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Hauraki regional harbour model : demonstration project : sediment and enterococci dispersion from multiple outfalls in the Eastern Bays area

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Hauraki Regional Harbour Model: Demonstration project: Sediment and enterococci dispersion from multiple outfalls in the Eastern Bays Area

John Oldman
Mike Timperley
Doug Ramsay

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Reviewed by:

Dr Rob Bell

Approved for release by:

Dr Mal Green

Formatting checked

1 Executive Summary

A high-resolution model grid has been nested within the baseline 100-m grid Regional Harbour Model (RHM) as part of the initial development of the RHM to demonstrate the use of the model in assisting the assessment of environmental effects of discharges to the marine environment.

The data used for this demonstration were the suspended sediment and enterococci loads discharged from 10 large stormwater outfalls (2 of these outfalls were composites of several small outfalls) between the western end of Okahu Bay and the eastern end of St Helier's Beach in Auckland City. The discharge loads were obtained from stormwater quality models calibrated with monitoring data collected by NIWA for Metrowater and Auckland City at a single point in the stormwater network draining to Mission Bay. The loads predicted for this monitored catchment were scaled on the basis of stormwater network catchment area to produce the discharge loads for each of the 10 outfalls.

These catchment-scaled suspended sediment and enterococci loads have not been validated and are likely to be of only moderate absolute accuracy. The reasons for this are that for suspended sediment, the loads are strongly influenced by the length of open unstabilised channel in the stormwater network and this length varies considerably among the catchments of the 10 outfalls, and for enterococci, wastewater overflows are a major influence and their contribution to enterococci counts in stormwater also varies greatly among the catchments of the 10 outfalls.

The project has been used to demonstrate:

- The effect of improved model grid resolution to better represent the spatial variation of tidal currents within localised areas of interest;
- The potential of the RHM in simulating the dispersal and concentration of a non-conservative pollutant (enterococci) from both single and multiple outfalls, during a single event and over an eleven-month time period, under different decay rates;
- The simulation of the dispersal, deposition and resuspension of sediments discharged from both single and multiple outfalls during a single event and over an eleven-month time period;
- Typical presentation of output results from such simulations.

The results presented in this report are, at best, semi-quantitative only because neither the stormwater outfall loads have been validated nor has the higher-resolution rested models in the RHM been calibrated for suspended sediment, sediment deposition on the seabed, or enterococci.

2 Introduction

2.1 Introduction

Auckland Regional Council (ARC) have commissioned the development of a hydrodynamic and water quality model to assist with the future assessment of both the near and far-field environmental effects of discharges to the marine environment, such as from stormwater and combined wastewater outfalls. This model, known as the Hauraki Regional Harbour Model (RHM), has been developed for the inner Hauraki Gulf and associated harbours and estuaries. Details of the development of the model are provided in the RHM Set-up, Calibration and Verification report (Oldman et al., 2004) and the RHM User Manual (Ramsay et al., 2004).

The purpose of this additional project is to demonstrate the use and potential of the RHM, specifically:

- How the resolution of the RHM can be "nested" down for a locally focussed investigation, within the wider framework of the regional model;
- A typical use of the model, in this case to investigate sediment dispersion and deposition, and dispersal of enterococci from ten small outfalls in the Eastern Bays Area of Auckland City (Okaku Bay, Mission Bay, Kohimarama Beach and St Heliers Beach) under a range of different conditions.

2.2 Demonstration overview

The demonstration project involves:

- Nesting a 33.3 m model grid (inside the 100 m RHM grid) covering the mouth of the Waitemata Harbour (extending between Tamaki Drive and Devonport), across the Rangitoto Channel to the western flank of the Tamaki Estuary;
- Nesting an 11.1 m model grid (inside the 33.3 m grid), to cover the frontage between approximately Hobson Point and Achilles Point;
- Deriving sediment and enterococci loads as input to the RHM for single and time-series events based on an existing stormwater model developed for Metrowater and Auckland City.

The demonstration project involves the simulation of a range of scenarios including:

- A single discharge from one outfall for a single event (largest storm event from the data collected) and associated tidal and wind conditions;
- Multiple discharges (from 10 outfalls) for a single event (largest storm event from the data collected), and associate tidal and wind conditions;

- Multiple discharges (from 10 outfalls) for an eleven-month flow time-series.

For each of these scenarios the following outputs will be presented:

- Plots of sediment dispersion and deposition patterns;
- Plots of relative maximum enteroccoci concentrations;
- Time series of enteroccoci concentrations or distributions at particular locations of interest, e.g. bathing beaches.

The following chapters describe the development and findings of the demonstration project in more detail.

3 Nesting model grids

3.1 The need for a nested grid

Nesting model grids is the process of incorporating a smaller, but finer, resolution grid within an existing hydrodynamic model. Primarily this is done to better resolve spatial (and / or temporal) variation in physical processes in a specific area where it is not computationally efficient to create a model grid at the finest resolution over the entire spatial domain of the model.

The baseline RHM grid was developed at a resolution of 100 m by 100 m. This is sufficient resolution to adequately model far-field (advection) processes but is not a high enough resolution to simulate high spatial variability of tidal currents, or the near-field smaller-scale processes (e.g., dilution and dispersion of individual discharges) that affect water quality and sedimentary dispersion. For example certain pollutants (e.g. faecal indicator bacteria) die off quickly on entering marine receiving waters under strong sunlight conditions. High concentrations typically occur near a sewage outfall but decrease rapidly with distance and time, due to die off, dilution and dispersion. Hence a relatively fine spatial and temporal scale is required in the vicinity of the outfall to adequately simulate these various processes but is less important some distance from a discharge when substantial mixing with the receiving waters has been accomplished and advection (i.e. flow processes) dominate.

In addition to the processes that are to be simulated, a further important consideration in determining the spatial resolution of the model grids is the adequacy of the data available to build the model. For example, if a finer resolution grid is to be used to better resolve spatial variations in tidal currents, the underlying spatial resolution of the bathymetry needs to reflect this, i.e., the spatial resolution of the bathymetry survey data needs to reflect the model grid resolution.

The MIKE 3 model used to develop the RHM, can nest higher-resolution model grids at a ratio of 3:1, with the ability for multiple nesting. Hence the 100 m grid resolution of the baseline RHM can be nested at higher resolutions of 33.3 m, 11.1 m and so on.

3.2 Nested grids used for demonstration project

To develop a satisfactory grid resolution to simulate near-field sediment and enterococci dispersal processes, 33.3 m and 11.1 m high-resolution grids were created from the RHM bathymetry dataset and nested within the RHM base 100 m grid (Figure 1). The spatial limits for the two nested grids are given in Table 1.

Figure 1:

The three grids used in the high-resolution demonstration project. Blue shading indicates the baseline 100 m RHM grid. Red shading indicates coverage of 33.3 m grid, and gray shading indicating limits of the 11.1 m grid. Co-ordinates in NZMG.

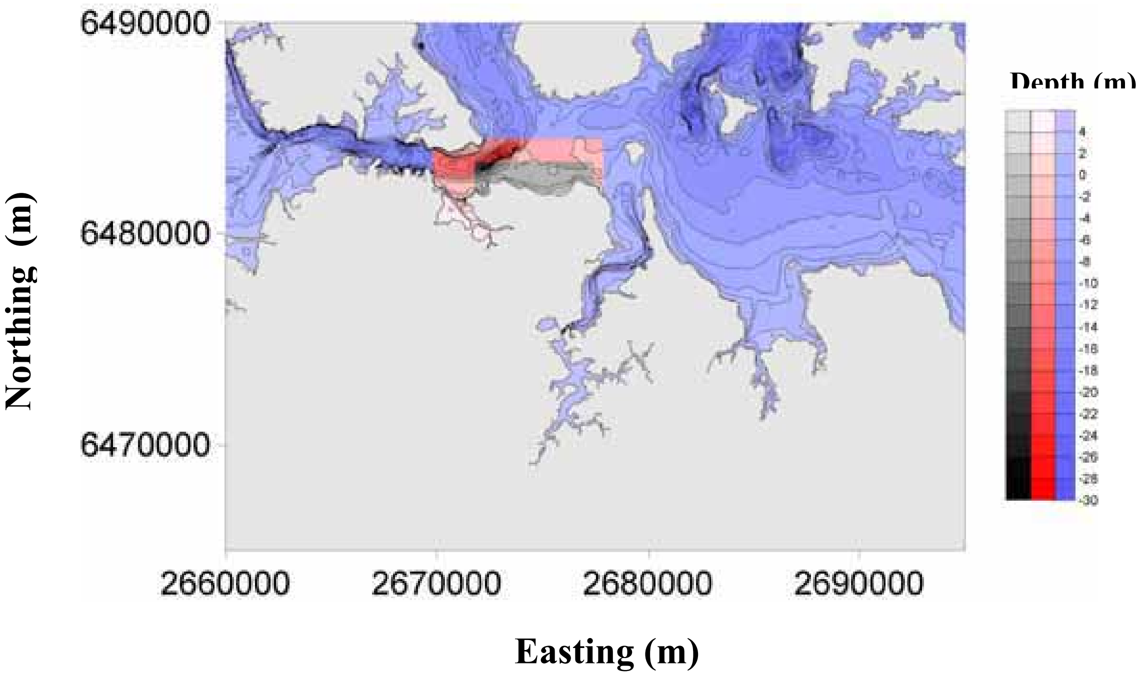


Table 1:

NZMG co-ordinates of the limits of the 33.3m and 11.1m grids.

	Easting	Northing
33.3 m grid:		
Minimum (bottom left)	2669800	6478800
Maximum (top right)	2677900	6484500
11.1 m grid:		
Minimum (bottom left)	2671800	6481200
Maximum (top right)	2677400	6483400

To ensure compatibility between the nested grids the edges of each of the grids are processed using a border adjustment tool. This essentially matches up the bathymetry of the finer grid to that of the coarser grid enabling the smooth transfer of boundary conditions (water levels and flow volumes) between the various grids. The underlying bathymetry offshore of the Eastern Bays area is derived from Navy charts and is therefore relatively sparse compared to the finest grid resolution. The gridded bathymetry, while maintaining the overall slope and shape of the intertidal areas, does not contain small-scale (i.e. 10-50m) features such as drainage channels. To include such features a bathymetric survey of at least equal resolution would need to be carried out.

4 Input data

4.1 Introduction

The demonstration project aimed to illustrate a number of different simulations of sediment and enterococci dispersion from both a single, and multiple, outfalls in the Eastern Bays area (Okaku Bay, Mission Bay, Kohimarama Beach and St Heliers Beach) of Auckland City, Figure 2. The demonstration project required input data for both a single storm event, and for a long time-series simulation.

4.2 Derivation of discharge, sediment and enterococci input data

Between November 2001 and July 2003, NIWA conducted an extensive monitoring programme of stormwater quantity and quality for Metrowater and Auckland City Council at 8 sites on the City's stormwater network. A model of stormwater quality was developed and was calibrated using the monitoring data from approximately 150 samples collected at each site during rainfall events over an approximately 12 month period. This model was then used to predict loads of contaminants at 5 minute intervals for each site over the monitoring period (Timperley and Reed, 2004). One of these sites was on the western edge of Aotea Reserve in the catchment of Mission Bay.

There are 8 large separate stormwater outfalls and two groups of smaller outfalls between the western end of Okahu Bay and the eastern end of St Helier's Beach. Each of the two groups of smaller outfalls was combined into an "equivalent" single outfall making 10 large outfalls for the RHM demonstration. Suspended sediment and enterococci loads at 5-minute intervals for each of these 10 outfalls were generated from the 5-minute loads predicted for the Aotea Reserve monitoring site, by scaling according to the catchment area of each outfall relative to the catchment area of the monitoring site.

When considering the results of the demonstration project presented in this report, it must be understood that the results are, at best, semi-quantitative. This is partly because the scaled outfall loads for each catchment have not been validated. Also, for this demonstration project, validation of the nested models for suspended sediment and enterococci has not been carried out.

For suspended sediment, the loads are strongly influenced by the length of open unstabilised channel in the stormwater network and this length varies considerably among the catchments of the 10 outfalls. The stormwater quality model cannot allow for this variation in open channel length so this factor was not taken into account in the scaling used to generate the suspended sediment loads for the 10 outfalls.

For enterococci, wastewater overflows can be a major influence on enterococci counts in stormwater. The number of overflows and presumably also the overflow volumes, vary greatly among the catchments of the 10 outfalls but again the stormwater quality model does not allow for this.

In effect, therefore, the scaled loads generated for the 10 outfalls are based on the assumption that the proportion of open unstablised channel to closed channel and the pro-rated contribution of wastewater overflows to stormwater quality, are exactly the same in the catchments of all 10 outfalls as they are in the catchment of the Aotea Reserve monitoring site.

The locations of the 10 outfalls (overlaid on the 33.3 m grid) are shown in Figure 2. Table 2 summarises the discharge, suspended sediment and enterococci data for each of the outfalls. This shows that the maximum discharge occurs at outfall number 7 (Kohimarama Beach).

Figure 2:
Locations of the ten Eastern Bays discharge sites overlaid with the 33.3 m grid. Co-ordinates in grid cell intervals of 33.3 m.

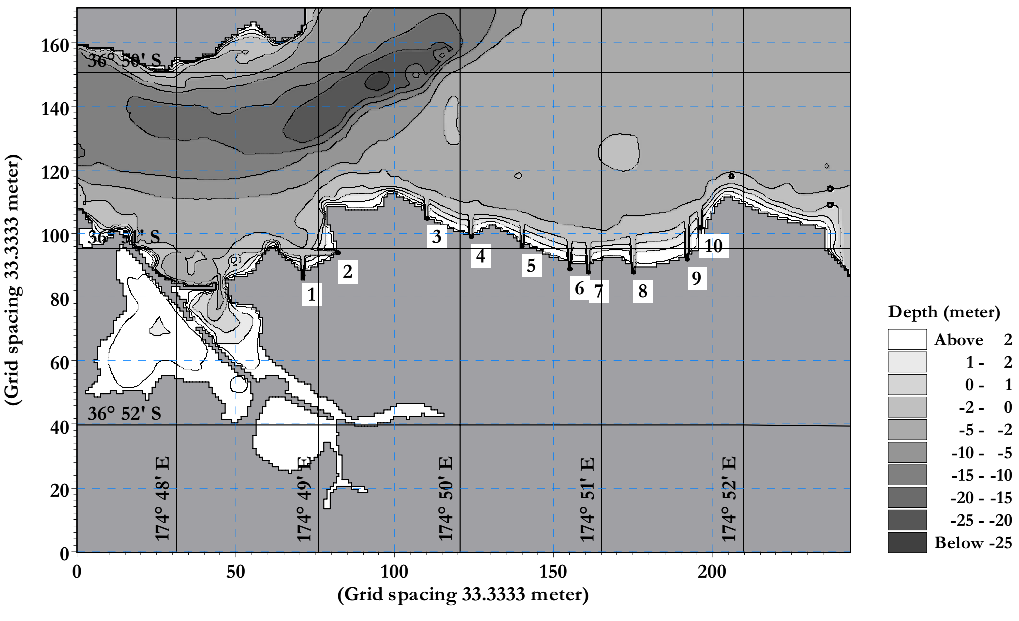


Table 2:

Summary of the estimated time series discharge data for the Eastern Bay sites (Outfall numbering shown in Figure 2 going from west to east).

Outfall	Mean flow (m^3/s)	Maximum flow (m^3/s)	Mean enterococci per 100 ml	Maximum enterococci per 100 ml	Mean suspended sediment (kg/m^3)	Maximum suspended sediment (kg/m^3)
1	0.0043	1.3130	2550.70	14101.00	0.05	0.24
2	0.0209	6.4137	2550.70	14101.00	0.05	0.24
3	0.0299	9.2086	2550.70	14101.00	0.05	0.24
4	0.0043	1.3201	2550.70	14101.00	0.05	0.24
5	0.0066	2.0360	2550.70	14101.00	0.05	0.24
6	0.0021	0.6403	2550.70	14101.00	0.05	0.24
7	0.0405	12.4460	2550.70	14101.00	0.05	0.24
8	0.0149	4.5827	2550.70	14101.00	0.05	0.24
9	0.0203	6.2482	2550.70	14101.00	0.05	0.24
10	0.0057	1.7482	2550.70	14101.00	0.05	0.24

Figures 3 to 5 shows the estimated time-series of discharge, suspended sediment and enterococci loadings respectively for Outfall 7 for the full eleven-month period of the long-term simulation. The highest estimated discharge occurs during a storm event commencing on the 2nd of May 2001. For this event sediment load peaked at 0.185 kg/m^3 and peak enterococci loading was 10,600 enterococci/100 ml. Highest sediment load occurred during the storm event of the 15th of September and highest enterococci load (14,101 enterococci/100 ml) occurs during an event on 7 November 2001. For the purpose of the demonstration, the 2nd of May 2001 event is used with Figures 6 to 8 showing the discharge, suspended sediment and enterococci loading data for that storm event.

Figure 3:

Estimated flow discharge data for Outfall 7 for the period 1st January 2001 through to the 30th of November 2001. Maximum discharge of 12.5 m^3/s occurs during the storm event commencing on the 2nnd of May 2001.

