Before a Board of Inquiry
Transmission Gully
Notices of Requirement and Consents

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under:	the Resource Management Act 1991
in the matter of:	Notices of requirement for designations and resource consent applications by the NZ Transport Agency, Porirua City Council and Transpower New Zealand Limited for the Transmission Gully Proposal
between:	**NZ Transport Agency** *Requiring Authority and Applicant*
and:	**Porirua City Council** *Local Authority and Applicant*
and:	**Transpower New Zealand Limited** *Applicant*

Statement of evidence of Colin John Roberts (Porirua Harbour Modelling) for the NZ Transport Agency and Porirua City Council

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Dated: 16 November 2011

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STATEMENT OF EVIDENCE OF COLIN JOHN ROBERTS FOR THE NZ TRANSPORT AGENCY AND PORIRUA CITY COUNCIL

QUALIFICATIONS AND EXPERIENCE

1 My full name is Colin John Roberts.

2 I am currently the Managing Director at DHI New Zealand, having joined the firm as a Principal Engineer in 2007.

3 I have a Bachelor of Engineering, majoring in Civil Engineering (Distinction) from the University of Bradford in the United Kingdom. I also have a Masters of Science in Hydraulic Engineering from the University of Newcastle upon Tyne in the United Kingdom.

4 I have over 20 years experience in hydraulic engineering and modelling. Before joining DHI, I was a Principal Hydraulics Engineer at Opus International Consultants in Sydney from 2005 to 2007. I also worked for Opus International Consultants in Wellington, where I joined the firm as a Senior Hydraulics Engineer in 2001, before becoming a Principal Hydraulics Engineer in 2003. I have also been an independent consultant hydraulic modeller in the United Kingdom, and I held various hydraulic modelling and hydraulic engineering positions during the 1990s in the United Kingdom.

5 I have specialist skills in hydraulic modelling, including harbour modelling. Recent examples of projects I have been involved in include:

5.1 Whakatane Harbour entrance redevelopment, where I am the Project Director for an extensive study applying river, littoral drift[1] and 2D hydraulic, wave and sediment transport modelling to determine an appropriate method for improving navigation through the harbour entrance;

5.2 Porirua Harbour tsunami study, where I was the Project Director for a study to investigate coastal inundation resulting from characteristic tsunami surges;

5.3 Opotiki capacity review, where I was the Project Manager and a project modeller for investigations into the morphological development of the Opotiki River mouth under existing and proposed bend cut configurations;

5.4 Bream Bay dilution and dispersion modelling, where I was the Project Director for a study to determine the preferred

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1 Littoral drift is the process of movement of non-cohesive sediments (e.g. sands) along the shoreline due to the action of breaking waves and longshore currents.

location for an outfall from a proposed wastewater treatment plant; and

5.5 Developing and delivering training courses to users of the MIKE by DHI software including the MIKE 21 harbour and coastal modelling software.

6 My evidence is given in support of notices of requirement and applications for resource consents lodged with the Environmental Protection Authority by the NZ Transport Agency (*NZTA*) and Porirua City Council on 15 August 2011 in relation to the Transmission Gully Proposal. My evidence does not relate to the Transpower New Zealand Limited components of the Proposal.

7 I am familiar with the area that the Transmission Gully Proposal relates to, and in particular with the Porirua Harbour.

8 I have read the Environment Court's Code of Conduct for Expert Witnesses as contained in the Environment Court Consolidated Practice Note (2011), and I agree to comply with it as if this Inquiry were before the Environment Court. My qualifications as an expert are set out above. I confirm that the issues addressed in this brief of evidence are within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

SCOPE OF EVIDENCE

9 My evidence will deal with the following:

9.1 Background and role;

9.2 Modelling strategy;

9.3 Reasons for the model;

9.4 Description of relevant processes in Porirua Harbour;

9.5 Conceptual model of the key processes;

9.6 Selection of appropriate numerical models;

9.7 Data collection in support of modelling;

9.8 Model set-up;

9.9 Sensitivity testing;

9.10 Scenarios simulated;

9.11 Response to submissions; and

9.12 Conclusions.

SUMMARY OF EVIDENCE

10 My evidence discusses the development of a coupled[2] hydrodynamic, wave and sediment transport computer model of the Porirua Harbour.

11 The intended use of the model was to predict the likely fate of terrestrial sediments[3] entering the harbour through freshwater inflows during rainfall events occuring on different land use scenarios.

12 Field surveys were carried out to collect data for use in assessing the processes occuring and for development of the computer model. Surveys were carried out during: March to April 2009 (collecting detailed bathymetry datasets); January to March 2010 (collecting wind speed and direction, tidal flows, water levels, water current speed and direction, wave heights, sediment size distributions, and total suspended sediment data); and July to october 2010 (collecting wind speed and direction, water levels, water current speed and direction, and wave heights).

13 The computer model has been validated against data collected from field measurements of harbour water levels, current speed, current direction, significant wave height and total suspended sediment under a range of conditions. In my opinion a satisfactory level of validation was achieved and confirms that the model is fit for its intended purpose in predicting the fate of harbour sediments.

14 The computer model has been used to simulate future events based and long term scenarios on both a "with Project" and "without Project" basis.

15 The model predictions were provided to SKM for analysis and for use in their work on the harbour water quality impacts assessment (refer to **Michelle Malcolm's** evidence) and by BML on the harbour ecology impacts assessment (refer to **Dr Sharon De Luca's** evidence).

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[2] Coupled in the sense that the individual models exchange information as the simulation proceeds.

[3] Terrestrial sediments meaning sediments eroded from the land and transported to the harbour through flows in the water courses.

BACKGROUND AND ROLE

16 I have been the Project Director for the development of a coupled hydrodynamic, wave and sediment transport model used to produce outputs that have been used to assess water quality impacts (refer **Michelle Malcolm's** evidence) and marine ecological impacts (refer **Dr Sharon De Luca's** evidence) of additional sediment supply during the construction phase of the Transmission Gully Project.

