plume modelling NIWA has undertaken quantifies this “extra turbidity”, which is the effect directly caused by the activity, over and above any background levels at the time of actual dredging.

84. The effects of dredging operations using either a moderate-size TSHD or *New Era* within the Harbour were assessed on the basis of sediment plume modelling for 14-day scenarios from five representative dredging sub-areas of the shipping channel (Figure 5). Dredging claims working both “predominantly-sand”[7] and “predominantly-silt” seabed deposits were modelled for each sub-area. A 14-day period was chosen to straddle a full spring-neap tide cycle and is often used as the rolling-average period for monitoring environmental turbidity limits for capital dredging operations to reduce aliasing by the spring-neap tide variations.

85. Dredging using a TSHD (including *New Era*) will generate two main sources of sediment plumes: a) bottom disturbances from the moving suction head; and b) overflows that commence when the hopper first fills with a seawater/sediment mixture. It has been conservatively assumed that when dredging predominantly-silt areas, the overflow will

---

[7] Based on geological investigations, a 2% silt content has been assumed for fine-sand deposits

last 4 minutes but in practice, dredging of silts normally ceases soon after the overflow occurs, primarily because of environmental and often economic reasons. In contrast, when dredging predominantly-sand areas, the overflow of supernatant[8] lasts for around 60 minutes for a larger TSHD and 70 minutes for *New Era* before the hopper fills with sand. The modelling simulations also include a zero discharge period in a repeating dredging cycle while the dredger is on its return voyage to and from the offshore disposal areas.

86. Details of the plume modelling set-up and parameters are provided in the 2009 Modelling Report for the moderate-size TSHD[9] representing Major Capital Dredging works. Further supplementary modelling was undertaken post-lodgement, as reported in the 2010 Modelling Report by Bell & Reeve (2010), repeating the 14-day plume simulations based on using a much smaller TSHD, the *New Era*, which is owned and operated by the Applicant, representing the Incremental Capital Dredging works.

87. Where possible, model parameters or set-ups have erred on the conservative side to provide more confidence in assessing potential upper limits on direct environmental impacts up to the stage where sediments first settle out of suspension. For instance conservatism has been built into the modelling by simulating:

a) the 4-minute overflow of supernatant at a high sediment discharge rate of 1000 kg/s (for a moderate-size TSHD) or 75 kg/s (for *New Era*) while dredging predominantly silts to pragmatically cover a slower shut-off of the overflow at times, especially when encountering stratified silt lenses in predominantly-sand areas;

b) suspended-sediment concentrations are based on saturated-sediment weight (rather than the conventional dry weight),[10] so

---

[8] Defined here as the liquid floating on the surface above the bulk of sediment in the dredge hopper.

[9] Explained in Section 7 of the 2009 Modelling Report, which is lodged Technical Report 10.

[10] It is easier to carry saturated bulk densities all the way through the chain from in-situ seabed deposits, hopper loads, plume discharge through to final in-situ seabed deposition again.

concentrations will be overestimates relative to the normal measurements expressed as dry-weight of sediment;

c) suspended-sediment concentrations are depth-averaged, so will be overestimates for surface concentrations;

d) no down time has been included for the dredger. I understand that for a moderate-size TSHD under contract, down time will be minimal, but for *New Era*, Port Otago have informed me it could be around half the time (allowing for other contract and maintenance dredging work);

e) sea-bed disturbance discharge rates of 30 kg/s (for a moderate-size TSHD) or 2 kg/s (for *New Era*) which are at the upper end of the range normally encountered during dredging with a TSHD;

f) some sediment discharge sites for the five lumped sub-areas (Figure 5) were located towards the inland end of the relevant channel reach e.g., the Harington Bend site covers dredging out to The Mole and the two Swinging Basin sites cover the reach from Port Chalmers out to halfway to Taylers Bend. This will tend to overestimate sediment deposition in the middle and upper parts of the Harbour.

88. Considering either predominantly-silt or predominantly-sand dredging claims, there will be little difference in the spatial extent of areas affected by silt plumes and deposition generated by either size of dredger. This implies that the cyclic silt discharges during a 14-day period based on a short 4-minute overflow simulated for higher-rate silt sources produces approximately the same effect as lower silt volumes discharged from the much longer 60–70 minute overflows working predominantly-sand sources.

89. Dispersion of the sediment plumes in the Harbour is dominated by material being transported up and down the main channels by tidal currents rather than by the more dispersive (spreading) processes that occur, for example, offshore in deeper waters. So the highest concentrations will be in the main channel, particularly around low water when there is limited opportunity for dispersion onto adjacent intertidal or shallow areas.

90. All dredging simulations for a moderate-size TSHD, based on a 24/7 operation, show that 14-day average suspended-sediment

concentration in the fairway, connecting side channels and intertidal banks adjacent to the fairway will reach 100–500 mg/L above the background concentration, with small patches from 500–1000 mg/L in the vicinity of the dredging.

91. All dredging simulations for *New Era*, based on a conservative 24/7 operation, show that 14-day average suspended-sediment concentration in the fairway will only reach 20–50 mg/L above the background concentration, with small patches from 50–100 mg/L in the vicinity of the dredging. These latter values predicted by the model match well with the results from a small-scale field test, undertaken by POL staff, sampling surface waters in and out of the sediment plume from *New Era* while dredging on 29 April 2008, allowing for reasonable mixing over a distance of about 100–150 metres from the vessel.

92. While *New Era* is dredging, the average suspended-sediment concentration on the intertidal areas in the Lower Harbour is predicted to only reach 20 mg/L with some limited areas adjacent to the main channels of up to 50 mg/L (both values above background concentrations).

93. For both Major Capital and Incremental Dredging, virtually all of the eastern side of the Lower Harbour from Te Rauone Beach through to the eastern side of Portobello Bay will be largely unaffected by extra turbidity, other than a few small patches likely of suspended-sediment concentrations up to 10 mg/L above background concentrations when dredging in the Harrington Bend zone. Similarly, the eastern side of the upper Harbour from Grassy Point to Dunedin would be also largely unaffected by extra turbidity.

94. Dredging undertaken at Harington Bend, the Entrance area and the offshore approach channel would have a negligible effect on the upper Harbour in terms of in-situ suspended sediment concentrations and seabed deposition for both sizes of dredger.

95. Dr James discusses the ecological effects on the Harbour of these different levels of suspended-sediment concentrations in his evidence.

96. Direct seabed deposition of silt-size sediments over a 14-day neap/spring tide cycle with varying winds was also simulated for both the moderate-size TSHD and the smaller *New Era*, assuming settled sediments are subsequently re-suspended by waves or currents. This

provides an upper-bound on deposition on areas where sediments initially settle out, while resuspension by waves and currents will generally reduce deposition below the simulated thicknesses.

97. For both Major Capital and Incremental Dredging, sediment deposition in the Harbour (excluding the deeper main channels) would be highest on the central intertidal bank that is both opposite Port Chalmers and north of Quarantine Island. Discharges from predominantly-silt dredging claims (with a 4-minute overflow) would cause slightly higher deposition thicknesses and rates of deposition than from predominantly-sand claims, but the overall spatial distribution of affected areas is similar for either type of seabed composition. This is due to the dominance of dispersion by currents, largely within the confines of the main channels, at low tide, but the plume will spread out further afield during higher stages of the tide.

98. Based on a moderate-size TSHD, the accumulated deposition over a fortnightly period, at or above a nominal upper level of 5 kg per square metre of seabed or approximately 3.8 mm thickness at a rate of 0.3 mm/day, is largely confined to the channels or flanking areas: a) the main shipping channel (all dredging claim areas); b) the subsidiary channel to the east from Quarantine Island; c) around Goat Island and up Victoria Channel to opposite St. Leonards for a discharge source on the west side of the Turning Basin; and d) some of the flanking intertidal flats to these channels. For Major Capital Dredging, 99% of the Harbour area outside the main channels will experience deposition rates of no more than approximately 1 mm/day, being highest on the intertidal banks opposite Port Chalmers, but most of these Harbour areas will be subject to less than 0.1 mm/day.

99. Based on using *New Era*, the accumulated deposition over a fortnightly period at or above the same nominal upper level of 5 kg per square metre of seabed, or approximately 3.8 mm thickness at a rate of 0.3 mm/day, will be confined to the immediate vicinity of the main shipping channel where *New Era* dredges.

100. For a moderate-size TSHD, most of the eastern parts of the Lower and Upper Harbour would be subject to little or no deposition. Exceptions will be the reach from Latham Bay to Yellow Head (west of Portobello Peninsula) for discharges from the eastern side of the Turning Basin,

Taylers Bend and through to the Cross-channel reach (Figure 5), and in the subsidiary channel from Te Rauone Beach to Ohinetu Point from the Harington Bend claim area. The reach west of Latham Bay may reach deposition fluxes of 1–5 kg per square metre of seabed over 14-days or a thickness of 0.8–3.8 mm at a rate of 0.06 to 0.3 mm/day. Along the Te Rauone Beach to Ohinetu Point reach, the deposition will be smaller at no more than 0.2 kg per square metre of seabed or a thickness of 0.15 mm over a 14-day period at an accumulation rate of 0.03 mm/day

101. Using *New Era*, most of the eastern parts of the Lower and Upper Harbours would also be subject to negligible or no deposition, apart from the reach west of Latham Bay for discharges from the eastern side of the Turning Basin. In this reach, deposition may reach 0.5 kg per square metre of seabed or a thickness of 0.4 mm over a 14-day period at an accumulation rate of 0.03 mm/day or less.

102. Flanking mid-harbour intertidal flats, where most of the non-channel deposition will occur, will exhibit sediment fluxes of 2–5 kg per square metre or sedimentation rates of 0.1–0.3 mm/day for the moderate-size TSHD. Using *New Era* for Incremental Dredging, the sediment fluxes for the same intertidal banks will be 0.2–0.5 kg per square metre or sedimentation rates of 0.01–0.03 mm/day.

