Review of: NIWA Client Report HAM2008-179

Port of Otago Dredging Project: Harbour and Offshore Modelling

by NIWA and MetOcean Solutions Limited

Part of Port Otago's Project Next Generation Channel Deeping
Resource Consent Application 2010

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Scope of Review

This independent review covers the physical numerical modeling undertaken to support Port Otago's resource consent application. The review is limited to the appropriateness of the methods and the robustness of the modeling detailed in the report HAM2008-179. It does not include a review of the results obtained or of the biological or other impacts of the proposed dredging program.

Modeling Aims and Approach

The modeling work aims to estimate the effects of the channel deepening on tides within Otago Harbour as well as the extent of the spread of sediment stirred by dredging and the spread of material from the proposed spoil dumping site. The hydrodynamic and wave modeling contains the elements you would expect to see to address the issues of

i) effects on tidal heights and currents within Otago Harbour
ii) the spread of fine material stirred up by the dredging within the Harbour
iii) the spread of fine material released during dumping
iv) the longer term dispersal of coarse material from the dump site

There are essentially two modeling elements

- A Harbour tidal model extending out to Landfall Tower outside the Harbour entrance, with a separate model for wind generated waves within the Harbour
- An offshore tidal and current model extending out to the steep edge of the continental shelf, with a separate wave and swell model extending over much of the area around the South Island

Computer Modeling Tools

Software from the MIKE suite developed by Danish international research and consultancy group DHI, was used to investigate the spatial extent of plumes from the dredging program. This suite of software has been used by many consultancy groups for engineering projects worldwide for decades and is continually being tested and improved. The MIKE-21 and MIKE-3 programs used in this work to model tides and currents are as close as its gets to industry standard software in the specialized field of hydrodynamic ocean modeling.

MIKE-21 which was used for the harbour models is a depth averaged model, i.e. is two dimensional which is reasonable for shallow well mixed areas like Otago Harbour. MIKE-3 is a three dimensional model, which was used here for the offshore model with three layers (i.e. the water depth was broken down into three horizontal layers).

For both the harbour and offshore models sediment transport was modeled using the MIKE Particle Tracking model (PA). This model releases large numbers of virtual particles (up to 100,000) into the modeled currents and traces their path through time and enables statistics to be developed about the fate of the virtual sediment particles. Particles are tracked horizontally and vertically (even in MIKE-21) as determined by currents and the settling speeds to estimate where they end up.

Wave modeling for the work was done using the University of Delft's SWAN wave model. SWAN (Simulating Waves Near-shore) is a third generation wave model specially developed for coastal areas. This freely available software is also close to the engineering standard for modeling waves, used extensively word wide for many years. It is also continually being improved and developed. SWAN propagates waves across the modeled area by allowing for wave refraction (changes in the direction of wave propagation due to the sea floor bathymetry). SWAN also allows for wind generation of waves within the area modeled, for propagation of waves and swell through offshore boundaries of the model, for wave energy losses due to breaking and bottom fiction, as well as for the effects that currents have on waves.

Harbour Hydro-dynamic Model, MIKE-21

Numerical models need calibration. In this case adjusting a single coefficient related to the bed roughness, the Mannings "n" value, for the whole model was done to give the best overall comparison with all the historical Braystoke measurements from the main channel. These 1988 measurements used now archaic instruments, so are only moderately accurate and only covered single tidal cycles. The model was then used to make predictions for the currents at the locations of three longer term 2008 S4 current meter deployed at sites within the Harbour (Table 4). The comparison is used to "validate " or check the calibration. Despite calibration being done against the relatively short term (13 hour) cruder older data the model's predictions for 2008 agree well with these new 10-14 day modern currentmeter measurements.

The S4's were also deployed outside the main channel where no historical data were available giving additional confidence in the model's performance in some of the shallower areas of the Harbour. Further S4 measurements would improve confidence in the model, but the important areas which are most likely to be impacted by fine sediments from the outer harbour channel, e.g. Portobello Peninsula and the outer parts of the shallow upper harbour, are covered. Visual comparison with the detailed 1999- 2000 moving vessel data was good, but detailed comparison at representative locations could provide further confidence in the model's performance.

Changes in Tidal Heights and Currents within the Harbour

Deepening parts of the channel will alter tidal heights and currents within the Harbour. To assess any changes model runs were carried out for pre- dredging and post-dredging channel water depths for an average tidal cycle and for a representative 14 day spring-neap cycle. The volume being dredged is relatively small in comparison to the total volume of water in the Harbour so, as would be expected, the effects are small, around the 1-2% level for tidal currents with small associated changes in heights and timings of the tidal water levels.