17 I have been part of the DHI team that schematised the model for its intended purpose. I have been involved in an oversight role throughout the Project to ensure that the model development and set up remained focused on its required purpose.

MODELLING STRATEGY

18 For clarity, it is useful to first define what a model is. A model is an abstraction, made as simple as possible, of the key processes of a system that will allow reproduction and prediction of the key responses of that system that are requiring prediction. The importance of the model being as simple as possible, but no simpler, is that simplicity results in model outputs that are robust and that can be assimilated and interpreted by the modelling professional.

19 The various stages of the development of models of physical systems are:

19.1 Conceptual model: develop an abstracted understanding of the key processes of the system (e.g. the harbour).

19.2 Mathematical model: express the conceptual model in mathematical equations that are generally not able to be solved.

19.3 Numerical model: break down the mathematical equations into components so that they are amenable to being solved efficiently on a computer.

19.4 Computer model: populate the numerical model with site specific data to make predictions about a specifc sytem.

20 It is often possible to utilise previously developed numerical models to avoid having to go through the full model development process. This approach has the added advantage that the provider of the numerical model has usually carried out an extensive range of tests to provide quality assurance of the reliability of the numerical model. For the modelling of Porirua Harbour DHI adopted the MIKE by DHI suite of numerical models designed for for modelling open

water bodies (e.g. rivers, lakes, harbours, estuaries, coasts and seas).

21 To provide confidence in a computer model's predictions, certain parameters describing external forcings[4] or internal processes[5] must be adjusted until the model predictions agree with site specific measured data in a process know as calibration. Model calibrations should ideally be checked against further site specific measured data in a process know as verification. In modelling of open water bodies it is commonly not possible to collect a comprehensive suite of data that affords an independent calibration and verification[6]. In this case it is accepted practice to carry out a combined model calibration and verification process referred to as model validation. The means of assessing the degree of agreement between measured and modelled data has been done using a visual comparison. This is often the case with data from a complex system and with a number of periods of data, as it allows the modelling specialist to assess the performance of the model over the range of inter-connected processes.

22 In carrying out the development of the model of Porirua Harbour the following modelling strategy was adopted:

22.1 Clearly define the required use of the model;

22.2 Review available literature and data on the relevant processes of Porirua Harbour;

22.3 Develop a conceptual model of the key processes in the harbour that will affect the model predictions (e.g. fate of terrestrially derived sediments);

22.4 Select appropriate numerical models to represent the conceptual model of the harbour;

22.5 Collect data necessary to populate the numerical model to make a site specific computer model – the Porirua Harbour computer model;

22.6 Validate the computer model to measured data and ensure that model predictions are sensible; and

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4 Forces that are external to the water and that drive the water and sediment movement such as tides and wind blowing on the surface of the water.

5 In contrast to the external forces, these are internal processes such as settling of suspended sediment downwards through the water body.

6 This is often due to the fact that the length of a data collection program to capture a sufficient number of interesting events would be beyond the feasible length of a project timeframe.

22.7 Utilise the model to make predictions relating to the fate of terrestrially derived sediments entering the harbour under different land use conditions.

REASON FOR THE MODEL

23 The intended use of the computer model was to predict the likely fate of terrestrial sediment loads[7] entering the harbour during rainfall events occurring on different land use scenarios.

24 The computer model has been used to simulate:

24.1 Event based scenarios for the "without Project land use";

24.2 Event based scenarios for the "with Project land use";

24.3 20 year long term simulation "without Project land use"; and

24.4 20 year long term simulation "with Project land use"[8] (refer to **Michelle Malcolm's** evidence).

25 Details of the work done in deriving the terrestrial sediment loads that are used as inputs to the computer harbour model are provided in evidence of **Michelle Malcolm**.

26 Details of the work done in analysing and using the model outputs to inform a harbour water effects assessment are also provided in the evidence of **Michelle Malcolm**.

27 Details of the work done in using the model outputs to inform a harbour ecological effects assessment are provided in the evidence of **Dr Sharon De Luca**.

THE RELEVANT PROCESSES OF PORIRUA HARBOUR

28 A review of previously produced reports[9], previously collected field data, familiarity with the harbour, data collected through the Transmission Gully Project and an appreciation of general harbour dynamics enabled the following summary of the physical description of the Porirua Harbour to be made:

28.1 The Porirua Harbour sediment system is a closed system. This means that whilst there is movement of sediment (both

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7 Terrestrial sediment loads are sediments eroded from the land and stream channels and transported to the harbour by flows in the water courses.

8 20 year long term simulation with project 2021 land use assumes 6 years of staged construction followed by 14 years of 2021 land use.

9 Gibb, J.G and Cox G.J, (2009); *Patterns and Rates of Sedimentation within Porirua Harbour*. Report prepared for Porirua City Council.

terrestrial and marine[10]) within the catchment, harbour and nearshore coastal area, there is minimal exchange of sediments with the wider coastal area to the north, south and west.

28.2 In alignment with the above statement, both the local terrestrial and marine environments are suppliers of sediment to the harbour. However, the terrestrial sediment appears to dominate the supply to the harbour.

28.3 Analysis of the marine sands in the coastal area of the harbour entrance show no evidence of the presence of cohesive sediments[11] and therefore the most likely source of the cohesive sediments being supplied to the harbour is from terrestrial sources.

28.4 Both the Onepoto arm and the Pauatahanui Inlet have central basins that are mostly composed of cohesive sediments with less than 10% non-cohesive sediments[12].

28.5 Most marine sands which enter the harbour are deposited on the flood tide deltas[13].

28.6 Non-cohesive sediments are transported into the harbour with the stream flow and they are then transported as bed load[14] and some minor suspended load[15] to form narrow width beaches around the perimeter of the harbour.

