11
PLUMES DURING DISPOSAL (MAINTENANCE)

LYTTELTON HARBOUR/WHAKARAUPŌ CHANNEL DEEPENING PROJECT

Simulations of suspended sediment plumes generated from the deposition of spoil at proposed maintenance disposal grounds

Prepared for Lyttelton Port Company Limited (LPC)

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1. INTRODUCTION

Lyttelton Port Company Limited (LPC) proposes deepening of the harbour shipping channel and turning basin to accommodate vessels with increased draughts, and disposing of the dredged material at an offshore site. A full description of the Channel Deepening Project (CDP) activities, location and methodologies is provided in Section Two (Project Description) of the associated Assessment of Environmental Effects (AEE), while Figure 1.1 provides an outline of the various maintenance grounds under consideration.

LPC has commissioned MetOcean Solutions Ltd (MSL) to undertake numerical model studies to investigate the dispersion of the passive plume associated with the discharge of sediment associated with maintenance dredging activities.

The characteristics of the disposal plume dispersion expected during the capital dredging campaign were investigated in report P0201-02 (MetOcean Solutions Ltd., 2016). To accommodate the expected increase maintenance dredging volumes following the channel deepening, new disposal alternatives are needed; this report investigates the passive plume dispersion from a new proposed maintenance ground located ~3 kilometres off Godley Heads (see Figure 1.1). Disposal of maintenance dredging spoil at the proposed capital ground is also considered.

For this study, the general characteristics of the plume dispersion were investigated by simulating disposal events during discrete time periods, with hydrodynamic and atmospheric forcing conditions typical of the disposal ground region. To produce robust probabilistic estimations of expected plume dispersion and deposition patterns, these short-term event-based simulations were supplemented by longer term numerical simulations of dredge spoil disposal over an annual period. Several reference sites were selected within the disposal grounds to allow a characterisation of spatial variation of dispersion processes across the disposal ground. In reality, spoil is proposed to be spread throughout the disposal ground in order to both distribute the sediment as evenly as possible within the disposal ground, and otherwise to managed disposal so as to minimise the potential excursion of associated plumes. A representative sediment grain size distribution based on the sediment expected to be dredged from the shipping channel was defined and used in the plume simulations.

The report is structured as follows; Section 2 briefly outlines details of the simulations undertaken. Results are provided in Section 3 and a summary of the work is provided in Section 4. References cited are listed in the final Section.

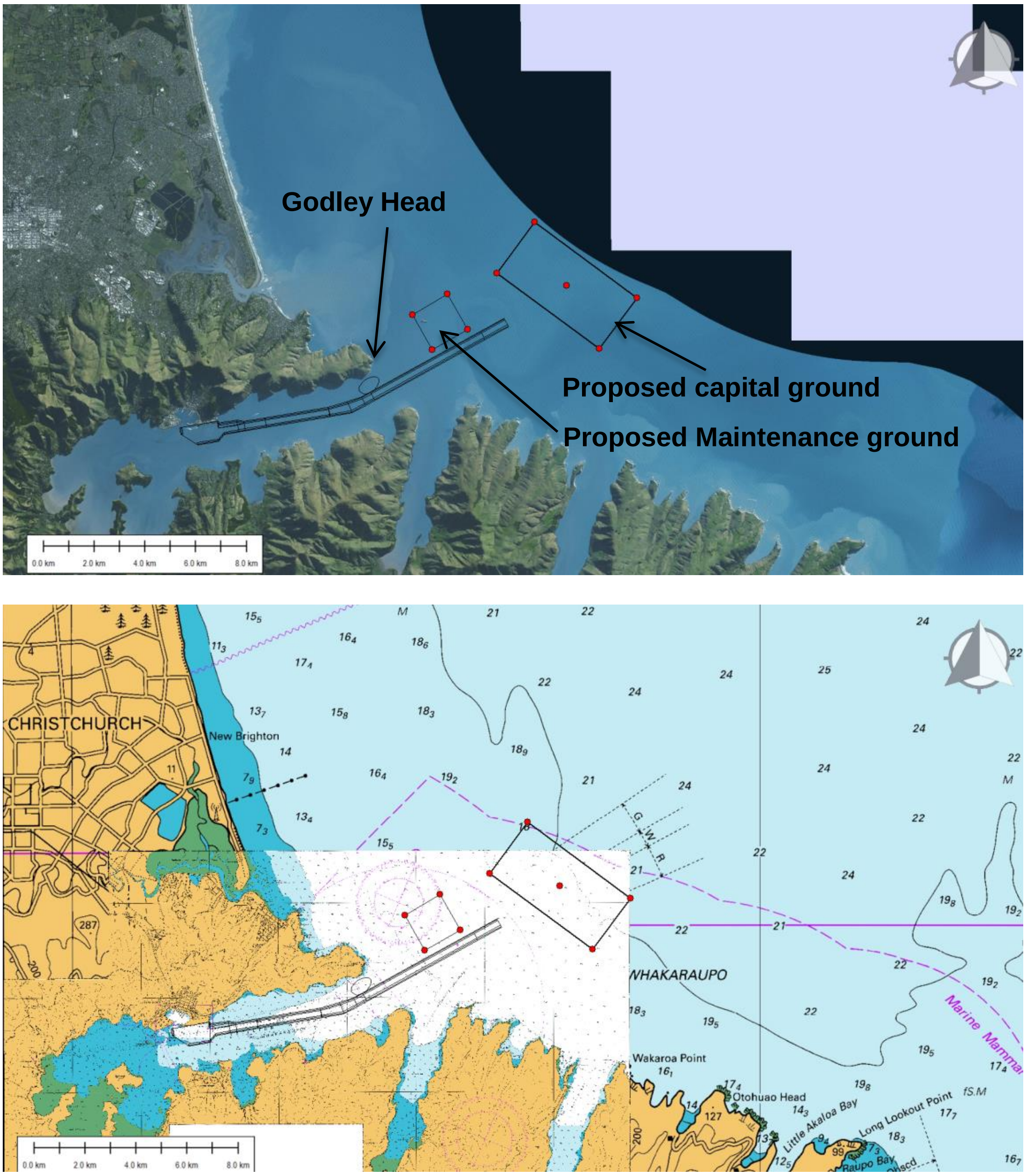


Figure 1.1 Footprints of the new proposed shipping channel and offshore disposal grounds for the capital and maintenance dredging campaigns. Release sites considered in the disposal simulations are shown in red. The proposed maintenance ground is located ~3 km off Godley Heads, and extends 1.6 km by 1.6 km (2.56 km^2). The proposed capital ground is located ~8 km off Godley Heads and extends 5 km by 2.5 km (12.5 km^2).

2. METHODS

A full description of the parameters, general methods and modelling approaches employed to generate the source historical hydrodynamic flow fields and simulate the dispersal of disposed sediment is included in the report P0201-02 (MetOcean Solutions Ltd., 2016), and as such is not repeated here.

This study is concerned with the disposal of sediment resulting from the maintenance dredging of the new channel. Most of the sediment is expected to be directed to a new “maintenance ground”, and this is the primary scenario modelled. The operational limits of the proposed maintenance dredger potentially allow sediment to be discharged at the proposed capital ground, and subsequent analysis of discharging maintenance material at the offshore capital disposal ground has been included in this report (see Figure 1.1). The disposal of sediment was therefore simulated at five representative positions within both the proposed maintenance and capital grounds (see Figure 1.1, and Table 2.1 - Table 2.2).

The details of the Mahury dredger (Figure 2.1) that is proposed to be used for the maintenance dredging are provided in Table 2.3. Source term magnitudes and release depths considered in the simulations are included in Table 2.4.

Table 2.1 Release sites with the maintenance dredging ground. Co-ordinates are given in WGS84

	Longitude	Latitude
Maint 1	172.8409	-43.5737
Maint 2	172.8278	-43.5710
Maint 3	172.8449	-43.5638
Maint 4	172.8548	-43.5763
Maint 5	172.8376	-43.5835

Table 2.2 Release sites with the capital dredging ground. Co-ordinates are given in WGS84

	Longitude	Latitude
Site 1	172.8690	-43.5563
Site 2	172.8875	-43.5383
Site 3	172.9187	-43.5832
Site 4	172.9372	-43.5651
Site 5	172.9031	-43.5607

Table 2.3 Details of the dredging vessels likely to be used for dredging and disposal works.

Vessel	Hopper load [m^3]	Draught [m]	Disposal cycle [hours]
Mahury	1840	-4.0	1.5

Table 2.4 Source terms and release depths.

Sources Terms	Percent of hopper volume	Release depth	Release type
Surface losses	1%	sea-surface to vessel draught	point source
De-entrained during descent	5%	vessel draught	point source
Density current	21%	2 m layer above seabed	300 m radius circle

Figure 2.1 The Mahury trailer suction hopper dredge (TSHD).

3. RESULTS

This section presents the key results of the various simulations of sediment disposal at the proposed maintenance and capital offshore disposal grounds for the discharge of maintenance dredge material.

The first section 3.1 outlines the sequential plume dispersion patterns following disposal under typical forcing conditions at the sites.

The probabilistic estimations of the mean *SSC* plume and deposition footprints derived from the annual hindcast simulations are described in the second section 3.2.

The third section 3.3 includes estimations of percentage of time several representative *SSC* thresholds are exceeded during typical summer and winter periods. These estimates can be used for ecological impact assessment.

3.1. Disposal plumes during typical events

As a first approach, discrete disposal events were simulated during time periods subject to hydrodynamic and atmospheric forcing typical of the site. Timing of events are given in Table 3.1, while Figure 3.1 provides the annual wind and current speed time-series. Predicted *SSC* plume dispersions during a 60-minute window are included in Figure 3.2 to Figure 3.4 for events with strong northwest current, strong southeast current and strong northeast wind and waves, respectively. The 60-minute window allows sufficient time for the majority of the disposed sediment to settle out of suspension.

The disposal of the hopper load initially results in relatively large *SSC* levels in the bottom layer that are associated with the density current, driven by the dynamic collapse of the dense sediment jet at the seabed. The bottom *SSC* plume spreads within a circular radius of ~300 m as prescribed by the near-field modelling undertaken by HR Wallingford for the disposal of capital dredging at the offshore site (Spearman pers. comm.) and is expected to initially consist of 21 % of the total hopper volume. These assumptions are considered to be conservative for the shallower depths at the proposed maintenance ground. The smaller and more compact *SSC* plumes in the mid-water and surface layers are associated with the de-entrainment of sediment from the dynamic plume during the descent of dense sediment “jet” (~5 % of total hopper volume) and losses near the surface (1%).

The sediment that is suspended in the water column through this initial phase is then subject to advection by the ambient currents, as well as diffusion (i.e. passive dispersion phase). In all three cases, dispersion directions are consistent with the ambient current forcing. In the bottom layer, the *SSC* plume is driven by the near-bed currents but sediment will deposit relatively quickly given the proximity to the seabed. In general, during these energetic events, most of the circular near-bed *SSC* component of the passive plume will settle within 500 metres of the release site in the 30-45 minutes following disposal. After 45 minutes the *SSC* plumes are very compact in the three depth layers and essentially consist of the residual suspended sediment that settled from the surface to mid-water layers or from the mid-water to bottom layer. The concentration fields at 120 and 180 minutes show no significant *SSC* plumes in the surface or mid-water layers with only very limited *SSC* patches in the bottom layer due to settling from the upper levels.

While dispersion during energetic events provide insights of the largest potential plume dispersions, simulations of sediment disposal during calm conditions can be used to examine the potential maximum *SSC* in the vicinity of the disposal site (i.e. limiting the excursion extent of consecutive discharges).

To provide a picture of the absolute worst case scenario with respect to the possible *SSC* levels in the ground vicinity, three successive hopper load disposals at the same site were simulated during calm conditions (current speed less than 0.05 $m.s^{-1}$ and wind speed less than 10 knots) (Figure 3.5 to Figure 3.7). At the proposed maintenance ground a disposal cycle of 1.5 hours was simulated, compared to a two hours cycle for the proposed capital disposal ground i.e. for the capital disposal ground actual disposal events occur at T+0, 120 and 240 minutes (i.e. top plots in Figure 3.5 to Figure 3.7).

Overall dispersion distances are expectedly increased relative to the strength of the current events. As mentioned above, the majority of the initial bottom *SSC* plume settles to the seabed within ~30 minutes. *SSC* levels in the bottom layers are then sequentially increased during transfer of suspended sediment from the surface and mid-depth layers (e.g. after 90 minutes) to the bottom layer, or the next disposal event (e.g. after 120 minutes). *SSC* plumes in the surface and mid-depth layers are initially very compact and relatively spread as they settle within the water column due to advection as well as diffusive processes.

The *SSC* plumes with the most significant extents and concentration magnitudes are consistently found in the bottom layer. However, the present simulations suggests that even under very unfavourable disposal conditions (i.e. low dispersion potential and same disposal site), *SSC* levels will typical drop below 100-200 $mg.L^{-1}$ within 1 km of the disposal location.

Table 3.1 Summary of simulation periods

Disposal simulations	Period
Strong southeast-directed current	07/06/2010-12:30
Strong northwest-directed current	01/08/2010-12:30
Large northeast wind/wave event	12/05/2010-18:30
Calm period	11/02/2010 0:00
January & August months (summer/winter)	01/2010 and 08/2010
10 year hindcast	2003-2012

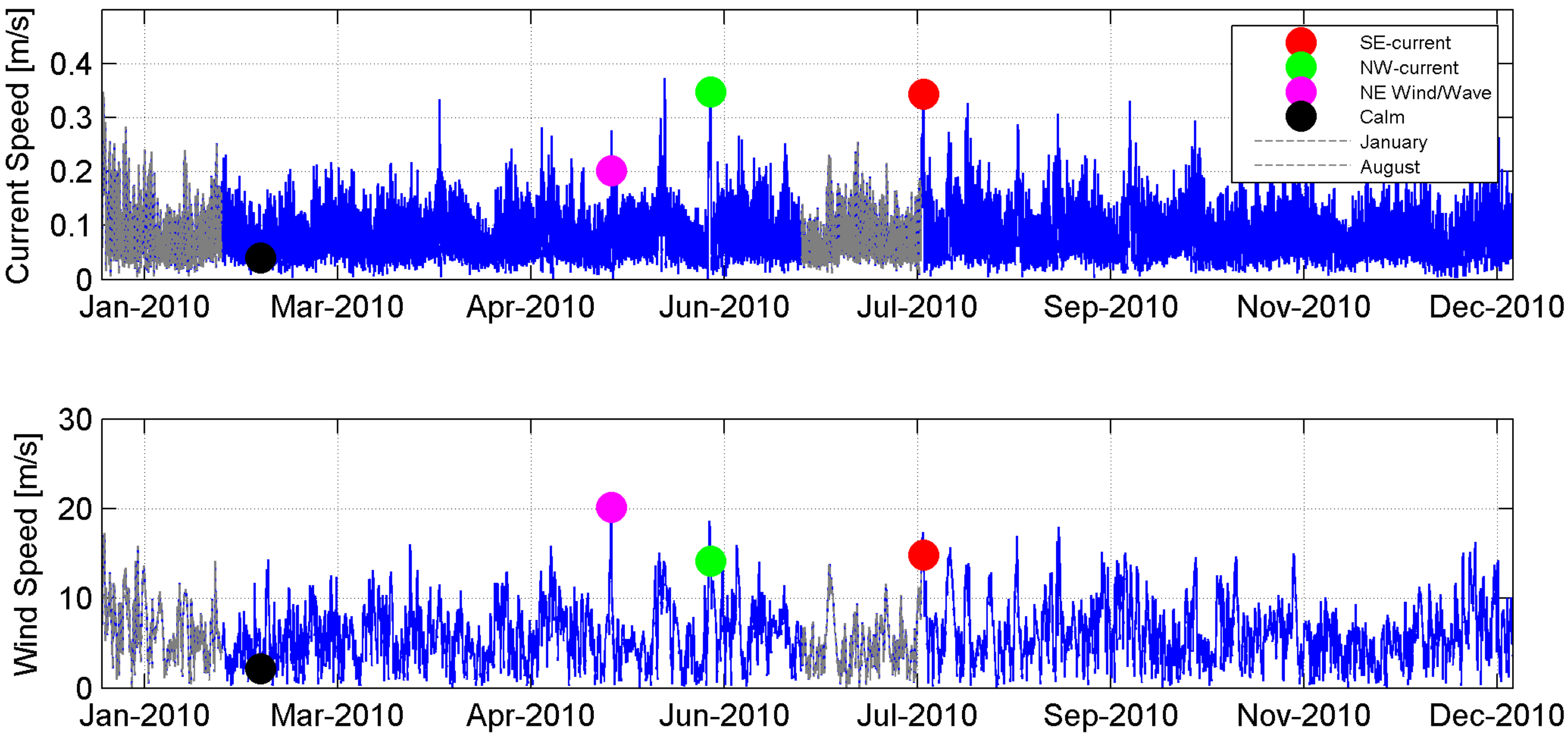


Figure 3.1 Time series of current and wind speed at the centre of the disposal site during 2010. The simulations periods are indicated as coloured dots and dashed lines. Coloured circles and greyed time-series lines show the discrete event simulated, as given in Table 3.1

Northwest Current

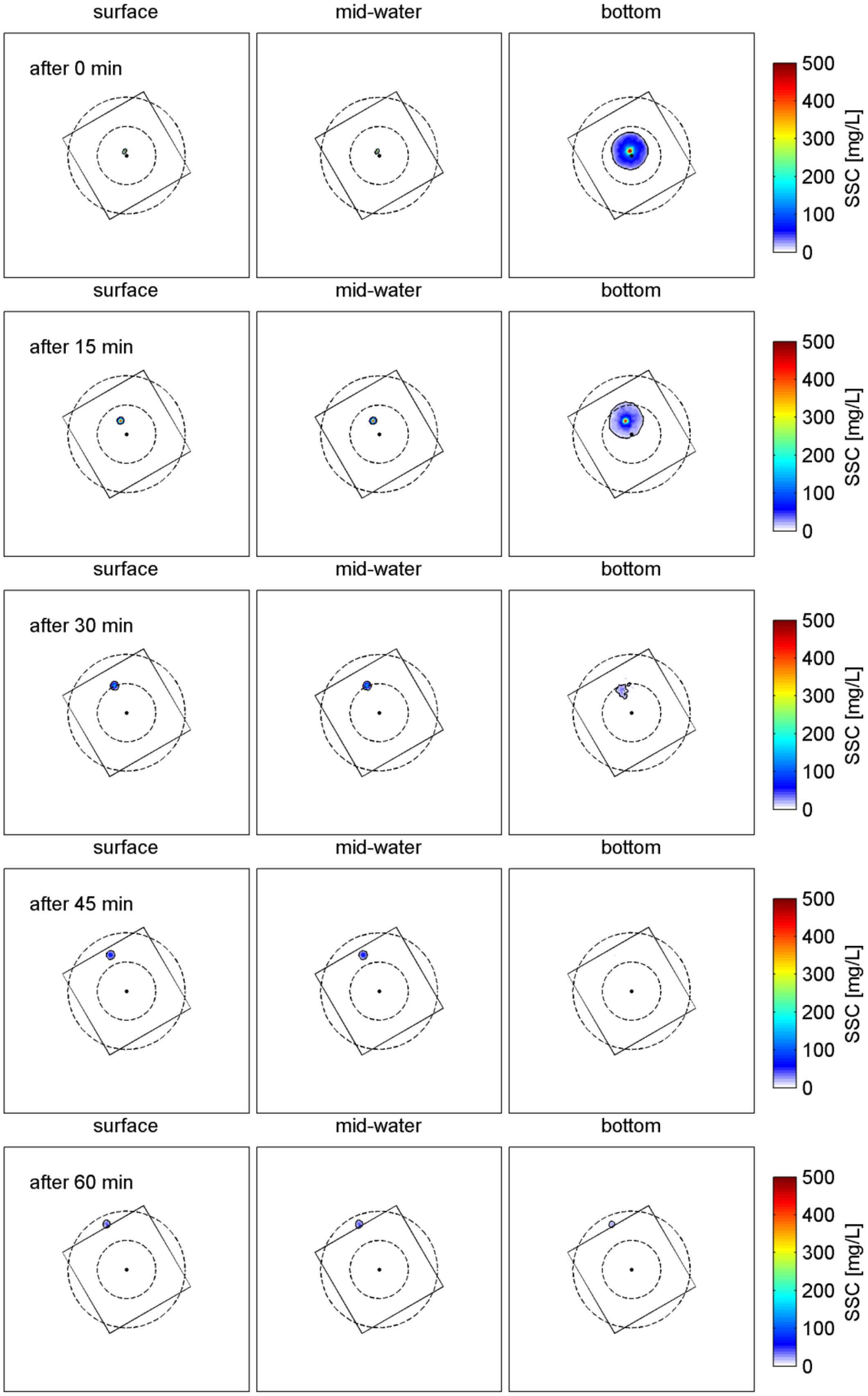


Figure 3.2 Disposal of one load of the Mahury vessel (V=1,840 m^3) at site Maint5 during strong northwest currents. Dashed circles have radiuses of 500 and 1000 m.