103. The ten-times smaller deposition rate for *New Era* is largely a function of the much smaller dredging capacity of *New Era* of about one-fifteenth less than the moderate-size TSHD, but with overflows from "predominantly-sand" claims discharging slightly longer for the *New Era*, and all overflows are discharged higher in the water column, than the larger dredger. However, using *New Era*, the dredging will occur over a longer time period, interspersed with periods of no dredging.

104. Dr James discusses the ecological effects of these deposition results in his statement of evidence.

Resuspension of silts in Otago Harbour

105. The long-term fate of re-suspended silts within the Harbour and their indirect impacts are difficult to address with modelling, as it would involve very long computer simulations with a combination of wave, tide and sediment-transport models. However, overall patterns of deposition

can be determined from the plume modelling results and an understanding of silt transport in the Harbour, based on the analogue of where fine sediment naturally accumulates from rivers and catchment runoff. Dr Single also considers the effects of long-term siltation for the beaches of the Harbour in his statement of evidence.

106. Firstly, the plume modelling shows that only the main channel and the side channel between Quarantine Island and Portobello Peninsula would be subject to the highest initial deposition thicknesses from direct settlement. Such deposition in channels will be reworked regularly by tidal currents, especially on spring tides, and spread via the entire channel system of the Harbour, preferentially settling in more quiescent sections of the channel system. A proportion of silts will also be quickly exported out the Entrance, as demonstrated by the 14-day plume model simulations in the 2009 and 2010 Modelling Reports.

107. Secondly, in the shallower sub-tidal areas, and intertidal banks, some of the initially-settled silt will be more likely to be remobilized by wind waves rather than currents, and then transported elsewhere in suspension by the current until hydrodynamic conditions favour settling. For typical 3-second wind waves, and an upper-range significant wave height of 0.6 m, the threshold for mobilizing non-cohesive medium silts (0.01 mm) would be exceeded in depths less than about 7 m, which includes most of the Harbour outside the main shipping channels, except a small part of the basin in Portobello Bay. Consequently, during moderate to high waves, silts available for reworking will be winnowed from the seabed surface, especially off exposed shallow areas and intertidal flats where wave orbital velocities can be high.

108. Residual silts in the long-term would be dispersed further and more thinly throughout the Harbour, as does silt from The Leith and surrounding margins of the Harbour, eventually finding their way into the main channel system to be exported to the ocean or preferentially settle “permanently” in quiescent areas where wave activity and currents are low or sporadic. Such settling areas, which naturally exhibit silt/mud substrates, are likely to be the seabed of the fairway in the upper Harbour, sheltered sub-tidal embayments (e.g., Careys Bay and the inner Port Chalmers and Dunedin berths), inlets in the Upper Harbour behind the railway embankments and the deeper basin (> 5 m depth) in Portobello Bay. In all these areas, apart from sections of the fairway

which efficiently trap silt, the final deposit thickness of silt from the dredging operations will be no more than several millimetres built up over a finite period of months to years, compared with ongoing siltation from catchment runoff. Dr Single considers the effects of long-term siltation for the beaches of the harbour in his evidence.

Sediment plume dispersion from dredged material offshore

109. All the dredged material from a Major Capital Dredging programme and the majority of material from Incremental Capital Dredging will be released from the relevant dredger's hopper at the offshore disposal ground at A0. This disposal site is on the submergent spit offshore in about 28 to 29 m water depth below mean sea level. The dredged material will be released at different parts of the 2-kilometre diameter disposal area to ensure an even spread of material in a mound at A0.

110. Some of the dredged material from Incremental Capital Dredging will be disposed of at the existing inshore disposal grounds off Heyward Point and Spit Beach. But I understand from POL, that this will only involve predominantly-sand or rock material to minimise the generation of silt plumes in the nearshore environment. Dr Single will cover the effects of sediment disposal at these inshore sites.

111. The effects of dredged-material disposal operations offshore at A0 were assessed on the basis of sediment plume modelling, which is primarily driven by a 3-layer offshore hydrodynamic model (described in the 2009 Modelling Report). Previously, in paragraphs 49 to 64, I discussed in detail the results from the offshore hydrodynamic model in the context of different magnitudes for the Southland Current and recent field measurements.

112. To simulate sediment plumes from cyclic hopper releases at A0, a passive particle-tracking plume model, MIKE-3 FM PT, was adopted, rather than a dynamic plume model. A dynamic plume model takes into account hyper-concentrated slurries and the rapid descent of the material en-masse that can occur in the near-field of the discharge point from the sudden release of a large hopper load of sediment. The passive plume model is more conservative for areas beyond the disposal area because it treats sediment particles as being independent

of each other, and therefore disperses more material than would occur in practice from a rapid hopper discharge.

113. The two key aspects for assessing environmental effects that are required from the offshore sediment plume modelling are information on the spatial extent of suspended-sediment concentrations in the water column and sediment deposition on the seabed. For suspended-sediment concentrations, that entails information on the magnitudes (mean or maximum) through the water column, while for deposition, what is required are estimates of the total seabed deposition and deposition rates over the total dredging period. Both these requirements needed a different approach to the set-up of the plume simulations.

114. Sediment plume modelling was undertaken using 2-day scenarios for disposal at five evenly-spaced sub-sites within the 2-kilometre diameter A0 area. Scenarios for simulating suspended-sediment concentrations in the water column included both an "average"[11] mix of silts and sands discharged from a dredge hopper and also "predominantly-silt" discharges.

115. Four classes of sediment size were modelled. Three silt size classes—fine silt (<0.00625 mm), medium silt (0.00625 to 0.02 mm), coarse silt (0.02 to 0.0625 mm) were simulated along with fine sands with grain sizes above 0.0625 mm. Most of the fine sand from the Harbour has an average grain size in the range 0.1–0.3 mm.

116. A 2-day simulation period for dredge disposal operations was chosen to provide sufficient time to determine any widespread and coastal effects of plume dispersal, yet short enough to accomplish over 50 separate 2-day simulations covering different wind and disposal sub-area combinations to integrate up the likely deposition footprint for an entire dredging operation.

117. The offshore plume model was driven by currents produced by a 3-layer hydrodynamic model that included tides, an average mean flow for the Southland Current off the Taieri River mouth area and forcing from three wind speeds each from the predominant north-north-east and south-

[11] Based on the average proportions of fine, medium and coarse silt and fine sand for the entire 7.05 million cubic metres of dredged material (excluding rock).

south-west. The top layer was 30% of the water depth, the bottom layer 20% of the water depth, with a larger mid-layer of 50% of the depth.

118. Details of the plume modelling set-up and parameters are provided in the supporting Technical Report 10 (2009 Modelling Report) for a moderate-size TSHD.[12] The dredge hopper was assumed to fully discharge within 10 minutes.

119. Further supplementary modelling by Bell & Reeve (2010) i.e., the 2010 Modelling Report, was undertaken post-lodgement, repeating the same 2-day plume simulations for "predominantly-silt" hopper loads, but based on plume source parameters for the smaller *New Era*, which included a discharge rate 14% of that from a moderate-size TSHD over a 4-minute period, and released higher in the water column at 2 m below the surface.

120. The average turnaround time simulated for both types of dredge was set at 2 hours, which includes the return voyage to the Harbour site, refilling the hopper and returning to A0. This means each 2-day simulation covers 24 hopper releases over a short duration of a few minutes, separated by no discharge at A0 for 1 hour and 50 minutes (1 hour 56 minutes for *New Era*) while it returns to the Harbour for another dredging run.

121. Suspended-sediment concentrations were analysed from single 2-day simulations of each of six wind scenarios from either NNE or from WSW for the larger TSHD. Both average and maximum concentrations were extracted from the model.

122. Average suspended-sediment concentrations will be substantially lower than the maximum values over the 2-day simulation, because the nearly 2-hour long gap between disposal from the dredging vessel allows in-situ concentrations to reduce from settling and dispersion. However, in the assessment of effects, the more conservative maximum concentrations have been used.

123. As expected, suspended-sediment concentrations will be highest in the bottom near-bed layer due to gravitational settling of sediment towards

---

[12] Explained in Section 7 of the lodged Technical Report 10: *Port of Otago Dredging Project: Harbour and Offshore Modelling*

the bed and having commenced discharge from the hopper at either 5 m or for *New Era* 2 m below the water surface.

124. Of the sediment size classes, medium silt cause the highest sediment concentrations in the bottom layer within a few kilometres of the disposal ground, but the fine silts are more dispersive spreading over a wider area (due to their much lower settling rate).

125. For the moderate-size TSHD, considering all silt-size classes in the vicinity of A0, a moderate (14 m/s) WSW wind will generate the most adverse conditions for sediment concentrations in the bottom layer. Across all silt-size classes and a predominantly-silt hopper load, maximum suspended-sediment concentrations for this scenario may reach around 900 mg/L above background levels just “downstream” of the disposal area. For an average sand/silt hopper load, the maximum concentration for all silt size classes would be about 30% less at around 620 mg/L. Out of the 6 wind scenarios, the highest surface-layer concentrations for all silt-size classes, will occur during light (3 m/s) NNE winds with a maximum concentration of around 270 mg/L above background, with about 30% less at 185 mg/L for an average sand/silt hopper load.

126. In the vicinity of the A0 disposal area, the suspended-sediment concentrations for predominantly-silt loads from *New Era* are predicted to be no more than 7–11 mg/L and 47–57 mg/L above background levels, in the near-surface and bottom ocean layers respectively. For an average sand/silt hopper load, peak concentrations would be similarly between 23–33% less than for predominantly-silt hopper loads.