28.7 There is little evidence of terrestrial and marine sands mixing. For example, there is little evidence of terrestrial sands being found on the flood tide deltas – where the marine sand deposits have been observed.

28.8 The relatively larger streams, in terms of flow and associated sediment load, have characteristic birds-foot deltas where sediments are deposited.

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10 Marine sediments in this context are sands.

11 Cohesive sediments in this context are muds, silts and clays.

12 Non-cohesive sediments in this context are sands.

13 A delta is a feature that forms as sediment carried in a flow is dropped out due to the slowing of the flow.

14 Movement of sediment particles under the action of flowing water by rolling along the bed.

15 Movement of sediment that is held in suspension in the flowing water.

28.9 There are circulation eddies[16] in both the Onepoto Arm and the Pauatahanui Inlet that are likely to be responsible for the formation of the central muddy basins.

28.10 There is evidence of sediments that enter the Onepoto Arm and Pauatahanui Inlet settling in the central muddy basins.

28.11 There are patterns of erosion along much of the Onepoto Arm shoreline, that could be as a result of wave energy[17] from wave reflections[18] from reclaimed land and shoreline responses to sea level rise.

28.12 Ocean waves travel in to the entrance of the harbour but do not appear to penetrate in to the Onepoto Arm or the Pauatahanui Inlet. Waves of height of 2.5m have been observed in the entrance and with associated waves of heights of less than 0.2m in the harbour.

28.13 Significant sedimentation occurred in Browns Bay in the mid 1970s as a result of increased sediment loads coming from catchments being subjected to urbanisation[19].

28.14 Net average annual[20] sediment deposition rates have been estimated for the harbour. The Pauatahanui Inlet was 9.1 mm / year (42,000 m^3 to 43,000 m^3 / year) and the Onepoto Arm was 5.7 mm / year (13,500 m^3 to 14,000 m^3 / year).

28.15 As a result of sediment deposition since 1974 the tidal prism[21] has reduced by 8.7 percent in the Pauatahanui Inlet and 1.7 percent in the Onepoto Arm.

28.16 At current sedimentation rates the Pauatahanui Inlet will cease to exist as a water body in the next 145 to 195 years and the Onepoto Arm in the next 290 to 390 years.

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16 Rotating water movement – just like stirring a black tea and watching the leaves move and settle in the middle of the cup.

17 Wave energy is the energy carried in a water wave. Wave energy can be passed from the wave to surrounding features through exchange of force. The energy content of a wave is proportional to the wave height squared.

18 When energetic waves hit a solid and impermeable barrier the energy can be reflected off the barrier back to the water and a wave reflection is created.

19 The urbanisation resulted in exposure of bare earth that was able to be more easily washed off than when it was covered with vegetation.

20 Over a year, sediment will be picked up from the bed and deposited on the bed. Net is used to provide a clearer appreciation of the trend in sedimentation. Sedimentation rates are expressed in annual averages to provide meaningful numbers for consideration.

21 Volume of water stored in the harbour during high tide and available for flushing sediments from the harbour as the high tide subsides

CONCEPTUAL MODEL OF THE KEY PROCESSES

29 The following processes have been identified as being key and requiring representation in the numerical model so that robust predictions can be made using the model:

29.1 Two dimensional water movement in the horizontal plane;

29.2 Water movement that results from diurnal tides[22];

29.3 Water movement that results from the friction effects of wind blowing on the water surface;

29.4 Water movement that results from the discharge of a stream flow into the harbour;

29.5 Water movement that results from movement of wave energy[23];

29.6 The generation of water waves by wind blowing on the water surface;

29.7 The transformation of the waves as they move through the water e.g. breaking and refraction, non-linear wave-wave interaction, dissipation due to bottom friction, dissipation due to depth-induced wave breaking, refraction and shoaling[24] due to depth variations, wave-current interaction, and effects of time varying water depth[25].

29.8 The fate of suspended cohesive materials by flocculation due to concentration, density effects at high concentrations, hindered settling, consolidation, and morphological bed changes[26].

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22 The regular rise and fall of the ocean water surface resulting from the pull on the water volume by, predominantly, the Sun and Moon.

23 Wave energy movement induces orbital movement of water particles resulting in the appearance that waves are the travelling of water, but in fact it is the jostling of water particles that is observed.

24 The effect whereby surface waves entering shallow water increase in height.

25 Refer to the MIKE by DHI software technical reference manual for full details of these terms included in the numerical model.

26 Morphological bed changes, in this context, relates to the changes over time of the levels and shape of the harbour bed as a result of forces from water movement and from sediment transport. Refer to the MIKE by DHI software technical reference manual for full details of these terms included in the numerical model.

SELECTION OF APPROPRIATE NUMERICAL MODELS

30 The MIKE by DHI MIKE 21 suite of numerical models was selected. This suite of models allowed the dynamic coupling of models of the hydrodynamics, waves and sediment transport:

30.1 The MIKE 21 HD (hydrodynamic) numerical model solves a set of mathematical equations that describe the movement of water in two dimensions (in the horizontal plane) caused by spatial and temporal differences in water level, density, temperature, atmospheric pressure and wind shear.

30.2 The MIKE 21 SW (spectral wave) numerical model solves a set of mathematical equations that describe the generation, movement, transformation (growth and decay) of surface water waves and wave induced water movement.

30.3 The MIKE 21 MT (mud transport) numerical model solves a set of mathematical equations that describe the fate of suspended cohesive materials in marine, brackish and freshwater areas including flocculation due to concentration; flocculation due to salinity; density effects at high concentrations; hindered settling; consolidation; and morphological bed changes. Non-cohesive sediments (sands) are included in the model as sand fractions, however only suspended transport and not bed load transport of these sands is predicted by the model.

31 The MIKE 21 modelling suit is ideally suited to modelling the processes occurring in Porirua Harbour and has been validated through a large number of applications.