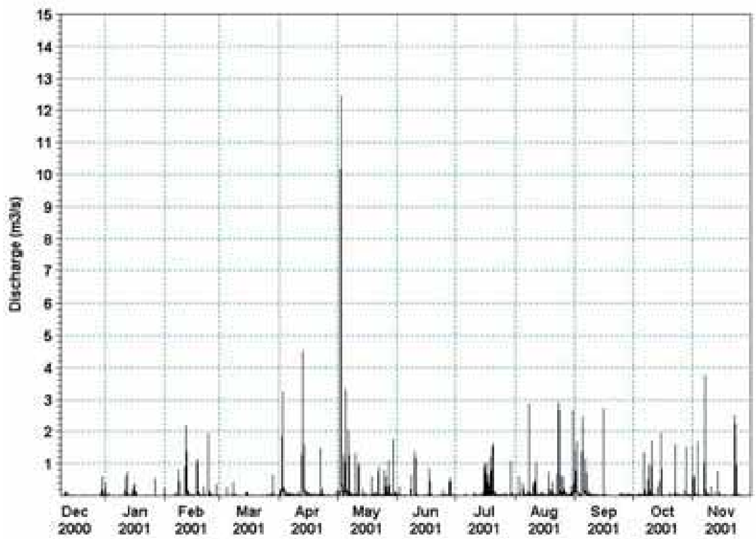


Figure 4:

Estimated suspended sediment loadings (kg/m3) for Outfall 7 for the period 1st January 2001 through to the 30th of November 2001. Maximum suspended sediment load of 0.24 kg/m^3 occurs during the storm event commencing on the 15th of September 2001.

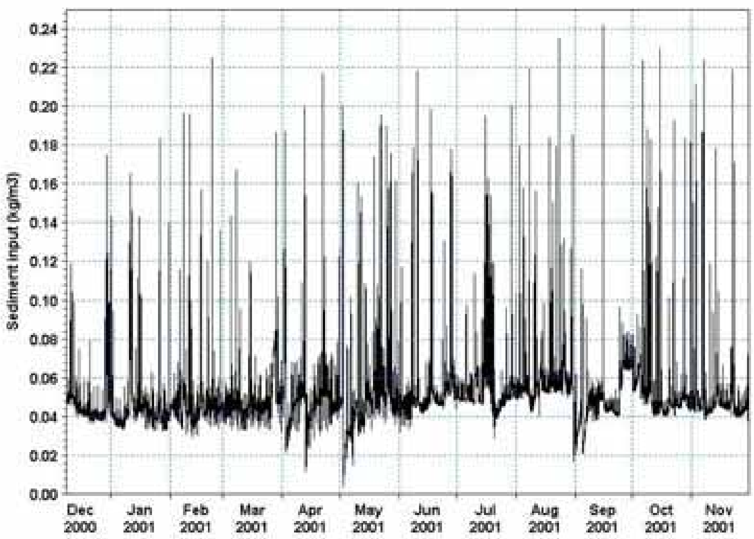


Figure 5:
Estimated enterococci load (enterococci/100 ml) for site 7 for the period 1st January 2001 through to the 30th of November 2001. Maximum count occurs of 14101 enterococci/100 ml occurs during the storm event commencing on the 23rd of November 2001.

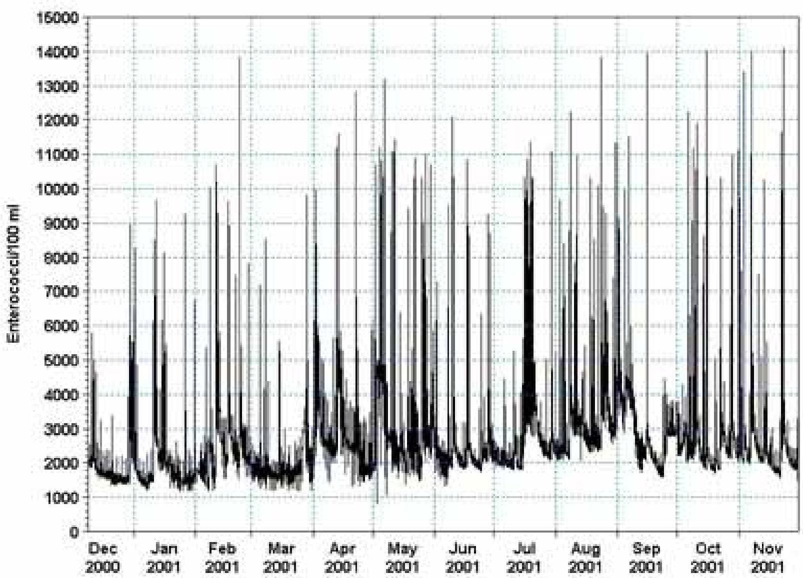


Figure 6:
Estimated flow discharge data for all outfalls during the storm event commencing on the 2nd of May 2001.

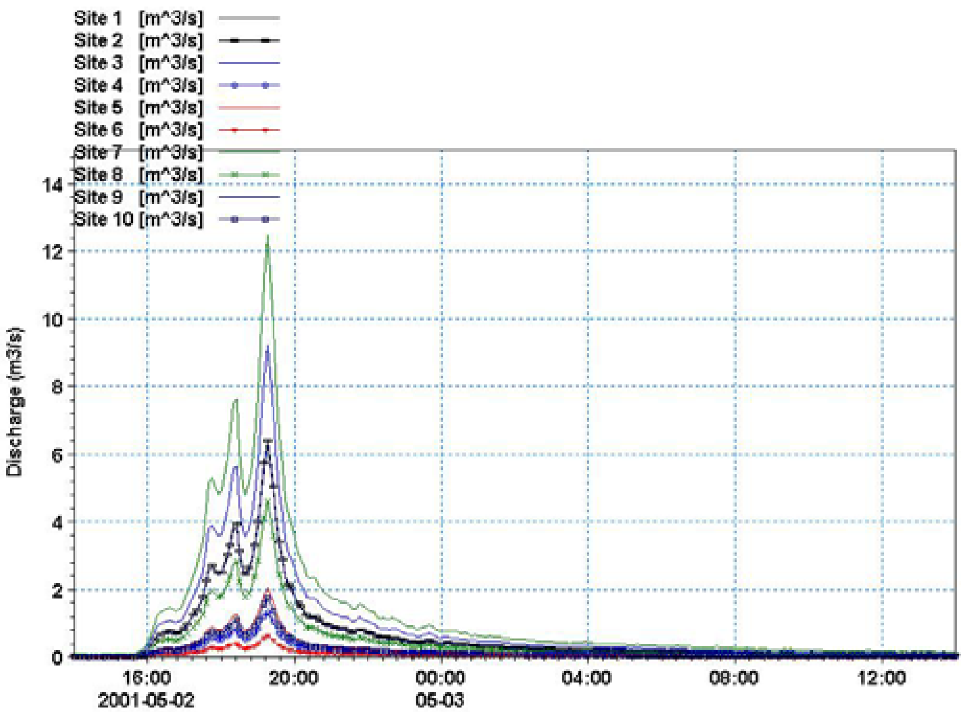


Figure 7:
Estimated suspended sediment load during the storm event commencing on the 2nd of May 2001.

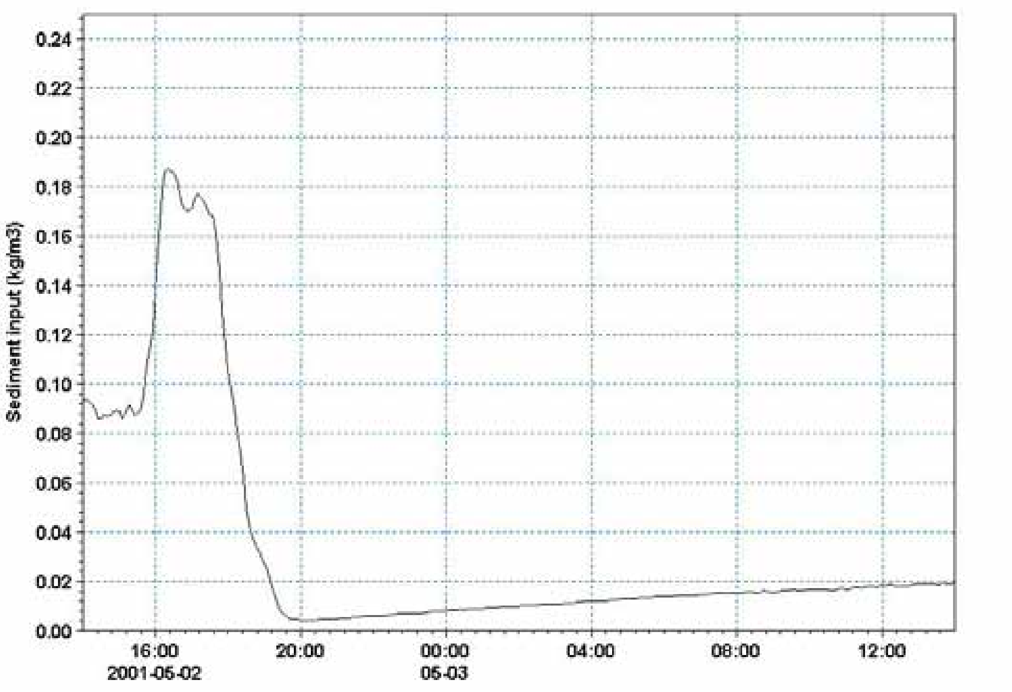
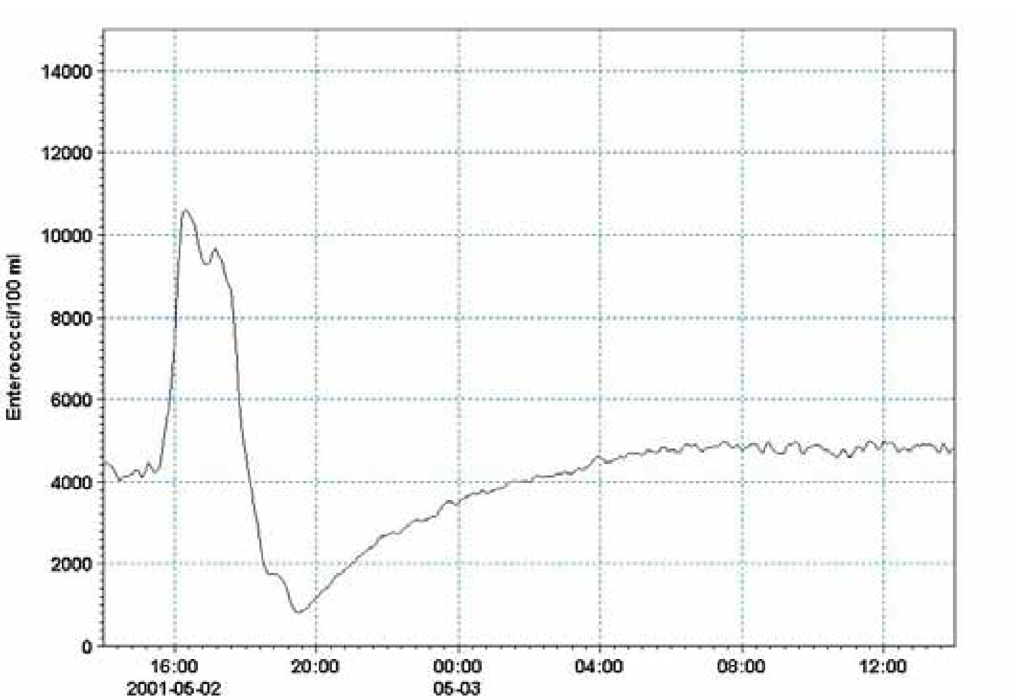


Figure 8:
Estimated enterococci loading during the storm event commencing on the 2nd of May 2001.

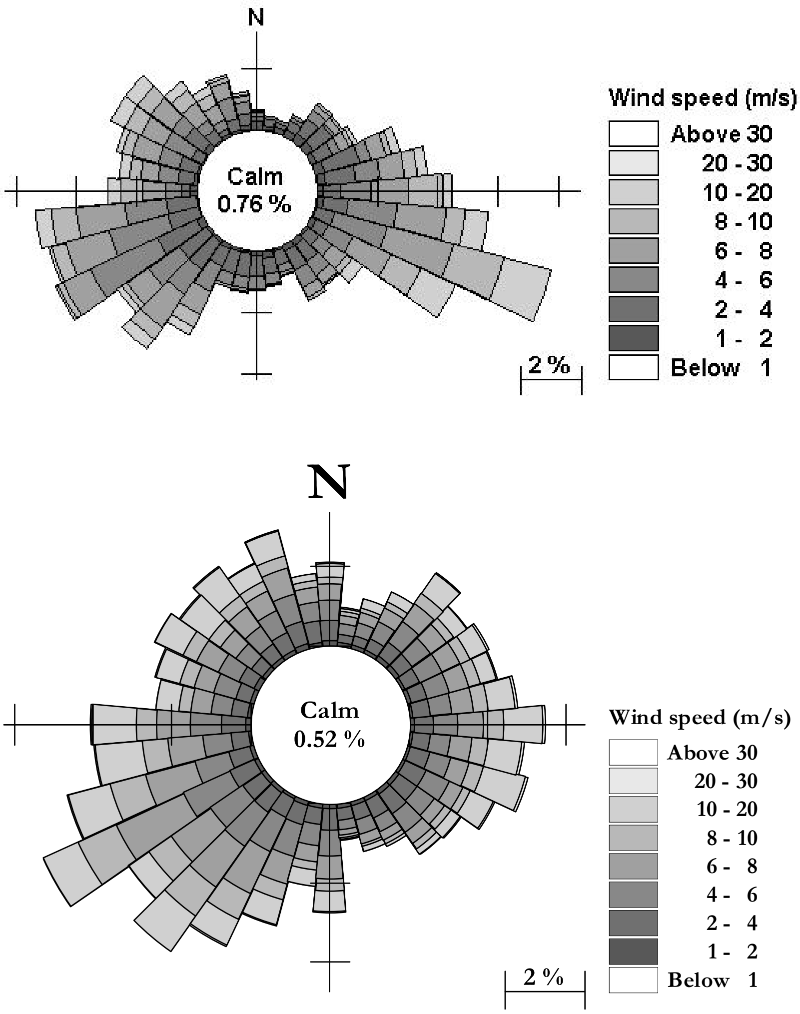


4.3 Wind and tidal level input data

Figure 9 shows the wind rose from the Mokohinau Islands Automatic Weather Station for the eleven-month period of the long-term simulation compared to the long-term (23 year) wind record. The demonstration project period has a larger proportion of stronger south-westerlies and south-easterlies than the overall long-term wind distribution and less winds from the north and south.

Boundary conditions for the 100 m grid for the same 11-month period were generated using the tidal constituent data obtained from the outer Gulf along the boundary of the RHM.

Figure 9:
Wind rose for from the Mokohinau Islands AWS (corrected to 10 m above sea level) for 2001 (upper) and from the 23-year record (lower). Wind speed is in m/s and directions are in meteorological convention i.e. winds blowing from direction.



5 Model demonstration simulations

5.1 Hydrodynamics within the nested grids

In many projects of this type, additional tide level, and more commonly, tidal current data would be collected to further verify that the hydrodynamic model is correctly reproducing the hydraulic processes within the local high-resolution area of interest. In this case no such data was collated for the eleven-month period over which the outfall discharge and load data estimates were made. Calibration and verification of the 100 m RHM has shown that tides are well simulated over the whole of the RHM domain. It would therefore be expected that the rise and fall of the tide offshore of Mission Bay would be well represented within the model. Currents at various locations within the RHM have also been well calibrated and, given the same calibration parameters are being used within the nested models, it would be expected that predicted velocities would be well represented.

Figure 10 shows the predicted tides offshore from Outfall 7 for the eleven-month period. Tidal level conditions during the rainfall event of the 2nd of May 2001 are shown in Figure 11. The storm occurred during a period of mean tide range with the peak outfall discharge occurring on the falling tide.

Figure 10:
Tidal level time series offshore from Outfall 7 (Kohimarama Beach) over the eleven-month period (Jan-Nov 2001). Levels relative to Chart Datum.