127. Further afield, the fringes of sediment plumes generated during disposal may sometimes, in theory at least, reach the coastline north of Karitane and around Otago Heads (Figure 2), but in practice the suspended-sediment concentrations of silts will be very small.

128. For the coastline north of Karitane, particularly north of Cornish Head, maximum concentrations in the dilute edge of the plume from predominantly-silt loads would not be elevated above background levels by more than about 0.02 mg/L in the Karitane area, and up to only 0.9 mg/L for a mid-size TSHD under light NNE winds. For the same stretch of coastline, the maximum concentrations for *New Era* will be no more

than 0.05 mg/L above background levels for the six different wind simulations undertaken.

129. Under light NNE or WSW winds, the dilute fringe of sediment plumes may also reach Otago Heads, in theory, where the maximum concentrations for silts will be no more than 2–3 mg/L above background levels for a moderate-size TSHD and 0.6 mg/L for *New Era*.

130. These coastline concentrations are so small, they would be difficult to detect in the field, and in effect, are an artefact from modelling a continuum down to infinitesimally small concentrations.

131. The plume is not likely to come into contact with Otago Heads during strong winds from either the WSW (21 m/s) or NNE (15 m/s). For the more obvious candidate wind direction from the NNE blowing onshore, stronger NNE winds in fact induce a return flow offshore that occurs in the bottom layer under such strong wind conditions.[13] Therefore, high wind situations from the NNE or NE will not result in any encroachment of the plume's edge at any part of the Otago coastline.

132. Patterns of sediment plume dispersion and areal extent of influence are broadly similar between the two sizes of dredger. This is expected as the sediment material is released at the same location, from which the same environmental processes e.g., tides, winds, currents, turbulent eddies govern the dispersal characteristics of the plume. There will however be subtle differences in the extent of influence, mainly along the onshore and offshore fringes of the plumes. These differences arise from the shallower discharge (2 m depth) from the *New Era* compared with the moderate-size TSHD (5 m release depth), which means the plume from the *New Era* is initially influenced by near-surface water processes for a slightly longer period while sediment settles through the 3 m discharge height difference between the two dredge sizes.

133. Dr James discusses the ecological effects on the offshore environment of these ranges of suspended-sediment concentrations in his evidence.

---

[13] For example, comparing Figure 11.10b with Figures 11.8b and 11.9b in the lodged Technical Report 10 (2009 Modelling Report)

Seabed deposition from sediment plumes offshore

134. Conservative estimates of seabed deposition of silt and sand on the continental shelf were determined for the moderate-size TSHD in the 2009 Modelling Report. This was achieved by accumulating the deposition in rectangular cells of 0.005° latitude and longitude[14] from the 51 two-day simulations that add up to a total discharge of 7.05 Mm^3 (excluding rock). This was done for each of the sediment size classes and then a combined total deposition depth and rate produced, assuming the entire Major Capital dredging project lasting the shortest-possible programme of 120 days. This scenario assumes a worst case for seabed deposition rates, where a moderate-size TSHD undertakes all the capital dredging works.

135. Calculating seabed deposition in this way will be conservative for areas affected by the footprint of the disposal sediment plumes that emanate from A0. This is because it assumes sediments remain on the seabed where they first settle out of suspension and are not subsequently re-suspended by waves or currents. In fact sediments will be actively re-suspended – a point I will come to shortly.

136. A map of seabed deposition rates in mm per day was determined from the 51 plume model simulations for a moderate-size TSHD and presented in the 2009 Modelling Report accompanying the AEE.[15] and reproduced as Figure 7 in my evidence.

137. The spatial pattern of seabed deposition was mainly to the north of A0, but also shows an offshore bias with an easterly component. The dominant northern deposition zone is derived from the predominant north to NNE residual current but the easterly extension of the deposition also fits in with recent current-meter measurements at A0.[16] Beyond the northern terminus of the submergent spit, 9 km north of A0, the deposition rate will be no more than 0.4 mm/day and total seabed deposition over the dredging period would be less than 50 mm, assuming no subsequent wave re-suspension. Clearly, nearer A0, the

---

[14] Equivalent to 555 m north-south and 390 m east-west on a cartesian projection.

[15] See Figure 11.22 or 12.24 in the 2009 Modelling Report: *Port Otago Dredging Project: Harbour and offshore modelling* – lodged with the AEE as Technical Report 10.

[16] See paragraph 54 to 55 of my evidence.

deposition rates will be higher, with a rate of ≥ 1.7 mm/day covering 11 square kilometres including the 3 square kilometre A0 deposition area.

138. A similar analysis of total deposition and daily deposition rates was not undertaken for *New Era*, as Incremental Capital Dredging will occur over several years, with lengthy gaps between dredging due to other dredging commitments and contracts and some of the capital dredging material (excluding silts) will be placed at inshore disposal areas, as I understand from Port Otago Ltd. However, the effect of Incremental Capital Dredging on daily deposition rates in the region of A0 will be considerably smaller than the upper-bound rates shown in Figure 7 for the larger TSHD. However, for an approximate upper bound, assuming continuous operation, dredge disposal using *New Era* would be approximately ten times less than the rates calculated for the moderate-size TSHD (based on suspended-sediment concentrations being about ten times less). For instance, using the same reference area beyond the terminus of the offshore submergent spit, the deposition rate will no more than 0.04 mm/day. In reality, due to crewing and non-productive time elsewhere for the *New Era*, this average could be halved over several years. Further, given the much longer dredging period of several up to 15 years using *New Era*, wave re-suspension and transport of previously deposited sediments will mean disposed sediments will be more widely distributed at lower thicknesses than the initial footprint for deposited sediments shown in Figure 7 for the moderate-size TSHD.

139. In contrast to sands, fine silt covers the widest area in terms of seabed deposition, which is expected in any open-shelf dispersive environment with very slowly-settling sediments.

140. Along the coastal fringe north of Cornish Head, minute sub-millimetre total deposition of settled fine silts could occur by the end of a Major Capital Dredging programme. Again this is an artefact of the plume model. In reality, it will be very unlikely for fine silts to even reach this small thickness, because of the continual wave activity in such nearshore environments causing frequent re-suspension and further transport. This is the reason why fine silts and muds are seldom seen in the exposed nearshore environments as they are winnowed out by wave activity, alongshore wave-induced currents, long-wave surging and beach rips.

141. The plume modelling for the moderate-size TSHD shows that virtually no sediments from the disposal operation would be deposited in Blueskin Bay or along the coast either side of Karitane Point. Were adverse conditions of sustained light north-east winds to occur, there may be minute levels of deposition in these areas, but again, wave resuspension will ensure such deposits are only temporary.

142. Dr James discusses the ecological effects on the offshore environment of offshore sediment deposition rates in his evidence.

Resuspension of silts on the Otago shelf

143. Now to the question of the ultimate fate of re-suspended silts in the offshore environment of the Otago shelf. In the medium term (months to years) this is a difficult technical problem to quantify, even with coupled sediment transport and current/wave models. The spread of silts will be strongly determined by the actual sequence and persistence of winds, waves, strength and direction of the Southland Current and the availability of silts to be mobilised, all of which are not readily predictable in advance nor is it tractable to run for several up to 15 years to include Incremental Dredging using *New Era*.

144. Mostly, in the medium term, the silt that is available to be resuspended, and not capped by the fine sands in the bulk of the disposed material at A0, will become widely dispersed in very thin deposits, mostly to the north and east of A0, based on the hydrodynamic modelling and field measurements of currents near the seabed. This same dispersive process occurs naturally, when flooded rivers such as the Taieri and Clutha discharge highly turbid and buoyant plumes comprising terrigenous silts and muds, which are continual state of flux from settling on the seabed and being re-suspended by subsequent wave activity on the shelf.

145. Silts seldom settle long in shallow nearshore waters because of continual wave activity, which is why open-coast beaches comprise only coarser sands and gravels.

146. In the longer term, silts derived from the dredge disposal operation may mostly end up in very thin layers across the shelf and ultimately in the

large canyons that dissect the continental slope further offshore, along with the ongoing quantities of terrigenous sediments from rivers.

147. There is a patch of surficial sediments with a higher silt content in the centre of Blueskin Bay (see Figure 2 in the evidence of Dr James). But only a minor proportion of silts from A0 will ultimately settle there, because of the strong north to east directionality of currents at A0, although the Blueskin Bay eddy will sweep a small proportion of the dredged silt material, from the dilute edge of the plume, over this area. In my opinion, the deposition thickness in Blueskin Bay, of silt sourced from disposal at A0, will be small.

Long-term evolution of the disposal mound at A0 and sediment transport

148. Within the disposal area at A0, a mound will form that is estimated to be between 1.1 to 1.7 m above the existing bed level using a moderate-size TSHD. The final height of the mound will depend on currents and waves at the time of disposal and dynamic plume characteristics, during the en-masse descent of dredged material released from the hopper.

149. Incremental Dredging using *New Era* (or a similar capacity dredge) over several up to 15 years will lead to a somewhat lower mound, as some of the disposed sediments will be transported away during the long dredging programme plus some of the capital dredging material (excluding silts) will be placed at inshore disposal areas.

150. The long-term deformation and deflation of the disposal mound, comprising mainly fine sands, assuming silts are regularly winnowed out of the surface sediments, requires knowledge of the sediment-transport rate of sands under combined waves and currents that are likely to be experienced at A0. This was tackled by my colleague Dr Malcolm Green for the case of a disposal mound quickly formed under a Major Dredging programme and is described in Chapter 12 of the 2009 Modelling Report.

151. In lieu of extensive measurements of bedload and suspended sediment transport of the actual disposed dredge material on the seabed at A0 to calibrate a complex sediment-transport model, my colleague Dr Malcolm Green developed a physics-based model to estimate the potential range of sand sediment-transport rates, based on waves and

currents that were measured during the four-month field programme at site A1. Dr Green bracketed the estimates[17] by using two different, but internationally-recognised, sediment transport equations developed by Nielsen (1992) and Rouse (cited in Raudkivi, 1990).