DATA COLLECTION

32 Data utilised in the modelling work was sourced from three different field surveys:

32.1 A survey was carried out in 2009, prior to the Transmission Gully Project study, by DML on behalf of Porirua City Council and collected a detailed bathymetry[27]data set for the period March to April 2009.

32.2 A data collection survey was carried out for the period January to March 2010, as part of the Transmission Gully Project, by Cawthron Institute on behalf of SKM-DHI. Data was collected for:

(a) wind speed and direction;

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27 Refers to terrain below mean low water springs.

(b) tidal flows;

(c) water levels;

(d) water current speed and direction;

(e) wave heights;

(f) sediment size distributions; and

(g) Total suspended sediment data.

32.3 A second data collection survey was carried out for the period July to October 2010, also as part of the Transmission Gully Project, by Cawthron Institute on behalf of SKM-DHI. The survey was implemented to supplement the data that would be available for model validation. Data was collected for:

(a) wind speed and direction;

(b) water levels;

(c) water current speed and direction; and

(d) wave heights.

33 **Figure 1** below shows the extent of the bathymetric survey undertaken by DML. The red areas in the figure were surveyed as a set of lines at a spacing of 10m to 20m. The blue areas in the figure were surveyed as a set of lines at a spacing of 50m to 100m.

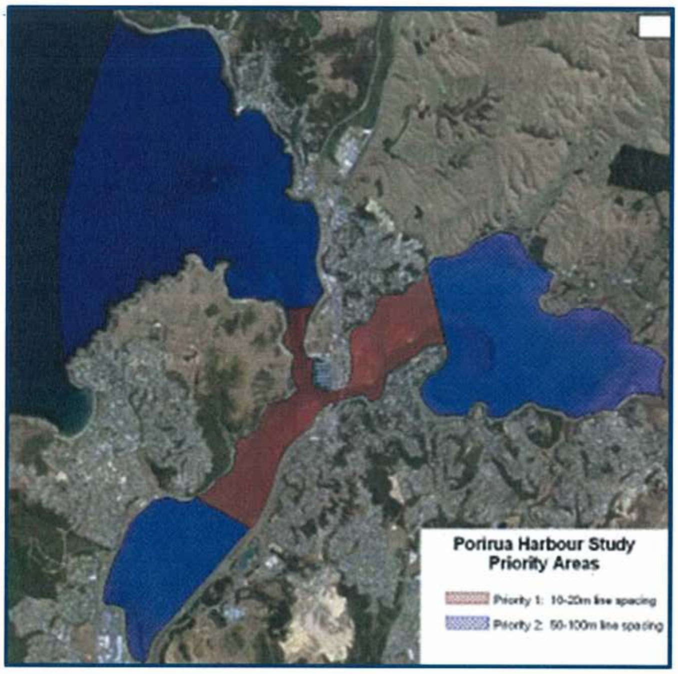

Figure 1: DML bathymetric survey areas

34 The bathymetry data was considered to be a comprehensive data set of sufficient resolution to be used in developing the computer model. It should be noted that the bathymetry data represents a snap shot in time of the harbour bed levels and that the predictions from the model are based on these bed conditions. Model validation has demonstrated that this is not expected to have an adverse impact on the robustness of the model predictions.

35 There were no long term wind data available within the harbour site. Wind data from a recorder site on Mana Island was obtained from the NIWA climate database (CliFlo). The data was obtained for the period September 2004 to May 2010 and July to October 2010. Analysis of the wind data indicated that there are two predominant wind directions at Mana Island: north – north westerly; and south – south easterly. Wind data from a recorder site in Tawa was obtained from the Greater Wellington Regional Council. The data was obtained for the period January to March 2010. Analysis of the wind data indicated that there are two predominant wind directions: north – north westerly; and south – south easterly.

36 Wind data was collected during the Cawthron surveys from an instrument located on one of the wave height recorders within the harbour. Data was collected in the Pauatahanui Inlet for the period January to February 2010. Analysis of the data indicates that the predominant wind directions for this period were similar to those of Mana Island.

37 Data was also collected in the Pauatahanui Inlet for the period July to October 2010 and the Onepoto Arm for the period September to October 2010. Analysis of the data indicates that the predominant wind directions were similar in the Onepoto Arm and the Pauatahanui Inlet, and similar to those of Mana Island.

38 It was concluded that there was sufficient wind data recorded within the harbour for model validation and that the Mana Island long term record was a suitable surrogate for the wind records at the harbour site for use in derivation of discrete event and long term simulations.

39 The numerical model equations make the assumption that wind speed and direction is recorded at 10m above the water surface. All wind data was adjusted by a scaling factor for use in the numerical model. When Mana Island wind speed (measured at approximately 100m elevation) and Pauatahanui Inlet wind speed (measured at 2m elevation) were scaled and compared there was an even better agreement between the two records.

40 Atmospheric pressure data from a recorder site at Wellington Airport was obtained from the NIWA climate database (CliFlo).

41 The atmospheric pressure data was used to make corrections to the recorded water levels from the surveys, as the water level recording instrument does not account for changes in water level resulting from changes in atmospheric pressure[28].

42 Instruments that record water level and current speed and direction at intervals throughout the water depth were deployed at two sites in the harbour: the entrance channel and the SH1 bridge site. The instruments recorded data for the period from January to February 2010[29].

43 Analysis of the vertical distribution of the speed of water movement indicated that the flow in the harbour model could be approximated by a two dimensional flow in the horizontal plane[30].

44 Similar instruments to those deployed in the main channels were also deployed in the Onepoto Arm and the Pauatahanui Inlet. At these locations there was no discernable relationship between

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28 An increase in atmospheric pressure will result in a decrease in water levels (more weight of air pushing down on the water surface) and a decrease in atmopheric pressure will result in an increase in water levels (less weight pushing down on the water surface). As an example, on 17th September 2010 it is estimated that water levels in the vicinity of the harbour rose by 30cm due to a low atmospheric pressure.