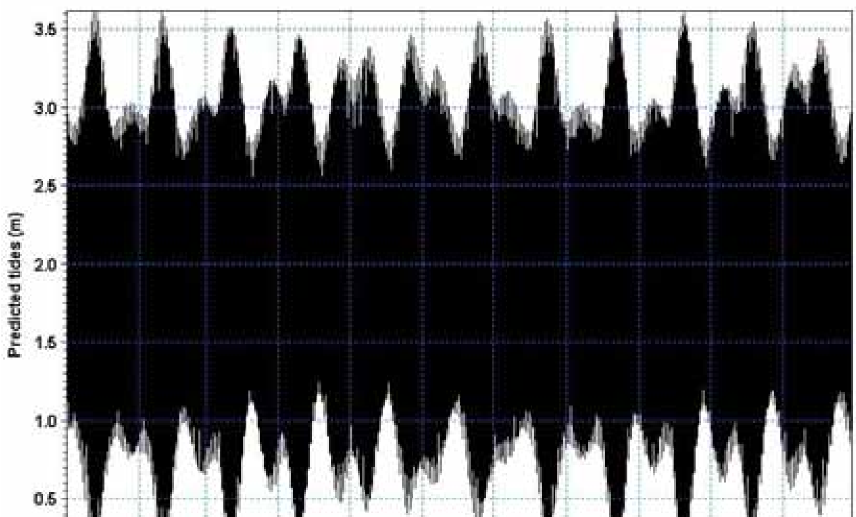
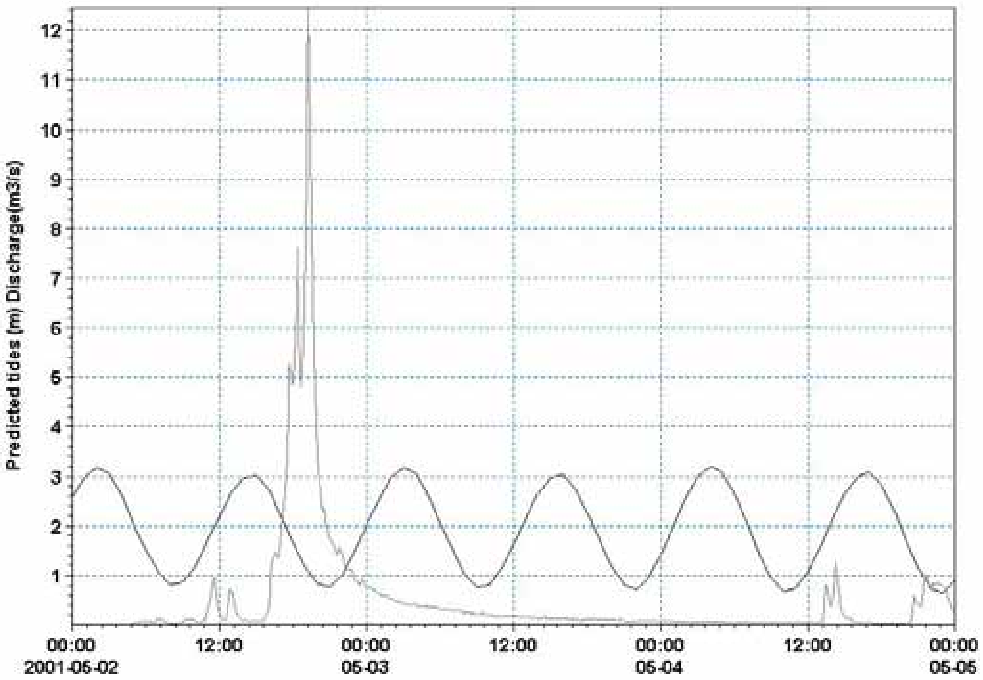
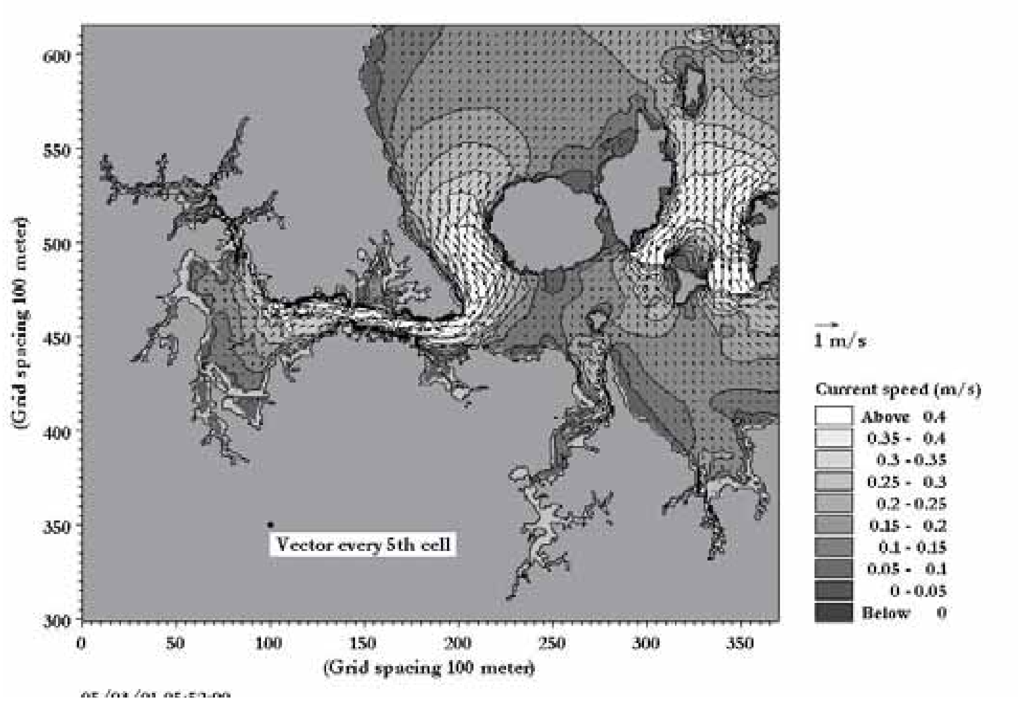


Figure 11:
Tidal levels (black line) offshore from Outfall 7 (Kohimarama Beach) during the storm event of 2nd of May 2001. The estimated flow discharge for Outfall 7 (grey line) for the event is superimposed on to the tide level record.



Figures 12 to 14 show the predicted velocities for the three grid resolutions (100 m, 33.3 m and 11.1 m). This shows that the nesting process maintains the overall tidal velocity pattern observed in the 100 m grid but at much greater detail. At the 11.1 m scale (Figure 14) the gradients in velocities can be seen in the vicinity immediately offshore of the western end of Mission Bay.

Figure 12:
Peak ebb (upper) and flood (lower) velocities for the 100 m resolution grid. Velocity vectors shown for every 5th cell.



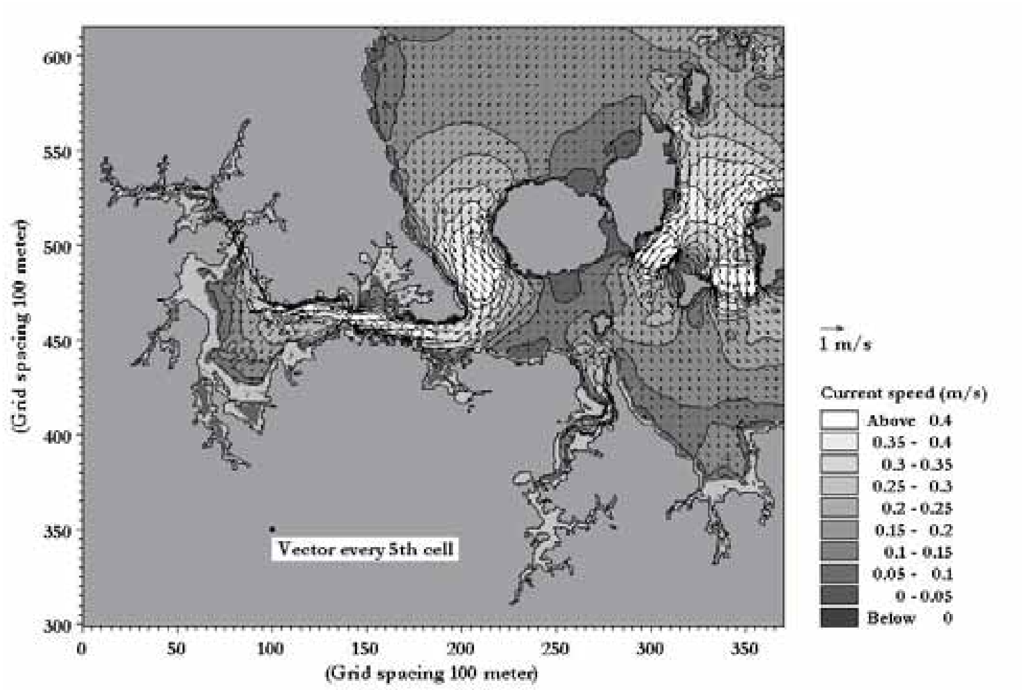
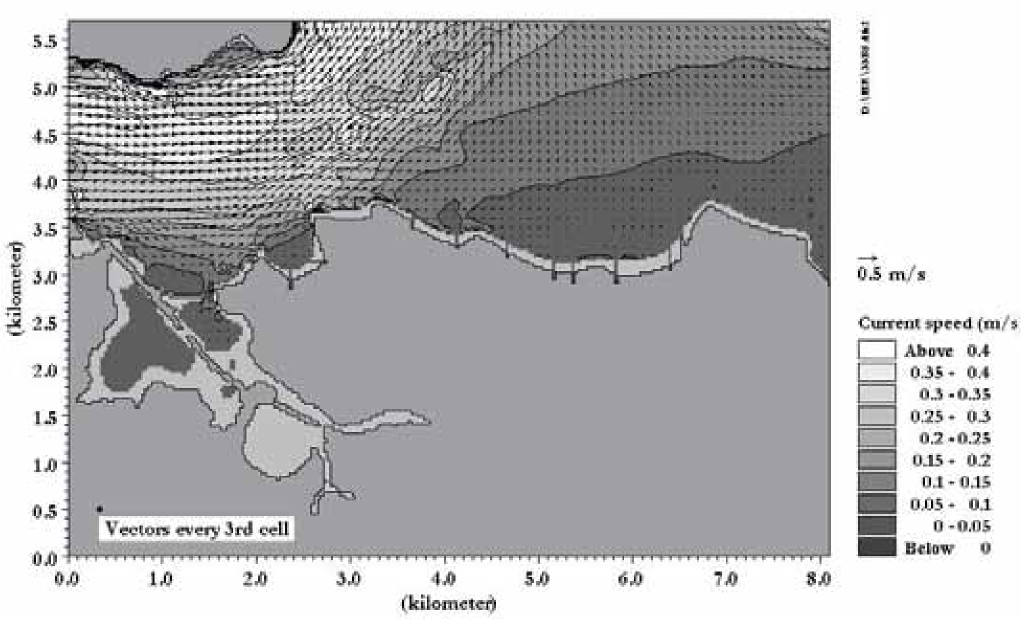


Figure 13:

Peak ebb (upper) and flood (lower) velocities for the 33.3 m resolution grid. Velocity vectors shown at every 3rd cell.



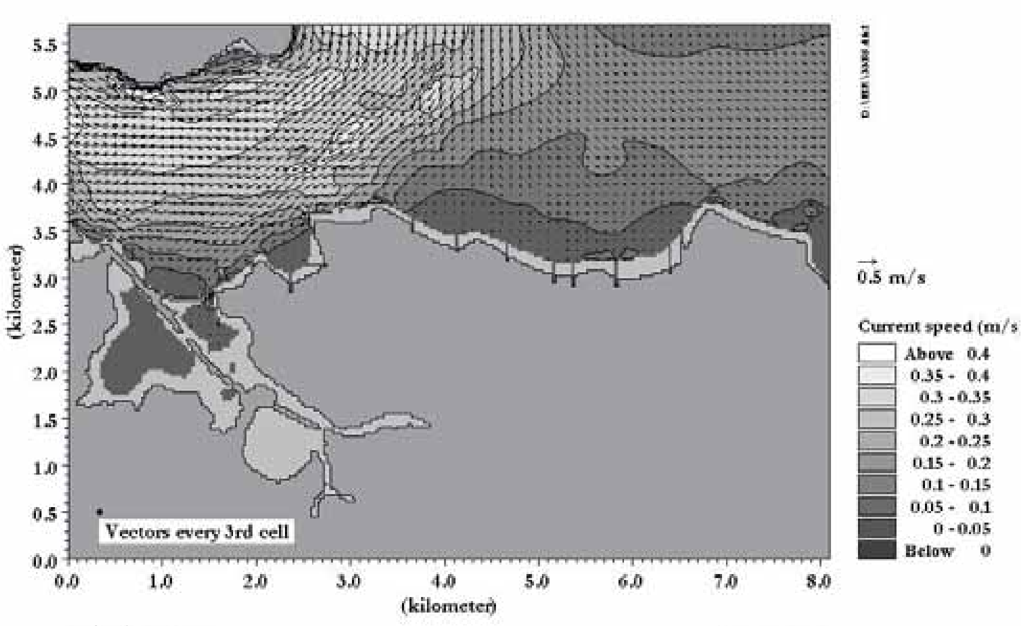
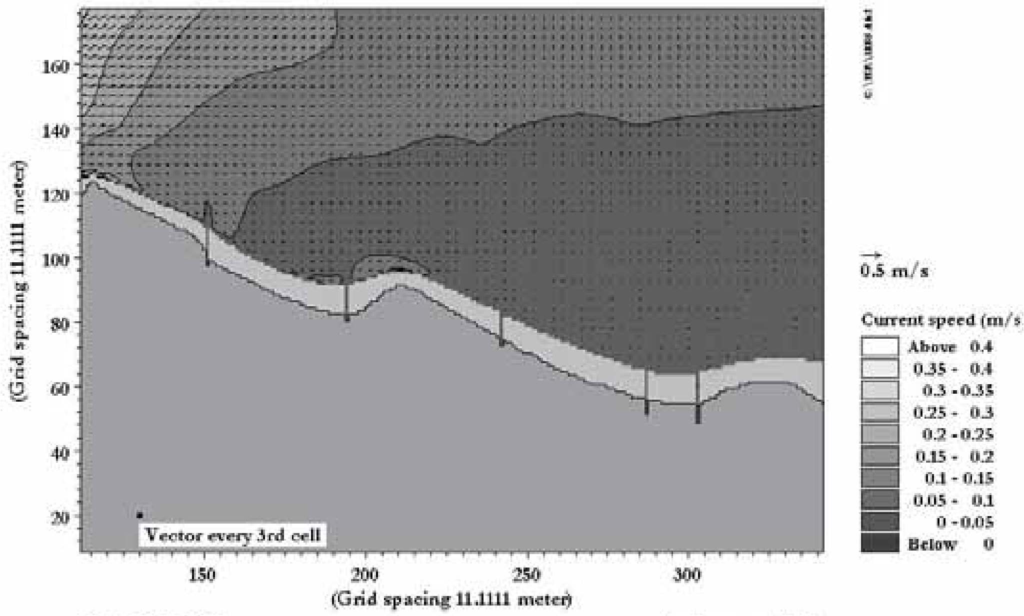
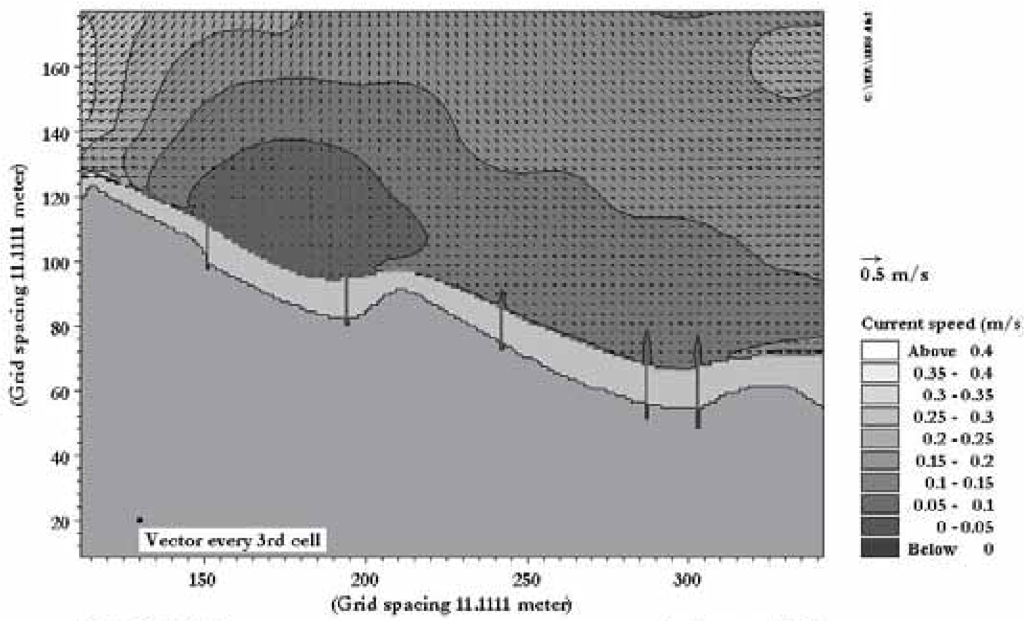


Figure 14:
Peak ebb (upper) and flood (lower) velocities for the 11.1 m resolution grid for the Mission Bay and Kohimarama Beach coast. Velocity vectors shown at every 3rd cell.





5.2 2nd May 2001 storm event – enterococci dispersal and concentration simulations

5.2.1 Single outfall simulations

The times series of enterococci loads, predicted tides and observed winds were input to the model for the storm event of the 2nd of May 2001. For the discharge from Outfall 7, the hydrodynamics from all three grids were used to show the effect of the different grid resolutions. Enterococci dispersion is simulated using the particle tracking model component of MIKE 3 (see Appendix 1 of Ramsay et al. 2004). On release each particle has associated with it a number of enterococci (N). Assuming the decay of enterococci is a liner decay process then the reducing number of enterococci per particle with time (t) can be defined as;

$$\frac{dN}{dt} = -kN \tag{1}$$

N being the number of enterococci per particle and k the decay factor.