152. The model shows that long-term sand transport from the A0 disposal area would predominantly be to the north or NNE, generally following the orientation of the submergent Peninsula Spit. Current measurements at A1 over a total period of 5½ months, and transferred to A0 by hydrodynamic modelling, show that the critical threshold velocity of around 0.4 m/s needed to mobilize 0.2 mm sands[18] is seldom exceeded by offshore currents acting alone. Therefore, sand transport will only occur when wave activity is sufficient to mobilize fine sands off the seabed in the region of the disposal mound, which will then be transported "downstream" by the current velocity at the time. In the absence of any current, wave orbital motions at the seabed in these depths of 27 to 28 metres, will be regular to and fro water movements, setting up to and fro sheet flow of surface sediments. Consequently, there is seldom any net sediment transport under waves acting alone–it requires a unidirectional current to provide any net transport in deep water.

153. At A0, mobilization of sands by wave orbital motions would be around 40% of the time on average over a year for grains of 0.2 mm and somewhat more, at around 50% of the time on average during the more energetic winter season.[19] An additional 4–5% of the time for mobilization will apply to the top of the final disposal mound, where the water depth will be less than the surrounding seabed, particularly for the much shorter dredging programme using a moderate-size TSHD where the mound has not had time to deflate by sediment-transport processes.

154. The time taken for deflation or reduction of the physical mound created at A0, from either type of dredge, is strongly dependent on whether the net northerly sediment transport of natural sediments from south of A0 is assumed to be zero (i.e. blocked by the mound) or whether it is

---

[17] See section 12.4, in the 2009 Modelling report

[18] This is the median grain size of the sediments that will be dredged from sandy areas.

[19] Determined from a 10-year hindcast of waves at A0 – see Section 12.4.2, in the 2009 Modelling Report.

included as "passing through" the disposal site. The selection of sediment-transport formula to be used also has a major bearing on the time for long-term deflation of the mound to occur, but I have given the lower-bound.

155. For a moderate-size TSHD, the resulting sediment mound at A0 of up to 1.7 m in height from Major Capital Dredging, may take many decades to diminish and blend in more with the local topography.

156. With Incremental Capital Dredging using *New Era*, the net mound height would only grow gradually or incrementally in steps for each dredging campaign over several up to 15 years. Further, taking into account ongoing sediment transport on the mound during active wave mobilisation during the lengthy Incremental Dredging programme, and some disposal in alternative inshore disposal sites, the final mound height at A0 will be considerably less than that for the Major Capital Dredging programme. For the latter, the mound level may reach 25.3 m below Chart Datum, so the suggested 25 m maximum height/minimum depth of the mound in the proposed Coastal Permit 2010.198 (Condition 4) is sufficient.

157. Based on multiple lines of evidence such as: a) the very long-term integration of net northerly sediment transport that is evident in the geomorphology and orientation of the submergent Peninsula Spit; b) the distance of over 11 to 13 kilometres from A0 to inner Blueskin Bay coastlines; c) the relatively weak, eddy in Blueskin Bay; d) and the results from sediment transport modelling simulations—it is my opinion that it is very unlikely that fine sands from the dredged material at A0 will reach the Otago coastline in any discernable quantities.

Effects of the disposal mound at A0 on waves

158. The presence of a physical mound of up to 1.7 metres above the existing bed level at the A0 disposal ground in 27 to 28 m water depth has the potential for small changes in wave patterns to occur.

159. Offshore wave modelling was undertaken by MetOcean Solutions Ltd. to determine the effects of such a seabed mound on wave patterns for two disposal areas A1 and A2, which bracket A0 (see Figure 2 or 3 for locations). The model demonstrated that a mound at site A2, which

would more closely mimic wave conditions and depths at A0, will have no discernable effect on wave patterns for mean wave heights. But for maximum significant wave heights of around 6 m, localised decreases of around 0.05 m in height on the north-west side of the mound and increases of a similar magnitude to the north and west of the final mound[20] may occur, gradually decreasing with time as the mound deflates. These minor effects on wave heights will be very similar to those experienced at A0, as it is on the same submergent spit and similar depths to A2.

160. The effects of a deeper and wider approach channel on nearshore wave patterns are covered by Dr Single in his evidence.

MONITORING CONDITIONS AND THE EMP

161. Most of the direct physical environmental impacts on receiving waters from dredging and disposal operations are usually monitored interactively by way of instruments to quantify in-situ turbidity and documenting changes in tidal hydrodynamics and seabed bathymetry during and after the capital dredging has been completed

162. Monitoring the intensity sediment plumes from fixed instrument locations poses difficulties given a continually moving vessel and offshore, plume movements from the disposal area can vary depending on the current direction. Quantifying plume intensity is therefore better accomplished through, one-off mobile plume monitoring exercises that are focused on confirming the veracity or conservatism of model predictions of sediment plume concentrations in the near-field region behind the dredge. This information can then provide improved confidence to stakeholders that the underpinning modelling matches or overpredicts in-situ concentrations.

163. Routine monitoring of in-situ turbidity at fixed locations is more appropriate for monitoring specific habitats that are potentially sensitive to turbidity, with appropriately-stepped trigger limits and responses. This approach for Harbour monitoring is covered by Dr James in his evidence. In my opinion, long-term monitoring of turbidity in the offshore

---

[20] See Figures 8.9 and 8.10 in the 2009 Modelling Report

shelf area around A0 or at sites along the Otago coast is fraught with problems in interpreting the results, particularly with regard to the high variability in background turbidity from wave stirring and river and catchment runoff. However, I have proposed limited turbidity monitoring near A0 in the draft Environment Management Plan (*EMP*) which I will describe shortly.

164. A third set of monitoring conditions are those that routinely document the evolution or changes in processes, without response criteria, other than to inform relevant stakeholders. Examples are routine bathymetric surveys of the disposal sites and any changes to tidal ranges or tidal velocities as a result of capital dredging. Such information is, for example, required to inform Land Information New Zealand for any updates needed of hydrographic charts or tide tables.

165. This three-pronged approach to monitoring receiving-water effects from dredging operations—a mix of confirmatory one-off plume intensity monitoring, routine turbidity monitoring conditions at key environmental sites in the harbour, and documenting changes in hydrodynamic processes and bathymetric changes to inform stakeholders—is consistent with internationally-accepted practices (e.g., Australia and USA).

Confirmatory plume intensity monitoring

166. In order to confirm the plume model, I have recommended that POL perform two sets of plume-intensity monitoring of suspended sediments in the plume behind the dredge when working both predominantly-sand and predominantly-silt claims inside Otago Harbour. These two sets should be repeated for each specific dredge that is used. Water samples (for suspended-sediment analyses) and light attenuation measurements should be obtained along the plume for up 1 kilometre downstream, following the approximate central trajectory of the plume and therefore site locations will be dynamic (relative to the moving dredge). A suitable control site will also need to be sampled to determine realistic background levels of turbidity and light attenuation. In conjunction with the in-situ sampling, geo-referenced vertical aerial photography could be undertaken to assist with interpretation of the results and can also be useful for guiding the on-water crew to the

centre of the plume. Such monitoring would be used as contextual information to:

a) assess the veracity of the harbour plume modelling results against the field measurements;

b) as input to ongoing reviews of the monitoring programme.

POL has volunteered this monitoring in the draft EMP and is also covered by Condition 10 &12 of the proposed Coastal Permit 2010.195.

167. Further, I recommended that POL also perform two intensive sets of monitoring of suspended sediments in the plume at A0 following disposal from the dredge's hopper for a load of predominantly-sand and predominantly-silt material respectively. These two sets should be repeated for each specific dredge that is used and ideally should be performed for the same dredge cycle, and hence hopper load, that was monitored inside the Harbour. The aims for the monitoring programme would be similar to those I outlined above for the Harbour plume tracking, except I would recommend tracking the plume offshore beyond 1 km if practicable, with guidance from the aircraft undertaking the aerial photography. POL has also volunteered to include this monitoring in the draft EMP. It is also covered by Condition 8 of the proposed Coastal Permit 2010.198

168. Undertaking these one-off monitoring programmes out at A0 should also be undertaken in relatively cloud-free conditions to enable a comparison to be made with MODIS satellite imagery (see Figure 6), which is routinely acquired and archived by NIWA from a receiver at Lauder. Such imagery could then be investigated as to its usefulness and latency in routinely monitoring the direction and spread of the offshore dredge-disposal plume relative to other naturally-occurring plumes, especially along the coastline.

Deployment of a fixed turbidity buoy at A0 for two 1-month periods

169. Finally, I recommended that POL undertake two separate 1-month deployments of self-recording[21] turbidity sensors near the surface and near the seabed[22] on the north-east corner of the A0 disposal area where the plume is most likely to travel past. This should be undertaken for a winter and a spring/summer period during Major Capital Dredging using a moderate-size TSHD.

170. Similar fixed-buoy 1-month deployments should also be undertaken for Incremental Dredging using *New Era*, but only if the mobile plume-intensity monitoring shows suspended-sediment concentrations in the top 5 m of the water column exceed something like 50 mg/L (or equivalent in calibrated NTU) after allowing for reasonable mixing e.g., 300–500 m downstream of *New Era*. This aspect has not yet been finalised by POL in the draft EMP.

171. No trigger levels or responses are envisaged, as in-situ levels are highly dependent on wave and weather processes and the direction of the current and it is not feasible to telemeter information in real-time for short deployments. This information will however provide contextual information to assess the general turbidity levels immediately to the north of the disposal area at A0 where the plumes are most likely to be transported, for cross-matching with MODIS satellite imagery, and input to reviews of the offshore monitoring programme.