Southeast current

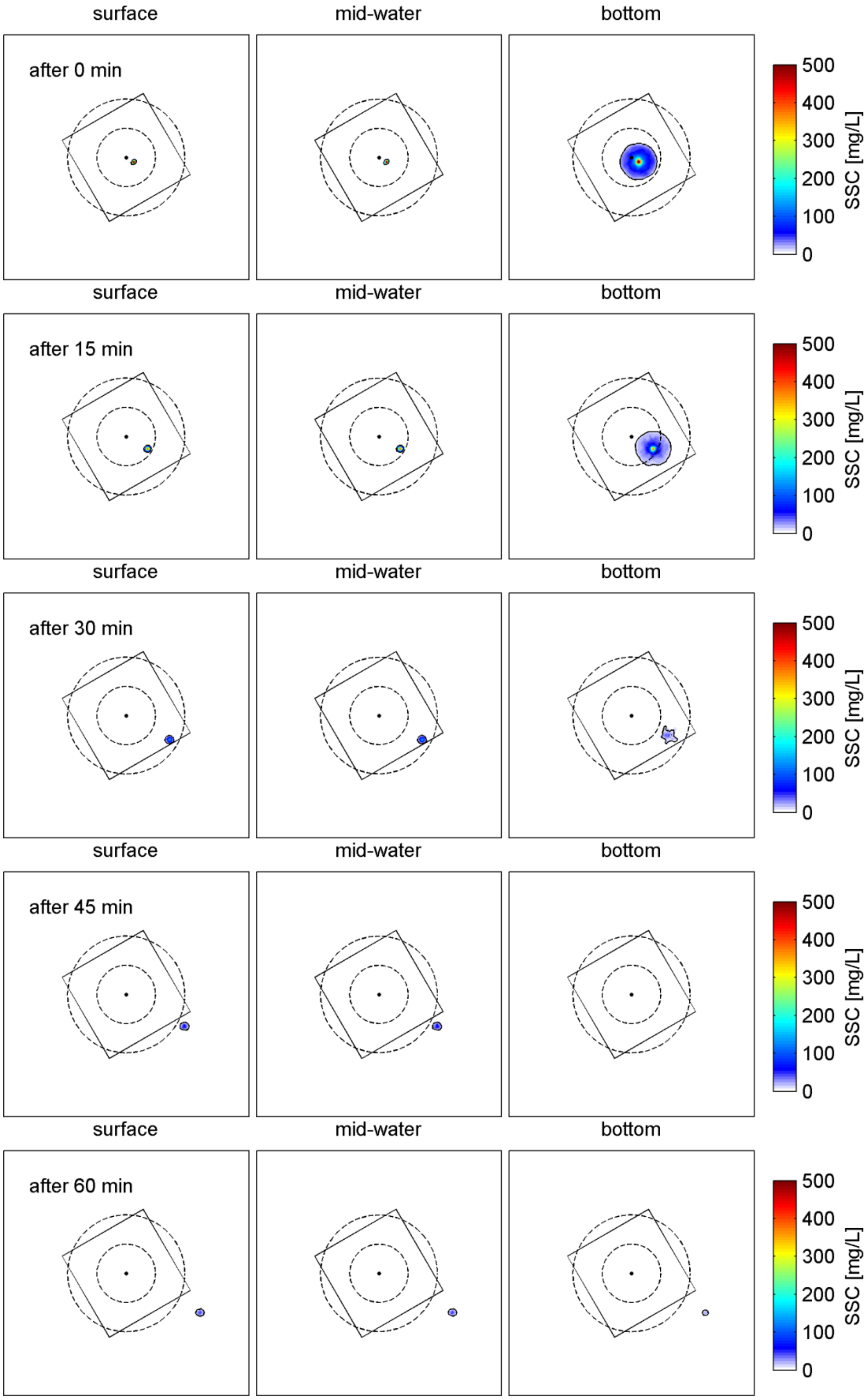


Figure 3.3 Disposal of one load of the Mahury vessel (V=1,840 m^3) at site Maint5 during strong southeast currents. Dashed circles have radiuses of 500 and 1000 m.

Northeast winds

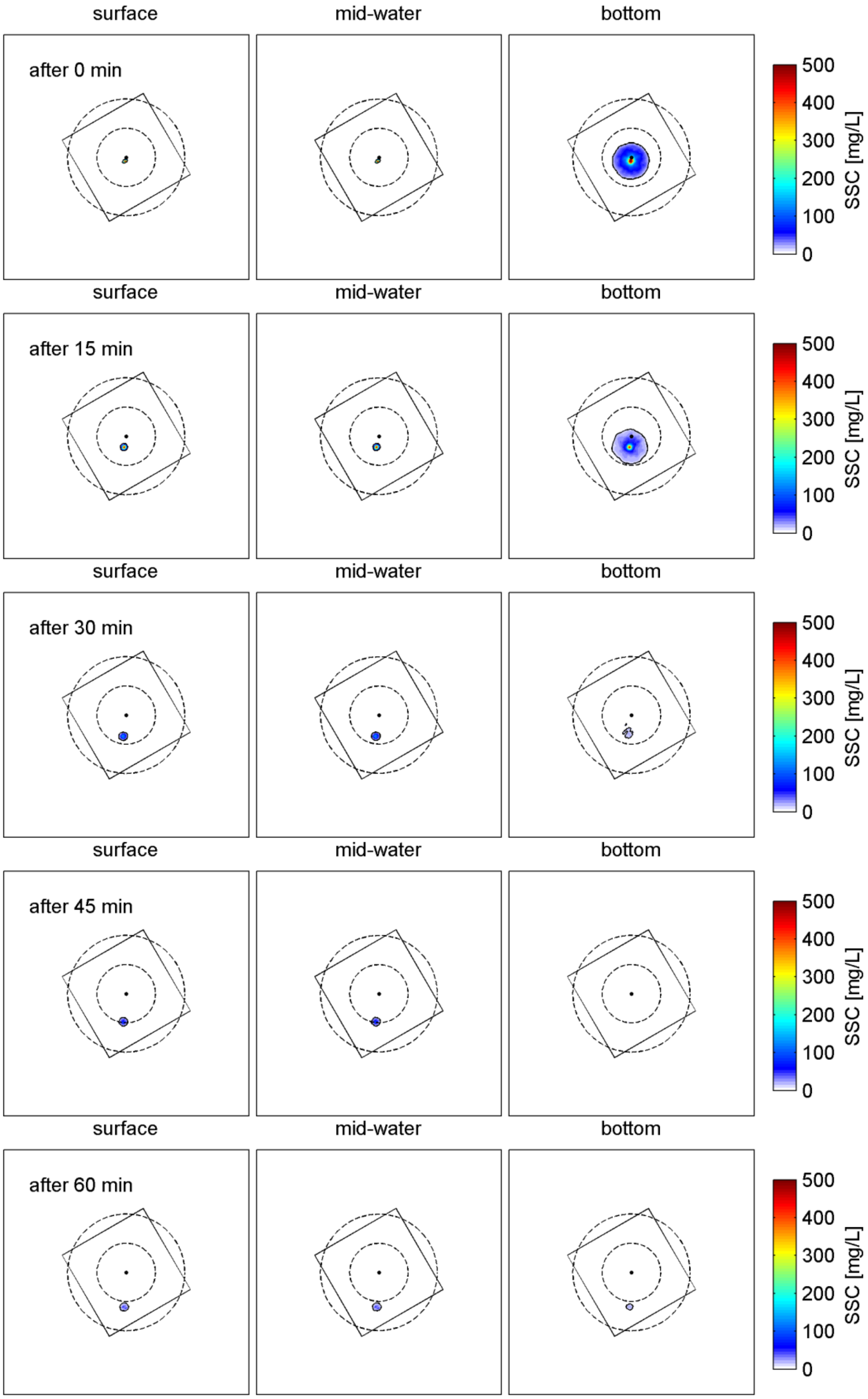


Figure 3.4 Disposal of one load of the Mahury vessel (V=1,840 m^3) at site Maint5 during strong northeast winds. Dashed circles have radiuses of 500 and 1000 m.

Calm conditions

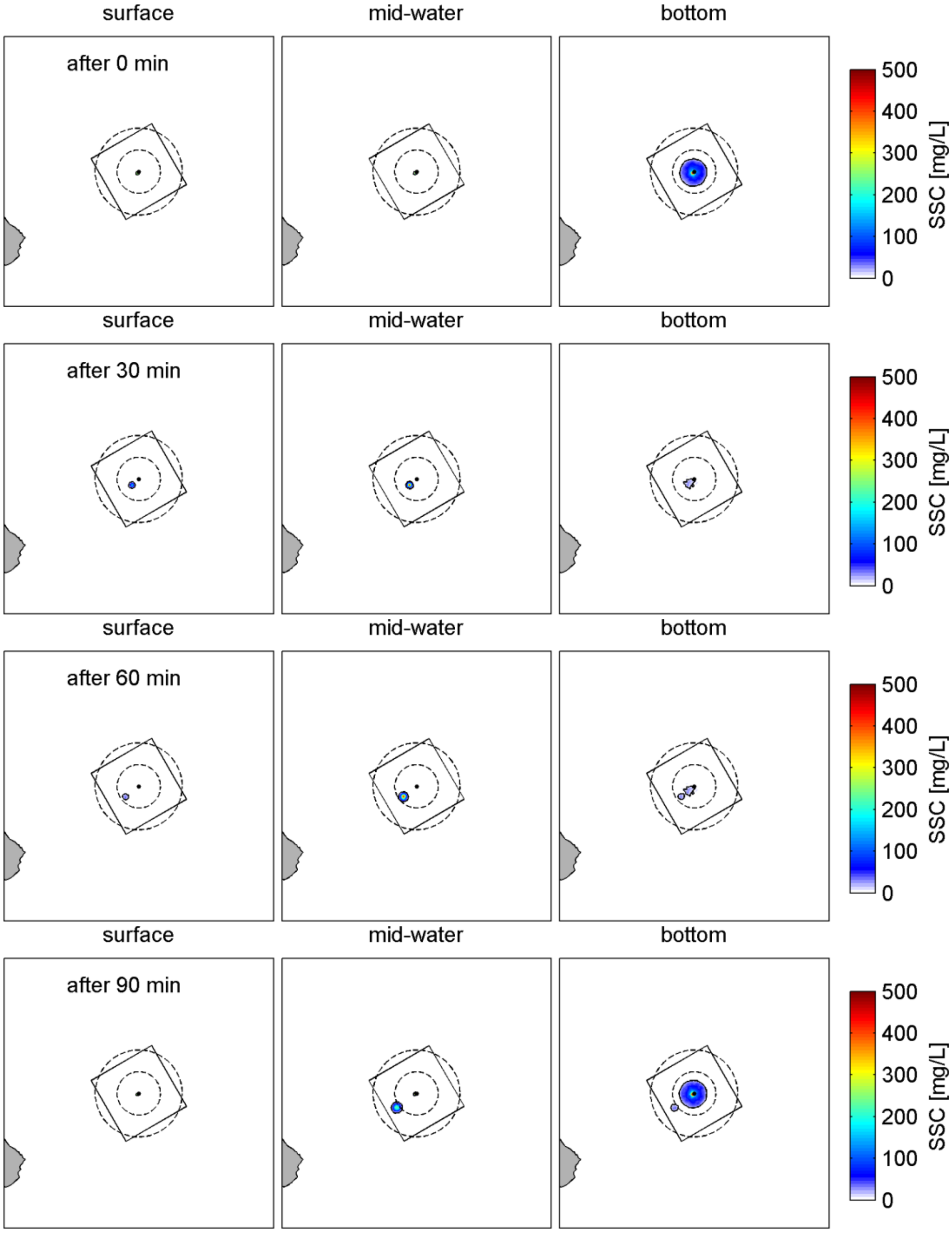


Figure 3.5 Disposal of three successive hopper loads of Mahury vessel (V=1,840 m^3) at site Maint5 during calm conditions: time period from 0 to 90 minutes after first disposal. Dashed circles have radiuses of 500 and 1000 m.

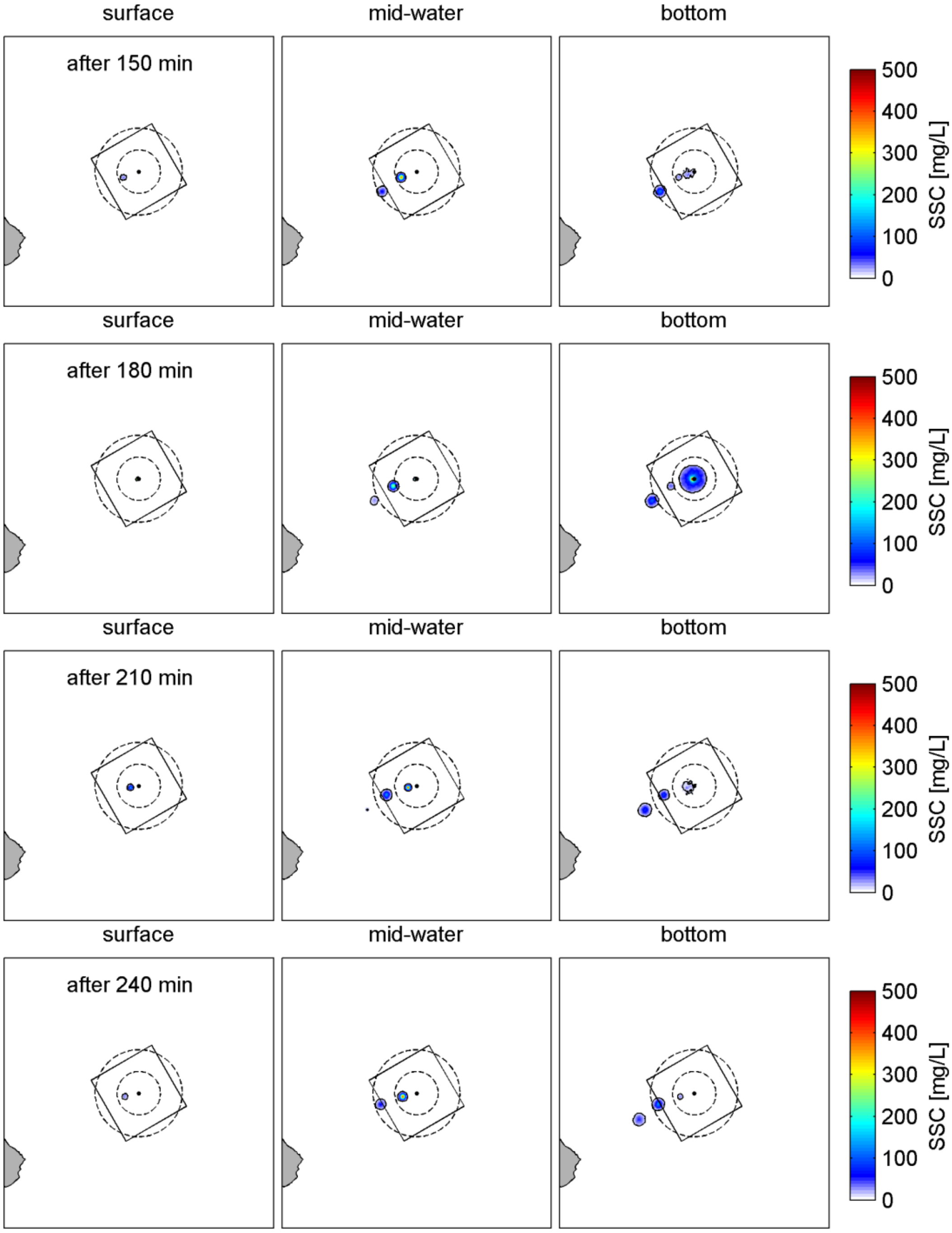


Figure 3.6 Disposal of three successive hopper loads of the Mahury vessel (V=1,840 m^3) at site Maint5 during calm conditions: time period from 150 to 240 minutes after first disposal. Dashed circles have radiuses of 500 and 1000 m.