Integration of this equation over time gives;

$$N(t) = N_0 \exp(-kt) \tag{2}$$

Where N_0 is the initial number of enterococci discharged. The decay period T_{90} is the time it takes for the number of enterococci per particle to be reduced to 10 percent of the discharge enterococci concentration;

$$\frac{N}{N_o} = 0.1 \tag{3}$$

which means the decay factor is;

$$k = \frac{\ln(10)}{T_{90}} \tag{4}$$

Previous measurements for enterococci decay from Manukau Harbour (Davies-Colley et al., 1991) were used to derive upper and lower limit values for T_{90} rates of 2 and 200 hours representing sunny mid-day periods in summer and night time conditions respectively. These decay rates will give an indication of the full range of enterococci values that could be expected during the simulated storm events. Actual decay rates (and hence enterococci values) will not only depend on the time of year and time of day of the discharge but also the salinity and turbidity of the receiving and discharge waters.

Depending on the study requirements, various output is available from the model, including:

1) the layer in which data is averaged e.g. a 1 m surface layer, over the whole water depth or the near bed 0.5 m layer;

2) time-averaged (over a user specified time-slot) or instantaneous (at the exact time the output is requested);

3) spatial extent (i.e. whole grid or sub-grid) and resolution (i.e. every 3rd cell etc.).

For the following simulations the model output was for every cell, averaged over a 30-minute time period for either the top 0.5 m layer (for enterococci and suspended sediment) or the bottom 0.5 m layer for deposition.

The following simulations use the slowest night-time decay rate for enterococci (T_{90}) of 200 hours (i.e. conservative results) and are carried out for a period of 5 days during the storm event of the 2nd of May 2001. This will result in the highest predicted enterococci concentrations for any given discharge event.

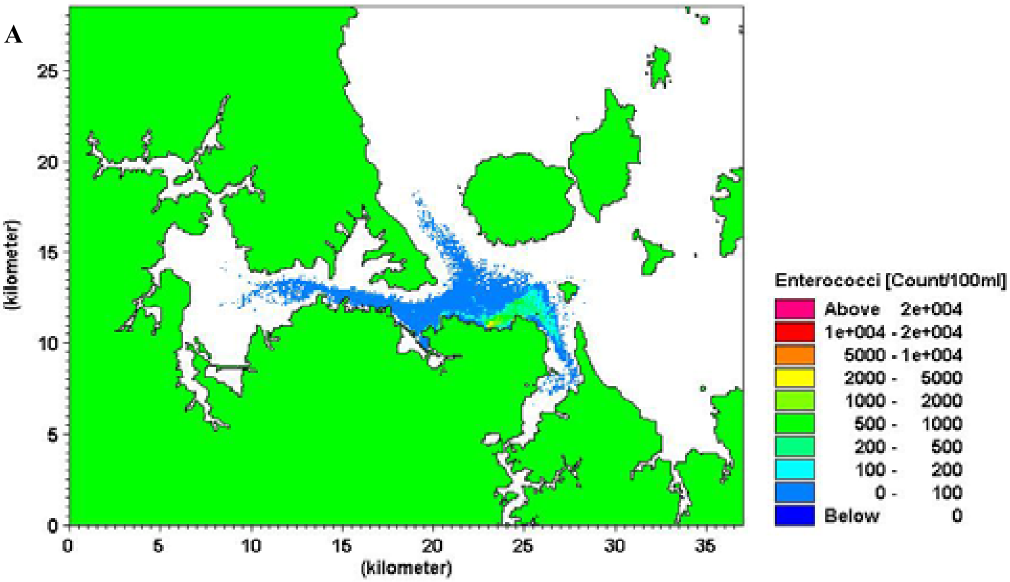
Figure 15(A) shows the predicted maximum enterococci concentrations in each cell of the 100 m grid at any time during the 5-day simulation. A peak maximum concentration of 9000 enterococci/100 ml is reported immediately offshore of the discharge. Because the peak discharge occurs on a falling tide the maximum plume concentrations occur to the east of the discharge site (green to blue in Figure 15(A)). The distribution of maximum enterococci concentrations in each cell (Figure 15(B)) has a mean value of 27 enterococci/100 ml and the 95th percentile value is 346 enterococci/100 ml. Figures 16 and 17 show the corresponding plots for the 33.3 m and 11.1 m resolution grids respectively. A peak maximum concentration of 240000 enterococci/100 ml is predicted using the 33.3 m resolution grid (Figure 16(A)). The distribution of maximum enterococci concentrations (Figure 16(B)) has a mean value of 179 enterococci/ 100 ml and the 95th percentile value is 1208 enterococci/100 ml. For the 11.1m resolution grid a peak maximum concentration of 270000 enterococci/100 ml occurs immediately offshore of the outfall discharge location (Figure 17(A)). The distribution of maximum enterococci concentrations (Figure 17(B)) has a mean value of 584 enterococci/100 ml and the 95th percentile value is 5722 enterococci/100 ml. Thus it can be seen that the grid resolution alone contributes to an apparent "initial dilution" factor because the model reports a cell-wide average value. The smaller the cell, the more likely a larger maximum concentration will be reported until the grid resolution matches the scale of the plume.

The resolution of the 11.1 m grid shows within the inter-tidal area higher concentrations occur to the west of the discharge point. Dispersal to the east also occurs within the inter-tidal zone but tends to be steered offshore by the underlying bathymetry and resulting flow pathways.

Figure 15:

(A) Maximum enterococci concentrations in the top 0.5 m surface layer for the 100 m resolution grid at any time during the storm event of 2nd May 2001 (T_{90} = 200 hours). (B) Distribution of maximum enterococci concentration. Discharge from outfall 7 only.

A



B

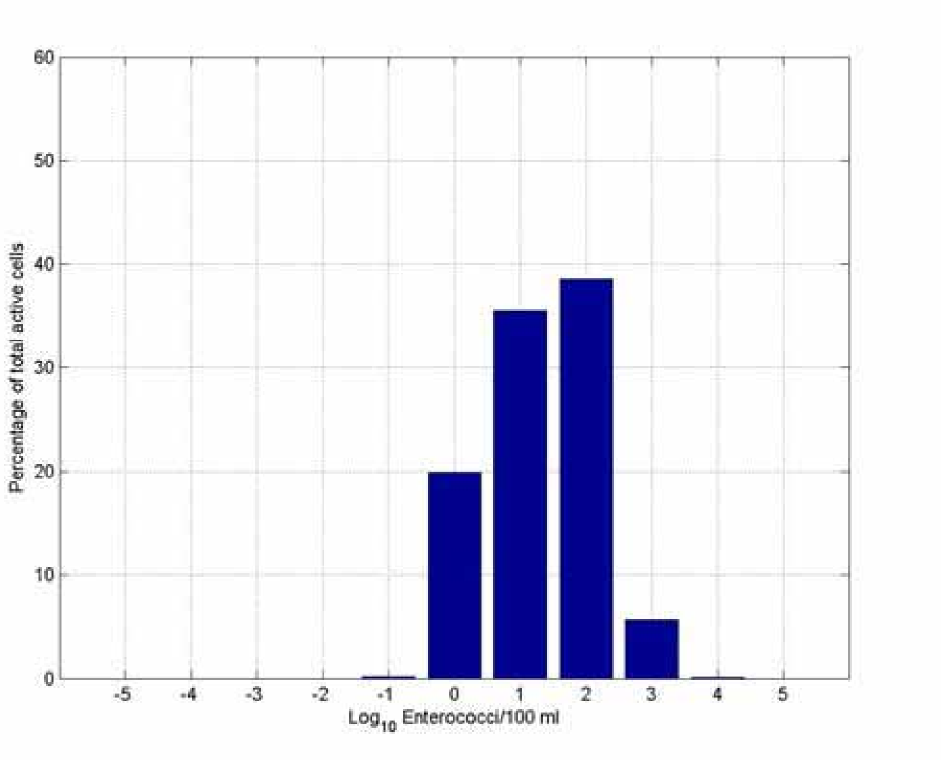


Figure 16:
(A) Maximum enterococci concentrations in the top 0.5 m surface layer for the 33.3 m resolution grid at any time during the storm event of 2nd May 2001 (T_{90} = 200 hours). (B) Distribution of maximum enterococci concentration. Discharge from outfall 7 only.

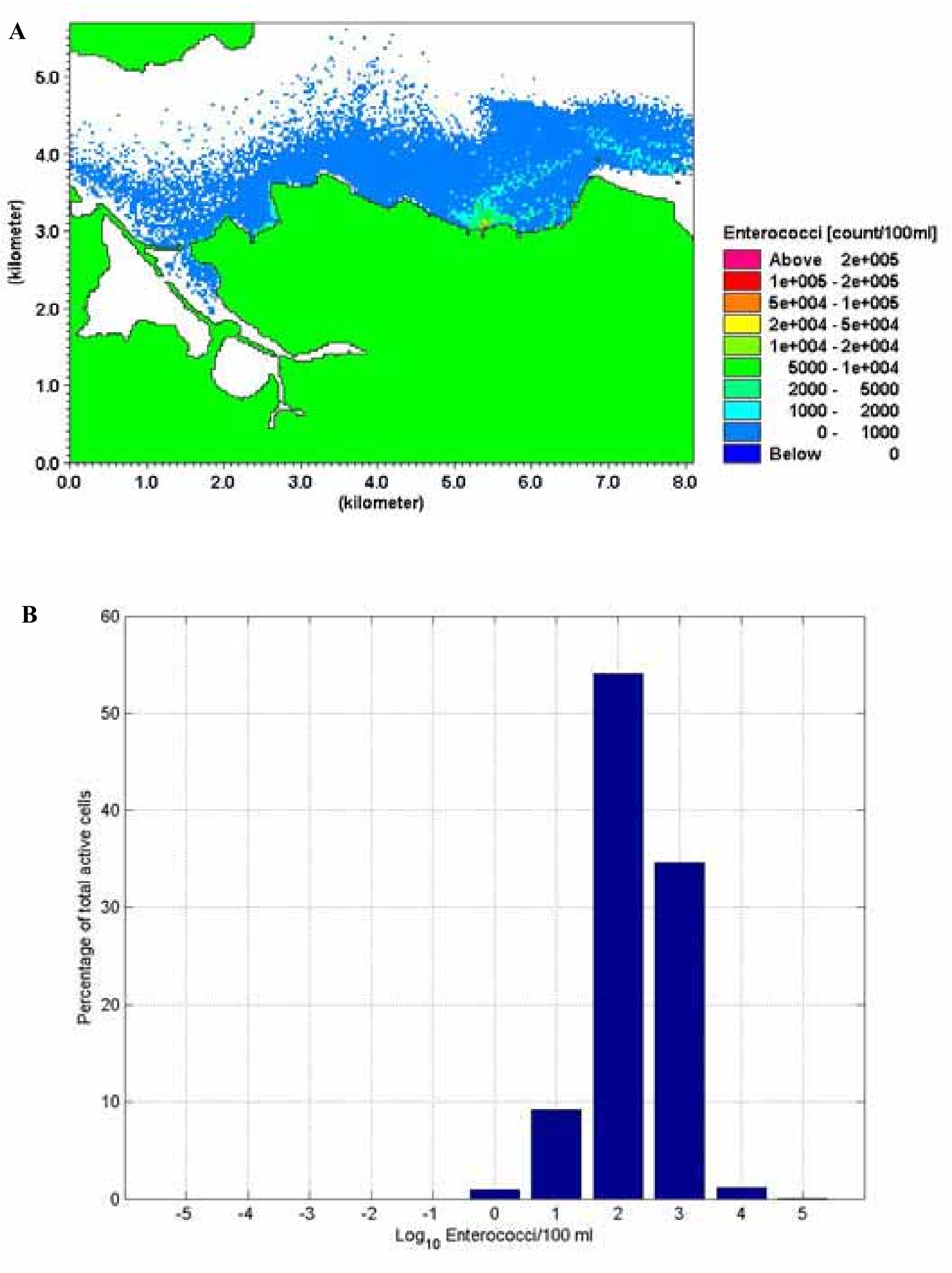
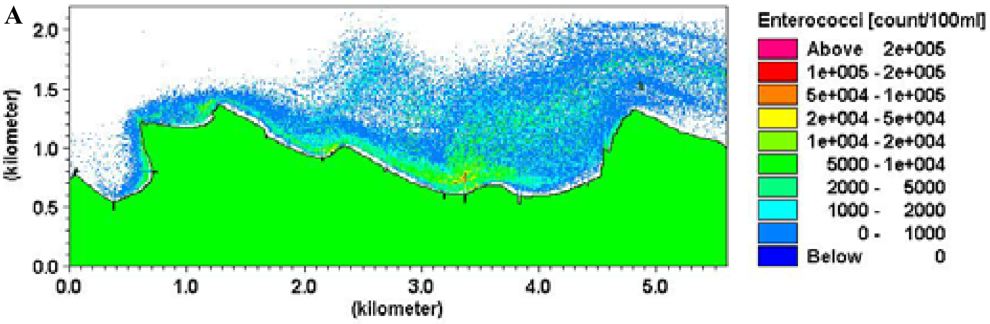


Figure 17:

(A) Maximum enterococci concentrations in the top 0.5 m surface layer from the 11.1 m resolution grid at any time during the storm event of 2nd May 2001. (T_{90} = 200 hours).

(B) Distribution of maximum enterococci distribution. Discharge from outfall 7 only.



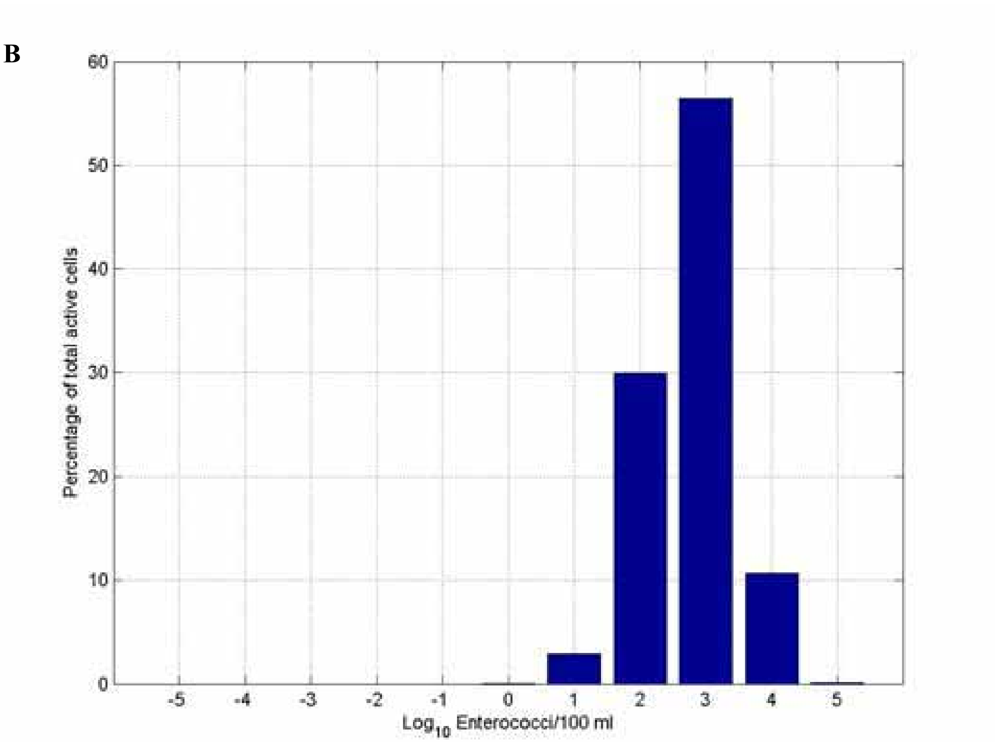


Figure 18 shows the percentage of time that the enterococci concentrations are greater than 100 enterococci/100 ml. Within the vicinity of the discharge, concentrations are above 100 enterococci/100 ml for just over 40% of the time. Within the inter-tidal areas enterococci concentrations are above 100 enterococci/100 ml between 10 and 40% of the time. Further offshore enterococci concentrations are above 100 enterococci/100 ml for less than 2% of the simulation.

Figure 18:
Percentage of time enterococci concentrations in the top 0.5 m surface layer are above a count of 100/100 ml for the storm event of 2nd May 2001 within the 11.1m grid covering a time period of 5 days. (T_{90} = 200 hours). Discharge from outfall 7 only.

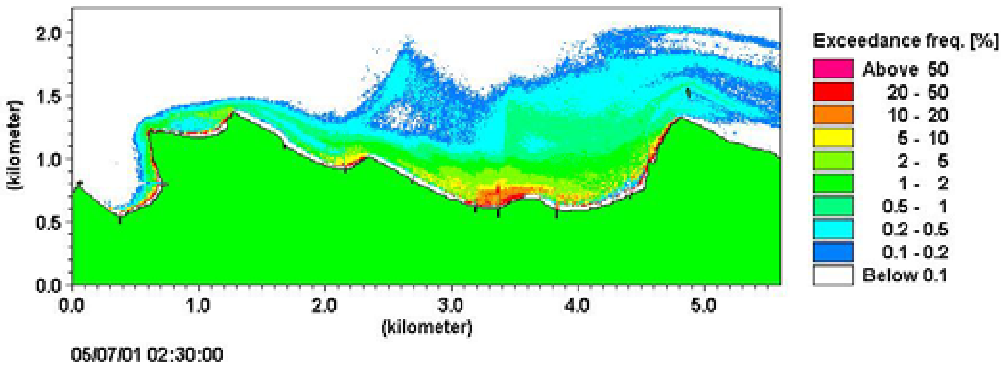


Figure 19 show the percentage of time that shoreline enterococci concentrations (between Bastion Point and Achilles Point) are above 277 enterococci/100 ml. This is the threshold for beach closures quoted in the 1999 Ministry for Environment Recreational Water Quality Guidelines. This plot uses the data from the simulation and extracts the predicted concentration on the first submerged 11.1 x 11.1 m cell (thus accounting for the rise and fall of the tide) along the length of the shoreline. Figure 20 shows the maximum waters edge concentration for the 5-day duration of the simulated storm event. Note that both of these plots (and subsequent plots using the same procedure) only show outfalls 3 to 10. The location of these outfalls is indicated by vertical black lines in the figure along the coastline.