172. POL has volunteered to include this in the draft EMP.

173. To maximise the interpretation of the results from the above-mentioned offshore monitoring, it will require ancillary information to be collected and archived during the plume-intensity surveys and turbidity-buoy deployments on:

    a) wave heights, periods and direction relevant to A0 that can be obtained from reliable wave model hindcasts or forecasts;

---

[21] i.e. not telemetered in real-time, but the data downloaded at the end of the month

[22] At approximately 3 m above the bed to be in the centre of the bottom layer used in the 3D model and to be clear of the ubiquitous wave-resuspension of seabed sediments.

b) winds from Taiaroa Head weather station, which is already routinely collected; and

c) ideally collect and collate suitable MODIS satellite images for low-cloud passes (approximately one or two images per week) to determine the occurrences of coastal and offshore plumes from both natural sources and dredge disposal.

Dredged material documentation

174. In my opinion it would be very useful for POL to document information from dredging operations covering key aspects such as:

a) What were the characteristics of the dredged material?— e.g., the broad type of material for each load (sand, silt, clay, rock).

b) How much was dredged?— e.g., sediment volumes dredged (based on either dry or wet bulk density) for each run.

c) Where did the dredged material come from?—e.g., start & end latitude/longitude position of run, date/time on and off.

d) Where was the dredged material placed?— e.g., disposal ground used, start & end lat/long position of disposal run, date/time on and off.

175. POL has included provision of most of this information in the draft EMP and is also covered by Condition 22 of the proposed Coastal Permit 2010.193 and Condition 9 of the proposed Coastal Permit 2010.198.

Monitoring the disposal mound at A0

176. In order to monitor the disposal mound at A0 I have recommended to POL that annually for Incremental Capital Dredging and immediately prior to and annually for 5 years after commencement of Major Capital Dredging, it should undertake the following:

a) bathymetric surveys of the A0 disposal area and out to 1 kilometre beyond the A0 boundary. Specifications will be finalised in the EMP submitted to the ORC for approval. These surveys should be undertaken during relatively calm wave conditions and along repeat traverses to enable accurate comparisons to be made of the mound evolution and deflation, resident volume and infer the direction of bedload transport over time. Ideally, one of these surveys should be undertaken using swath sounding equipment[23];

b) During each annual bathymetric survey, carry out grain-size analyses from seabed grabs of surficial sediments at several locations in the A0 disposal area (e.g., possibly those in Figure 11.4 of the 2009 Modelling report.);

c) Compile an annual report following these surveys that tracks the changes with time of the disposal mound shape, volume, direction of movement and surficial grain size distribution.

177. POL has included most of these aspects in the draft EMP and is covered by Condition 10 of the proposed Coastal Permit 2010.198.

Monitoring changes in tidal characteristics of Otago Harbour

178. I have recommended that POL continue to collect and archive tide gauge data from Dunedin Wharf (T Shed), Port Chalmers and Spit Jetty throughout the capital dredging programme and for one year after completion of capital dredging. Subsequently, I recommend that POL compile a report to the ORC documenting any changes in tide height and phasing conditions at periodic intervals for Incremental Capital Dredging and following completion of both Major and Incremental Capital Dredging

179. Changes in tidal currents outside the main fairway would be mostly below the accuracy that can be achieved by current meters. Changes that will be measurable will be in those channel flank areas which are presently shallow but will be dredged as part of the Project e.g., east side of the Swinging Basin and the flanks of the Entrance Channel (Pile 1A opposite Harington Point). It is recommended that measurements of tidal currents, before and after capital dredging and at periodic intervals for Incremental Capital Dredging, are undertaken at these sites under a

[23] Swath imaging of the seabed provides full coverage of the seabed topography, resulting in a more accurate calculation of volume, provides backscatter which can be matched to sediment types, and picks up ripples or dunes which are useful to determine sediment pathways.

matching average[24] tide range. The results should be combined and presented in the same reports I discussed in the previous paragraph.

180. These recommendations have essentially been adopted by POL in the draft EMP and covered by Condition 12 of the proposed Coastal Permit 2010.193. These monitoring conditions have no management response or trigger levels included; rather they are documenting any permanent changes for future navigational purposes, as the changes in tidal heights and phasing will be small and changes in currents on the flanks of the fairway to be dredged are anticipated.

RESPONSE TO SUBMISSIONS

181. Most of the general issues raised in submissions have already been dealt with in earlier paragraphs of my evidence. However, I will now give some responses on specific issues, related to hydrodynamics, particularly current patterns), sediment plumes, modelling and monitoring that were raised by submitters are addressed below.

Otago Harbour hydrodynamics

182. Submitters #41 (Greager) and #148 (Dunedin City Council) expressed some concern about the effect of the dredged channel on raising tide levels and hence increasing the exposure to coastal inundation. I previously covered this issue in paragraphs 24.6, 80 and 81.

Harbour plume modelling

183. Submitter #135 (Southern Clams) raised several issues with the plume modelling approach.

183.1 While the 2009 Modelling Report only covered the case of a moderate-size TSHD, recent modelling for *New Era* does cover the effects of a smaller TSHD and any small amount of back-hoe

[24] Model predictions on potential changes to tidal characteristics for the AEE were based on an average tide, so enables a direct comparison with actual changes.

dredging required will have less impact again on suspended sediments.

183.2 In response to the comment that the modelling underestimates suspended-sediment concentrations (SSC) and deposition, I have covered these points in paragraph 87 and in Chapter 6 of the 2009 Modelling Report, which describes the work on sensitivity testing of the plume model parameters.

183.3 In respect of the SSC being higher near the bed compared to the depth-averaged results, this is correct, because of the downward gravitational effect of settling of sediments eventually merges into sediment-deposition flux in kg per square metre just above the seabed, which is also output from the model and presented in the 2009 and 2010 Modelling Reports. Further, the depth-averaged SSC doesn’t apply at mid-depth, but rather is weighted by the higher SSC lower in the water column, being more applicable down around 60–80% of the depth well away from the dredge i.e., nearer the seabed. Wave and current resuspension processes also concentrate suspended sediments near the bed, so higher SSC near the bed is also a natural phenomenon.

183.4 *New Era* overflows were modelled for a surface discharge and complement the earlier plume modelling for dredging to extend the Swinging Basin that was undertaken at 1 m depth below the surface, with the results being very similar.

183.5 My reasons for why the background concentration was not included in the plume modelling were covered in paragraphs 25 and 83. This was also raised by submitters #141 (NZ Marine Science Society), #165 (Dept. of Marine Science) and #65 (Barker, Dept. of Marine Science). Basically, what has to be demonstrated are the effects of the activities or works relative to the existing environment and the background SSC can vary markedly depending on weather and wave conditions and river flows, which can’ not be forecast ahead of time. Consequently, that is why the fixed-site turbidity monitoring programme has been established with environmental limits, including a site to measure the background turbidity, to manage the effects during the dredging operation.

183.6 In reply to the comment of why resuspension was not included in the plume modelling, I refer to paragraphs 105 to 108. To reiterate, it is quite a complex modelling process to undertake subsequent resuspension of sediments from the Harbour seabed, as it depends on multiple processes such as weather, river, tidal and wave conditions, availability of sediments to be resuspended, bed texture and composition. To do this properly requires coupling tidal hydrodynamic, river catchment and wave models to sand and mud/silt transport models. Sediment-transport models require extensive field measurements to establish erosion thresholds for different substrates and grain sizes under different combinations of waves and tidal currents. Also, it is difficult to separate out and track those sediments derived from the dredging operation from sediments sourced from other marine or terrestrial sources, including allowances for sequencing of dredging operations and rainstorms and river floods that also bring in silt material to the Harbour. So I have relied instead on natural analogues of where silt/mud areas preferentially settle in the Harbour and which areas are exposed to waves and hence resuspension, to infer where silts derived from dredging may ultimately drift to. The same approach has been adopted for the offshore shelf region, for which a similar issue was raised by several submitters.

184. The Ministry of Fisheries (#124) raised the issue of why the plume modelling didn't take into account the sediment-trapping properties of sea-grass. At the 30 m by 30 m cell size in the model grid (covering approximately a quarter acre), it is not possible to adequately incorporate sub-grid processes such as physical interactions with benthic vegetation. However, the plume model results for initial deposition in both the 2009 and 2010 Modelling Reports are expressed as a vertical sediment flux in kg per square metre descending onto the seabed for each cell, which provide an estimate of the <u>initial</u> exposure to sedimentation. Ongoing monitoring of these habitats is covered by Dr James in his evidence.

Offshore plume modelling for A0

185. A number of submissions[25] have commented on various aspects of plume modelling for the offshore disposal area at A0 which I have largely addressed through my evidence. I will however reiterate some aspects covering recurring themes in these submissions.

186. Several queried why only a North/South or “straight line” model of predicted currents was used, why has model concentrated on 30-m depths, and why the Blueskin Bay eddy wasn’t included. The model is a 3-dimensional model on a triangular grid of cells covering the mid-Otago shelf and comprising 3 depth layers. It includes tides, winds and a lower-range constant Southland Current. As such it is not a north-south model, nor does the hydrodynamic model (that drives the plume model) concentrate on the 30-m depth zone. Also the 3-D hydrodynamic model does produce a weak anti-clockwise eddy in the greater Blueskin Bay as shown by the residual current plots in Figure 3 and 4, and discussed in detail paragraphs 49 to 66 of my evidence. Also the deposition plot shown in Figure 7, overlain on the present seabed bathymetry, shows a close match of the modelled deposition pattern with the submergent Peninsula Spit, whose alignment is indicative of a long-term net residual current to the NNE that has shaped this large sedimentary body.