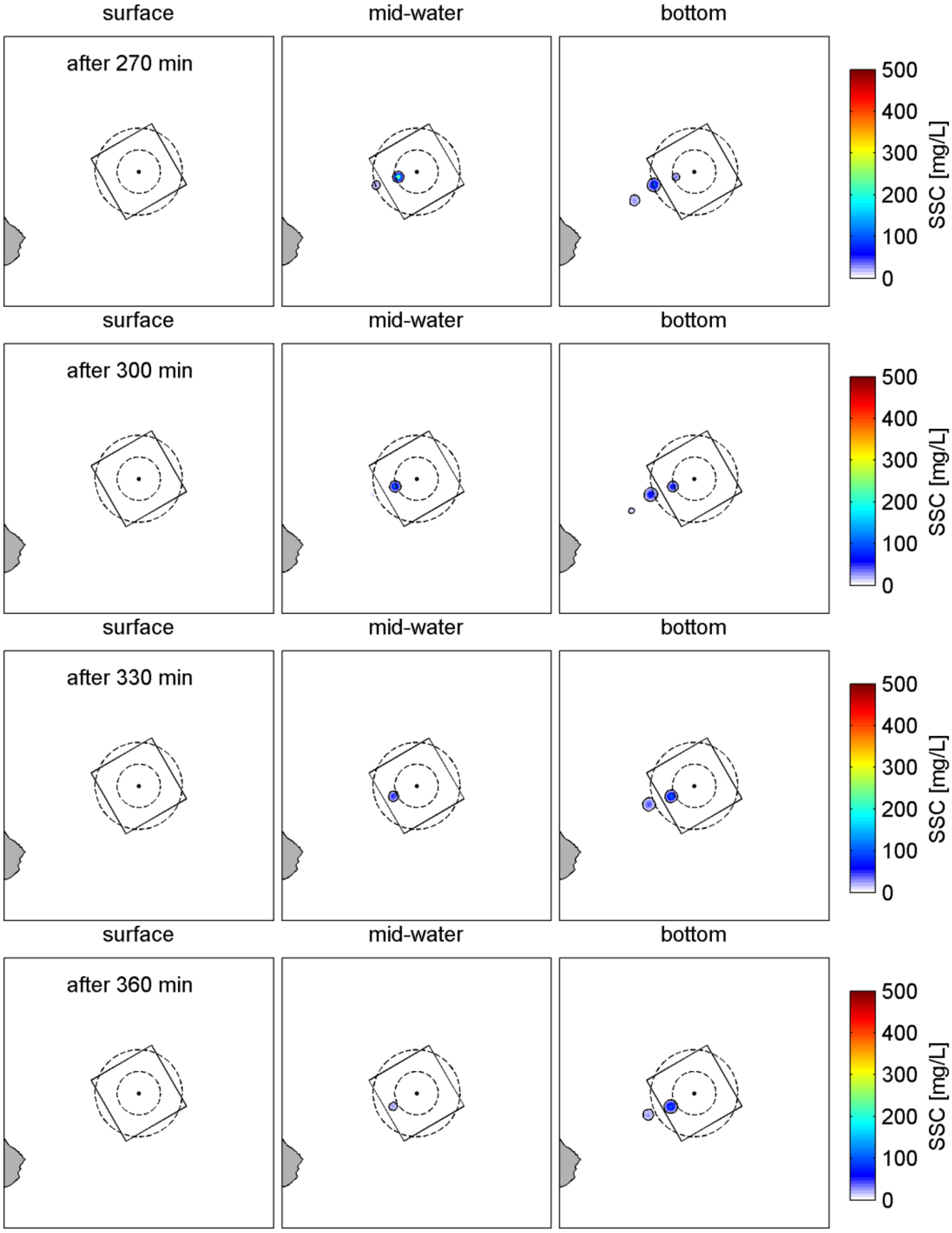


Figure 3.7 Disposal of three successive hopper loads of the Mahury vessel (V=1,840 m^3) at site Maint5 during calm conditions: time period from 270 to 360 minutes after first disposal. Dashed circles have radiuses of 500 and 1000 m.

3.2. Annual mean disposal *SSC* plumes and deposition thicknesses

3.2.1. Suspended sediment concentration plumes

In practice, the exact timing of the future disposal operations is unknown and it is therefore beneficial to consider the entire range of forcing conditions that could be encountered at the site to have a more robust picture of the potential plume dispersion patterns. In this study, this issue was addressed by running long-term hindcast simulations of continuous disposal during a full year period. The approach allows capturing the entire range of forcing conditions at the site and the resulting *SSC* plume tracks. The results of the simulations were time-averaged to produce the mean *SSC* fields associated with the disposal of one hopper load. The year time period ensures that the produced results are statistically relevant and produced results should be interpreted as probabilistic, statistically based dispersion patterns of the disposal-related *SSC* plume rather than being representative of an individual plume.

The mean *SSC* plumes resulting from sediment disposal at the centre and corners of the proposed disposal ground, with the Mahury vessel, are presented in Figure 3.8 and Figure 3.9 for disposal of maintenance dredge material at the proposed maintenance and capital disposal grounds respectively. A large zoom level is applied to illustrate their positions and extents relative to the shoreline. Note the colour scale was adjusted from the figures in Section 3.1 for a better resolution of the smaller *SSC* levels at some distance from the release point.

The *SSC* plumes expectedly show the largest extents and magnitudes in the bottom layer. Relatively high *SSC* levels are found within the 300 metre radius around the release due to the density current source term included in simulations; the overall shape ranges between almost circular (at the proposed maintenance disposal ground) to elliptic in the northwest-southeast axis at the proposed capital disposal ground, consistent with the tidal ellipse at the site (Metocean Solutions Limited P0201-04, 2015).

For all cases, and at both the proposed maintenance and capital disposal ground, the 10 $mg.L^{-1}$ contour generally stays within 1 km of the disposal location for all layers considered. In the surface plume and mid-water, although some *SSC* traces are indeed predicted, extents are very limited and magnitudes remain below 10 $mg.L^{-1}$, and are therefore not rendered in the plots. This is a function of the comparatively small volume associated with the Mahury dredge vessel (V=1,840 m^3). Mean *SSC* plumes patterns and magnitudes will effectively be modulated by the choice of the disposal vessels used due to hopper load capacity and thus net amount of sediment released in the water column, but also by the draft depth.

To illustrate the effect of increasing magnitude of the disposal, Figure 3.10 provides a comparison between a single hopper plume for the Volvox Asia dredger (which has a hopper volume of 10,800 m^3) and the Mahury dredger at the proposed capital disposal ground and at the proposed maintenance ground. Here, the use of the Mahury vessel will result in relatively less sediment released in the water column, but the shallower draft means that a fraction of the sediment will be released higher in the water column and will have more time to disperse from the disposal location. Conversely, more sediment will be released in the water column when using the Volvox Asia vessel but at a deeper depth which relatively reduces the time for a fraction of the suspended sediment to disperse (Figure 3.10).

3.2.2. Depositional footprints

Besides the *SSC* plumes, the annual simulation also allow characterising the expected patterns of sediment deposition associated the passive plume dispersion. The mean sediment deposition fields resulting from the disposal of one hopper load of the Mahury vessel are shown in Figure 3.11 and Figure 3.12 for the proposed maintenance and capital dredging sites respectively. Most of the deposition is distributed within the 300 m radius around the release site with a circular to elliptic shape developing further away from the release site consistent with the *SSC* plume patterns. For all cases and both disposal grounds, the 1 mm depositional contour is consistently contained within the 500 m radius around the release location. It is stressed that the presented depositions fields are for the passive plume only and do not include the large fraction that settles immediately to the bottom following the dynamic collapse (i.e. ~70 %). This fraction of sediment will be contained within the 300 m radius around release position as predicted by the nearfield modelling (Spearman, pers. comm.), with most of the sediment actually depositing in close vicinity of the point of impact.

As a comparison, the modulation of the depositional thickness between the Volvox Asia dredger (which has a hopper volume of 10,800 m^3) and the Mahury dredger at the proposed capital disposal ground and at the proposed maintenance ground is provided in Figure 3.13. The deposition thicknesses associated with the larger Volvox Asia dredger are expectedly larger than for the Mahury vessel, however most of the significant increases are contained within a 300 m radius around the release point and the 1 mm contour remains within 500 m of the disposal location.

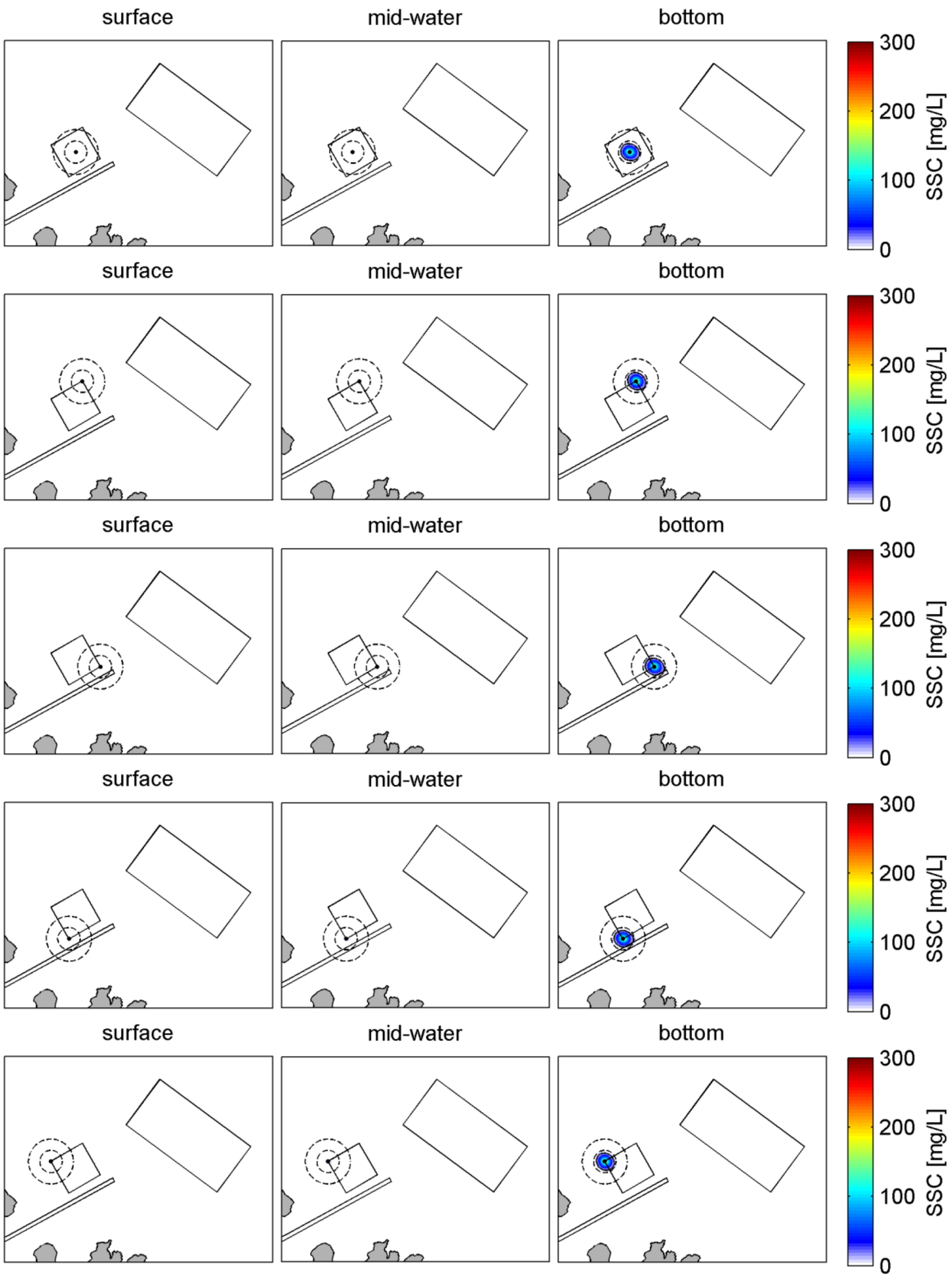


Figure 3.8 Mean *SSC* fields resulting from the disposal of one hopper load of the Mahury vessel (V=1,840 m^3) at the maintenance dredging ground. The 10 $mg.L^{-1}$ *SSC* contour line is shown in dark. Dashed circles have radiuses of 500 and 1000 m. The mean SSC fields were derived from an annual simulation.

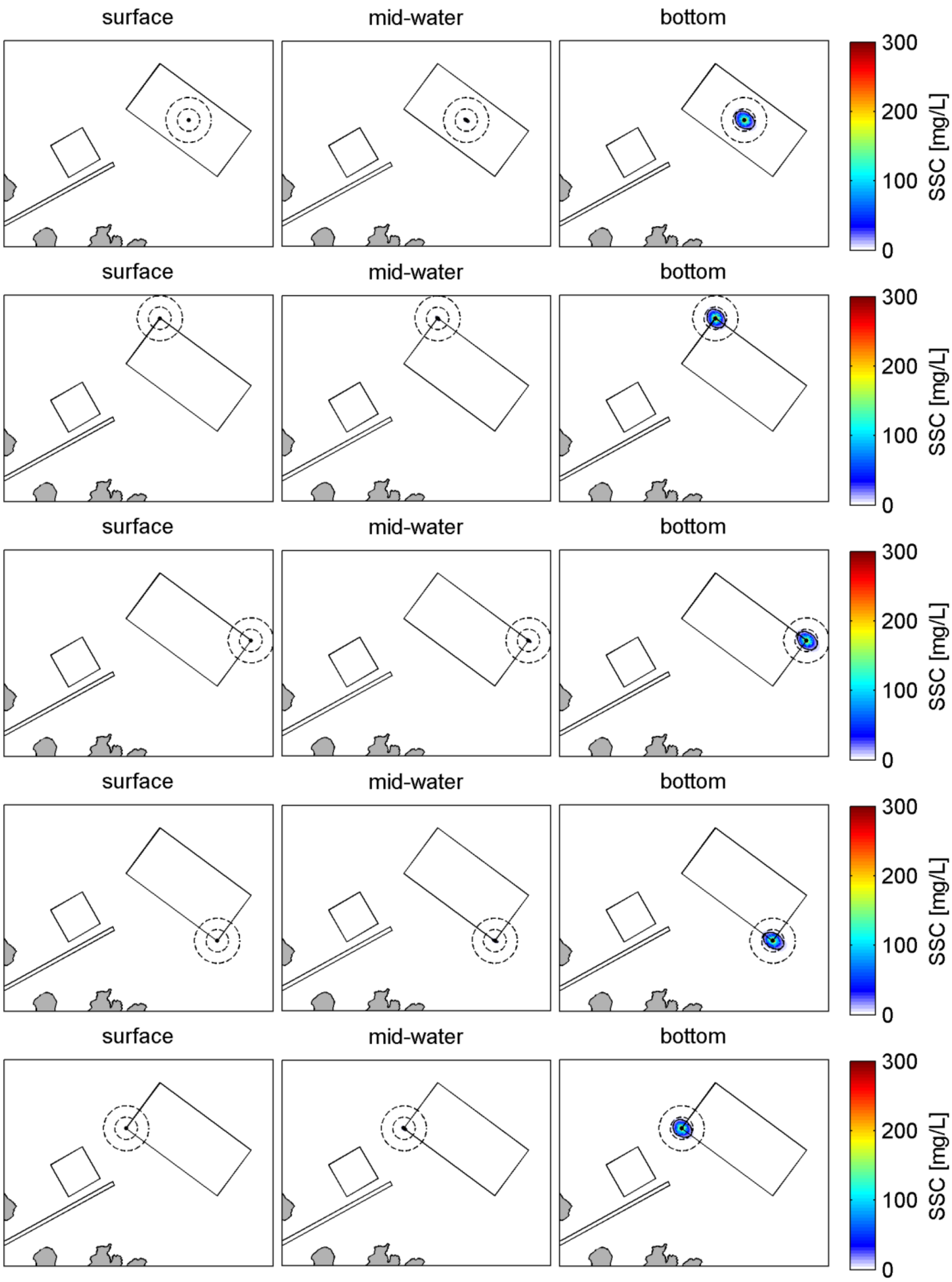
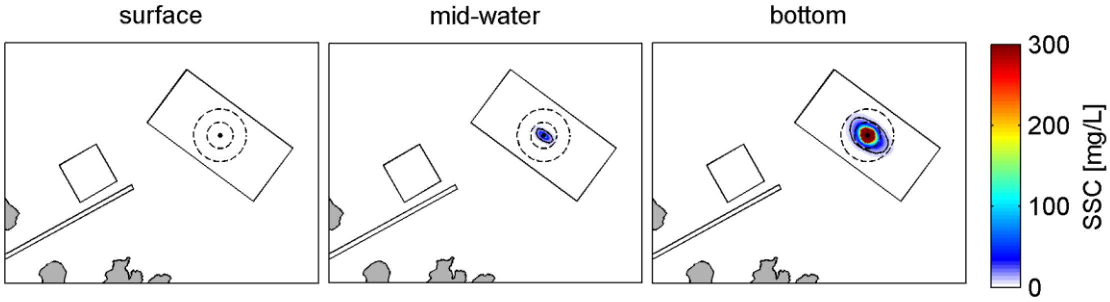
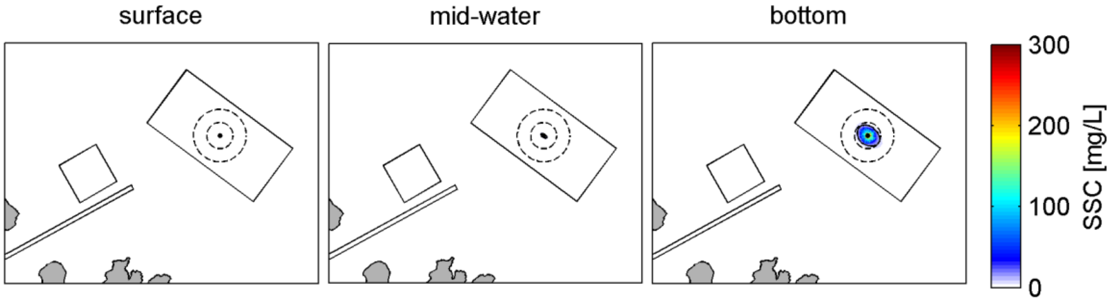


Figure 3.9 Mean *SSC* fields resulting from the disposal of one hopper load of the Mahury vessel (V=1,840 m^3) at the capital dredging ground. The 10 $mg.L^{-1}$ *SSC* contour line is shown in dark. Dashed circles have radiuses of 500 and 1000 m. The mean SSC fields were derived from an annual simulation.