Figure 19:
Percentage of time enterococci concentrations in the top 0.5 m surface layer at the waters edge are greater than 277/100 ml for the storm event of 2nd May 2001 covering a time period of 5 days. (T_{90} = 200 hours). Discharge from outfall 7 only – discharge points 3 to 10 (from left to right) are shown as black lines at the bottom of the plot.

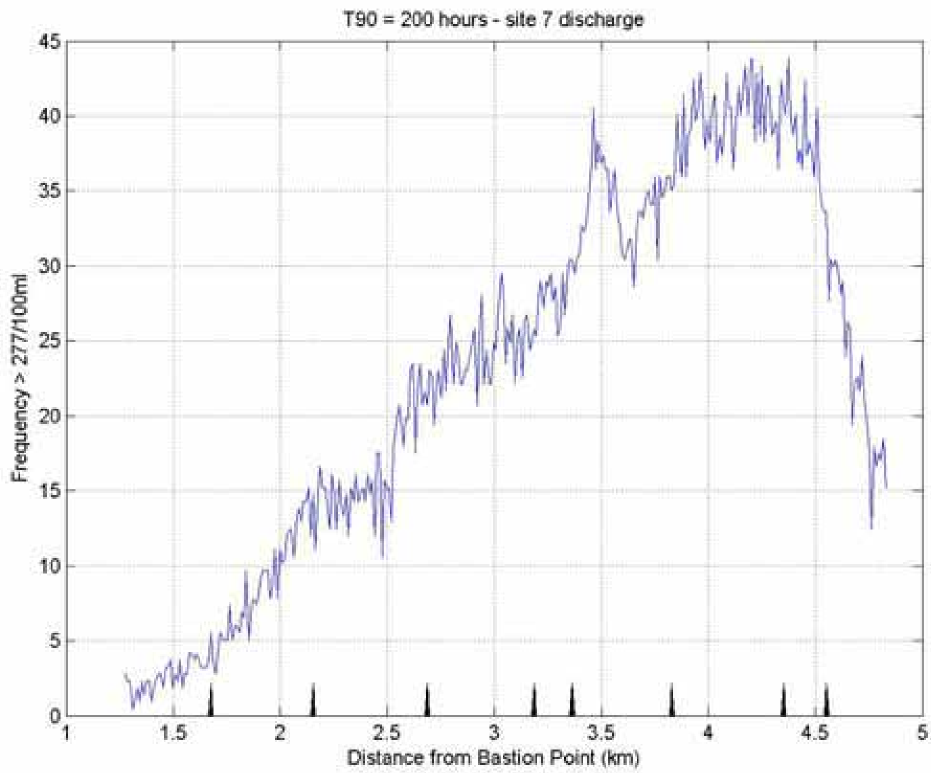
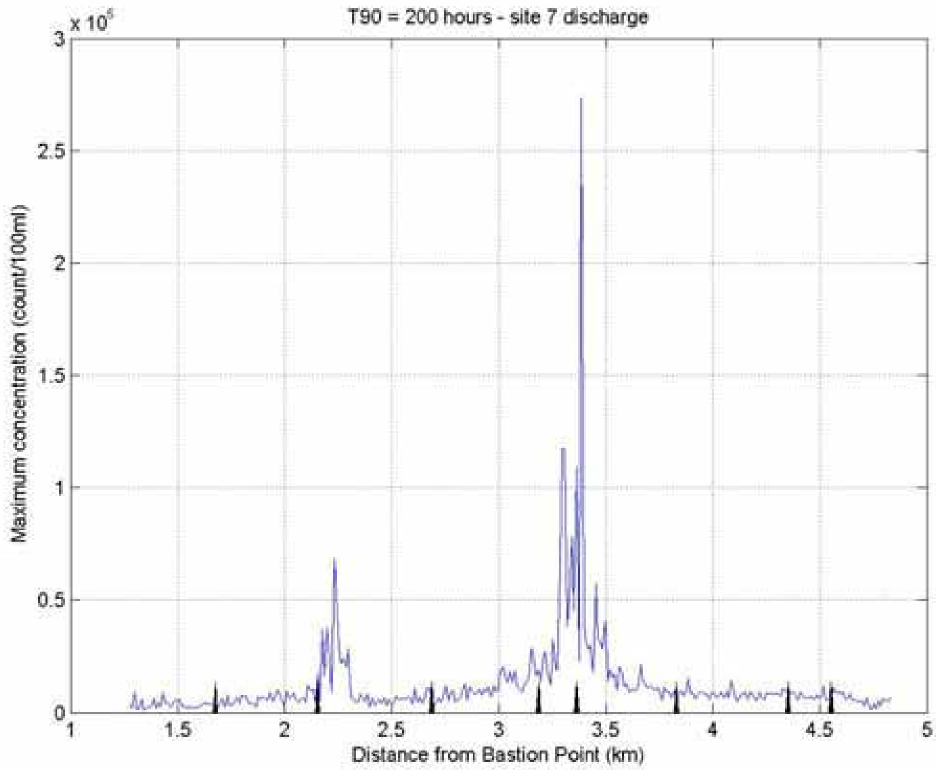


Figure 20:
Maximum enterococci concentration in the top 0.5 m surface layer at the waters edge for the duration of the storm event of May 2nd 2001. (T_{90} = 200 hours). Discharge from outfall 7 only. Discharge locations 3 to 10 (from left to right) are shown as black lines along the x-axis



5.2.2 Multiple outfall simulations

The following set of results show the enterococci concentrations for the same storm event (2nd May 2001) but with the catchment-scaled discharges occurring from all ten outfalls. Figure 21 shows the maximum enterococci concentrations at any time for each cell during the 5-day simulation and the distribution of maximum concentration values, with Figure 22 showing the percentage of time enterococci concentrations are greater than 100/100 ml. Figures 23 and 24 show the percentage of time enterococci concentrations are greater than 277/100 ml at the waters edge, and the maximum enterococci concentrations at the waters edge respectively. Comparing these plots with Figures 16 to 20 above shows the importance of modelling multiple outfalls. For example, the maximum time that enterococci concentrations were greater than 277/100 ml with only outfall 7 discharging was just under 45% with the peak value occurring offshore of outfall 7 (Figure 19). With all the discharges operating the maximum time that enterococci concentrations are greater than 277/100 ml increases to just over 55% (Figure 23) and the peak value occurs 1000 m to the east of outfall 7. The absolute maximum enterococci concentration still occurs offshore of the outfall of the highest discharge at outfall 7 (and is not significantly increased) but with all discharges operating local peaks occur at each of the discharges (Figures 21A and 24). With all discharges operating the distribution of maximum enterococci concentrations (Figure 21B) has a mean enterococci concentration of 729 enterococci/100 ml and the 95th percentile value is 7887 enterococci/100 ml.

Figure 21:
(A) Maximum enterococci concentrations in the top 0.5 m surface layer from the 11.1 m grid for storm event of 2nd May 2001. (T_{90} = 200 hours). (B) Distribution of enterococci concentration. All discharges operating.

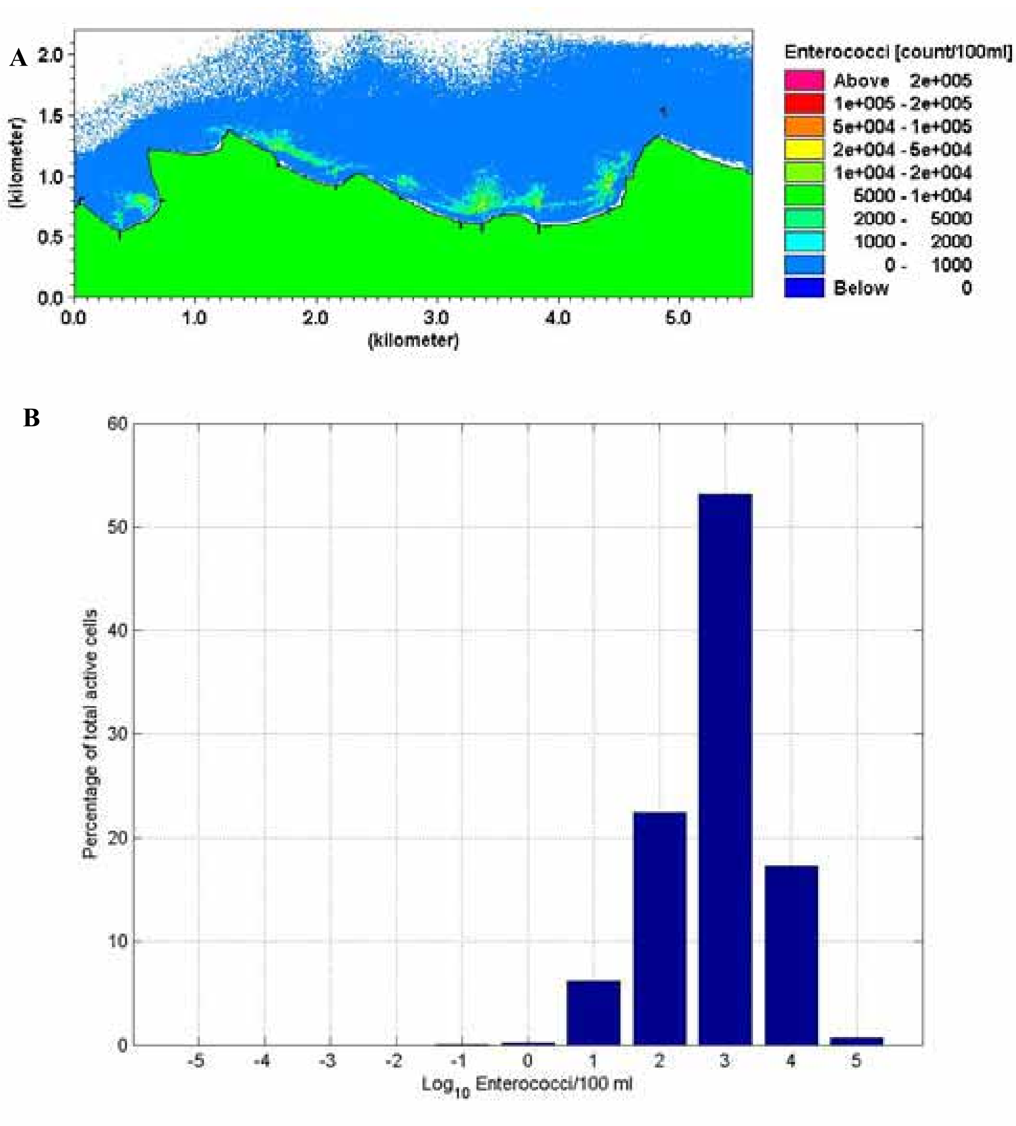


Figure 22:
Percentage of time enterococci concentrations in the top 0.5 m surface layer are greater than 100/100 ml for the storm event of 2nd May 2001 covering a period of 5-days. (T_{90} = 200 hours). All discharges operating.

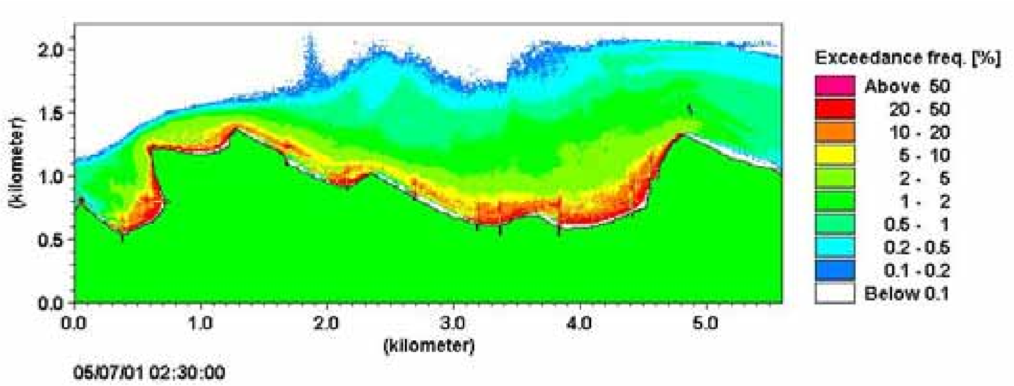


Figure 23:
Percentage of time enterococci concentrations in the top 0.5 m surface layer at the waters edge are greater than 277/100 ml for the storm event of 2nd May 2001 covering a period of 5-days. (T_{90} = 200 hours). All discharge operating. Discharge locations 3 to 10 (from left to right) are shown as black vertical lines along the x-axis.

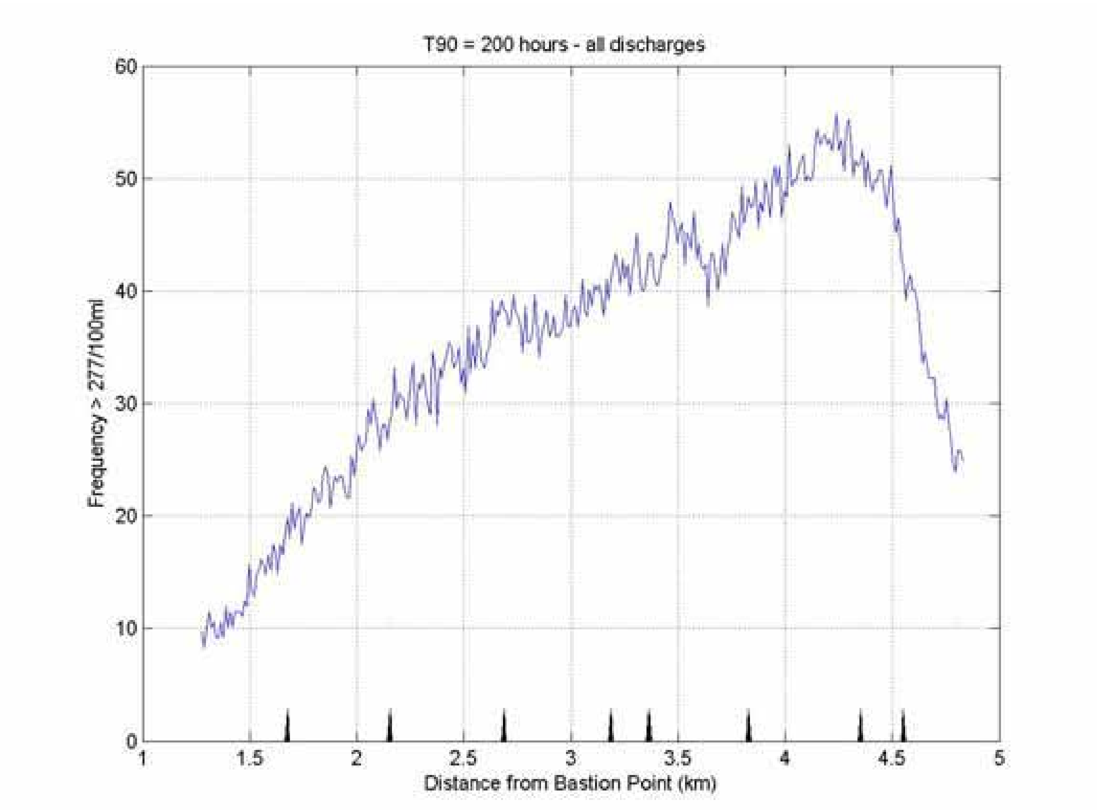
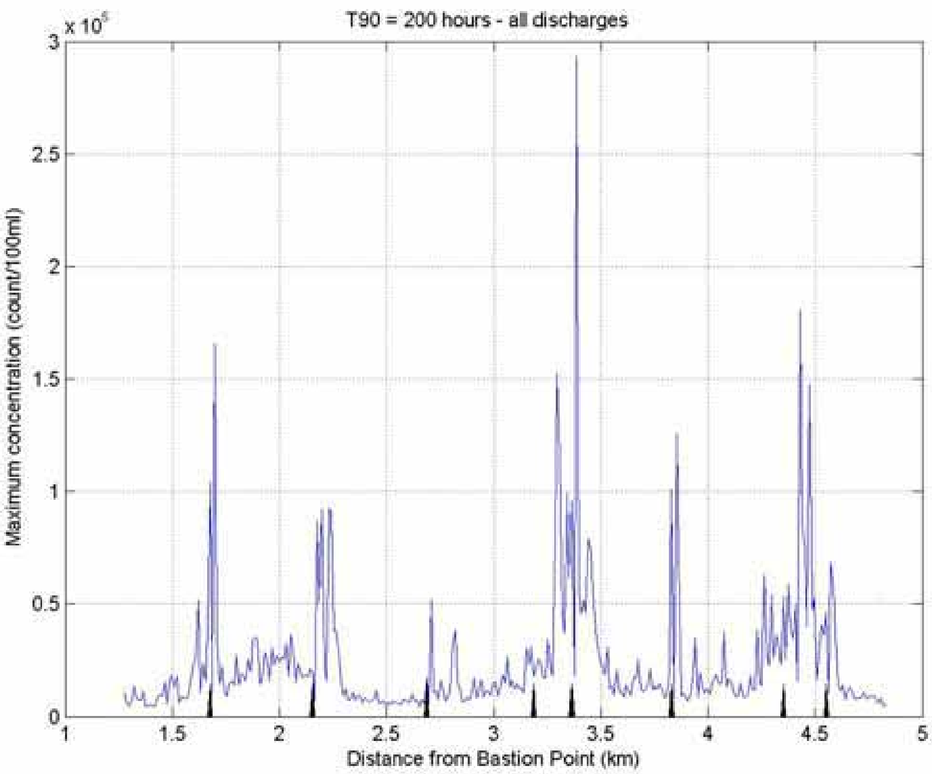


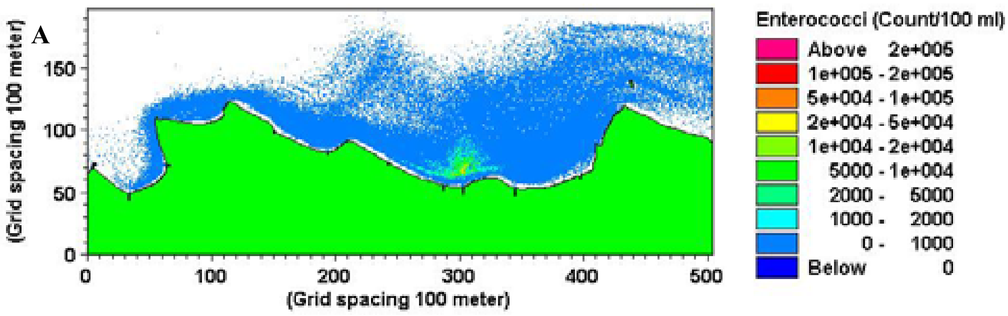
Figure 24:
Maximum enterococci concentration in the top 0.5 m surface layer at the waters edge for the duration of the storm event of May 2nd 2001 covering a period of 5-days. (T_{90} = 200 hours). All discharges operating. Discharge points 3 to10 (from left to right) are shown as black lines at the bottom of the plot.