187. The issue of no field measurements at A0, even though the field reference site at A1 is only 3 km WSW from A0, has been subsequently addressed by a deployment near the seabed at A0 in late 2010. Again, paragraphs 49 to 66 of my evidence, reconcile the modelling results with the recent field measurements at A0.

188. Several submitters also raised the issue of why waves were not included in the plume modelling, as waves are mostly directed onshore and would bring suspended sediments to the coast. As I discussed for seabed sediment transport in paragraphs 69 and 152, the same applies to the to and fro orbital motions produced by waves and swell in the water column in deeper waters, with virtually no net suspended-sediment transport in the onshore direction from waves heading onshore. Winds, however, are included in the model for the two

---

[25] Submission Nos. #11, 32, 34, 44, 64, 69, 71, 108, 129, 130, 137, 140, 141, 144, 149, 153, 155, 163, 167, 168, 171, 179, 183, 185, 193 and 198.

dominant wind directions, and the results show that strong or storm winds lead to little or no encroachment of the plume on the Otago coastline due to the offshore return flow that occurs in the bottom-layer of the water column.

189. Several submitters, particularly the NZ Marine Sciences Society (#141), raise issues about the subsequent resuspension of silts on the shelf not being included in the sediment-transport model, while long-term sand transport was. My response is the same as that presented in paragraph 183.6 for the same issue inside the Harbour. Re-distribution of resuspended silt-size sediments will be an ongoing dispersive process that also occurs naturally with silts/muds from catchment runoff and river discharges. Resuspension rates are highly variable on the Otago shelf, depending on drivers such as wind and wave, river discharge and the meandering and strength of the Southland Current, as well as substrate composition and the availability of silts, sourced from A0 disposal, for subsequent erosion and resuspension. In contrast, estimating sand transport off a specific mound area at A0 is a much more tractable situation to estimate transport rates, which my colleague Dr Green has done by bracketing the results with two different, but well-regarded sediment-transport formulae.

190. The NZ Marine Sciences Society (#141) also suggests that deposition of sediment will be patchier than the results shown by the plume modelling (Figure 7). The intention of these results is to provide an upper-bound on initial deposition thicknesses and rates of sediment accumulation to underpin the assessment of effects on benthic communities that Dr James presents in his evidence. In reality, the distribution may be patchier, depending on current-velocity variability, but silt-size sediments are unlikely to form deep patches on the seabed due to the more smoothly-varying dispersion processes that spread and dilute suspended material. Patchiness in deposits is therefore more likely from heavier particles such as coarser silts and especially fine sands.

191. The NZ Marine Sciences Society (#141) and East Otago Taiapure Management Committee (#153) also question the validity of basing the calibration of the hydrodynamic model on water movements at three discrete points in close proximity to the disposal area, and extrapolating model predictions to the wider Blueskin Bay. This type of approach is

standard practice for hydrodynamic modelling of ocean, shelf or harbour areas, and having more than 4 months data throughout the water column at A1 provides a sound basis for the calibration at that location. The 3-D hydrodynamic model used, incorporating 3 depth layers for this application, has all the physics incorporated into the equations that the model solves to describe flows on the shelf. The critical aspects for accurate coastal-shelf models are acquiring an accurate description of the seabed bathymetry, which we have from hydrographic charts and POL surveys, and care in specifying the tidal boundary levels and the downstream current, which in this case is the Southland Current on the southern boundary (see paragraphs 49 to 66 of my evidence). Otherwise, extrapolating over reasonably large distances is normally accepted, as the bathymetry and eddy dispersion largely steer the flows. Given the Blueskin Bay eddy appears in the hydrodynamic model result and it matches well with residual currents in the middle of Blueskin Bay and off Heyward Point (Bell & Hart, 2008), I see no reason to doubt why the model can't be used as an estimate of current behaviour for the wider Blueskin Bay area, notwithstanding the variability in the Southland Current, which I have explained in paragraphs 49 to 66 of my evidence.

Offshore plume monitoring

192. Several submitters (#1, 5, 119, 126, 141 and 170) seek to have the offshore disposal area at A0 monitored for turbidity or at least all steps taken to minimise mobilisation of sediment. In my opinion, there is no need to <u>continuously</u> monitor turbidity at A0 from fixed buoy sites, because:

a) variations in current direction will mean the plume may often by-pass a fixed buoy(s);

b) background levels of suspended-sediment will vary markedly depending on wave conditions, and could mask the dredge plume.

However, as I outlined previously in paragraphs 166 to 173, one-off plume-intensity monitoring to check the veracity of the modelling and two 1-month monitoring periods for a single fixed turbidity buoy north-east of A0, should provide sufficient information to confirm whether the plume concentrations are similar or lower than those predicted by the modelling studies.

COMMENTS ON THE OFFICER'S REPORT

193. For the effects of dredging operations within the Harbour, the Reporting Officer has rightly concentrated on monitoring the effects, particularly turbidity. The modelling results I have presented are mainly to provide a context in which effects are assessed, whereas in-situ monitoring within an adaptive management approach is the modern way of managing the effects of suspended sediment from dredging operations.

194. Overall, the sections 7.2.3 and 7.2.4 on the offshore disposal effects in the Officers Report fairly reflect a summary of the investigations I have undertaken.

195. I concur with the Officer's conclusions on sediment and dredging aspects in sections 522, 524, 532, 534 and 535 that are within my area of expertise. I also concur with most of section 531, but any requirement to limit disposal site A0 to "only sand grain sized particles to be deposited at this site" is not consistent with the purpose of A0 to be a disposal area for silt-size classes as well as fine sands.

CONCLUSIONS

196. My evidence has covered an evaluation of the dispersion and deposition of sediment discharges from dredging activities and assesses the hydrodynamic effects of an altered seabed bathymetry arising from the Project on both Otago Harbour and the Otago shelf in the region of the proposed disposal area at A0.

197. In both the Harbour and offshore environments, I have quantified suspended-sediment concentrations in the resulting plumes and seabed deposition for both a moderate-size TSHD (Major Capital dredging) and using the small capacity *New Era* or similar-sized TSHD (Incremental Capital dredging).

198. Suspended-sediment concentrations and deposition rates are around ten times less for Incremental Capital Dredging compared with Major

Capital Dredging, as expected, although the former will be undertaken periodically over a much longer time span of several up to 15 years.

199. For both dredging intensities, suspended–sediment concentrations and deposition rates will be small on most of eastern side of the Harbour and minute along the Otago coastline.

200. There is no hydrodynamic mechanism that will move any significant fine-sand material from A0 to the Otago coastline and turbidity levels along the same coastline will be very small as a result of disposal at A0 for both dredging intensities.

201. The effects of the widened and deepened channel of the main fairway on the tidal hydrodynamics of Otago Harbour will be minor. Similarly, the effect of a sediment mound of up to 1.7 m at A0 will have a negligible effect on offshore wave heights.

202. Monitoring conditions have been included to check the veracity of the modelling results and to provide input to adaptive management of the dredging programme.

Robert Gordon Bell

REFERENCES

Bell, R.G.; Hart, C. (2008). Offshore ADCP deployments (Otago Peninsula) for Port of Otago dredging project. NIWA Client Report HAM2008-178 prepared for Port Otago Ltd., 75 p. [**Technical Report 11, lodged documents**]

Bell, R.G.; Reeve, G. (2010). Sediment plume dispersion modelling: Comparison of a larger dredger and the *New Era*. NIWA Client Report HAM2010–119 prepared for Port Otago Ltd. 57 p.

Bell, R.G.; Oldman, J.W.; Beamsley, B.; Green, M.O.; Pritchard, M.; Johnson, D.; McComb, P.; Hancock, N.; Grant, D.; Zyngfogel, R. (2009). Port of Otago dredging project: Harbour and offshore modelling. NIWA Client Report HAM2008-179 prepared for the Port Otago Ltd., 340 p. [**Technical Report 10, lodged documents**]

Chiswell, S.M. (1996). Variability in the Southland Current, New Zealand. *NZ Journal of Marine & Freshwater Research 30*:1–17.

James, M.; Probert, K.; Boyd, R.; Sagar, P. (2009). Biological resources of Otago Harbour and offshore: assessment of effects of proposed dredging and disposal by Port Otago Ltd. NIWA Client Report HAM2008-152 prepared for Port Otago Ltd., August 2009. **[Technical Report 1, lodged documents]**

MetOcean Solutions Ltd. (2011). Current measurements at A0 disposal ground: Filed data report. Report 0068-01 prepared for Port Otago Ltd. by MetOcean Solutions Ltd., 12 p.

Ministry for the Environment (2008). Coastal Hazards and Climate Change. A Guidance Manual for Local Government in New Zealand. 2nd edition. Revised by Ramsay, D., & Bell, R. (NIWA), Report ME892 published by the Ministry for the Environment, viii + 127 p. http://www.mfe.govt.nz/publications/climate/coastal-hazards-climate-change-guidance-manual/

Nielsen, P. (1992). *Coastal bottom boundary layers and sediment transport*. Advanced Series on Ocean Engineering, Vol. 4, World Scientific, Singapore.

Oldman, J.W.; Bell, R.G.; Stephens, S.A. (2008). Port of Otago Dredging Project: Preliminary hydrodynamic modelling and scoping further work. NIWA Client Report HAM2007-152 prepared for Port Otago Ltd. [**Technical Report 13, lodged documents**]

Opus International Consultants Ltd. (2008). Factual report of geotechnical investigations: Port Otago–Project Next Generation, Report No. 1230, prepared by S. Greene, Opus International Consultants Ltd. for Port Otago Ltd., August 2008. [**Technical Report 16, lodged documents**]

Pullar, A.; Hughes, S. (2009). Project Next Generation dredging methodology and disposal alternatives. Report prepared for Port Otago Ltd, December 2009. [**Technical Report 18, lodged documents**]

Single, M.; Bell, R.; McComb, P. (2010). Physical coastal environment of Otago Harbour and offshore: assessment of effects of proposed dredging by Port Otago Ltd. Report prepared by Shore Processes and Management Ltd. for Port Otago Ltd. [**Technical Report 9, lodged documents**]

Raudkivi, A. (1990). *Loose boundary hydraulics*. 3rd Edition, Pergamon Press, UK p. 166-168.