29 And to the 3rd of March at the bridge site.

30 This assumption implies that the speed of the water movement is the same at different depths below the surface.

current speed and its direction and the state of the tidal flow. Further analysis showed that the tidal currents and directions were related more strongly to the effect of wind blowing on the surface of the water and inducing a movement of water. It was evident in the data that relatively large circulation eddy currents were measured. These circulation eddies were even recorded to occur during the small tidal range variation of a neap tide[31].

45 Measured water levels displayed a clear response to tidal fluctuations at all sites.

46 An instrument that records the significant wave heights[32] was deployed in the Onepoto Arm between January and February 2010 and the Pauatahanui Inlet for the period February to March 2010.

47 The wave heights recorded in the Onepoto Arm and the Pauatahanui Inlet are relatively small, typically with a maximum significant wave height of the order of 10cm to 20cm. Such wave heights are consistent with the maximum wave heights that can be sustained by the physical and hydrographic characteristics of the harbour.[33]

48 Another instrument that records mean wave direction, significant wave height and water level was deployed in the approaches to the harbour entrance at Tokaapapa Reef. Data collected at this site shows that there was an event that generated significant wave heights of approximately 2.5m (on the 13th February 2010). The event coincides with waves recorded in the Pauatahanui Inlet. Wind recorded data shows that there was a local event in the harbour that generated the local waves. The data further shows that large waves from the open ocean do not penetrate in to the harbour.

49 The instrument component that records significant wave heights and that was deployed in the Onepoto Arm during the survey period of July to October 2010 malfunctioned for the majority of its deployment. The instrument deployed in the Pauatahanui Inlet for the same survey period recorded a number of wave events with significant wave heights reaching 20cm.

50 A measurement of the water flowing into and out of the harbour was carried out in February 2010 when the tidal range was

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31 Neap tide is when there is the smallest difference between high tide and low tide.

32 Average of the highest 1/3 of waves – this gives a representative wave height and is an accepted standard representation of wave height.

33 They are consistent with fetch and depth limited wave heights calculated using equations 3-39 and 3-40 from the Shore Protection Manual (Coastal Engineering Research Center, 1984). For example, for a 10 m/s wind event in Pauatahanui Inlet and assuming a fetch ≈ 0.5 km and a depth ≈ 1.5 m, a significant wave height of 13cm is calculated, which is consistent with the significant wave heights observed in Pauatahanui Inlet.

approximately 70cm[34]. The measurements were made along a line across the main harbour entrance and across the entrance to the Pauatahanui Inlet. The measurements showed that 60 percent of the volume of water flowing through the main harbour entrance flows in to the Pauatahanui Inlet[35].

51 Sediment sampling was undertaken at twenty locations within the harbour as shown in **Figure 2** below. The samples were taken by 'grabbing' material off the harbour bed. The samples were analysed for grain size distribution. The analysis shows that the sediments on the harbour bed are a mixture of fine sands, very fine sands and silt & clay. The silt & clay is predominantly found in the central and upper harbour arm areas and the sands in the lower harbour arms and the main harbour entrance and coastal area.

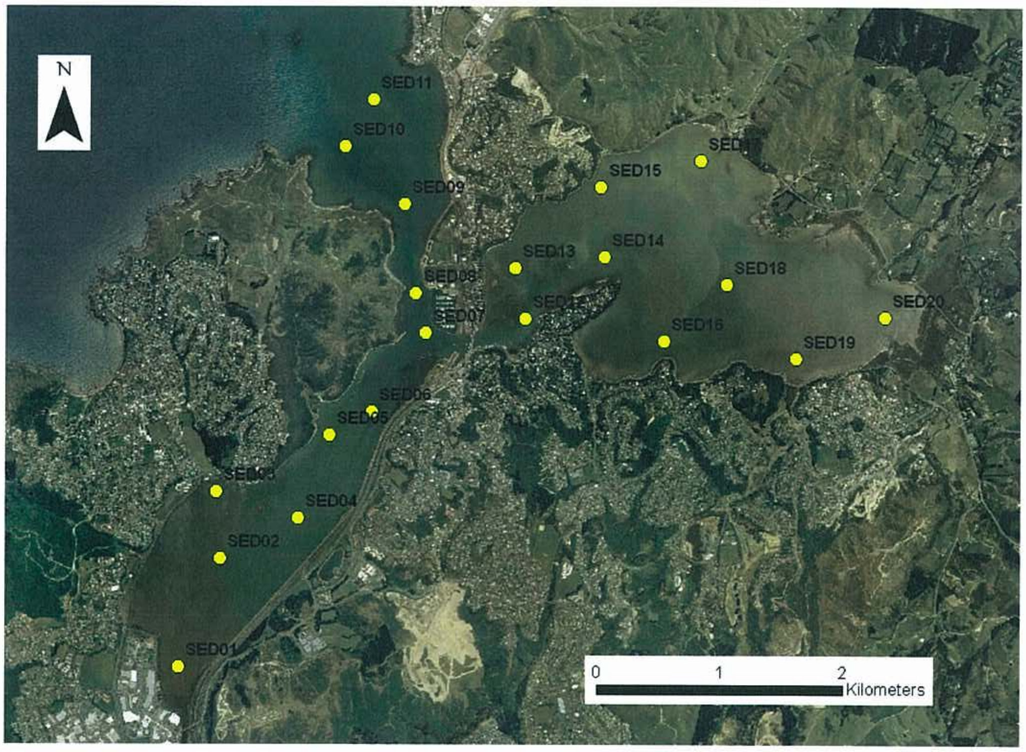

Figure 2: Sediment sampling locations

52 Instruments measuring the turbidity of the water were deployed during the survey periods. The locations of turbidity measurements were the same as for the water level, current and wave measurements. A site specific relationship relating turbidity and total suspended sediment concentration was derived for each location and this was used to generate data for total suspended

34 26 February 2010.