Volvox Asia (V= 10,800 m^3)



Mahury (V= 1,840 m^3) – capital ground



Mahury (V= 1,840 m^3) – maintenance ground

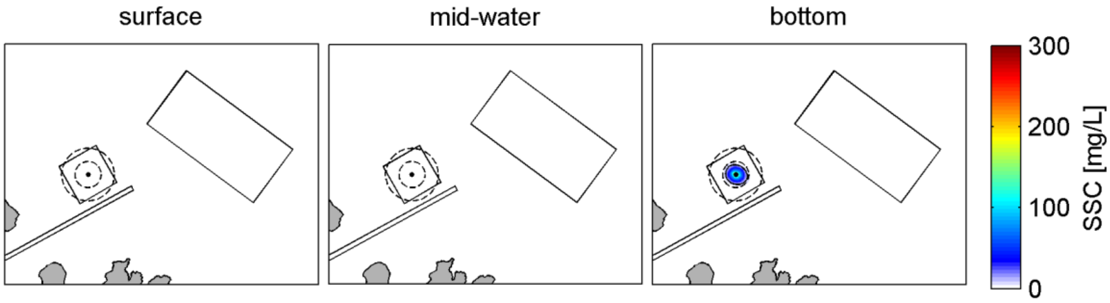


Figure 3.10 Comparison of mean *SSC* fields resulting from the disposal of one hopper load of the Volvox Asia vessel (V=10,800 m^3) and Mahury vessel (V=1,840 m^3) at the proposed capital ground (top and middle), and proposed maintenance ground (bottom). The 10 mg.L^{-1} *SSC* contour line is shown in dark. Dashed circles have radiuses of 500 and 1000 m. The mean SSC fields were derived from an annual simulation.

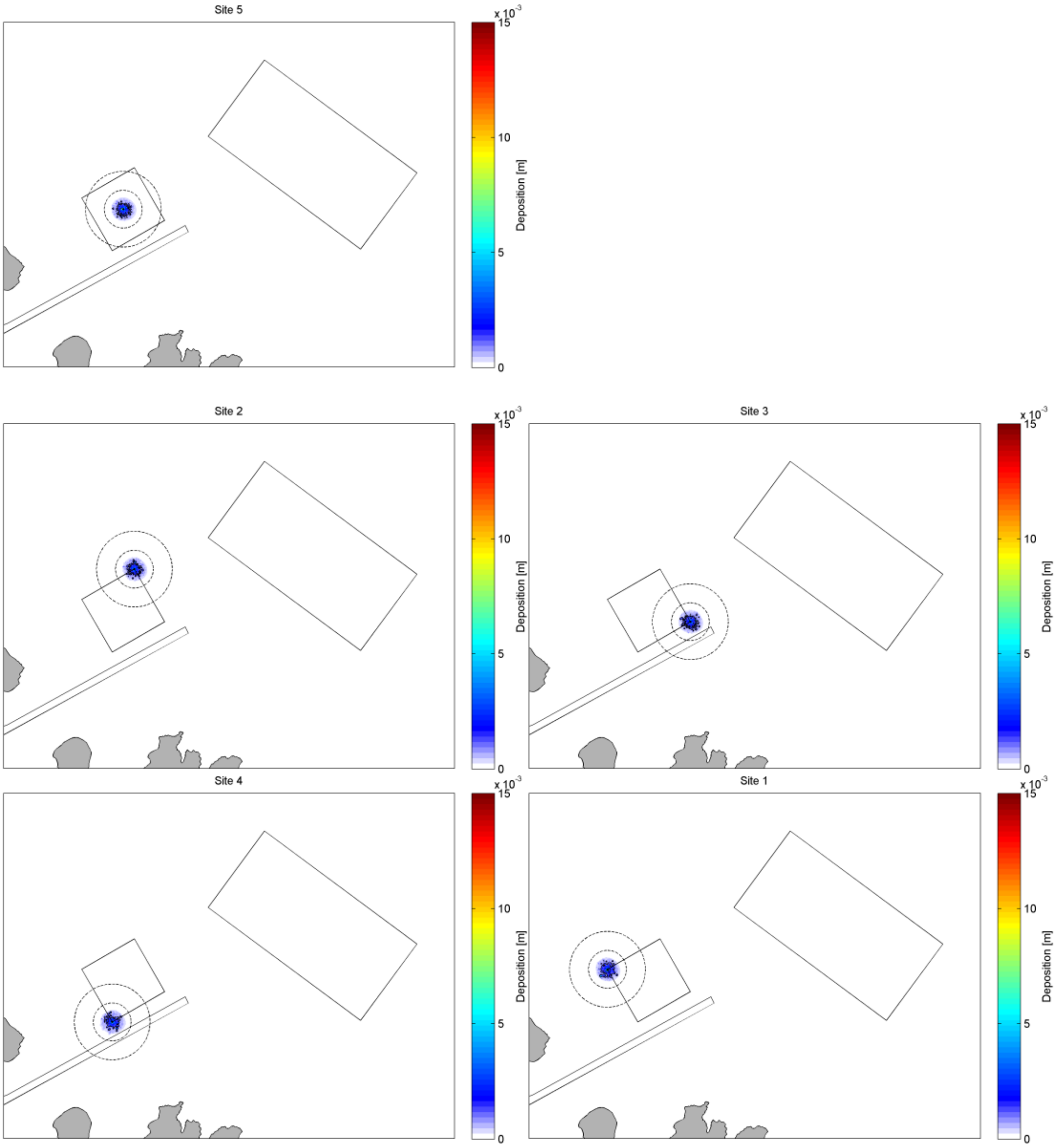


Figure 3.11 Mean deposition fields resulting from the disposal of one hopper load of the Mahury vessel (V=1,840 m^3) at the maintenance ground. The 1 mm contour line is shown in dark. Dashed circles have radiuses of 500 and 1000 m. The mean deposition fields were derived from an annual simulation.

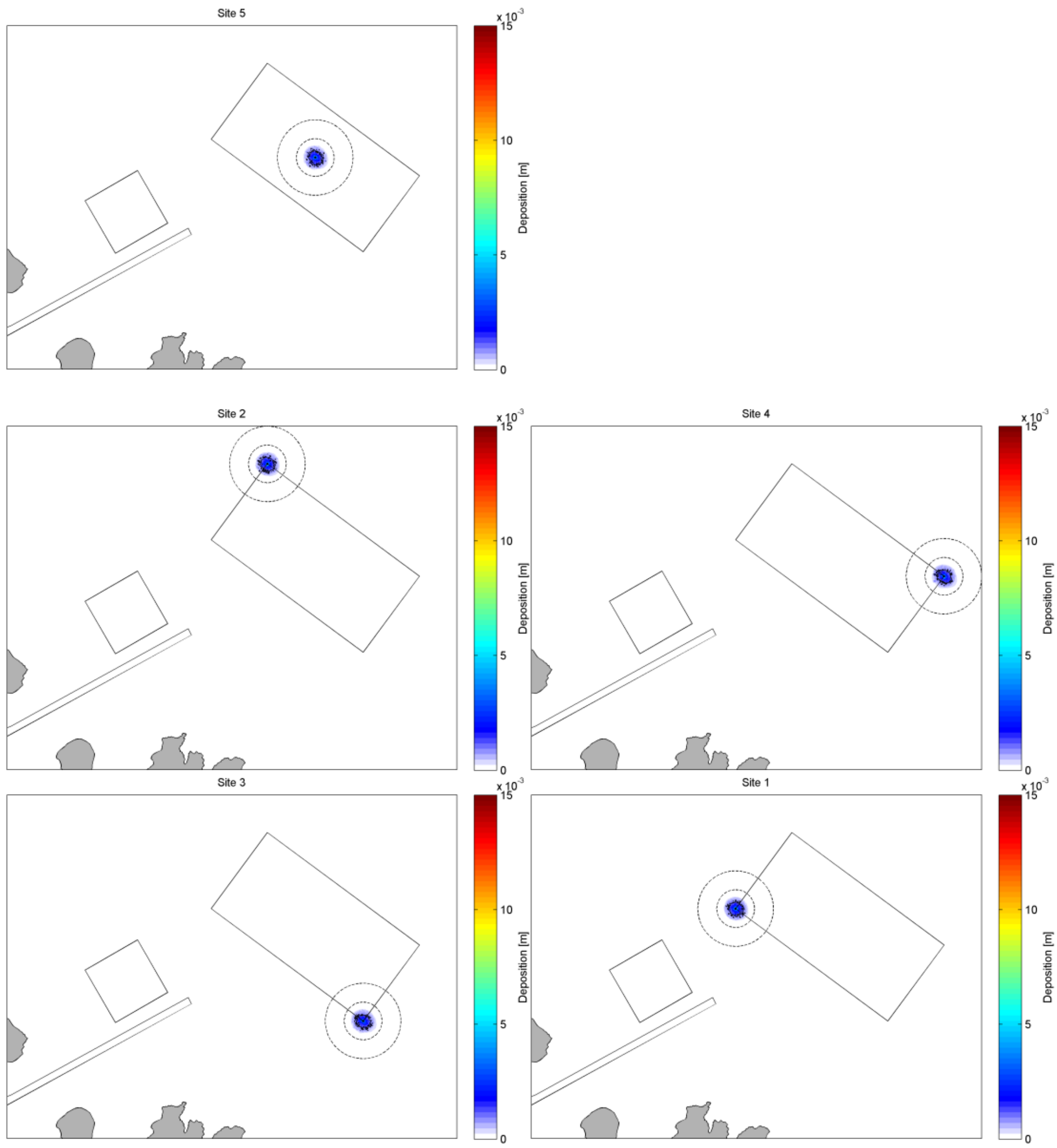
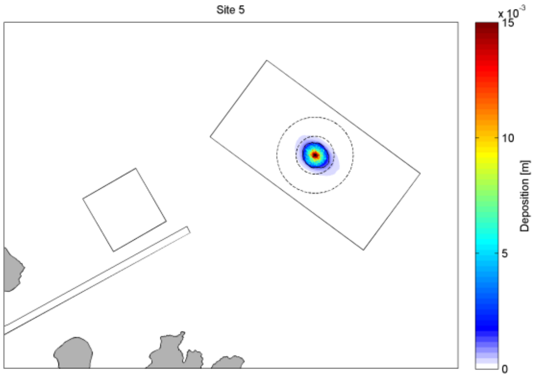
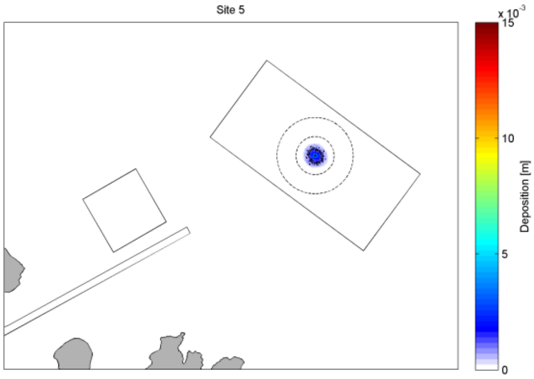


Figure 3.12 Mean deposition fields resulting from the disposal of one hopper load of the Mahury vessel (V=1,840 m^3) at the capital ground. The 1 mm contour line is shown in dark. Dashed circles have radiuses of 500 and 1000 m. The mean deposition fields were derived from an annual simulation.

Volvox Asia (V= 10,800 m^3)



Mahury (V= 1,840 m^3) – capital ground



Mahury (V= 1,840 m^3) – maintenance ground

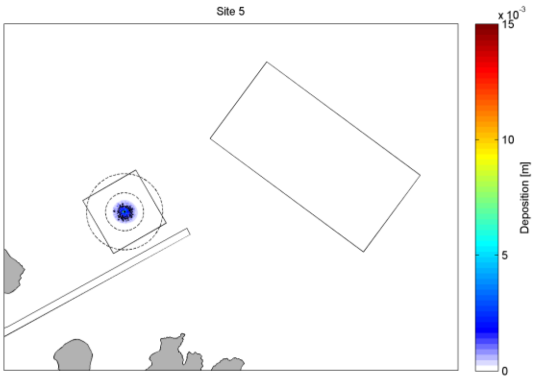


Figure 3.13 Comparison of mean deposition fields resulting from the disposal of one hopper load of the Mahury vessel (V=10,800 m^3) and Mahury vessel (V=1,840 m^3) at the proposed capital ground (top and middle), and proposed maintenance ground (bottom). The 10 mg.L^{-1} *SSC* contour line is shown in dark. Dashed circles have radiuses of 500 and 1000 m. The mean deposition fields were derived from an annual simulation.

3.3. *SSC* threshold exceedence during disposal activities

Besides the general patterns of the disposal plume dispersion and deposition, an important metric of the disposal-related plumes is the percentage of time a given *SSC* level is exceeded during disposal operations; notably in the context of ecological impact assessment for example.

This section includes exceedence time percentage for three *SSC* thresholds, i.e. 10, 50 and 100 $mg.L^{-1}$. These thresholds were chosen based on the empirical information available on the ambient *SSC* levels within Pegasus Bay. The available records suggest mean levels in the range of 10-20 $mg.L^{-1}$, reaching levels of the order 50 $mg.L^{-1}$ at times, while values of up to 100 $mg.L^{-1}$ are assumed to occur in rare occasions given the sediment entering the environs from river and overland run-offs.

The determination of the exceedence time percentage can become very computationally demanding for long time-periods because it requires estimating full concentration fields at every time step of the simulation. In the present application, two–hourly sediment disposals were simulated continuously over a 1-month period spanning both January and August 2010, capturing typical summer and winter forcing conditions, respectively.

Results are presented for disposal at the two sites closest to the shoreline within the proposed maintenance (site Maint1 and 4), assuming disposal with the Mahury dredging vessel. These were supplemented by shorter term simulations during the energetic and calm events considered in section 3.1 (see 3.1) which can be useful in the context of an adaptive management of the disposal operations with respect to the instantaneous forcing conditions.

The exceedence time percentages are presented in Figure 3.14 and Figure 3.15 for the summer month of January, and Figure 3.16 - Figure 3.17 for the winter month of August. The results generally indicate that near-bed *SSC* thresholds are more frequently sustained or exceeded, and have a greater spatial spread compared with both the mid and near-surface concentrations. These results are consistent with results presented in the previous sections. As expected, the actual extents of the predicted SSC exceedence patches reduces as the SSC threshold increases from 10, to 50 and 100 $mg.L^{-1}$.

For the January simulations, in the near-bed layer the 10 $mg.L^{-1}$ threshold is typically exceeded 10-15 % of the time within a radius of ~300 m of the disposal site. Exceedence times of order 5 % may extend up to ~1 km from the release position and tapper off to zero with distance. In the mid-water level, exceedence of up to 5 % are contained within a 500 m radius and become insignificant past the 1 km radius. The 10 $mg.L^{-1}$ is very rarely exceeded in the surface layers.

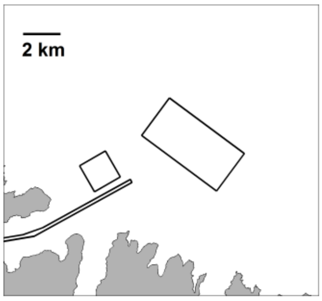
The overall exceedence regions reduce as the *SSC* thresholds are increased. However even the 100 $mg.L^{-1}$ level is expected to be exceeded in the near-bed layer for approximately 5-10 % of the time (within 100-200 m radius of the disposal site). This indicates that instantaneous *SSC* levels can be relatively high in the near-bed layer; however associated extents are relatively limited. It is important to recognise that repeated disposal at the same site introduces a degree of conservatism in these predictions because in practice, sediment disposal will be spread throughout the disposal ground.

No significant differences are apparent between the exceedence patterns considering disposal at sites Maint1 and 4. With respect to potential coastal impacts, results show that even the low exceedence contours (e.g. <1 % exceedence time) remains up to 1 km from the closest point to the shoreline.

The general magnitudes of the percentages of time each *SSC* threshold level is exceeded in each water column layer are slightly larger in August (Figure 3.16 - Figure 3.17) than for January (Figure 3.14 and Figure 3.15). This modulation is due to the plumes being typically more dispersed, resulting in slightly higher probability of *SSC* exceeded thresholds along that main northwest-southeast axis. This contrasts with the relatively more homogenous spreading of the plumes in January (i.e. more circular contours).

Similar exceedence plots have been produced assuming continuous disposal activities at a single site (i.e. hopper load release every 1.5-hours) under the forcing events given in Table 3.1. Each simulation was run during a 2-day period centred on the event peak. Because of the shorter simulation duration (2 days, compared with a complete month), the results tend to show a more banded appearance, with individual dredge discharge plumes distinguishable. Results for release at sites Maint1 and 4 are given in Figure 3.18 to Figure 3.25, and illustrate that consecutive disposals at the same location can increase the frequency of *SSC* exceeding the different thresholds (i.e. up to ~20-25% in the bottom layer). An increased frequency of threshold exceedence is expected for both the energetic and more ambient conditions, due to the sequential plumes being dispersed in a consistent direction (e.g. strong current) and limited potential for dispersion under calm conditions, respectively.