Wood, I.R.; Bell, R.G.; Wilkinson, D.L. (1993). *Ocean Disposal of Wastewater*, Advanced Series on Ocean Engineering – Vol. 8, World Scientific Publishing Co., Singapore. 425 p.

FIGURES

Figure 1: Otago Harbour, with main sites or features annotated. [*Source*: Google Earth, July 2009]

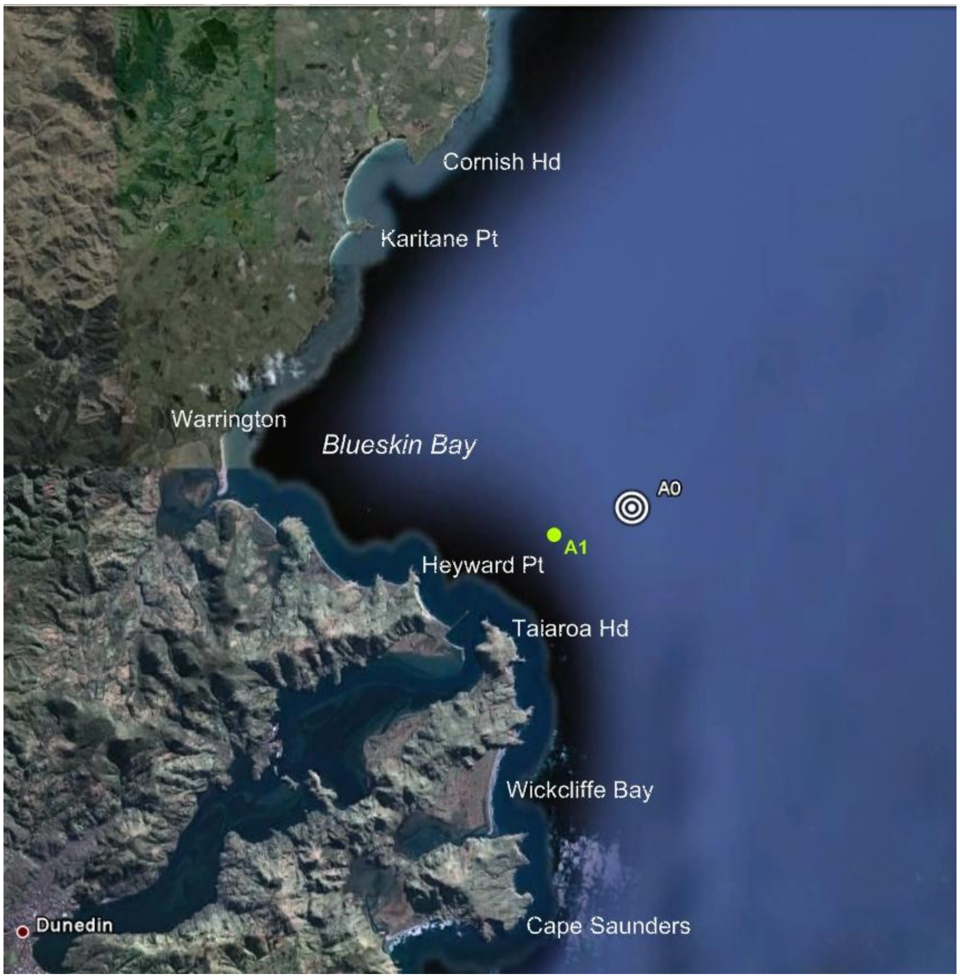

Figure 2: Otago coastal area, with main sites or features annotated, including the disposal area A0 and the 4-month current-meter mooring site at A1. [*Source*: Google Earth, July 2009]

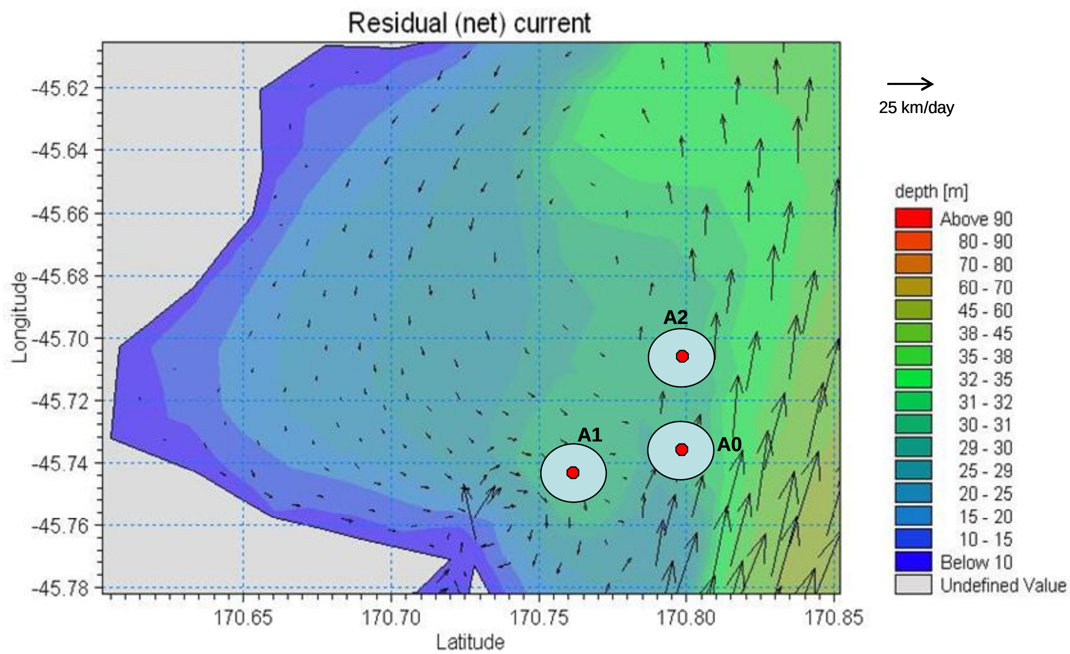

Figure 3: Location and extent of disposal site options investigated during the offshore plume modelling process, with a backdrop of the depth-averaged residual current pattern from the calibrated offshore hydrodynamic model, coinciding with the period of the initial two current-meter deployments at A1 from mid-March to May 2008. [*Source*: Figure 11.2, 2009 NIWA Modelling report, Technical Report 10 of the lodged documents]

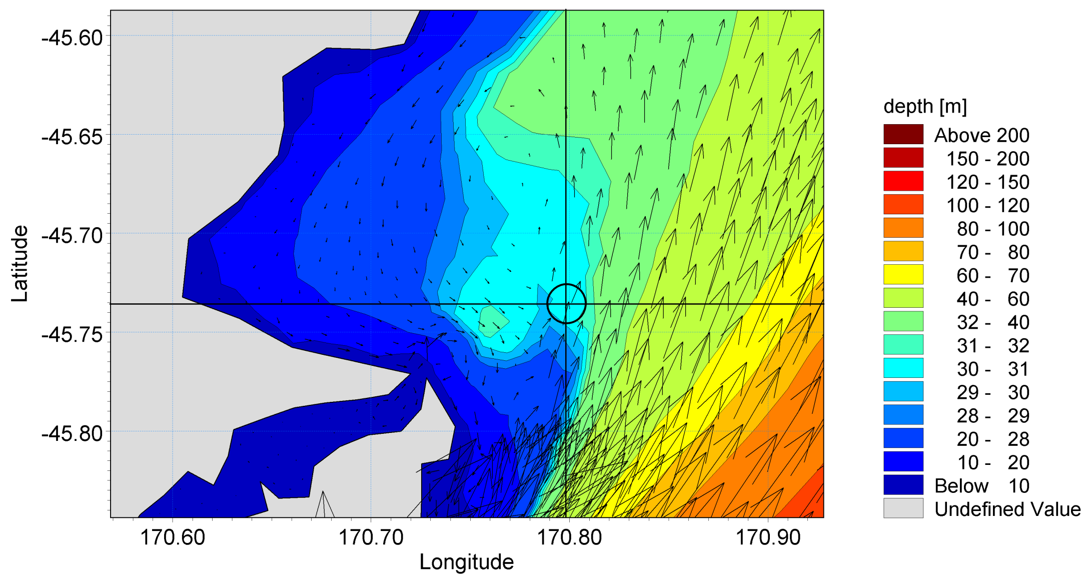

Figure 4: Overall residual current pattern for the bottom layer (akin to the deployment depth for the recent 2010 current-meter measurements at A0) from the long simulation described in the 2009 Modelling Report. The centroid of the A0 area is shown by the cross-hairs.