5.2.3 Influence of decay rate on enterococci concentrations

Enterococci decay is strongly influenced by solar radiation that penetrates the water column. This section examines the role of the T_{90} value on predicted concentrations. For these runs a typical mid-summer mid-day decay rate for enterococci (T_{90}) of 2 hours was used (compared with the 200 hours relevant to night-time or highly turbid conditions used in the previous section). Figures 25 to 28 show the maximum concentrations, distribution of maximum concentrations and percentage of time enterococci concentrations are greater than 277/100 ml for the discharge from the single outfall (No. 7) for the 2nd of May 2001 storm event, with Figures 29 to 32, the corresponding figures with all ten discharges occurring. Under these conditions the maximum concentration (Figure 25A, 29A) is significantly lower than for the slow-decay simulations (65000 cf. 270000 enterococci/100 ml for single outfall simulation and 77000 cf. 293000 enterococci/100 ml for all discharges operating). For the single outfall simulations (Figure 25B) the mean enterococci value is 0.03 enterococci/100 ml and the 95th percentile value is 367 enterococci/100 ml. With all discharges operating (Figure 29B) the mean enterococci value is 0.7 enterococci/100 ml and the 95th percentile value is 1189 enterococci/100 ml. The cumulative effect of a discharge impinging on itself and also being impacted on by other discharges is less pronounced (because bacterial decay is occurring within a much shorter distance from the discharges). Consequently the maximum concentrations tend to be evenly spread over the embayment (Figure 32).

Figure 25:
(A) Maximum enterococci concentrations in the top 0.5 m surface layer from the 11.1m grid for storm event of 2nd May 2001 covering a period of 5-days. (T_{90} = 2 hours). (B) Distribution of maximum enterococci concentrations. Discharge from outfall 7 only.



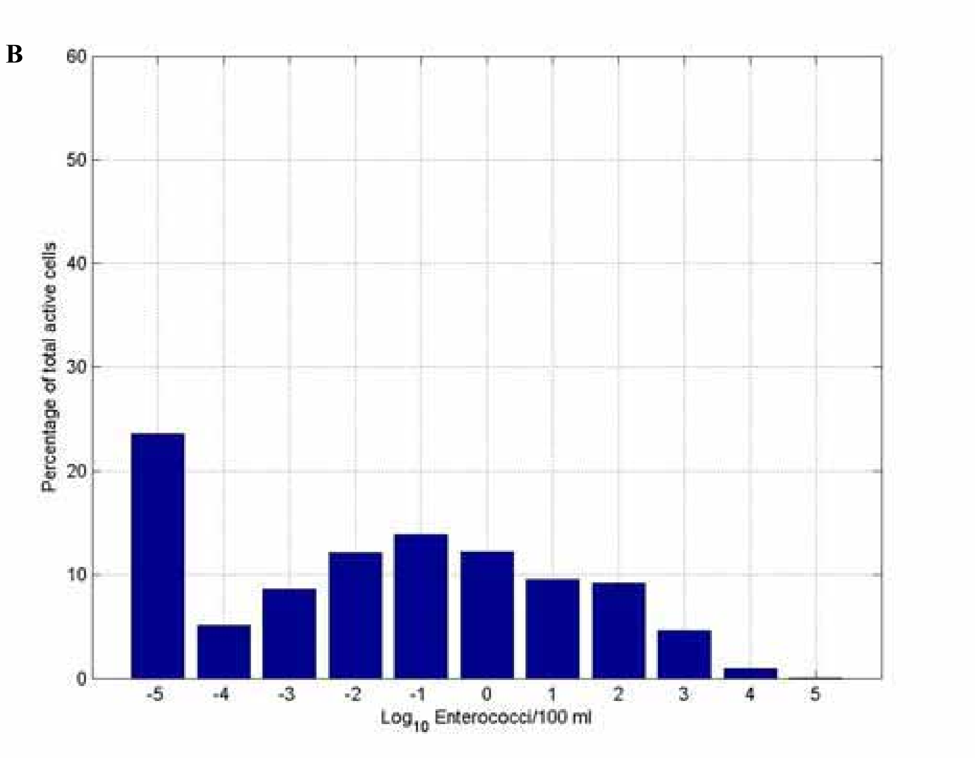


Figure 26:
Percentage of time enterococci concentrations in the top 0.5 m surface layer are greater than 100/100 ml for the storm event of 2nd May 2001 covering a period of 5-days. (T_{90} = 2 hours). Discharge from outfall 7.
only.

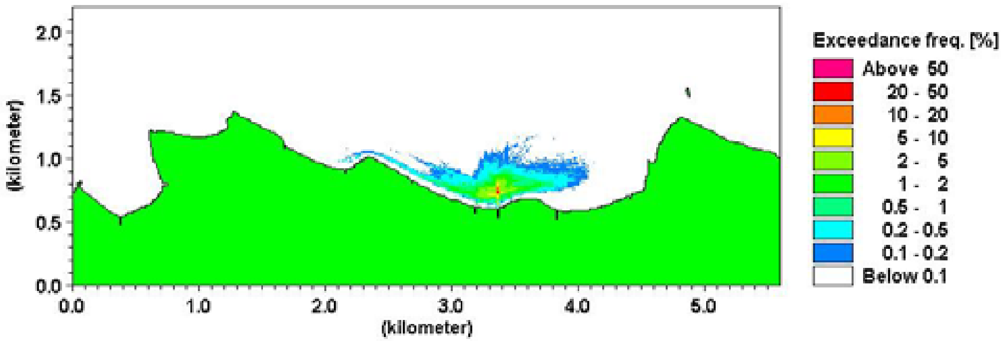


Figure 27:
Percentage of time enterococci concentrations in the top 0.5 m surface layer at the waters edge are greater than 277/100 ml for the storm event of 2nd May 2001 covering a period of 5 days. (T_{90} = 2 hours). Discharge from outfall 7 only – discharge points 3 to 10 (from left to right) are shown as black lines at the bottom of the plot.

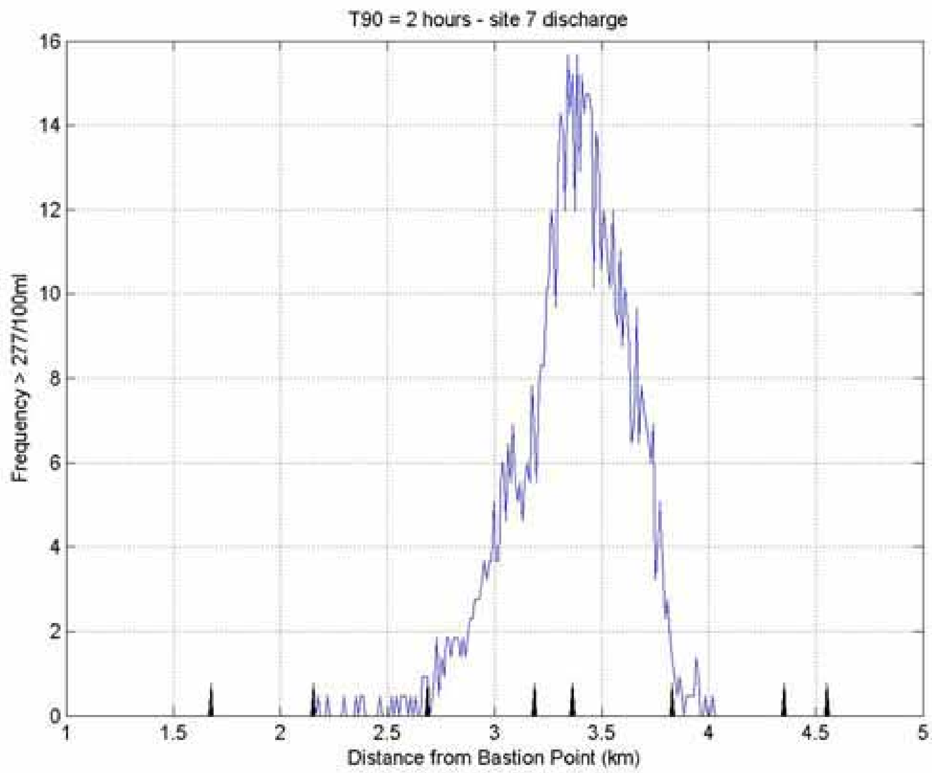


Figure 28:

Maximum enterococci concentration in the top 0.5 m surface layer at the waters edge for the duration of the storm event of May 2nd 2001 covering a period of 5-days. (T_{90} = 2 hours). Discharge from outfall 7 only - discharge points 3 to 10 (from left to right) are shown as black lines at the bottom of the plot.

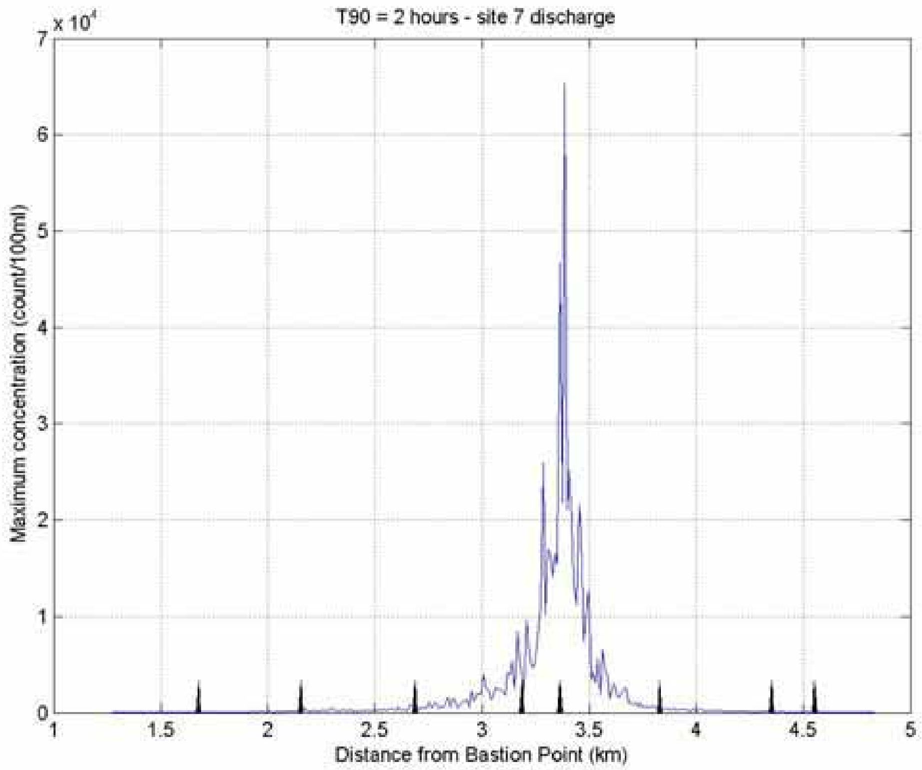


Figure 29:
(A) Maximum enterococci concentrations in the top 0.5 m surface layer from the 11.1 m grid for storm event of 2nd May 2001 covering a period of 5-days. (T_{90} = 2 hours). (B) Distribution of maximum enterococci concentrations. All discharges operating.

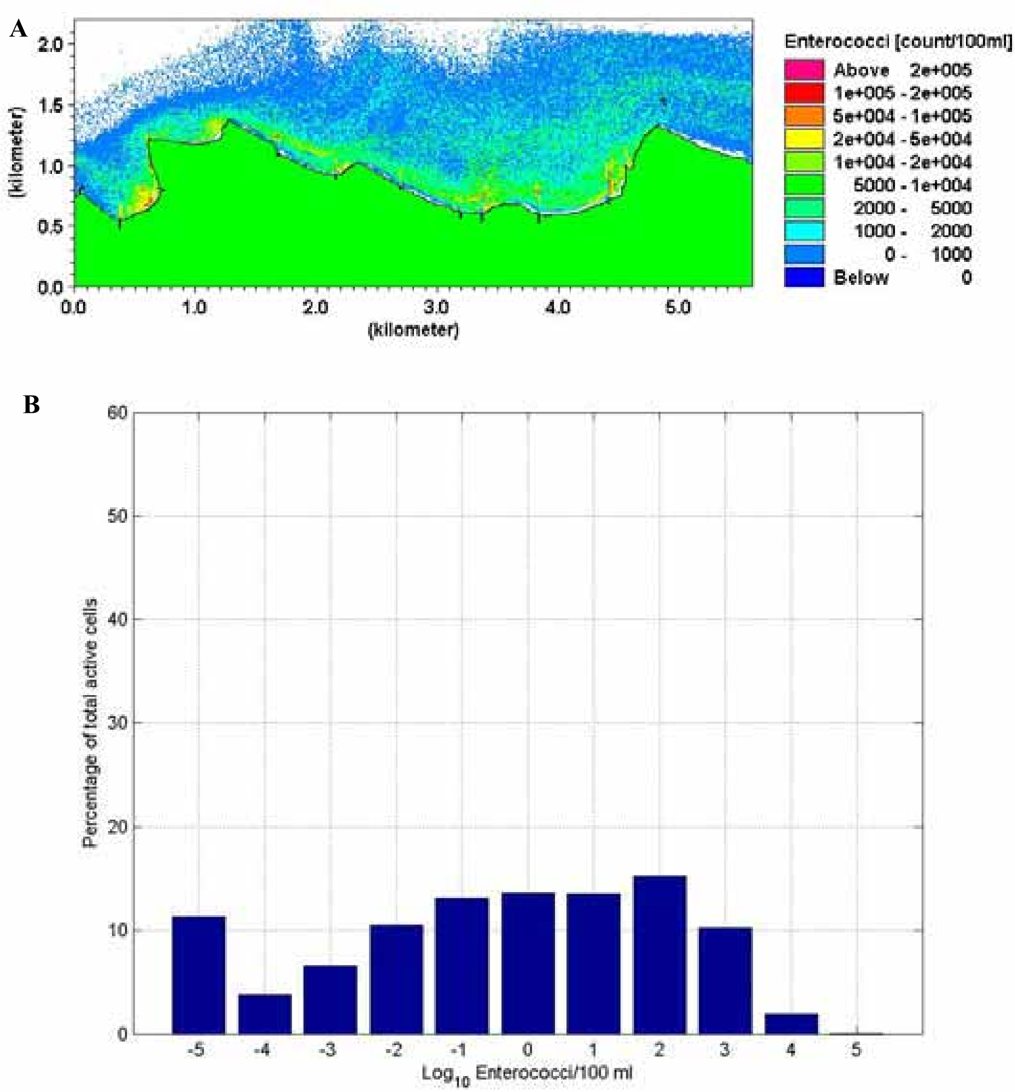


Figure 30:
Percentage of time enterococci concentrations in the top 0.5 m surface layer are greater than a count of 100/100 ml for the storm event of 2nd May 2001 covering a period of 5-days. (T_{90} = 2 hours). All discharges operating.