The volume fluxes across three transects near the entrance (the amount of water crossing the three lines in cubic meters per second) also show almost imperceptible changes as the result of channel deepening. The two outer transects (Fig 5.9) are close to the outer boundary of the Harbour model at Landfall Tower. The jet forming during ebb tides almost extends to Landfall Tower, thus the outer boundary would ideally be further offshore. This may have some impact on the volume fluxes across the outer two transects (#2 and #3) but is unlikely to affect the most important transect (#1) across the channel at Spit Wharf, which changes by only around 1%. Given the focus is on changes in volume flux due to dredging the effects of the proximity of the model's boundary on transects #2 and #3 is not likely to be a significant issue.

Harbour Plume Model

The extent to which the fine sediment plume is spread around the Harbour by tidal currents and wind driven currents is modeled using the MIKE 21 PA model. This uses the currents from the MIKE 21 model. From this statistics about how many particles end up settling in each of the 30m boxes which make up the model's grid can be compiled. The particle model is passive, i.e. assumes the sediment does not affect the density of the fluid mixture enough to cause density driven currents. This is reasonable for the generally low concentrations of fine sediment expected outside of the immediate vicinity of any discharges. The particle model requires choosing horizontal and vertical dispersion coefficients, which allow for small random motions within the model's 30m grid. Ideally these dispersion coefficients would be measured within Harbour using dye tracing experiments or by other means. The report however shows that for a variety of wind scenarios the extent of the plume after 14 days is insensitive to the value of these coefficients within a reasonable range of values, and reasonably opts for mid range coefficients.

The likely discharges over a dredge cycle from both sand and silt sources are used as input for the plume model. This is an area of uncertainty. Ideally measurements of discharges due to overflows or stirring by the suction head would be made. However, not knowing which particular dredge will be used and how much this particular dredge would disturb the sediments present in Otago Harbour, means that these discharges must be estimated. The report takes a conservative approach to several aspects of these discharges which are likely to overestimate the sediment inputs due to the dredge. Some of these are

1) The drag head disturbance rate of 30kg/s is higher than that found in other areas dredging silty sediments.
2) The way the sediment concentrations are reported.
3) Using the shorter distance to the original offshore dump site A1 rather than the now proposed A0 which is further offshore. This gives a higher rate of discharge.
4) Not allowing sediment to be re-suspended by waves or subsequent tidal currents within the typical 14 day modeling cycle once they settle to the bottom. This results in the model over estimating sediment thickness accumulating nearer the discharge.

The plume modeling covers five representative dredging sites, and is careful to include both eastern and western sites from the Port Chalmers turning basin, which give significantly different results. This is the area most likely to give significant differences in the extent of the sediment plume for a relatively small change in location of dredging due to the Portobello side channel at the Halfway Islands.

The suspended sediment concentrations are reported in terms of depth averaged values, which are likely to be higher near the bottom, particularly near the dredge. Thus more work may be needed to quantify near bottom concentrations experienced by benthic organisms. This does not affect how the amounts of sediments settling on the bottom and where they accumulate are reported.

Offshore Hydro-dynamic Model

The Mike 3 model used for the offshore tide and current model did not include the effects of water density on the flows. The effects of density on currents are important offshore, but given that the water column is well mixed in the area of focus (water depths less than 30m) the neglect of density for the inshore circulation is reasonable. The Southland current at the southern boundary was derived from a much larger ocean model of the NZ region. Tides were included but these produce weak currents in the area of interest. The circulation is dominated by the effects of wind and the northward flowing Southland Current. The Southland Current was kept constant in the offshore model. It is not clear what value was chosen, but the nearest long term current measurements in the Southland Current (at Nugget Point, Chiswell 1996) show strong variability from 0 to 0.5m/s over 5-10 day periods associated with weather patterns over the ocean to the south of the South Island. It is not clear if the constant Southland Current set at the model's southern boundary was an average value or a conservatively high value. Given that plume dispersion from the proposed site appears mostly due to the Southland Current, with some wind effects it would be useful to clarify this. If an average Southland Current was used then it would be useful explore the sensitivity of the results to a reasonable range of Southland Current speeds.

The offshore model does not include a detailed Otago Harbour, other than as a source of fluid to a coastal ocean. Given the small size of the Harbour compared to the area modeled this is a reasonable approach. The comparison of the modeled currents with the measured currents at A1 is very good, giving reasonable confidence in the model's performance, particularly as measured currents at A1 show almost exclusively south east flows. A1 sits on the shoreward side of a small eddy, a couple of kilometers in diameter, which forms in the lee of Tairoa Head due to the northward flowing Southland Current. This small eddy has not been documented before. On the bigger scale the model shows the expected much larger weak circulating eddy within Blueskin Bay creating weak south westward flow but mainly confined to water depths more than 20m.