January - Site Maint1



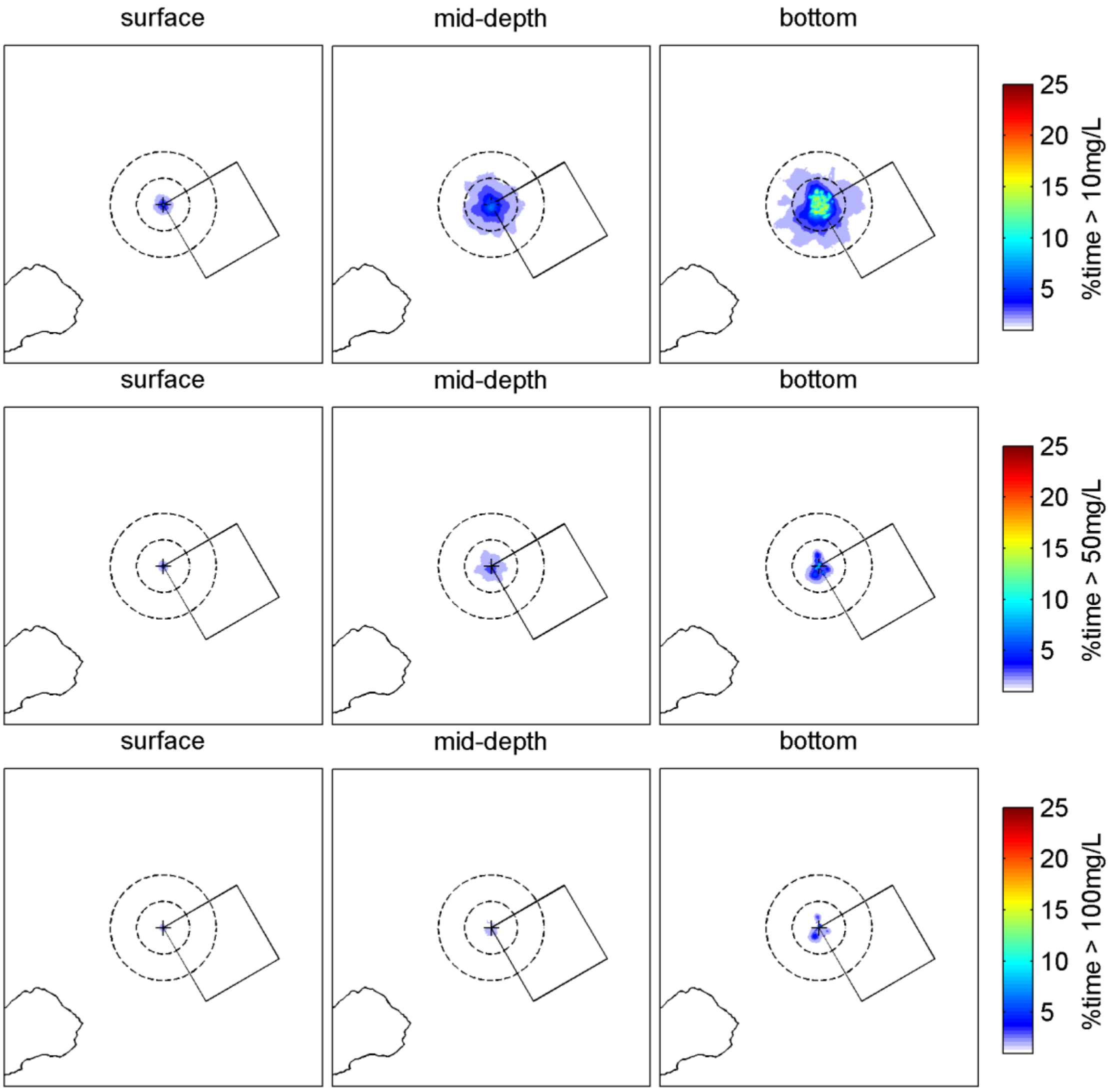
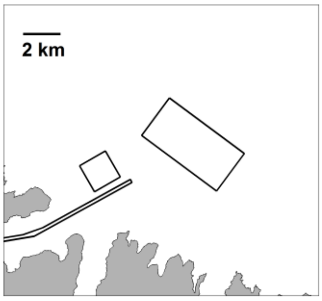


Figure 3.14 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during the summer month of January, assuming a 1.5 h disposal cycle at site Maint1 with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



January - Site Maint4

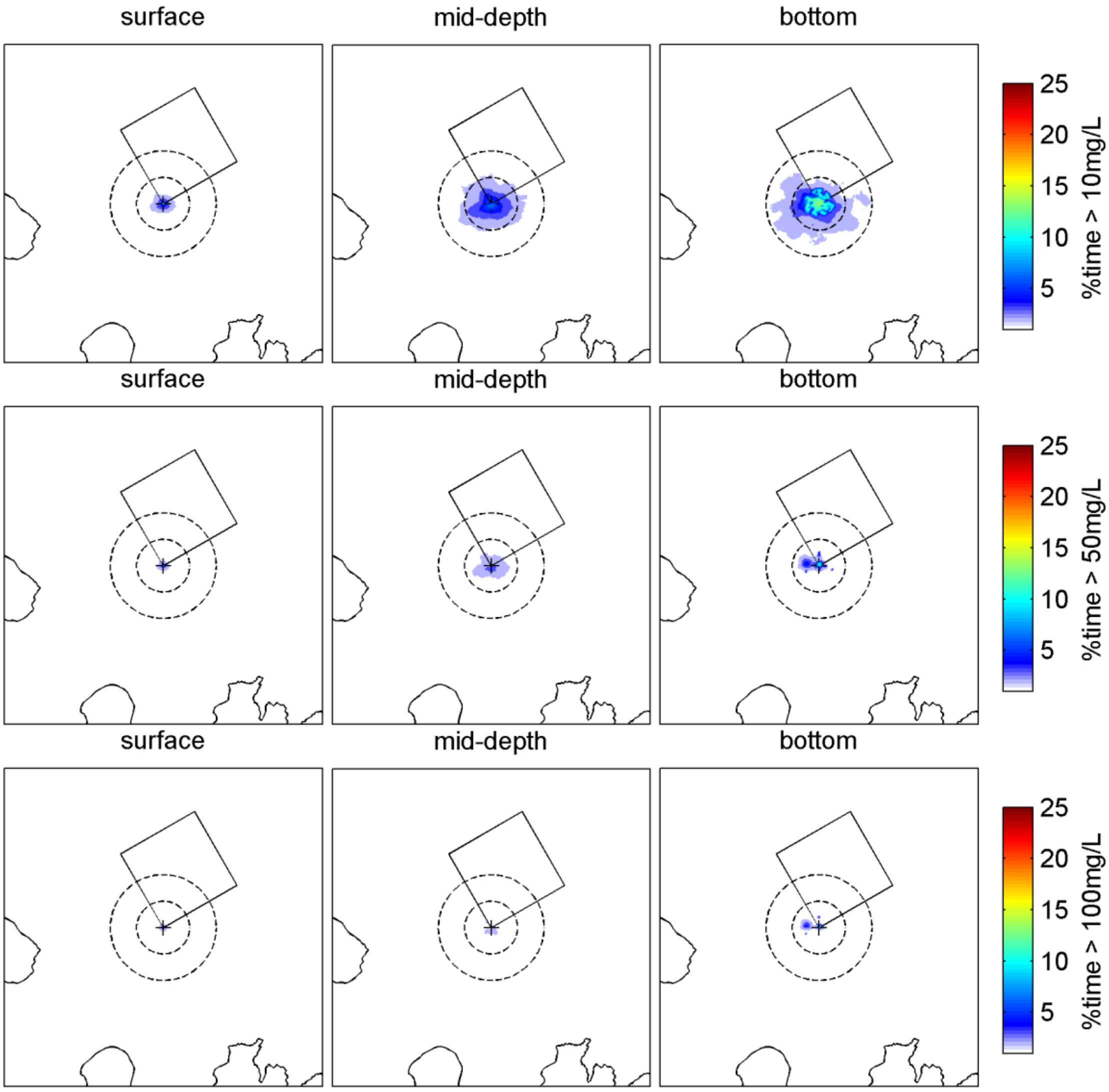
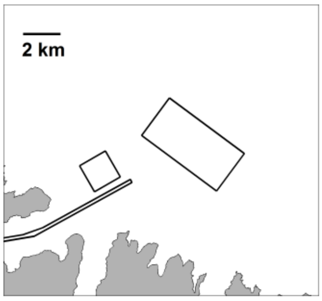


Figure 3.15 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during the summer month of January, assuming a 1.5 h disposal cycle at Maint4 with the Mahury vessel (V=1,840 m^{3}). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



August - Site Maint1

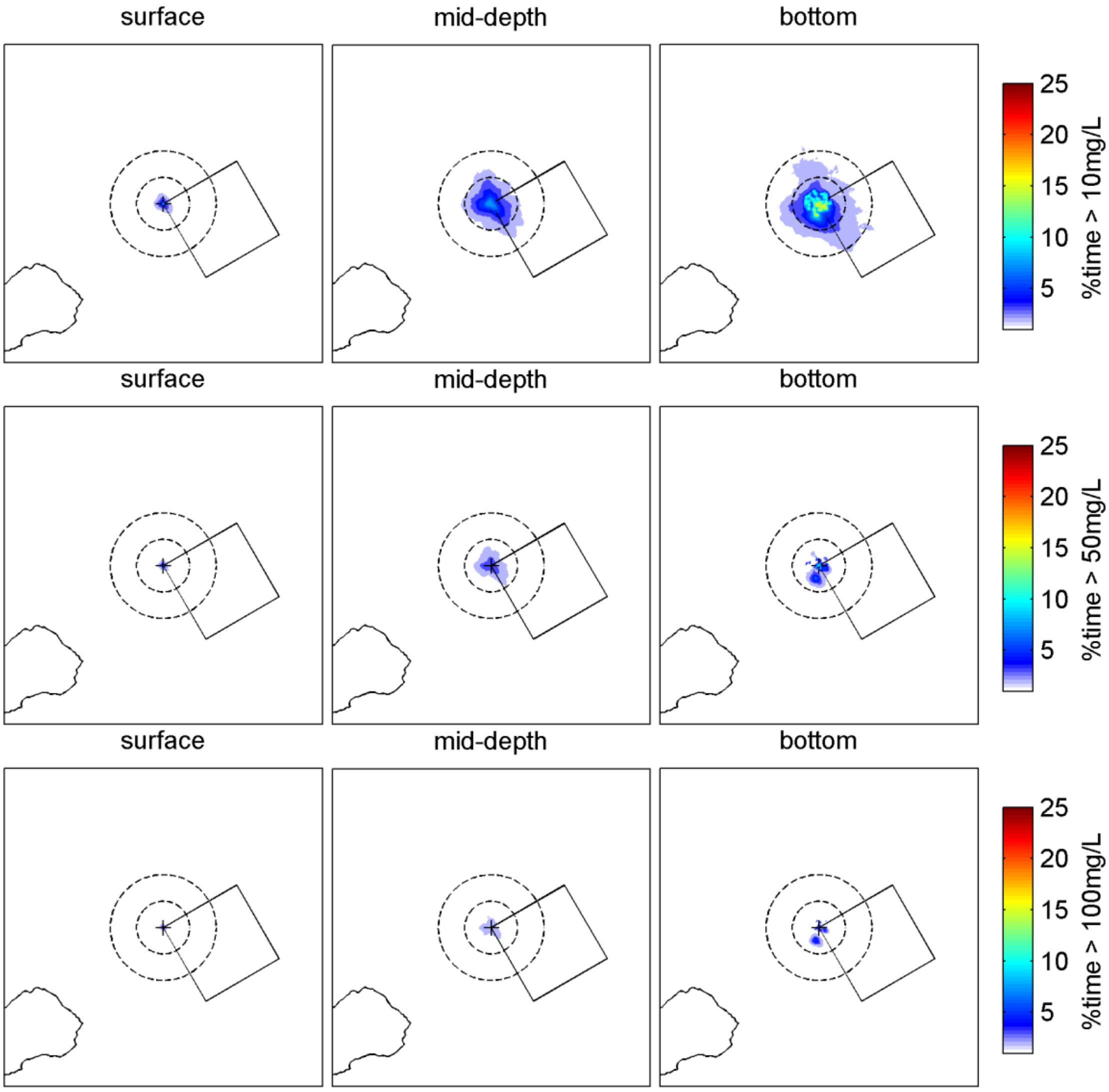
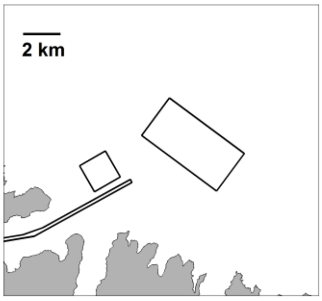


Figure 3.16 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during the winter month of August, assuming a 1.5 h disposal cycle at site Maint1 with the Mahury vessel (V=1,840 m^{3}). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



August - Site Maint4

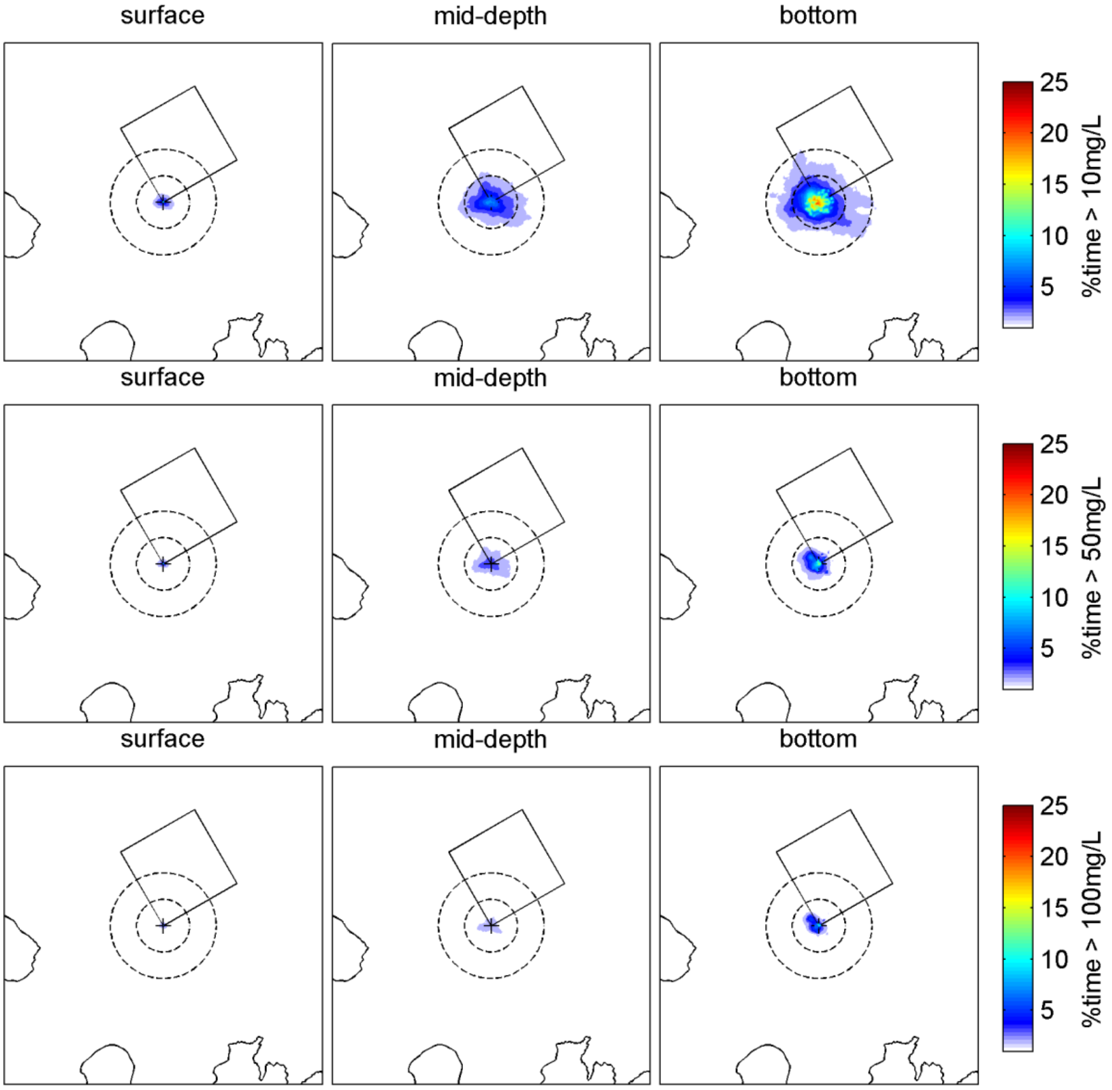
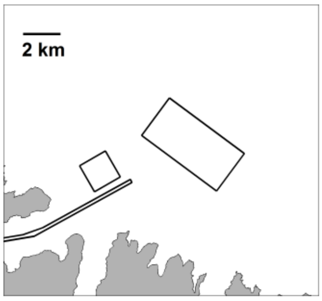


Figure 3.17 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during the winter month of August, assuming a 1.5 h disposal cycle at Maint4 with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



Northwest current

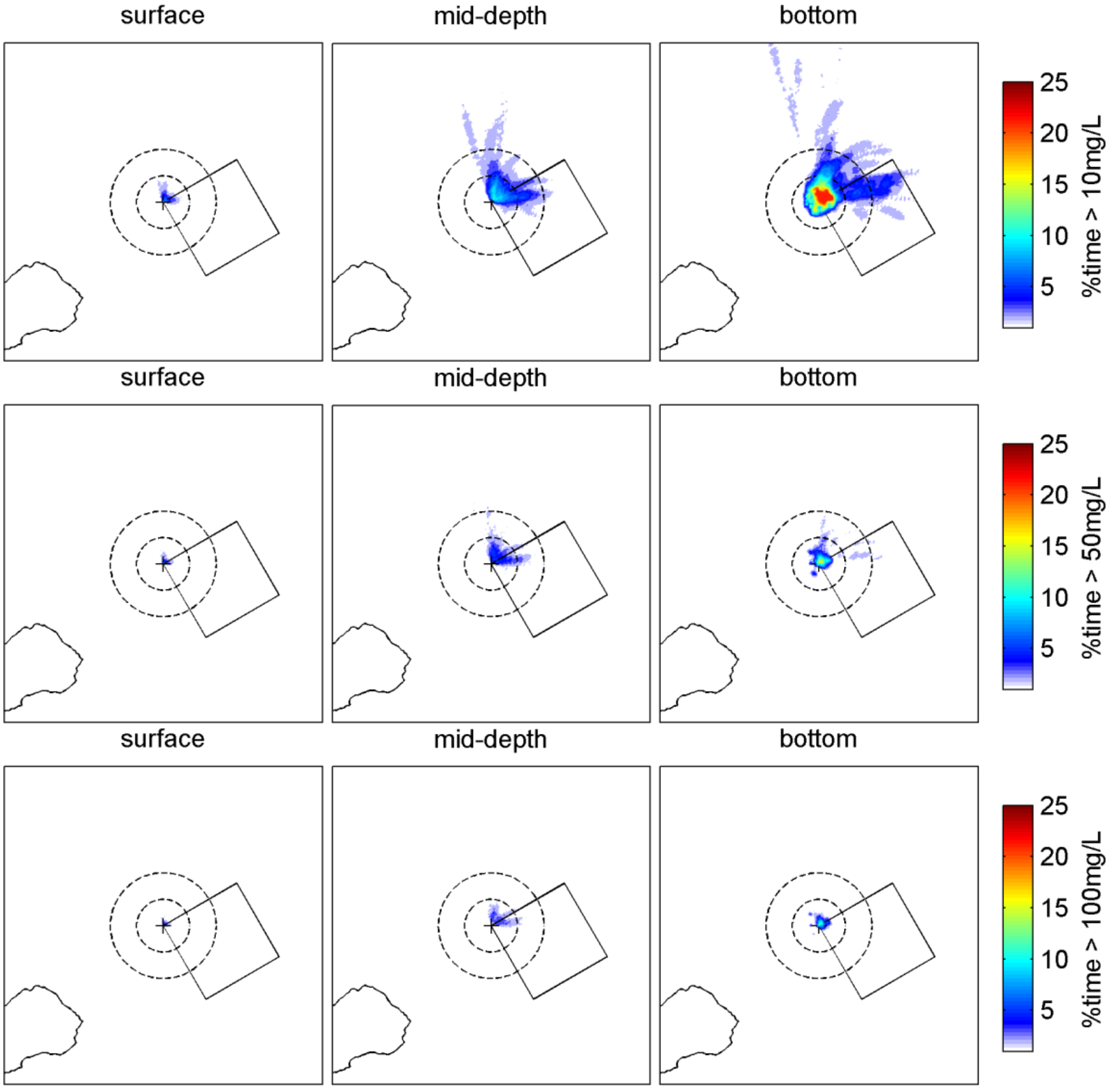
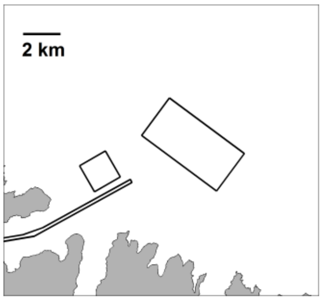


Figure 3.18 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during a strong northwest current event, assuming a 1.5 h disposal cycle at site Maint1 with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.