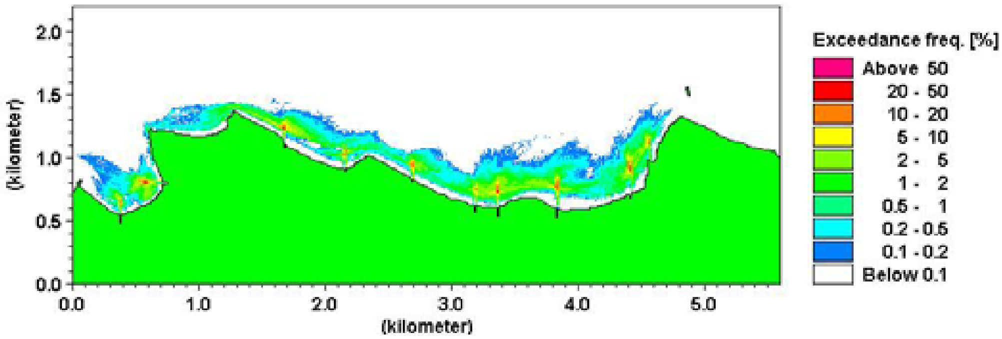


Figure 31:
Percentage of time enterococci concentrations in the top 0.5 m surface layer at the waters edge are greater than 277/100 ml for the storm event of 2nd May 2001 covering a period of 5-days. (T_{90} = 2 hours). All discharges operating – discharge points 3 to 10 are shown as black lines at the bottom of the plot.

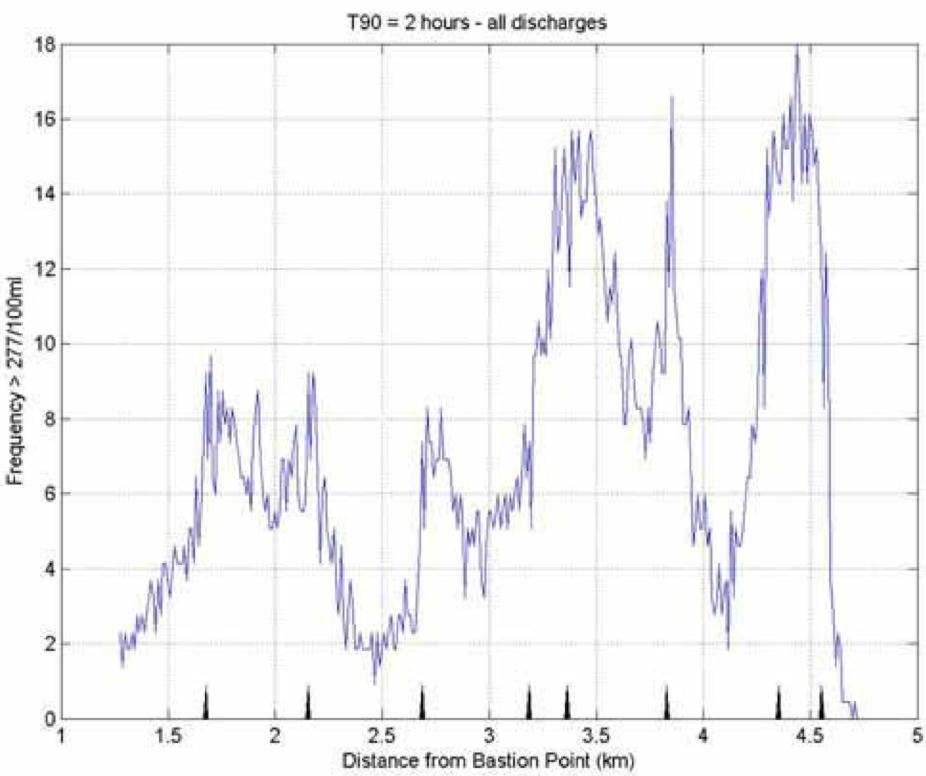
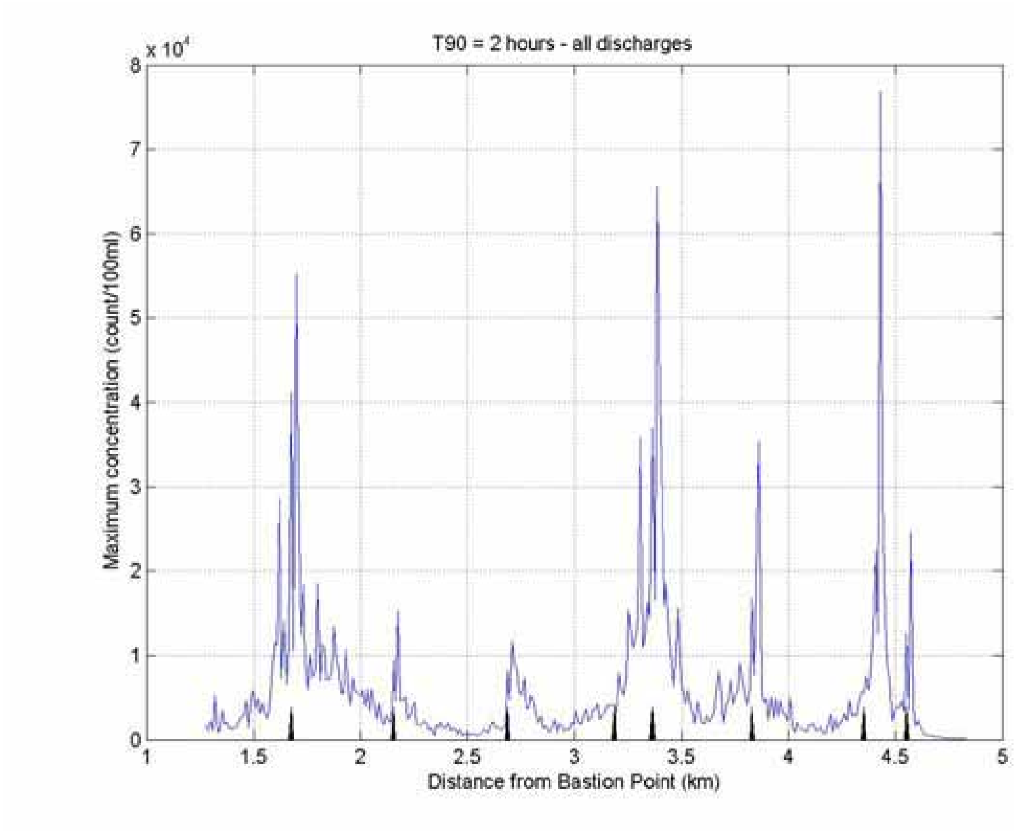


Figure 32:
Maximum enterococci concentration in the top 0.5 m surface layer at the waters edge for the duration of the storm event of May 2nd 2001. (T_{90} = 2 hours). All discharges operating. Discharge points 3 to 10 are shown as black lines at the bottom of the plot.



5.3 2nd May 2001 storm event – Suspended sediment concentrations and deposition

Using the same discharge values for the 2nd May 2001 storm event, the dispersal model was then used to simulate the dispersal, deposition and resuspension of sediments discharged from both a single, and multiple outfalls within the Eastern Bays Area. Sediment resuspension is a function of near-bed tidal currents alone - no account is taken of wave activity. The sediment particle size distribution used (Appendix 1) was derived from samples of stormwater collected from the Mission Bay monitoring site described in Section 4.2).

The same particle tracking model component of MIKE 3 (see Appendix 1 of Ramsay et al. 2004) used for the enterococci modelling was also used to model the movements of sediment discharged from the various outfalls. In this case, for each particle released into the simulation it is assigned a sediment grain size so that the overall distribution of grain size at the outfall release point matches that being delivered in the discharge. The fall velocity and resuspension of each individual particle depends upon its grain size. The model simulates the overall deposition patterns and suspended sediment concentrations.

Simulations can also be carried out using a single grain size, for example a fine-grained material associated with a particular contaminant. The overall pattern of deposition and suspended sediment concentrations is often closely related to grain size with coarser grained material tending to deposit close to the release point and the final distribution of fine-grained material tending to be over a much greater extent than coarser material.

Figures 33 and 34 how the maximum suspended sediment concentrations and depth of deposition respectively, at the end of the 2nd of May 2001 storm simulation for the discharge from outfall 7 only. The corresponding figures where discharge is occurring from all ten outfalls for the same storm event are shown in Figures 35 and 36. Maximum suspended sediment concentration of just over 0.5 kg/m^3 occur just offshore of outfall 7. East of outfall 7 maximum suspended sediment concentrations are around 0.2 kg/m^3. With all discharges operating (Figure 35) localised suspended sediment concentrations of around 0.2 kg/m^3 occur at each discharge location. Similar patterns of deposition are seen in the vicinity of outfall 7 (Figure 33 & Figure 35). A maximum deposition of 7.4 mm occurs following the storm event with just outfall 7 discharging and with all discharges operating the maximum deposition is 9.9 mm. In both cases the maximum deposition occurs just offshore of outfall 7.

Even with the very fine sand the majority of the deposition tends to occur locally with only a small portion of the discharged sediment remaining in suspension (or being resuspended) and transported away from the point of discharge. Higher flows on the outgoing tide tend to migrate sediment to the east of outfall 7. Higher localised flows in the vicinity Bastion Point (sites 3 & 4) result in a wider spread of deposition in this region.

Figure 33:
Maximum suspended sediment concentration in the top 0.5 m surface layer from the 11.1 m grid for storm event of 2nd May 2001 covering a period of 5-days. Discharge from outfall 7 only.

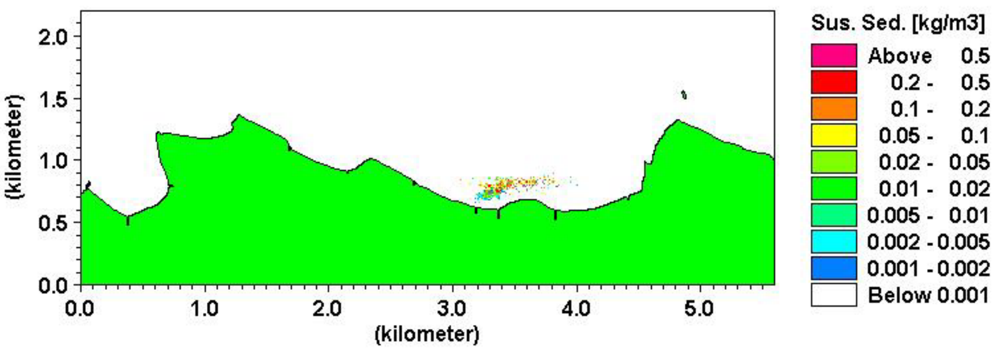


Figure 34:
Sediment deposition depth at the end of the 5-day simulation of the storm event of 2nd May 2001 covering a period of 5 days. Discharge from outfall 7 only.

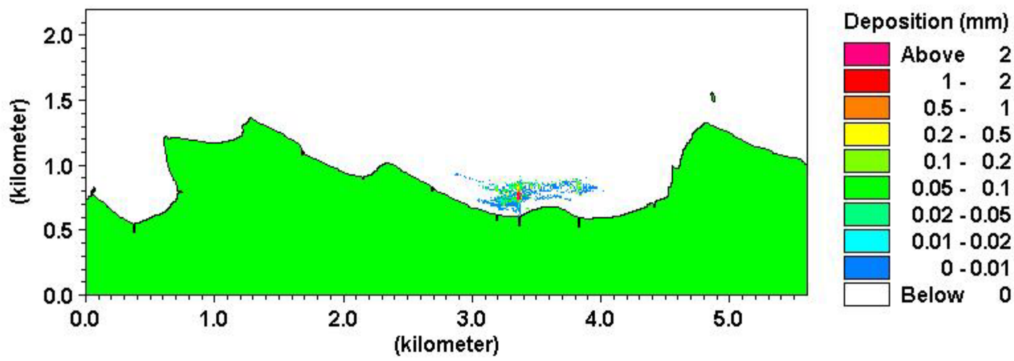


Figure 35:
Maximum suspended sediment concentration in the top 0.5 m surface layer from the 11.1 m grid for the storm event of 2nd of May 2001 covering a period of 5-days. All discharges operating.

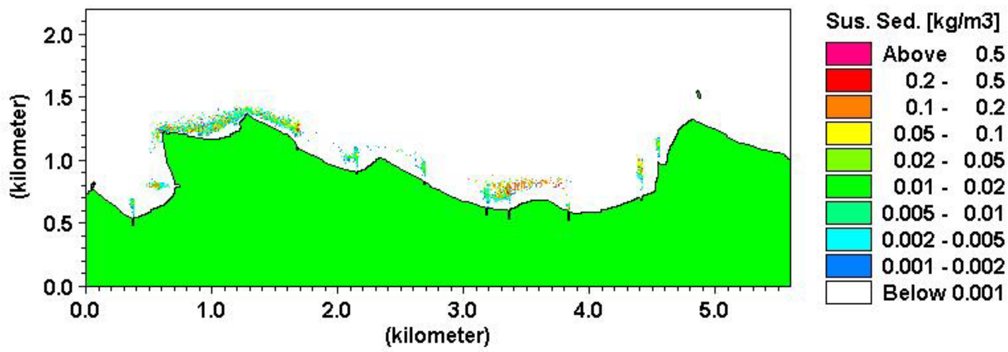
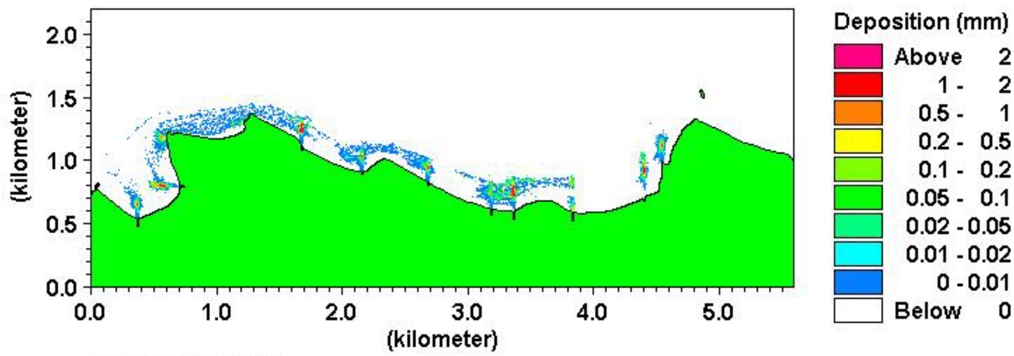


Figure 36:
Sediment deposition depth at the end of the simulation of the storm event of 2nd May 2001. All discharges operating.



5.4 Long term simulation

5.4.1 Enterococci concentrations and dispersal

In addition to simulating a single storm event, the demonstration project also included a simulation of both enterococci and sediment dispersal over a long time period, in this case 11 months (1 January 2001 to 30 November 2001) from all ten outfalls. Figures 37 and 38 summarise the percentage of time enterococci concentrations at the waters edge were above counts of 277/100 ml and the maximum enterococci concentrations reached at the waters edge respectively for typical midday summer decay rates (T_{90} value of 2 hours). Figures 39 and 40 show the corresponding figures for typical night time decay rates (T_{90} value of 200 hours).

These results show that over the long-term the percentage of time that enterococci concentrations are greater than 277 enterococci/100 ml is generally less than 3% and 10% of time for midday summer and night time decay rates compared to 15% and 40% of time for the 5-day storm event. This is a function of the proportion of time that significant loads are discharged after rainfall relative to the period of model simulation.

Estimated maximum concentrations are very similar to the single 5-day storm event with the exception of a higher concentration (110000 enterococci/100 ml cf 35000 enterococci/100 ml) at the west end of St Heliers Bay (outfall 8 at 3.8 km). For the night time decay rate simulation there tends to be higher maximum concentrations (in the range 200000-400000 enterococci/100 ml) towards the eastern end of St Heliers Bay (4-5 km). This arises due to the cumulative effect of closely-spaced storm events.

Figure 37:

Percentage of time enterococci concentrations in the top 0.5 m surface layer at the waters edge are greater than 277/100 ml for the long-term (11-month) simulation. (T_{90} = 2 hours). All discharges operating – discharge points 3 to 10 shown as black vertical lines at the bottom of the plot.