35 This is consistent with previous observations e.g. Wynne, K.E., (1981); *Porirua Harbour Activity Harbour Investigation*, Unpublished consulting report prepared for the Porirua Harbour Authority. 37p.

sediment concentrations. Analysis of the data indicates that spikes in total suspended sediment concentrations correlate with periods of wind events in the harbour, and waves in the harbour, providing evidence that the action of waves on the water surface is sufficient to pick up sediment off the harbour bed and move it in suspension with the flow. There was only one event where a spike in total suspended solids occurred when no surface waves were recorded. This event corresponded with the occurrence of a rainfall event in the Horokiri catchment. The rainfall event was estimated to have a probability of occurrence of 10 percent in any given year[36].

53 It should be noted that it is difficult, in general, to obtain data for the measurement of turbidity because of the frequent fouling of the instruments within marine environments.

MODEL SET-UP

54 The numerical model requires that the harbour area be discretised into a grid providing a set of elements upon which to make calculations. An unstructured triangular and rectangular elemental grid was defined. Adopting an unstructured grid allowed different resolutions to be applied in different areas of the model domain resulting in an efficient simulation time without compromising the robustness of the model.

55 A second model grid was established that was more coarse. This model grid was used for carrying out the continuous simulations. Coarsening of the grid was required to produce a model simulation time that was reasonably short to allow results to be used within the project timeframe.

56 The bathymetry data was turned into a digital elevation model that was then used to assign levels (depths) to each of the model grid elements. These levels are the ones used in the model calculations.

57 A tidal curve recorded at Mana Marine was used as a boundary water level to drive the tidal currents in the model for the validation period.

58 The scaled wind data recorded in the Pauatahanui Inlet was used as surface wind to drive the waves in the model for the validation period. It is assumed that the wind data recorded at Pauatahanui Inlet is representative of the wind field over the whole harbour area.

59 Freshwater and associated sediment inflows from twenty three drainage catchments have been included in the model. The freshwater and sediment inflow derivation was carried out by SKM

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36 Further details of the analysis of the rainfall events are given in Technical Report 15, Section 12.5.

and is described in the evidence of **Michelle Malcolm**. The freshwater inputs were located adjacent to the channel outlet and just below the mean low water springs level[37]. The inflows were given a flow velocity directed along the axis of the channel to ensure that the momentum of the flow was transferred to the harbour water[38].

60 The model validation process involved validating the model predictions against measured data as detailed earlier in my evidence. The model was validated for: water levels; current speed and direction; significant wave height; and total suspended solids.

61 Four periods, each of seven days, were chosen for use in the water level and current speed and direction validation. Within these periods there were a number of calm wind events as well as a number of significant wind events (both northerly and southerly events). The model predictions were in general agreement with measured water levels for all of the sites[39].

62 The modelled current speeds and directions were in general agreement with the measured values for calm conditions and also for southerly and northerly wind conditions.

63 A comparison of the modelled and measured discharge through the main harbour entrance and through the Pauatahanui Inlet entrance was carried out. The comparison of modelled and measured discharges was in good agreement. This validates the models capability in predicting the tidal prism.

64 Four periods, each of six days, were selected for use in wave model validation. A comparison of the modelled and measured significant wave heights was carried out. The periods were chosen where there was significant wind to generate waves higher than 10cm in the Onepoto Arm and Pauatahanui Inlet. There were a number of significant northerly wind events recorded in the Pauatahanui Inlet and a less significant southerly wind event recorded in the Onepoto Arm.

65 The model was able to satisfactorily reproduce significant wave heights compared to measured data for significant wave heights greater than 10cm. For wave heights less than 10cm the model was consistently overestimating the significant wave heights. This was deemed acceptable since it is the larger wave events which are mostly responsible for the re-distribution of sediment throughout

37 Done to enhance the stability of the numerical model.

38 Based on flow through a 5m wide by 1m deep channel or where flows enter through a culvert then a diameter of 25cm was assumed.

39 There was some slight underpredicting of modelled water levels at the harbour entrance recorded site, but this was still within acceptable limits.

the harbour, hence it was more important that the model was able to reproduce these large wave events compared with smaller wave events.

66 A comparison of the modelled total suspended solids with those recorded in the Onepoto Arm and Pauatahanui Inlet demonstrate that the model is satisfactorily validated for total suspended solids for both re-suspension events and for catchment inflow events.

67 The validity of the coarse resolution model was investigated by comparing the two models' predictions. In my view, the results were in close agreement for all the parameters that were used in the fine resolution model validation.

SENSITIVITY TESTING

68 As described above, the sediment transport model has been validated by setting appropriate model parameters describing the movement of sediment within the harbour. To assess the sensitivity of the model parameters selected for the validated sediment transport on the predicted deposition patterns, a series of sensitivity tests have been carried out for parameters (or equivalent) identified as the critical model parameters. A 1 in 10 year rainfall event in the Horokiri catchment with a northerly wind was selected as a simulation to test the sensitivity of the parameters. A simulation with wind was selected, because it is important to test the parameters' influence on keeping sediment in suspension and re-suspension, and to understand the effect of those parameters on the ultimate fate of the sediment. The sensitivity of depositional patterns on state of tide (neap or spring) has also been assessed.

69 The predicted deposition that occurred three days after the commencement of a 1 in 10 year rainfall event in the Horokiri catchment with a northerly wind was analysed. The majority of deposition occurred in the sub-tidal muddy basins of the arms. There are two areas of comparatively increased deposition that occurred in the southern part of Onepoto Arm and south eastern part of Pauatahanui Inlet.