The initial proposed dumping site, A1, lies on the shoreward side of the small eddy in the lee of Tairoa Head. The eddy is seen in both measured currents and modeled currents. The eddy causes generally southwards flow at this site, opposite to the northwards flow of the Southland Current further offshore. As a result a plume from dumping at A1 may contact the shore line, particularly if it interacts with the Harbour's ebb tidal jet. Thus a new site A0, further offshore, became the proposed dump site. This site sits within the northward flowing Southland Current, leading to a more extensive northward dispersal of the plume, which only under some wind conditions results in low concentrations of sediment at the shoreline to the north of Blueskin Bay. A1 lies on a small natural underwater ridge or spur. The spur extends to the north east of A1 and was likely formed by sediment from the south being transported past Otago Peninsular.

There are no current measurements at the proposed site A0, and none of the of sites where current measurements were made lie within the Southland Current. The Southland Current has a significant impact on dispersal from A0. Thus direct measurements of currents and waves at the proposed A0 site would increase confidence in the results, particularly as the Southland Current is so variable.

The modeling approach uses a number of weak, medium and strong wind scenarios from two directions and a range of sediment class sizes to look at the extent of dispersal of material fine enough to remain in the water column after dumping. Like the Harbour model, plume modeling in the offshore model is conservative in its approach. For example not allowing re-suspension of sediment means modeled accumulations are likely to be overestimated near the dump site. Re-suspension of sediments by waves is likely to spread material further, with smaller accumulations over a wider area.

Offshore Wave Model

The offshore wave model utilizes the standard SWAN model in a typical nested model approach. Models of a larger area are run to give information at boundaries of finer models of areas within the larger coarse model. This allows the fine model to have very detailed water depth information to bend or refract waves and swell as they propagate. In this case the wave model was tested against long-term wave data from the North Island for the outermost coarse grid and tested against shorter wave data records from Tahuna, Dunedin. The wave model reproduced the Tahuna record well (Fig 8.4) giving confidence in its results, with a tendency to overestimate the larger wave heights.

The effects on wave heights over the mounds created by dumping are very small, i.e.0.05m for typical wave heights on 0.8-1m. The effects on typical wave heights are localized to the mounds and to the north and east. (Fig 8.9). The mounds do not appear to affect wave heights at the coast, except for a small increase in maximum wave heights of 0.02m near Heyward Point under the extreme conditions of over 2.0m maximum waves at the coast (Fig 8.10).

Dredging of a deeper channel outside the Harbour has a slight effect on the propagation of waves and swell across the channel. Locally it reduces typical 0.5m wave heights at Aramoana by around 0.01m and by 0.02-0.04m at Shelly beach (Fig 8.9). Maximum wave heights are reduced by around 0.05m for the 2.0m maximum waves which occur near the inshore end of the Mole at the eastern end of Aramoana Beach (Fig 8.10). These reductions in wave heights occur before the waves grow and break at the shore, i.e. are reductions in wave heights outside the surf zone.

The offshore wave model was used to estimate re-suspension of coarse material from the dump site and its subsequent spread by currents. There are no direct measurements of sediment dispersal from the site to calibrate the model with. The model used 10 years of model wave data to estimate the times when water movements near the sea bed due to waves and swells are capable of stirring material off the bottom. On their own currents are rarely capable of re-suspending the material, but will move it once waves have stirred it off the bottom. The results show that sediment spread along the natural spur or spit formed downstream by sediment moving northwards along the Otago coast carried by the Southland Current (Fig 12.24) . This gives some confidence in the model's ability to predict the dominant direction of dispersal from the site. The rate at which this dispersal occurs has a wide range of uncertainty, with bounds given in Table 12.15.

Summary

The modeling approach used here is reasonable to address the aims of the work and has the elements you would expect for such a study. The work uses engineering standard software tools with a best practice application of these tools to estimate the extent of sediment dispersal and effects on tides within the Harbour. The models are used to simulate many scenarios for winds, waves etc., in a careful comprehensive approach to the modeling.

The biggest uncertainties lie in the amounts of fine sediments disturbed by the dredge, lost due to overflowing from the dredge within the Harbour and in the amounts of fine sediment which remain in the water column immediately after dumping. To address these uncertainties the approach taken has been to be conservative on several aspects of the modeled discharges, such as the volumes and rates of fine sediment discharge, as well as the behavior of the sediments once released. One example is in not allowing fine sediments to be re-suspended by waves or currents once they fall to the bottom. As a result sediment net accumulations are likely to be overestimated in the extent of the plumes shown by the model. Smaller accumulations over wider areas are more likely.

There are additional aspects which would further enhance confidence in the model's robustness. For example the proposed dumpsite lies on the edge of the northward flowing Southland Current. The highly variable Southland Current plays a significant role, probably more significant than wind or tides, in the short term dispersal of fine material from the dump site, as well as the long term dispersal of coarse material. Long term wave and current measurements at this site and/or drifter studies from this site would further enhance confidence in the findings.