Southeast current



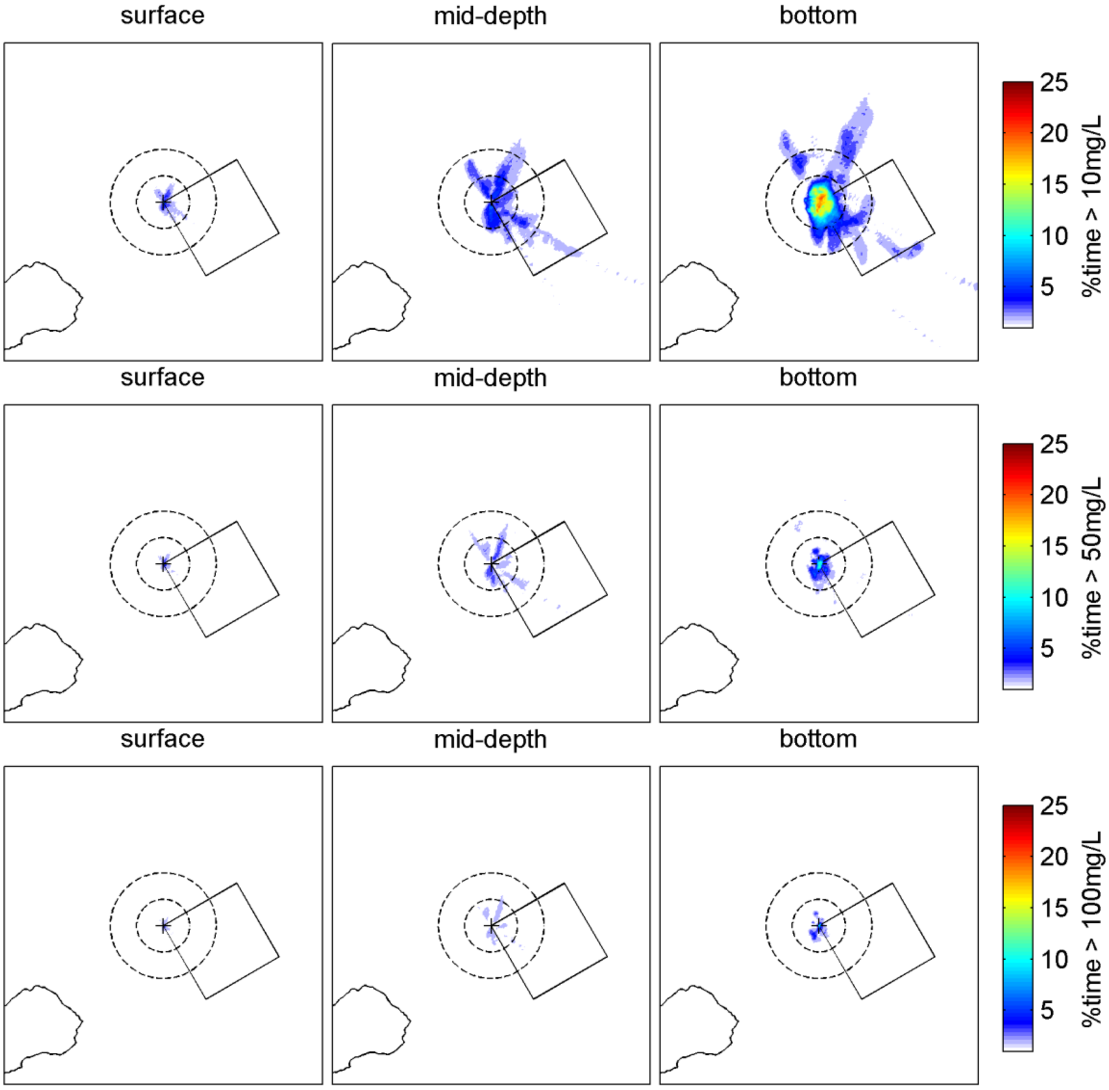
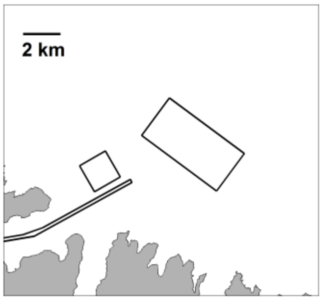


Figure 3.19 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during a strong southeast current event, assuming a 1.5 h disposal cycle at site Maint1 with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



Northeast wind/wave

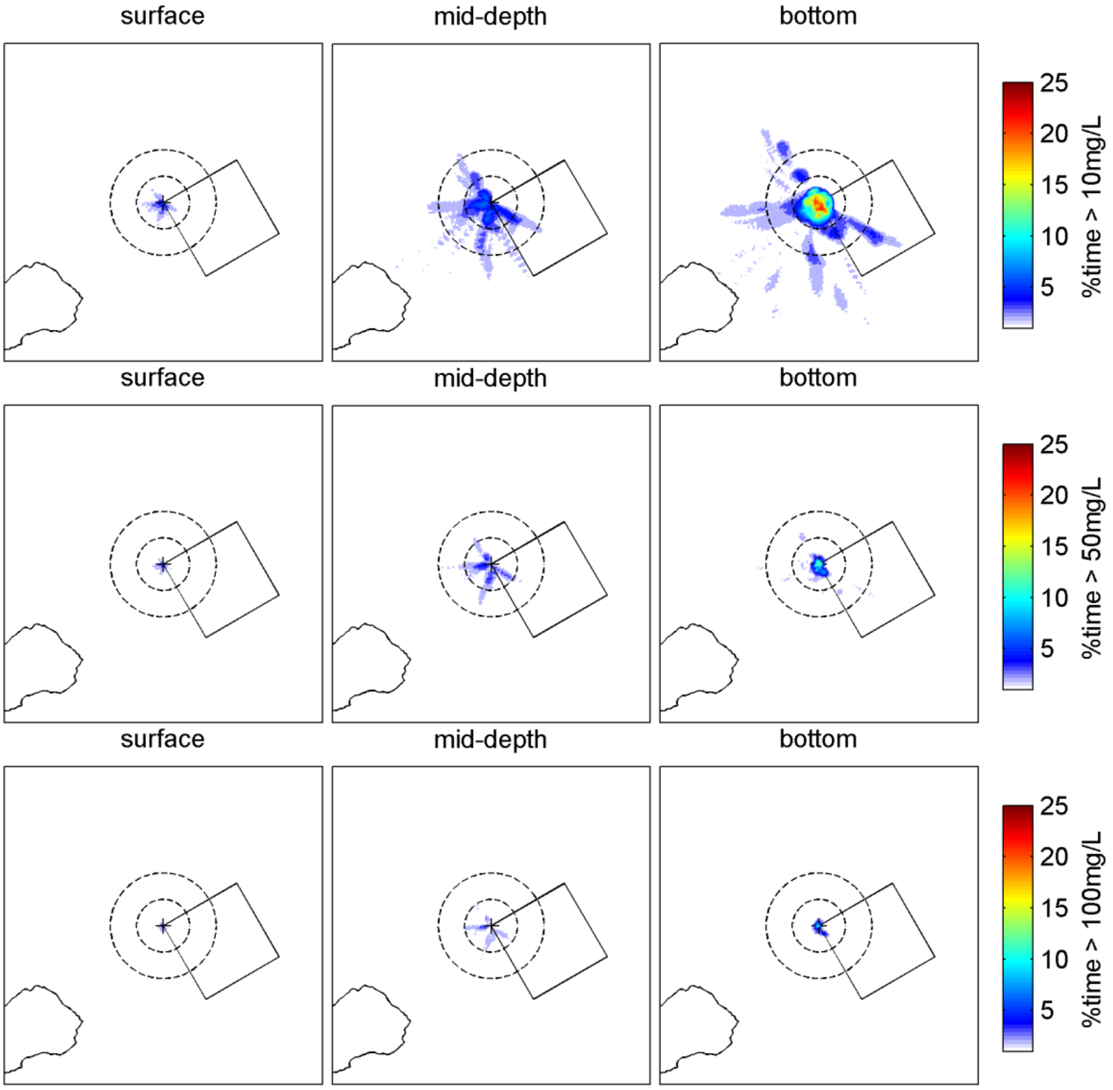
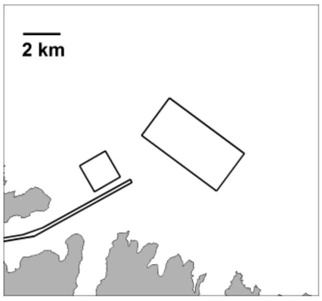


Figure 3.20 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during a strong northeast wind/wave event, assuming a 1.5 h disposal cycle at site Maint1 with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



Calm conditions

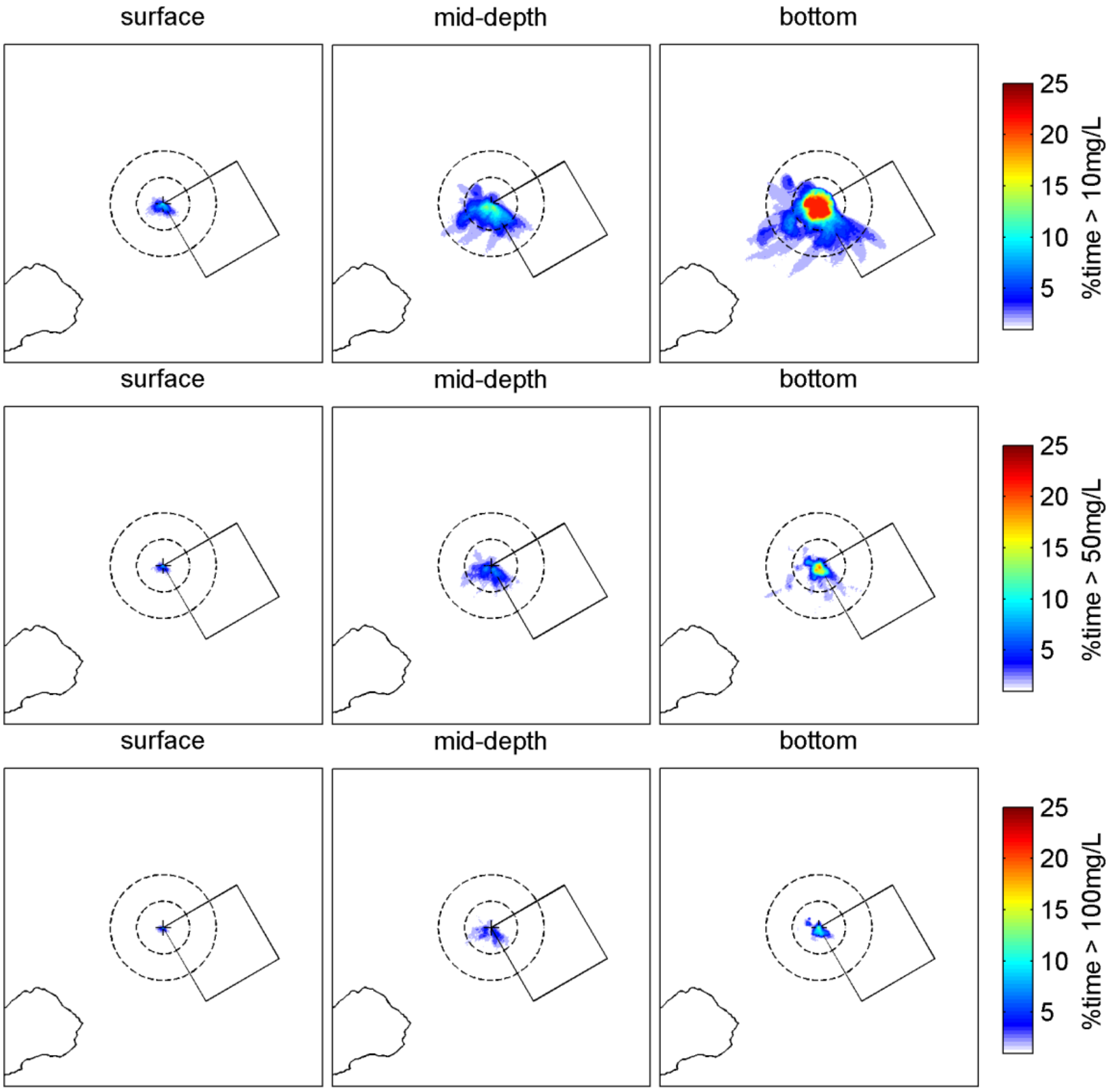
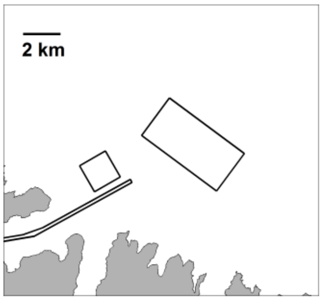


Figure 3.21 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during calm conditions assuming a 1.5 h disposal cycle at site Maint1 with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



Northwest current

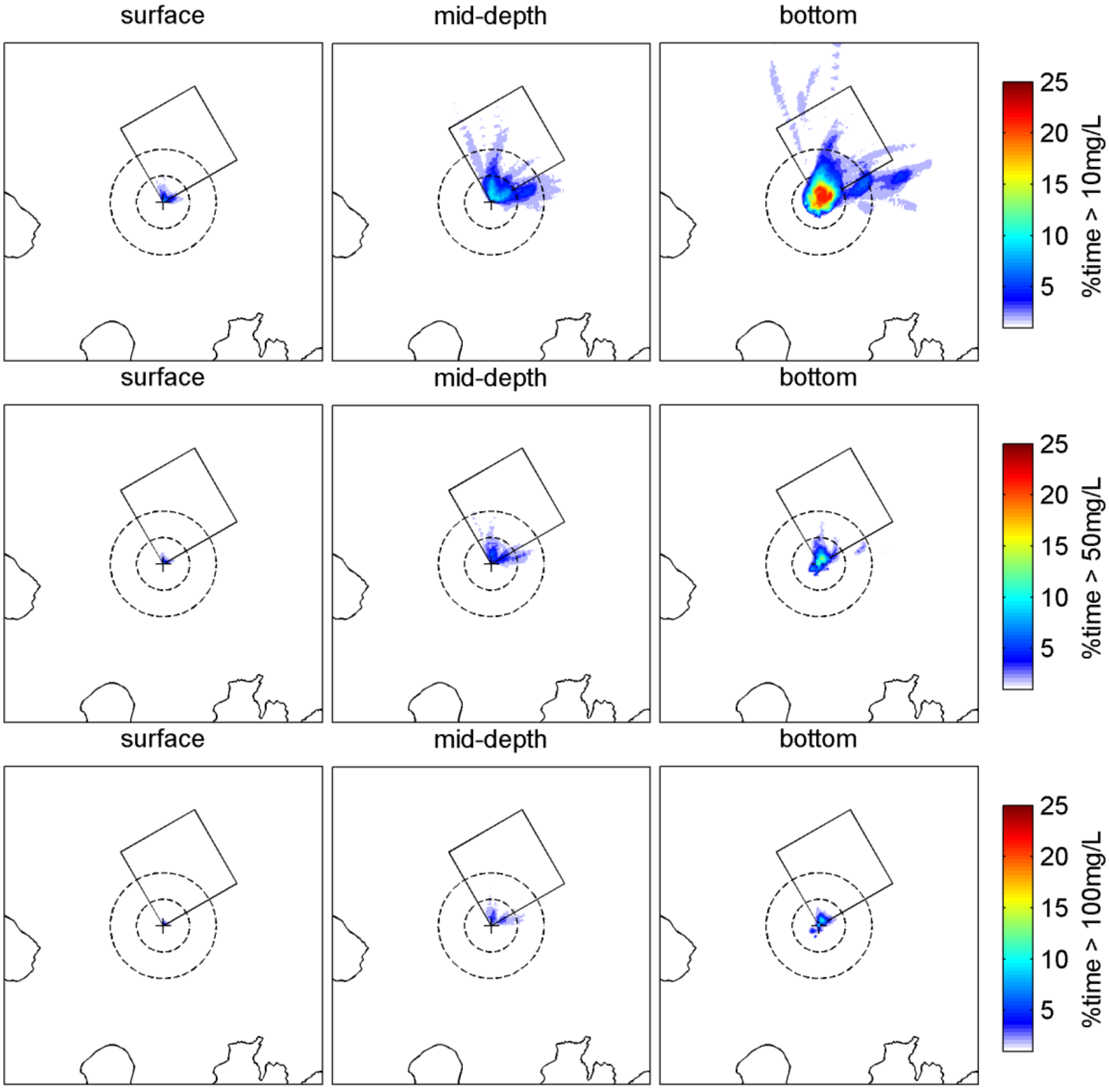
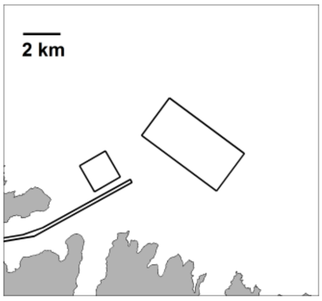