70 With significant wind, the state of the tide does not have a significant impact on deposition. There is increased deposition in the southern part of Onepoto Arm and south eastern part of Pauatahanui Inlet and decreased deposition for a small area in the north of Pauatahanui Inlet. This shows that wave and wind driven currents dominate tidal currents within the harbour arms during significant wind events.

71 Variability in the sediment behaviour parameters (critical shear stress for deposition, critical deposition, settling velocity and bed density) did not have a significant effect on deposition throughout

the harbour. There were only minimal differences in deposition that occurred. The largest area where there was a difference was the south eastern part of Pauatahanui Inlet. The bed layer density affected more areas of the harbour, however the difference in deposition was very small.

72 The terrestrial sediment entering the harbour could have a range of characteristics which have been lumped together into three sediment characteristics for representation in the harbour model. The sensitivity tests highlight that this lumped approach is satisfactory since the main driver for where the sediment deposits is the hydrodynamics within the harbour. For example, in areas of the harbour where there is sufficiently strong wind, wave and tidal induced currents, sediment will be transported, or re-suspended and transported, and will ultimately settle out in areas where the induced currents are no longer sufficient to keep the sediment suspended in the water column. This behaviour would be consistent for sediment of a range of characteristics.

SCENARIO SIMULATIONS

73 The validated computer harbour models[40] were used to carry out both event based simulations[41] and long term simulations[42] to produce results showing the fate of the terrestrial sediment within the harbour. The results of these simulations are discussed below and generally accord with what I would have expected results to be (given my experience with similar projects).

74 Details of the water quality assessment using the harbour model outputs are provided in the evidence of **Michelle Malcolm**. Details of the ecological assessment using the harbour model outputs are provided in the evidence of **Dr Sharon De Luca**.

Event based scenario simulations

75 A series of twenty-one event based scenarios were defined that covered a range of different weather conditions. Three annual recurrence interval flood[43] events were included in the scenarios. Details of the design of the events are provided in the evidence of **Michelle Malcolm**. **Appendix A** presents a summary the configuration of the event based scenarios.

76 Two dominant wind conditions were identified from scaled Mana Island wind data and the 90th percentile wind speeds were calculated for these directions. The two winds scenarios were a

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40 Fine and coarse resolution models.

41 Using the fine resolution model.

42 Using the coarse resolution models.

43 The probability, over a long term average, of having one of these events in any given year.

10.2 m/s south – south easterly wind (170°) (herein referred to as a southerly wind) and a 11.4 m/s north - north westerly wind (340°), (herein referred to as the northerly wind). Mana Island wind data was used in the absence of an extensive record for Porirua Harbour. The Porirua Harbour wind data did not cover a long enough period to be able to determine predominant wind directions for Porirua Harbour. The wind data from both sites was shown to have a good match for wind speed and a similar behaviour for wind direction.

77 Heavy rainfall events were developed with a 24 hour duration with the beginning of the storm event timed to occur on the second day of the simulation. Details of the rainfall event derivations are provided in Technical Report No. 14.

78 Inflow hydrographs and associated total suspended solids concentrations were generated for 2, 10 and 50 year ARI flood events for the Kenepuru, Duck, Horokiri, Porirua and Pauatahanui catchments. It should be noted that during the construction of the proposed road, sediment inflows are only predicted to increase significantly for Kenepuru, Duck and Horokiri catchments during periods of major earthworks. There will only be a small increase for Porirua and Pauatahanui catchments. Details of the rainfall event derivations are provided in Technical Report No. 14.

79 Simulations were carried out for a fifteen day spring/neap tide cycle, to include a full tidal range in the scenarios, with the flood event coinciding with approximately a spring tide. Real water level data collected in the approaches to the harbour was used for the open ocean boundary of the simulations. Sensitivity tests confirmed that due to weak tidal currents in the basins of harbour arms, the impact of spring or neap tide was negligible.

80 Three sediment fractions were included in the sediment transport model to account for clay/silt (<63 μm), fine sand (63 μm – 125 μm) and sand (125 μm – 250 μm). The clay/silt fraction was included as a cohesive sediment with a settling velocity coefficient consistent with the calibration model.

81 Fine sand and sand were included as non-cohesive sand fractions with settling velocities calculated using Stokes law assuming a diameter of 100 μm for fine sand and 200 μm for sand.

82 The sediment grain sizes which were represented in the model were derived by SKM and DHI based on samples taken from the surrounding streams.

83 All other model parameters for the sediment transport model were taken from the calibration model.

Long term scenario simulations

84 Two 20 year long term scenarios were simulated: the "without Project land use"; and the "with Project land use".

85 Long term scenarios have been simulated with the aim of predicting the fate of sediment loads to the harbour resulting from the two different land use conditions. The long term simulations cover a representation of the possible different weather and oceanographic conditions that can occur over a 20 year period.

86 The 20 year simulation covers the period 1st January 2011 - 1st January 2031. These dates are for reference only and it should be noted that there was no attempt to predict what will occur for these actual dates. To achieve realistic run times the coarse resolution model was used.

87 In the absense of any long record of local wind data a twenty year time series for wind speed and direction was produced by taking five years of scaled Mana Island wind data and repeating this four times.

88 A twenty year time series for the open ocean tidal boundary condition was produced by carrying out a harmonic analysis for one year of water level data from Mana Marina. The harmonic analysis calculated the phase and amplitude for 32 tidal constituents from which a twenty year time series of water level was generated.

89 A twenty year time series for daily averaged inflow hydrographs and associated total suspended solids concentrations for the 23 catchments surrounding Porirua Harbour was provided by SKM, as discussed in the evidence of **Michelle Malcolm**.

90 All model parameters are the same for the coarse model compared with the higher resolution model.

Verification of long term simulation results

91 To assess the ability of the coarse model to predict the long term movement of sediment within Porirua Harbour the predicted rates of sedimentation within Onepoto Arm and Pauatahanui Inlet were compared with the observed rates of sedimentation.