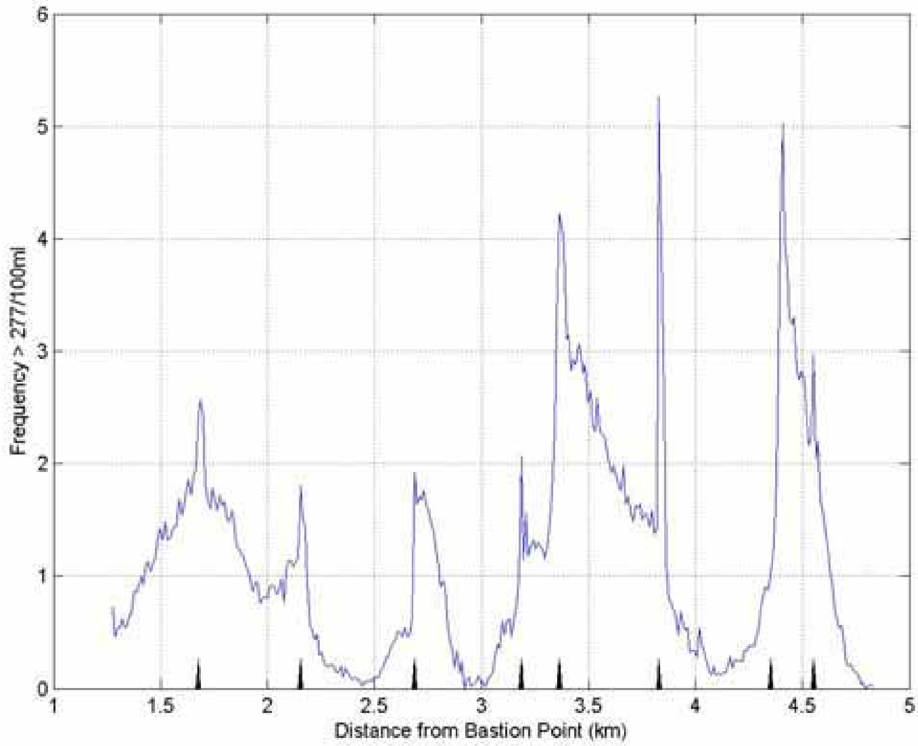


Figure 38:
Maximum concentration at the waters edge in the top 0.5 m surface layer for the duration of long-term (11-month) simulation. (T_{90} = 2 hours). All discharges operating – discharge locations 3 to 10 are shown as vertical black line at the bottom of the plot.

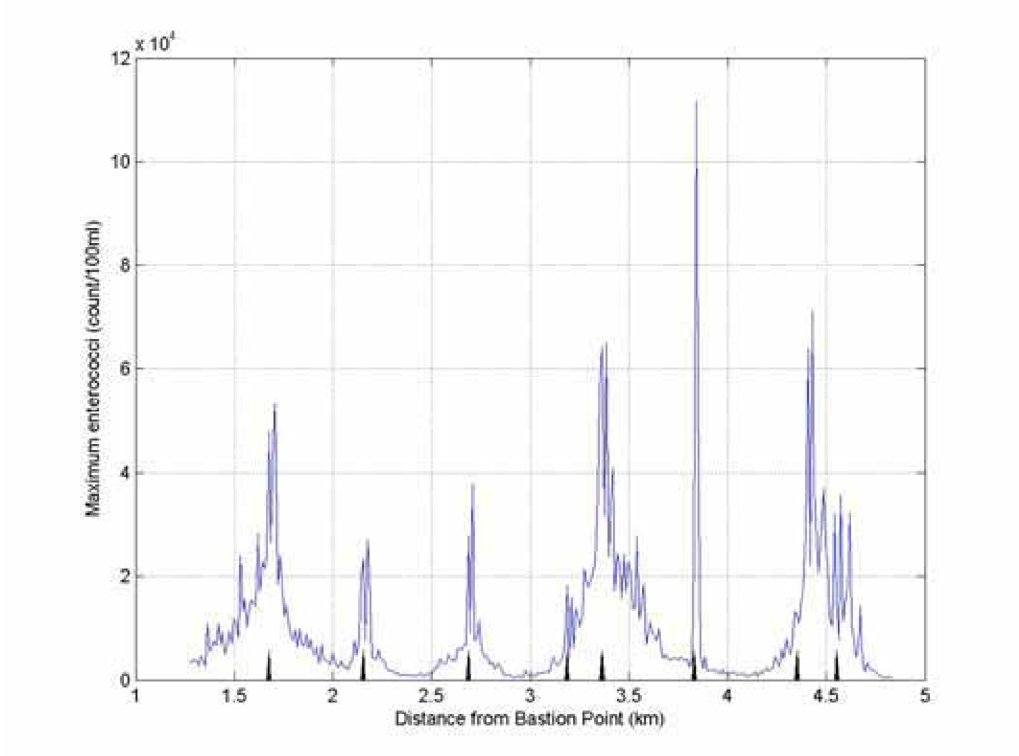


Figure 39:
Percentage of time enterococci concentrations in the top 0.5 m surface layer at the waters edge are greater than 277/100 ml for the long-term (11-month) simulation. (T_{90} = 200 hours). All discharges operating – location of sites 3 to 10 shown as black vertical lines in the figure.

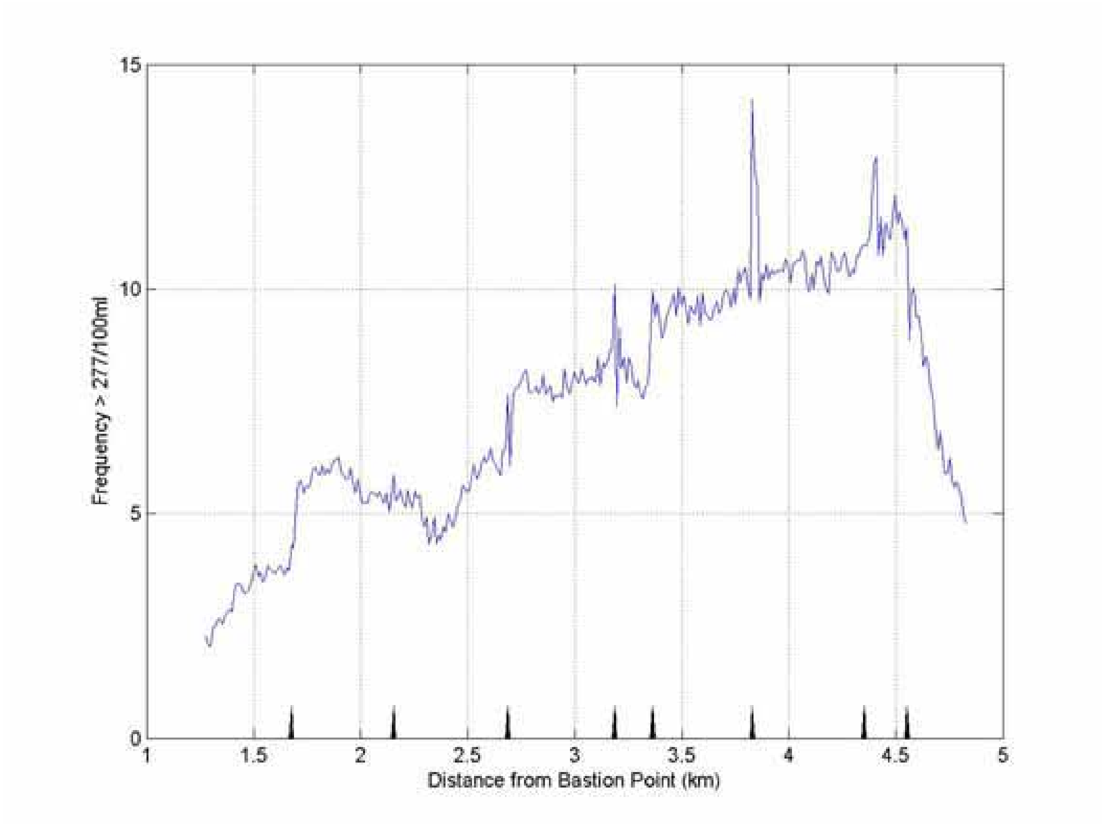
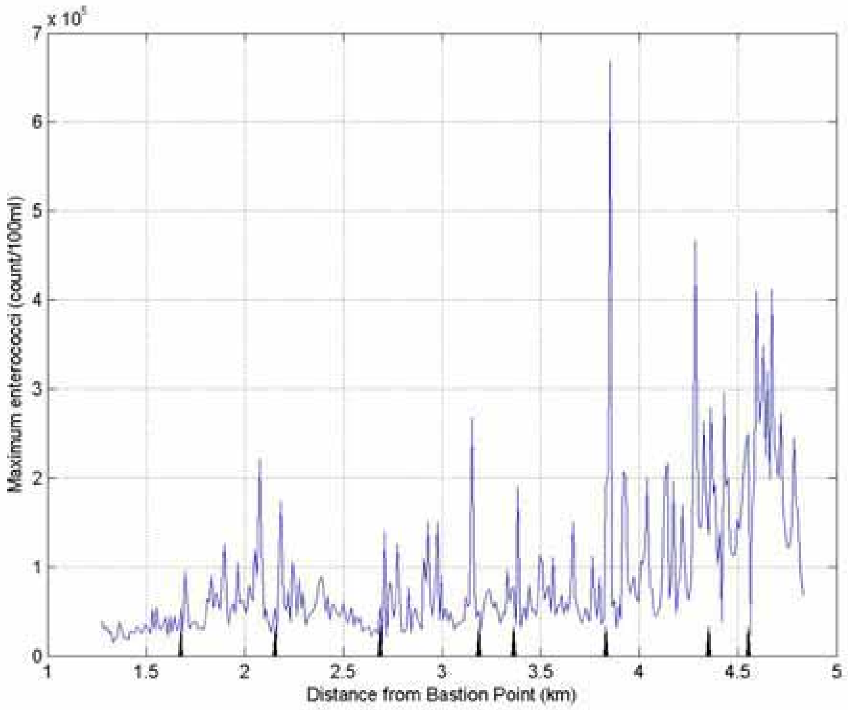


Figure 40:
Maximum enterococci concentration in the top 0.5 m surface layer at the waters edge for the duration of long-term simulation. (T_{90} = 200 hours). All discharges operating – location of sites 3 to 10 shown as black vertical lines in the figure.



5.4.2 Suspended sediment concentrations and deposition

An eleven-month simulation of dispersal, deposition and resuspension of sediments discharged from the ten outfalls within the Eastern Bays area was also conducted. We used the same discharged sediment grain-size distribution as used for the 2nd of May 2001 storm simulation (Appendix 1). Figure 41 summarises the maximum suspended sediment concentration within the top 0.5 m of the water column during the eleven-month simulation. Figure 42 summarises the total sediment deposition depth over the simulation period. Maximum suspended sediment concentration of around 0.6 kg/m^3 occur just offshore of site 7. The maximum deposition is 67 mm (compared with 9.9 mm for the single storm event) with the majority of the area where deposition occurs (3164 cells) having less than 0.5 mm of deposition. Note allowance was made for re-suspension by tidal currents but not due to wave stirring.

Figure 41:

Maximum suspended sediment concentration in the top 0.5 m surface layer for the long-term (11-month) simulation.

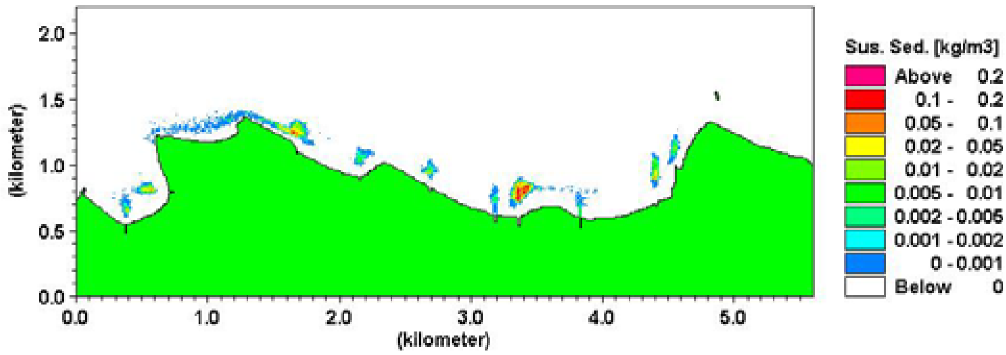
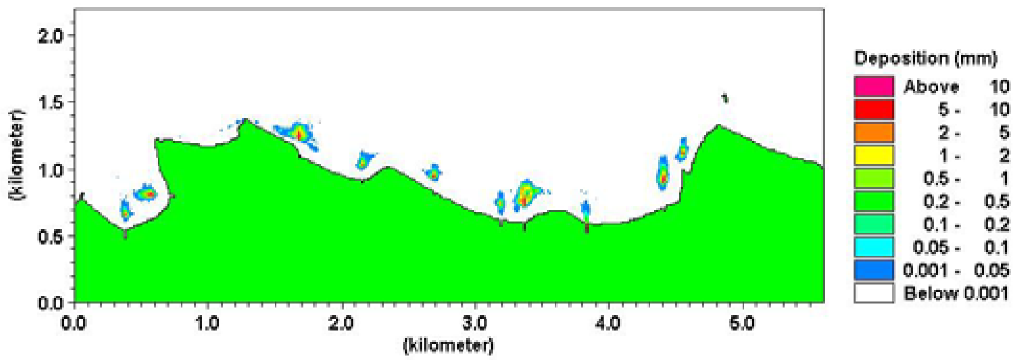


Figure 42:
Sediment deposition depth at the end of the long-term (11-month) simulation.



6 Discussion and Conclusions

6.1 Discussion of the demonstration simulations

The results presented within this project show the capabilities of the RHM to address site-specific questions at a higher resolution than the baseline study resolution of 100 m. It has been shown that overall patterns of water level fluctuations and flows are maintained on grids at 100 m, 33.3 m and 11.1 m spacing. However at the lowest resolution (largest grid cells), dilutions are over predicted (i.e. predicted concentrations are lower) due to the aggragation of the finer-scale mixing processes over large grid cells. Far-field dilutions (i.e. several 100s of metres away from sources) at the different resolutions are more closely matched, because the length scale of the dispersed plume is closer to the larger grid scale.

The underlying bathymetry of the inter-tidal areas in the region of the 11.1 m grid is relatively coarse. Therefore the gridded data while maintaining the overall shape of the inter-tidal area does not contain small-scale features which would be expected to form in the vicinity of significant discharge points. Accurate high-resolution bathymetry would improve the predicted flows, flooding and drying and subsequent dispersal in the vicinity of the outfalls.

Data for the enterococci simulations highlight the sensitivity of the results to the chosen decay rate (T_{90}). Predicted patterns of enterococci counts have been shown to vary by over an order of magnitude between typical night time and midday summer enterococci decay rates. Calibration against field data would rely on having accurate values of the discharge rate, discharge concentration and subsequent dilution of a conservative tracer (i.e. freshwater/dye) and then applying suitable bacterial decay rates throughout a daily 24-hour cycle (based on previous work or on site specific decay experiments) to match model predictions to the observed enterococci counts. As such these results should only be taken in the context of demonstrating the use of the higher resolution capabilities of the RHM

Data presented show the overall patterns of deposition and suspended sediment concentrations that could be expected to occur during a single storm-event (5-days) and in the long-term (11 months). Given the fact that the results are under-pinned by a well calibrated hydrodynamic model and use real sediment grain-size distribution data the overall patterns of deposition and sediment suspension will be relatively accurate for the storm event but become less and less accurate with the length of simulation. This is due to effects of sediment consolidation with time leading to different resuspension characteristics, layering of different fractions (i.e. coarse over-layering fine or vice-versa) of sediments during a sequence of storms, dewatering of sediment with long-term exposure during flooding and drying.

The example data presented in this report represents only a small portion of the simulated data produced by the RHM. For example, data from the various sub-surface layers within the model could be presented in much the same way as the surface data has been presented. Similarly depth-averaged data could be presented. To help visualise plume dispersal, movies can be created with data from key sites summarised (time-series, maximum values, exceedance curves) depending on the requirements of the study.

6.2 Conclusions

Two high-resolution model grids have been nested within the baseline 100-m Regional Harbour Model (RHM) as part of the initial development of the RHM to demonstrate the use of the model in assisting the assessment of environmental effects of discharges to the marine environment.

The project has been used to demonstrate:

- The effect of improved model grid resolution to better represent the spatial variation of tidal currents within localised areas of interest;
- The potential of the RHM to simulate the dispersal and concentration of a non-conservative pollutant (enterococci) from both single and multiple outfalls, during a single event and over an extended time period, under different decay rates;
- The simulation of the dispersal, deposition and resuspension of sediments discharged from both single and multiple outfalls during a single event and over an extended time period;
- Typical presentation of output results from such simulations.

7 References

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Timperley, M.H., & Reed J. (2004) Contaminants in Auckland City stormwater: Quality model development and interim estimates of city-wide loads. NIWA Client Report No HAM203-086. (DRAFT). Prepared for Auckland Regional Council.

8 Acknowledgements

The authors thank Metrowater Ltd. and Auckland City Council for making their stormwater monitoring and modelling information available for use in this project.

9 Appendix 1: Sediment grain-size distribution data (excluding bed load and floating litter)

Table A1:

Sediment grain-size distribution for Mission Bay.

Size (microns)	**Local (%)**
0.0 - 1.0	0.116
1.0 - 2.0	0.545
2.0 - 3.0	0.775
3.0 - 4.0	1.347
4.0 - 5.0	1.092
5.0 - 6.0	0.877
6.0 - 7.0	0.862
7.0 - 8.0	0.773
8.0 - 9.0	0.749
9.0 - 10.0	0.761
10.0 - 15.0	4.110
15.0 - 20.0	3.751
20.0 - 25.0	2.910
25.0 - 30.0	2.221
30.0 - 35.0	2.271
35.0 - 40.0	3.012
40.0 - 45.0	2.877
45.0 - 50.0	3.266
50.0 - 75.0	26.795
75.0 - 100.0	17.056
100.0 - 125.0	13.758
125.0 - 150.0	7.189
150.0 - 175.0	1.906
175.0 - 200.0	0.844
200.0 - 225.0	0.144
225.0 - 250.0	0

Figure A1:
Sediment grain size distribution for Mission Bay sites.