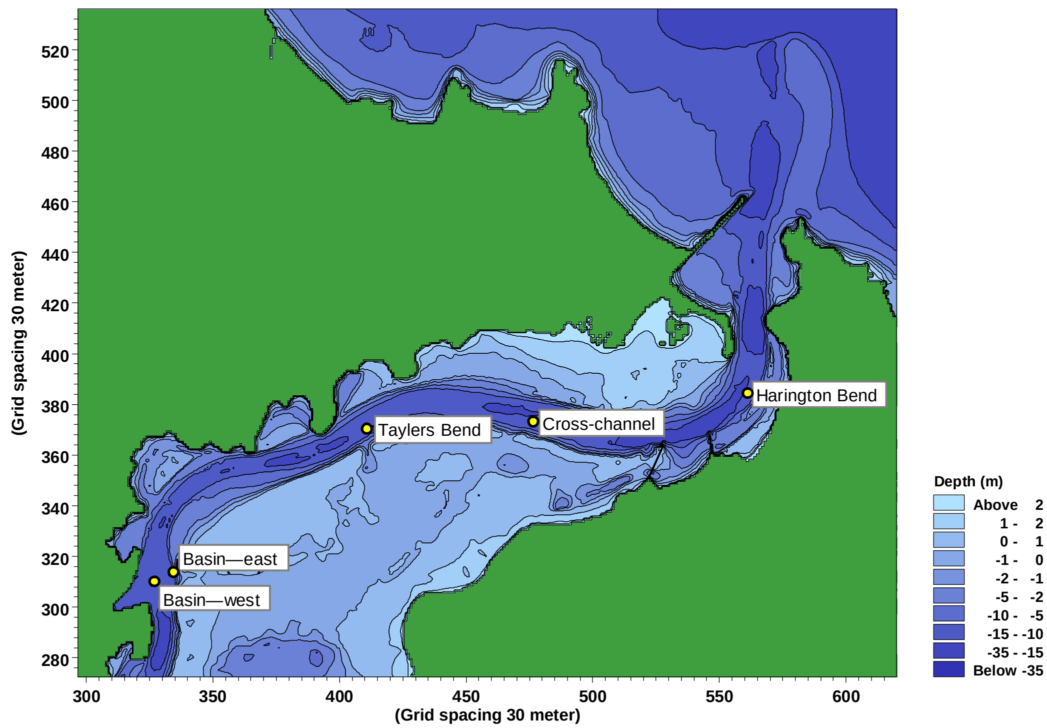

Figure 5: The five representative channel source-area sites used as the discharge source locations for suspended-sediment plume simulations over 14-day dredge cycles inside Otago Harbour. [*Source*: Figure 7.2, 2009 NIWA Modelling report, Technical Report 10 of lodged documents]

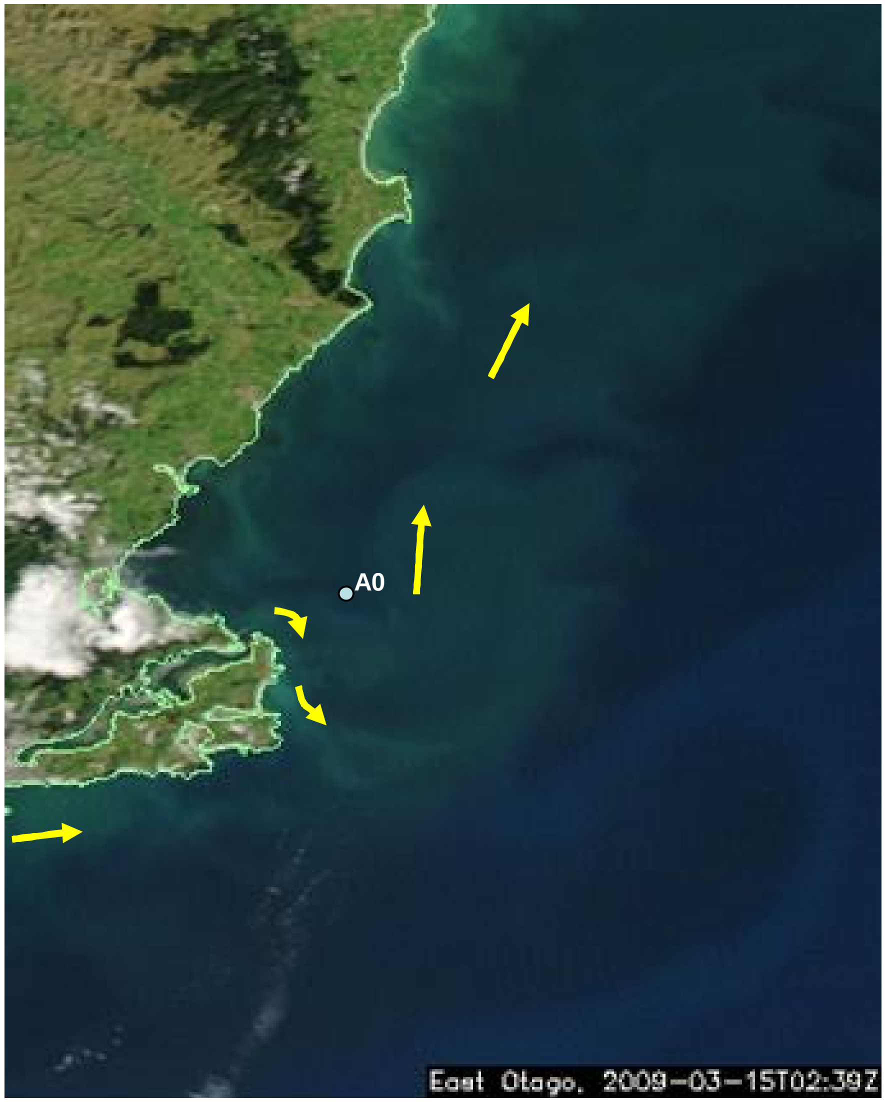

Figure 6: Example of a pan-sharpened 250-m resolution MODIS satellite image taken at 1439 (NZST) on 15 March 2009. A light north-east wind was present during the previous 24 hours preceded by 36 hours of south-west winds. The superimposed arrows highlight the circulation patterns approximately inferred from the naturally-occurring plumes, including the north to north-east drifting plumes offshore in the main Southland Current beyond A0. [*Source*: NASA and processed by NIWA]

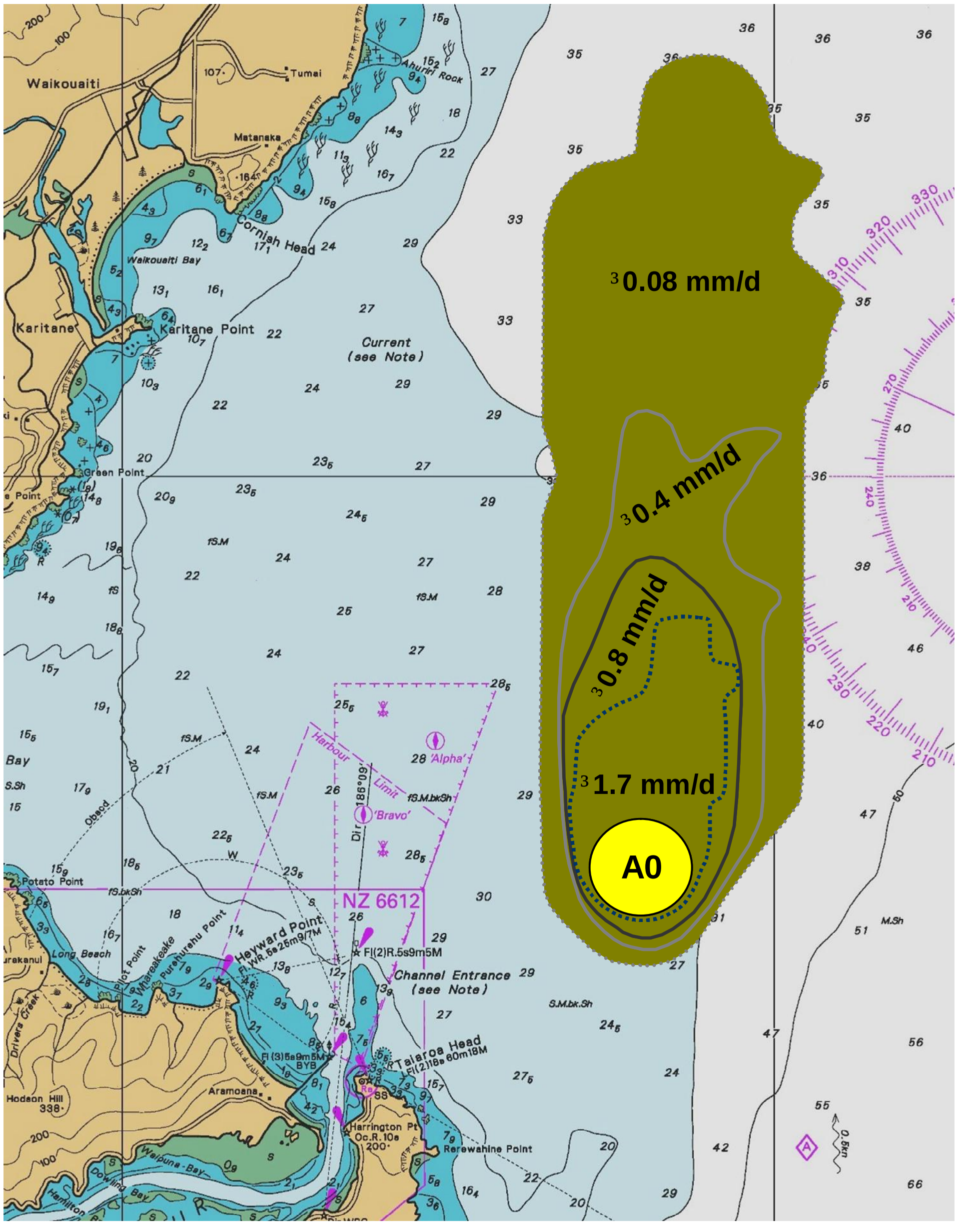

Figure 7: Zones within which various average deposition rates (mm per day) are exceeded for all sand/silt fractions from the disposal plume modelling over the entire dredging programme solely using a moderate-size TSHD. The deposition rates are conservative, being applicable to a TSHD of 10,800 m^3 capacity where the dredging extends for the shortest-possible continuous dredging period of 120 days. [*Source of background map*: Chart NZ661, LINZ]. *Source of Figure*: Figure 11.22, from the 2009 NIWA Modelling report, Technical Report 10 of lodged documents.