Figure 3.22 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during a strong northwest current event, assuming a 1.5 h disposal cycle at site Maint4 with the Mahury vessel (V=1,840 m^{3}). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



Southeast current

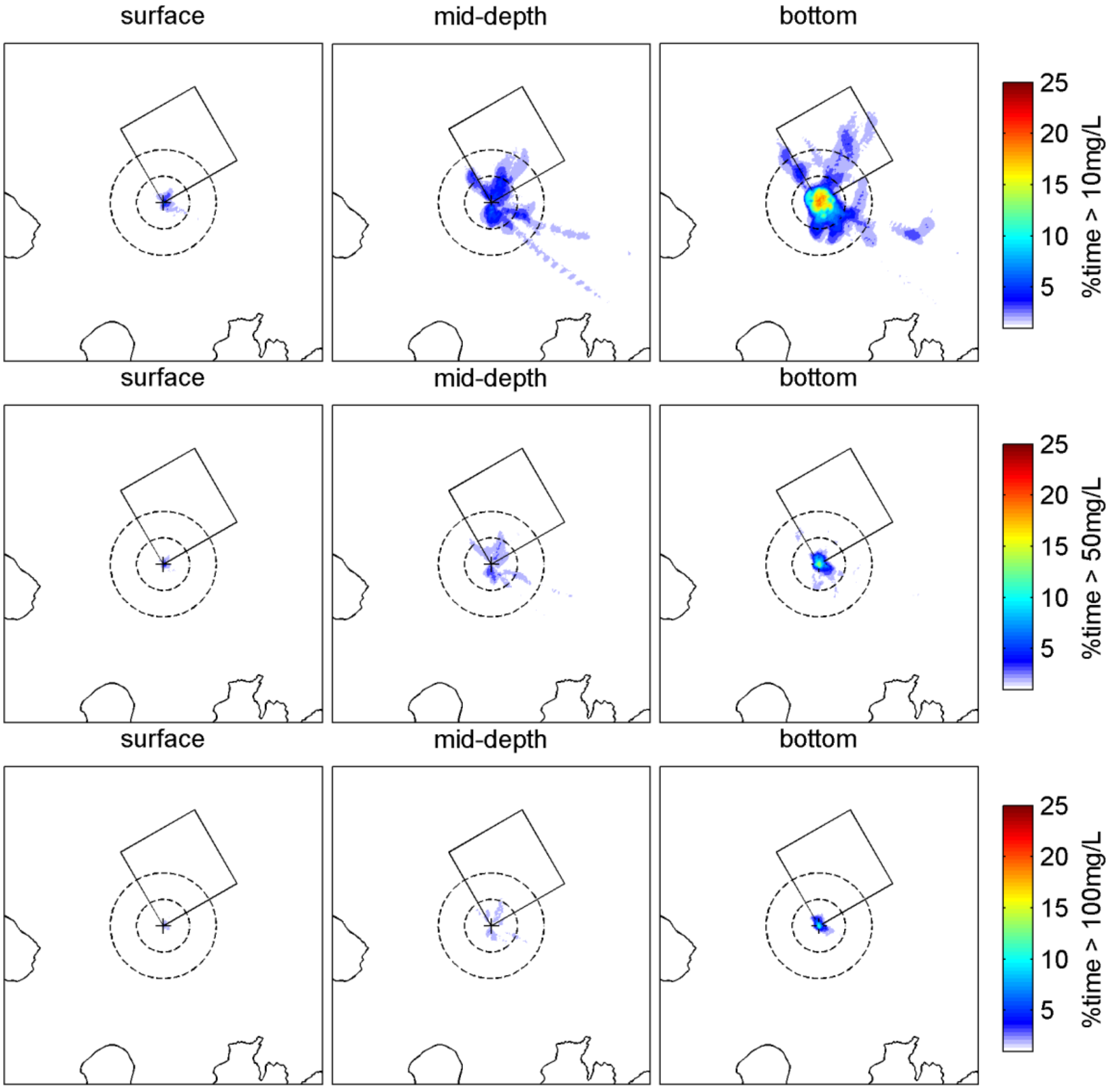
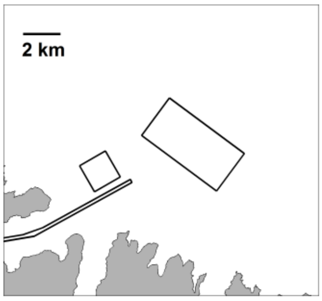


Figure 3.23 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during a strong southeast current event, assuming a 1.5 h disposal cycle at Maint4 with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.



Northeast wind/wave

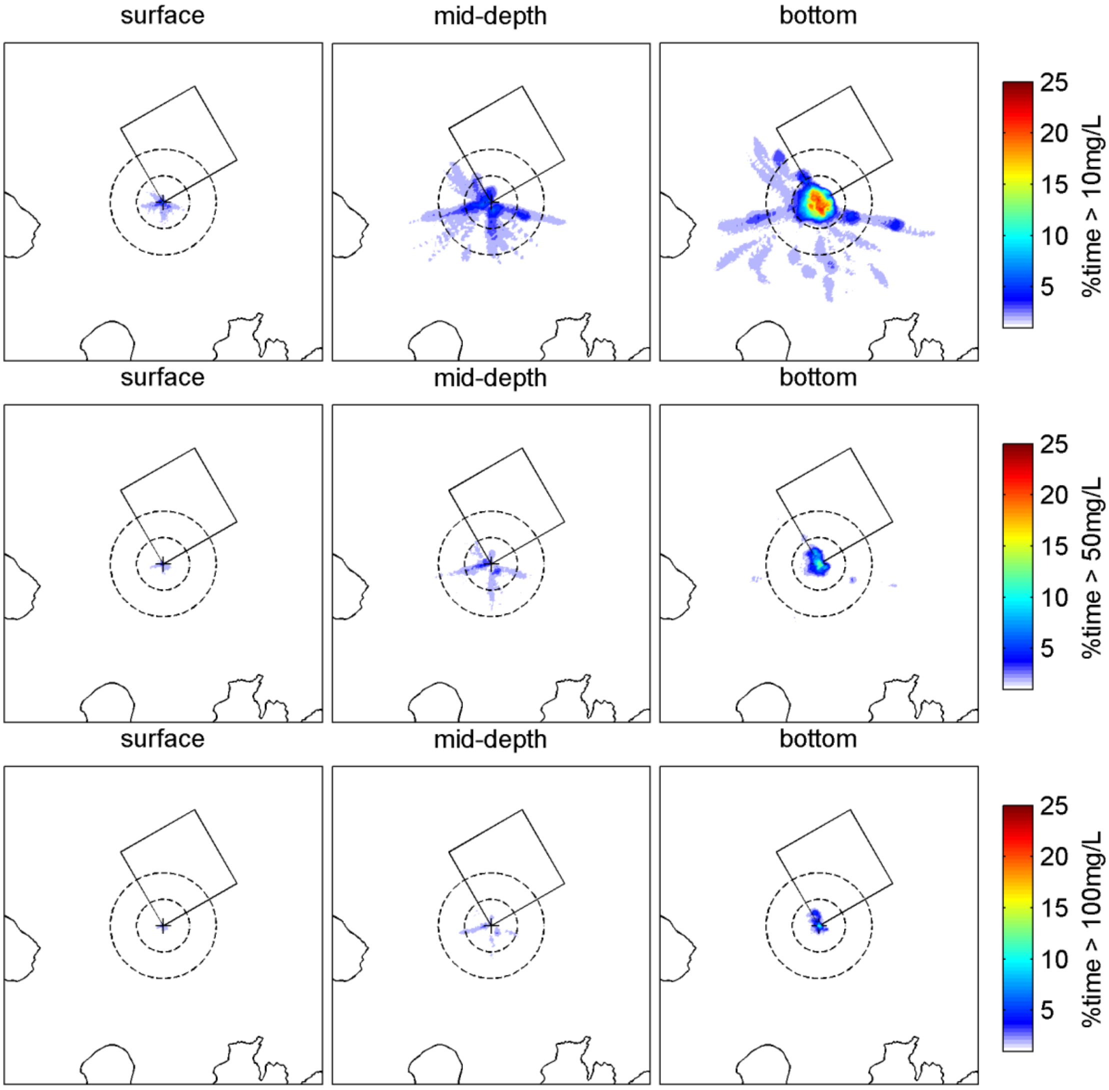
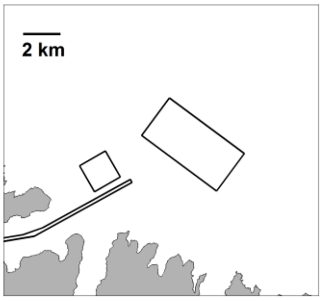


Figure 3.24 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during a strong northeast wind/wave event, assuming a 1.5 h disposal cycle at Maint4 with the Mahury vessel (V=1,840 m^{3}). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.

Calm conditions



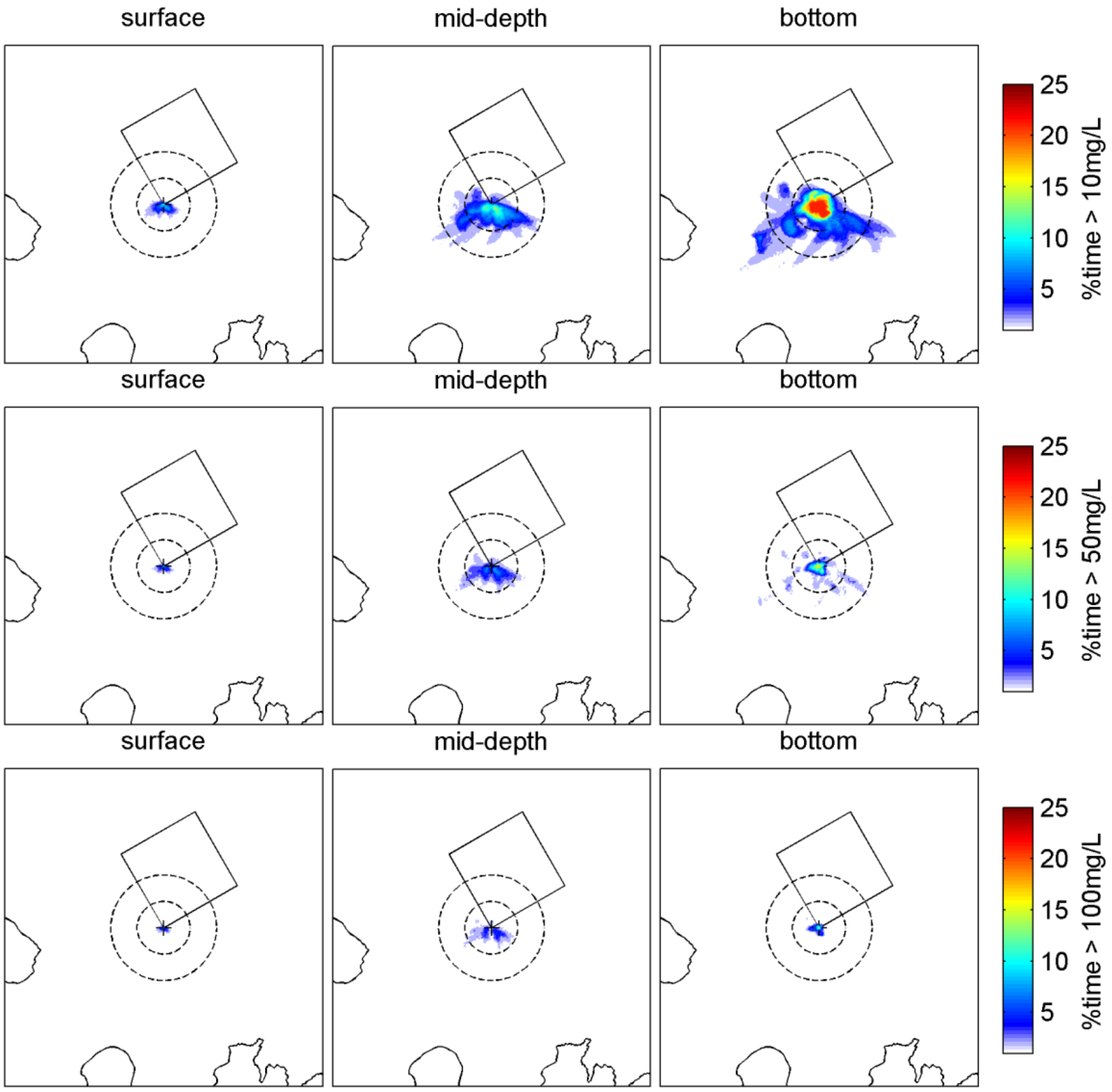


Figure 3.25 Percentage of time *SSC* thresholds of 10, 50, 100 mg.L^{-1} are exceeded during calm conditions, assuming a 1.5 h disposal cycle at Maint4 with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. Background concentrations are of the order 10 mg/L.

3.4. Extreme particle dispersion footprints

The results of the particle tracking simulations can be used to estimate the extreme particle dispersions footprints. These footprints are defined by determining the individual particle distances from the release point and then defining a range of distance statistics, notably the extreme excursions such as the 90^{th}, 95^{th}, and 99^{th} percentiles distances. These extreme excursion distances are used to define a polygon around the release location (convex hull) which spatially defines the extreme particle dispersion and worst-case scenarios of plume dispersion. Maximum distances are not included to avoid irrelevant polygon skewness due to individual outliers.

Actual plume *SSC* levels are expected to quickly decrease away from the initial release point, with effective *SSC* levels near the extreme footprint edges being well below ambient levels.

Results are presented for both the proposed maintenance disposal ground and the proposed capital disposal ground considering an annual climatic variability and assuming discharge of sediment from the Mahury dredger (Figure 2.1).

3.4.1. Proposed maintenance disposal ground

For the proposed maintenance disposal ground, the extreme *SSC* extents for disposal at the centre and the two sites closest to the shoreline (site Maint1 and 4) are presented in Figure 3.26 for the surface, mid water and near bed. Near-surface discharged particles are expected to be contained within less than 1-km of the release point, while mid water released particles may be transported 1-2-km from the release point. Results suggest that limited suspended sediment in the near-bed region may reach towards the coastline at Godley Head, southeast of Port Levy / Koukourārata, however in reality these levels are likely to be well below ambient concentrations and sediment is not expected to settle at or near the shoreline due to the energetic nature of the coastal zone.

In order to provide a summary picture capturing the absolute extreme dispersion footprints valid for sediment disposal at any position within the proposed maintenance ground, the individual excursion polygons were determined for all 4 corners of the disposal grounds and combined by taking the convex hull of all polygons points. Results are presented in Figure 3.27 for the suspended sediment associated with disposal at the proposed maintenance ground. The combined extreme dispersion footprints expectedly produce an elliptic shape elongated in the northwest-southeast axis, with near shore expressions of the SSC between Godley Head and southeast of Port Levy / Koukourārata, however in reality these levels are likely to be well below ambient concentrations and sediment is not expected to settle at or near the shoreline due to the energetic nature of the coastal zone.

The extreme dispersion footprints for disposal at the centre and two sites closest to the shoreline (site Maint1 and 4) are presented in Figure 3.28, while results for a convex-hull of all 4 corners of the proposed maintenance disposal ground are provided in Figure 3.29. The extreme excursion footprints have a general elliptic shape elongated in the direction northwest-southeast, consistent with previous results, with near shore expressions of the depositional footprint between Godley Head and southeast of Port Levy / Koukourārata.

These results do not consider the re-entrainment and subsequent transport by combined wave and currents (addressed in MetOcean Solutions Ltd: P0201-04, 2016), and in reality the fine sediment contained within the discharged plumes are unlikely to settle at or near the shoreline due to the energetic nature of the coastal zone.

3.4.2. Proposed capital disposal ground

For the proposed capital disposal ground, the extreme *SSC* extents for disposal at the centre and the two sites closest to the are presented in Figure 3.30 for the surface, mid water and near bed. Near-surface discharged particles are expected to extend slightly further than 1-km of the release point, while mid water released particles may be transported 2-4-km from the release point. The results indicate no connection of the extreme footprints with any of the closest coastlines and bays, with extreme excursion polygons remaining 1 to 2 km off the closest coast at all time.

In order to provide a summary picture capturing the absolute extreme dispersion footprints valid for sediment disposal at any position within the proposed maintenance ground, the individual excursion polygons were determined for all 4 corners of the disposal grounds and combined by taking the convex hull of all polygons points. Results are presented in Figure 3.31 for the suspended sediment associated with disposal at the proposed capital ground. The results indicate no connection of the extreme footprints with any of the closest coastlines and bays, with extreme excursion polygons remaining 1 to 2 km off the closest coast at all time.

The extreme dispersion footprints for disposal at the centre and two sites closest to the shoreline within the proposed capital ground are presented in Figure 3.32, while results for a convex-hull of all 4 corners of the proposed maintenance disposal ground are provided in Figure 3.33. The extreme excursion footprints have a general elliptic shape elongated in the direction northwest-southeast, consistent with previous results, with no coastal or shoreline impact expected.

These results do not consider the re-entrainment and subsequent transport by combined wave and currents (addressed in MetOcean Solutions Ltd: P0201-04, 2016), and in reality the fine sediment contained within the discharged plumes are unlikely to settle at or near the shoreline due to the energetic nature of the coastal zone.