92 Measurements from 1974 – 2009 show a net average deposition rate of 5.7mm per year in the Onepoto Arm and a net average deposition rate of 9.1mm per year in the Pauatahanui Inlet.

93 The rates of sedimentation were calculated for Onepoto Arm and Pauatahanui Inlet from the 20 year long term simulation results for the "without Project land use".

94 The model predicts a net sedimentation rate of 3.5mm per year to 3.9mm per year for the Onepoto Arm. The model predicts a net sedimentation rate of 6.0mm per year to 7.5mm per year for the Pauatahanui Inlet.

95 There are potentially two main reasons for discrepancies between the observed and predicted rates of sedimentation within the harbour:

95.1 Marine supplied sediment is not accounted for in the model; and

95.2 From 1974 – 2009 there was considerable urban development in the catchments surrounding the harbour (especially Whitby, Papakowhai and Browns Bay), which would have resulted in significantly increased sediment loads into the harbour.

96 This is supported by plots of the model predicted final bed thickness after 20 years for the "without Project land use" scenario. Compared with sedimentation patterns from literature[44] there is a good agreement between the deposition patterns in the western part of Pauatahanui Inlet and southern part of Onepoto Arm. There is poorer agreement for the eastern part of Pauatahanui Inlet and northern part of Onepoto Arm. These are areas where sedimentation patterns would have been influenced by marine supplied sediment and from urban development in catchments surrounding the harbour.

RESPONSE TO SUBMISSIONS

97 The submissions from the Pauatahanui Inlet Community Trust (sub 35) and the Guardians of Pauatahanui Inlet Inc (sub 32) both suggested that the NZTA contribute to restoring the tidal prism or increasing the flushing ability of the harbour. Measures suggested to achieve this include dredging of the sub-tidal basins, deepening of strategic channels, removal of existing reclamations, and removal of tidal restrictions.

98 The submitters are correct that the harbour model could be used to determine the effectiveness of any of these measures. However, it should first be determined whether the ecological, property and other effects of these suggestions would be acceptable.

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[44] Gibb, J.G and Cox G.J, (2009); *Patterns and Rates of Sedimentation within Porirua Harbour*. Report prepared for Porirua City Council.

CONCLUSIONS

99 A coupled hydrodynamic, wave and sediment transport computer model of the Porirua Harbour has been developed.

100 The intended use of the model was to predict the likely fate of terrestrial sediments entering the harbour through freshwater inflows during rainfall events occurring on different land use scenarios. The results of the model were used by SKM and BML in carrying out water quality and ecological assessments.

101 Three separate field surveys were carried out to collect hydrographic and hydrometric data for use in the computer model development.

102 The computer model has been validated against data collected from field measurements of harbour water levels, current speed, current direction, significant wave height and total suspended sediment under a range of conditions. A satisfactory level of validation was achieved and confirms that the model is fit for its intended purpose in predicting the fate of harbour sediments.

103 The computer model has been used to simulate: event based scenarios for the "without Project land use"; event based scenarios for the "with Project land use"; 20 year long term simulation "without Project land use"; and 20 year long term simulation "with Project land use" (refer to **Michelle Malcolm's** evidence).

104 The model outputs were used as inputs to work carried out by SKM on the harbour water quality impacts assessment (refer to **Michelle Malcolm's** evidence) and by BML on the harbour ecology impacts assessment (refer to **Dr Sharon De Luca's** evidence).

Colin John Roberts
16 November 2011

APPENDIX A

Scenarios for event based assessment.

Scenario	Wind	Freshwater and Sediment Inflows	Simulation ID	
			Existing Situation	Peak Construction
1	Calm	50 year ARI in Kenepuru and Porirua catchments, 2 year ARI elsewhere	E1	PC1
2	Calm	50 year ARI in Pauatahanui and Duck catchments, 2 year ARI elsewhere	E2	PC2
3	Calm	50 year ARI in Horokiri catchment, 2 year ARI elsewhere	E3	PC3
4	Northerly	50 year ARI in Kenepuru and Porirua catchments, 2 year ARI elsewhere	E4	PC4
5	Northerly	50 year ARI in Pauatahanui and Duck catchments, 2 year ARI elsewhere	E5	PC5
6	Northerly	50 year ARI in Horokiri catchment, 2 year ARI elsewhere	E6	PC6
7	Southerly	50 year ARI in Kenepuru and Porirua catchments, 2 year ARI elsewhere	E7	PC7
8	Southerly	50 year ARI in Pauatahanui and Duck catchments, 2 year ARI elsewhere	E8	PC8
9	Southerly	50 year ARI in Horokiri catchment, 2 year ARI elsewhere	E9	PC9
10	Calm	10 year ARI in Kenepuru and Porirua catchments, 2 year ARI elsewhere	E10	PC10
11	Calm	10 year ARI in Pauatahanui and Duck catchments, 2 year ARI elsewhere	E11	PC11
12	Calm	10 year ARI in Horokiri catchment, 2 year ARI elsewhere	E12	PC12
13	Northerly	10 year ARI in Kenepuru and Porirua catchments, 2 year ARI elsewhere	E13	PC13
14	Northerly	10 year ARI in Pauatahanui and Duck catchments, 2 year ARI elsewhere	E14	PC14
15	Northerly	10 year ARI in Horokiri catchment, 2 year ARI elsewhere	E15	PC15
16	Southerly	10 year ARI in Kenepuru and Porirua catchments, 2 year ARI elsewhere	E16	PC16
17	Southerly	10 year ARI in Pauatahanui and Duck catchments, 2 year ARI elsewhere	E17	PC17
18	Southerly	10 year ARI in Horokiri catchment, 2 year ARI elsewhere	E18	PC18
19	Calm	2 year ARI for all catchments	E19	PC19
20	Northerly	2 year ARI for all catchments	E20	PC20
21	Southerly	2 year ARI for all catchments	E21	PC21