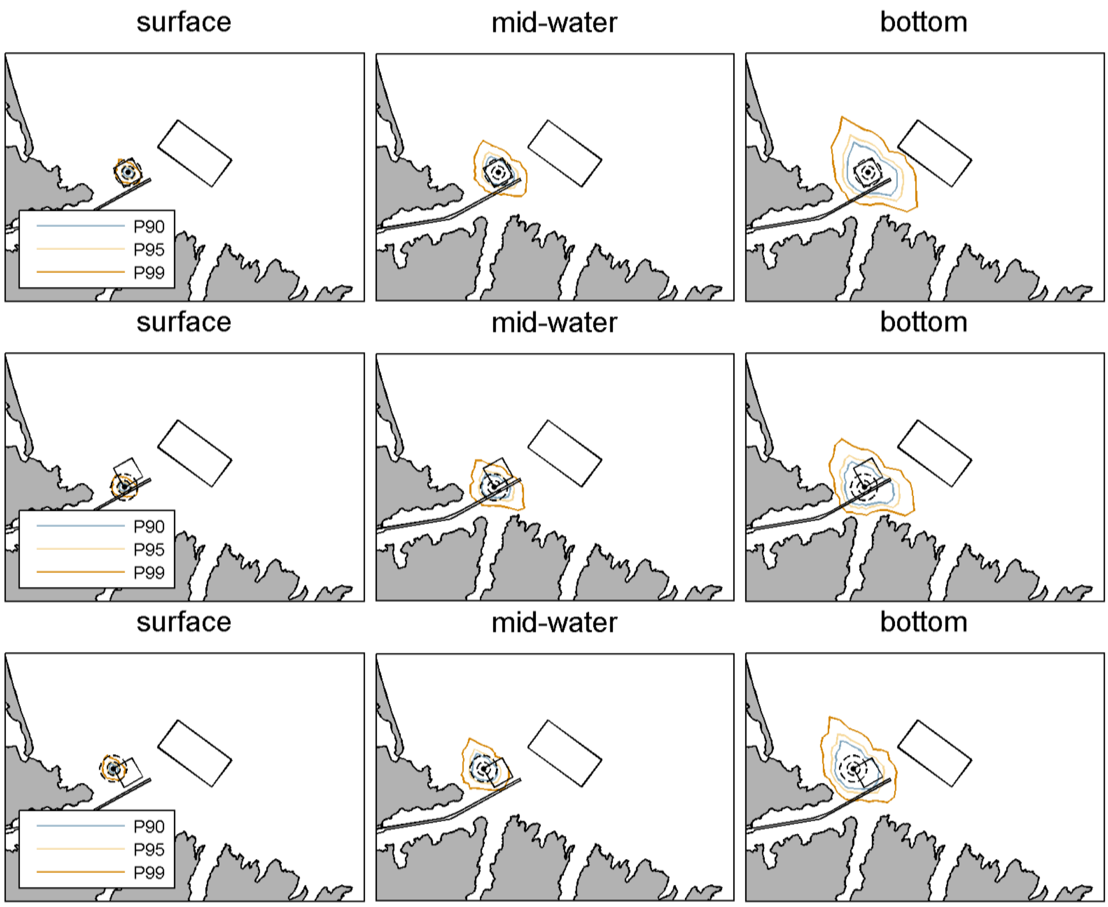


Figure 3.26 Comparison of extreme excursion footprints of *SSC* plumes resulting from sediment disposal at sites Maint1, Maint4, and Maint5 with the Mahury vessel (V=1,840 m^3) on the surface, mid water and bottom layers of the water column. Dashed circles have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

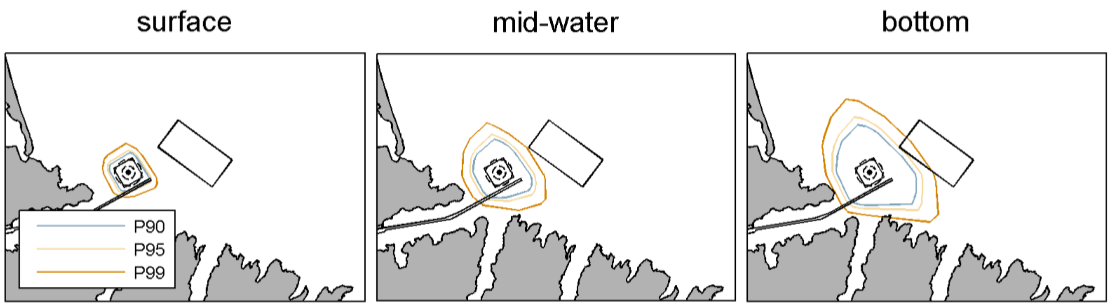


Figure 3.27 Combined extreme excursion footprints of SSC plumes resulting from sediment disposal at the maintenance ground corners with the Mahury vessel (V=1,840 m^3), on the surface, mid water and bottom layers of the water column. Dashed circles have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

Figure 3.28 Comparison of extreme excursion footprints of sediment deposition resulting from sediment disposal at sites Maint1, Maint4, and Maint5, with the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

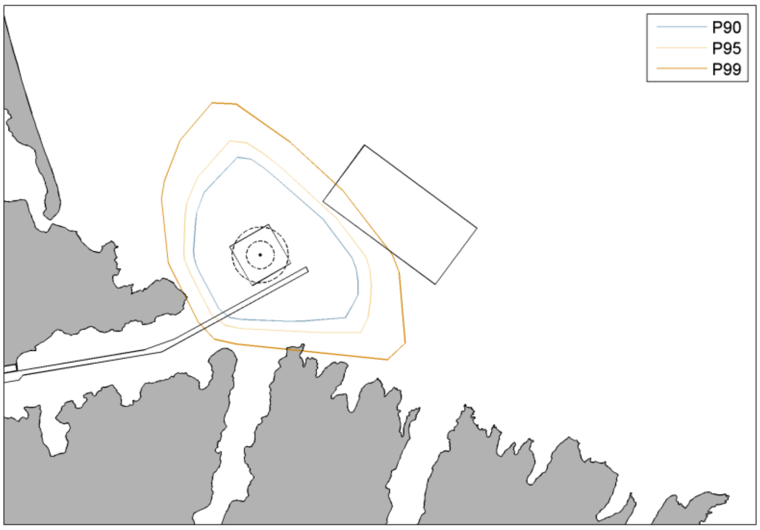


Figure 3.29 Combined extreme excursion footprints of sediment deposition resulting from sediment disposal at the maintenance ground corners, for the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

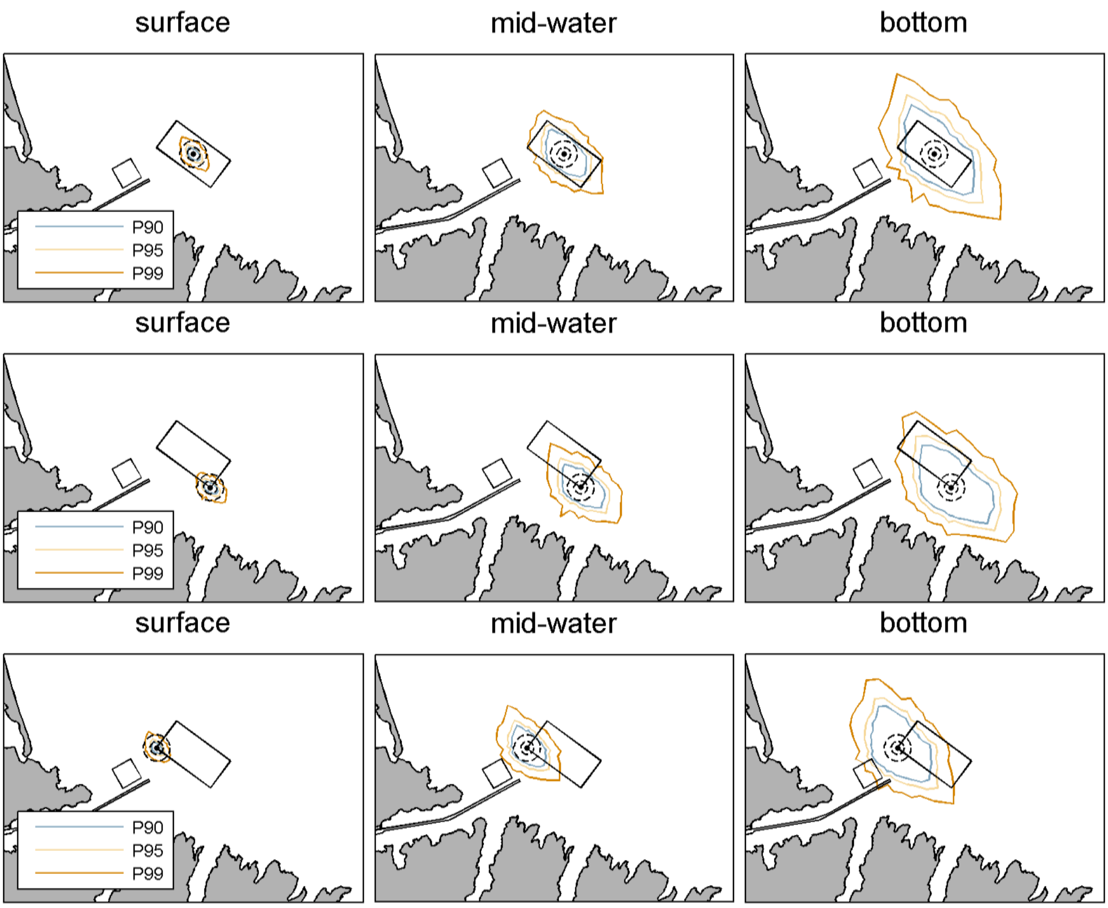


Figure 3.30 Comparison of extreme excursion footprints of SSC plumes resulting from sediment disposal at sites 1, 3, and 5 with the Mahury vessel (V=1,840 m^3), on the surface, mid water and bottom layers of the water column. Dashed circles

have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

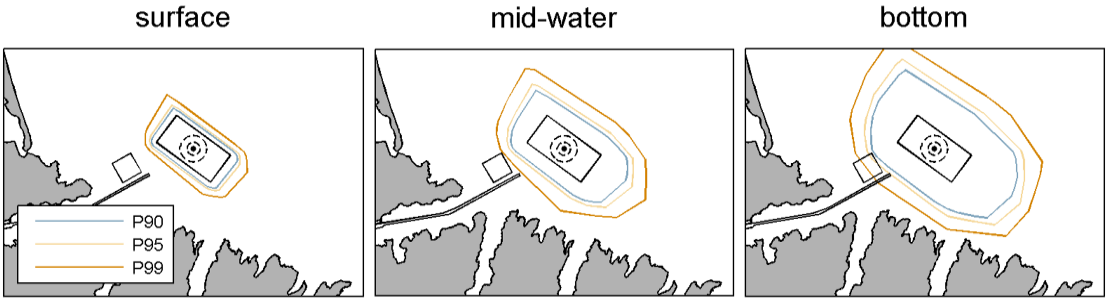


Figure 3.31 Combined extreme excursion footprints of SSC plumes resulting from sediment disposal at the capital ground corners, for the Mahury vessel (V=1,840 m^3), on the surface, mid water and bottom layers of the water column. Dashed circles have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

Figure 3.32 Comparison of extreme excursion footprints of sediment deposition resulting from sediment disposal at sites 1, 3 and 5 with the Mahury vessel (V=1,840 m3) at the capital ground. Dashed circles have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

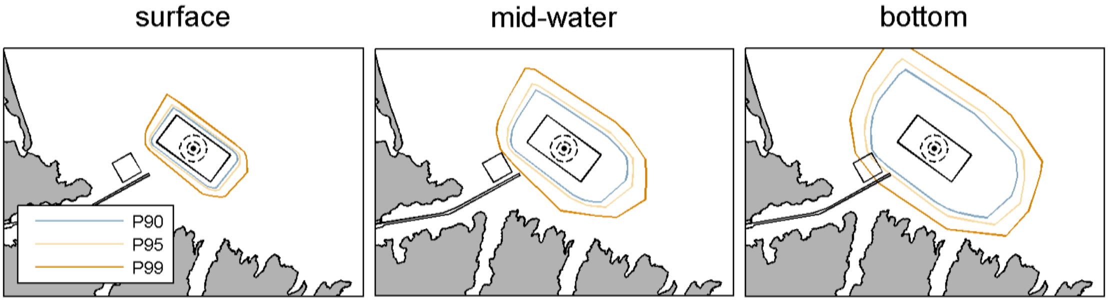


Figure 3.33 Combined extreme excursion footprints of SSC plumes resulting from sediment disposal at the capital ground corners, for the Mahury vessel (V=1,840 m^3), on the surface, mid water and bottom layers of the water column. Dashed circles have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

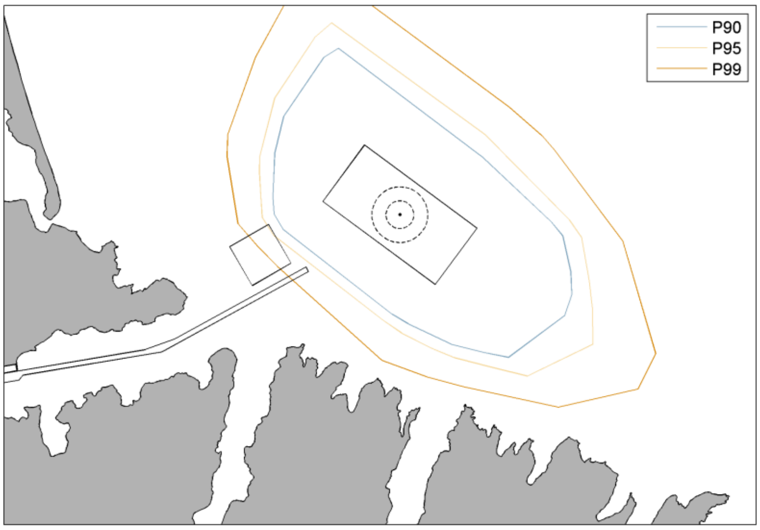


Figure 3.34 Combined extreme excursion footprints of sediment deposition resulting from sediment disposal at the capital ground corners, for the Mahury vessel (V=1,840 m^3). Dashed circles have radiuses of 500 and 1000 m. These results were derived from an annual simulation.

4. SUMMARY

In the context of the proposed Channel Deepening Project (CDP) at Lyttelton Port, Christchurch, the present study assesses the dispersion characteristics of the passive plume associated with the disposal of maintenance dredged sediment at both a proposed maintenance and capital offshore disposal ground in Pegasus Bay.

The passive disposal plume dispersion was simulated with a Lagrangian particle-tracking model and a validated high-resolution hindcast of the Pegasus Bay hydrodynamics. The suspension of sediment in the water column during the sediment disposal, eventually forming the passive plume, was assumed to be the results of two main source terms, namely de-entrainment of sediment into the water column during sediment descent (as a density driven jet) and sediment suspension due to the density current formed following sediment load impact on the seabed. A degree of conservatism was introduced by considering an additional sediment source for possible loss in the near surface layer during disposal operations.

The general dynamics of the plume dispersion were firstly investigated based on a range of short-term simulations of events during hydrodynamic and atmospheric forcing conditions considered to be representative of the expected range at the disposal site.

To derive robust statistical estimations of the plume dispersion and deposition, a second approach consisting of running long-term 1-year simulations of disposal activities were undertaken in order to capture the natural climatic variability of the forcing conditions at the site

The results were finally supplemented by estimations of the suspended sediment concentration (*SSC)* exceedence times with respect to several relevant thresholds relating to the ambient level present in Pegasus Bay.

The key findings of the study are summarised below:

- At both the proposed maintenance and capital disposal grounds, the most significant *SSC* levels are found in the bottom layer due to sediment suspension by the density current formed following sediment load impact, and are contained within a 300 m radius from the release position. Sediment settling is rapid given the proximity of the seabed. Surface and mid water *SSC* plumes are dispersed for longer period but have limited spatial extents and *SSC* levels (relating to the expected percentage of sediment entering the passive plume at these levels).

- Mean *SSC* derived from the annual plume hindcast of sediment disposal indicates approximate elliptic plume patterns with the major axis consistent with the northwest-southeast direction of the dominant ambient currents. A slight skewness (i.e. asymmetry) to the southeast can be present which is consistent with the expected residual current.

- At the proposed maintenance ground, In the bottom layer, the 10 mg.L $^{-1}$ contour line generally stays within 1 km of the disposal location In the mid and surface layers, *SSC* plumes are very limited, with typical magnitudes below 10 mg.L^{-1}.Concentraion levels reflect the volume of sediment expected to be discharged from the Mahury maintenance dredger (i.e. V=1,840 m^3))

- At both the proposed maintenance and capital disposal sites, patterns of the mean sediment deposition fields associated with the passive plume have an elliptic pattern with the major axis directed northwest-southeast, with a slight skewness to the southeast. The mean deposition thickness field resulting from the disposal of the passive plume component of one hopper load indicates that the 1 mm contour line typically remains within a radius of 500 m from the discharge position.

- For the proposed maintenance disposal ground, the extreme extents of the *SSC* plumes and deposition footprints extend towards Godley Head and southeast of Port Levy / Koukourārata, however in reality SSC levels are likely to be well below ambient concentrations and sediment is not expected to settle at or near the shoreline due to the energetic nature of the coastal zone.

- For the proposed capital disposal ground, the *SSC* plumes and deposition footprints remain 2 to 3 km from the nearest shoreline point, even when sediment is disposed on the southernmost disposal ground corner (i.e. point closest to the coast in the disposal ground).

- Suspended sediment concentration exceedence times relative to specific thresholds relating to the approximate mean ambient concentration naturally occurring in Pegasus Bay, and slightly elevated levels (10, 50 and 100 mg.L^{-1}) have been estimated. These values are several orders of magnitude less than the estimated average surface water *SSC* at the mouth of the Waimakariri River (estimated to be an average *SSC* of 1400 mg.L^{-1}).

- On average, the 10 mg.L^{-1} threshold is exceeded 10 to 20 % of the time in the bottom layer within a radius of ~300 m from the discharge site. In the mid-water level, exceedances of up to 5 % are contained within a 500 m radius and become insignificant past the 1 km radius. The largest *SSC* threshold of 100 mg.L^{-1} is typically exceeded 5-10 % of the time within 100 - 200 m from the release position in the bottom layer but very rarely in the mid water and surface levels.

- Similar *SSC* exceedence times were also estimated during the shorter-term representative events. These indicates that the considered *SSC* levels can be exceeded more frequently (up to ~20-25% in the bottom layer) due to either dispersion of the plume in a predominant direction (e.g. following a strong current) or limited ambient potential for dispersion (e.g. very calm weather periods).

REFERENCES

MetOcean Solutions Ltd., 2016. CHANNEL DEEPENING PROJECT (CDP) Simulations of suspended sediment plumes and associated deposition from offshore disposal (Technical report prepared for Lyttelton Port Company Limited No. P0201-02).