14th November 2024

Bath Modelling Report

Meil Bay

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Summary

Cooke Aquaculture Scotland Ltd. (CAS) have developed a particle tracking model, driven by a decoupled hydrodynamic model, to simulate bath medicine release in the Wide Firth and Shapinsay Sound region. This determines the safe medicinal quantities that are permitted to be used on site, based on concentration and area Environmental Quality Standards (EQS) outlined by SEPA.

A multi-point calibrated and validated hydrodynamic model and calibrated particle tracking model with dye and drogue surveys were used to predict medicine advection and dispersion from the proposed Meil Bay site. A wellboat-based treatment method was applied, using realistic multiple treatment schedules. For Azamethiphos, this simulated 16 treatments with a 3-hour treatment interval and a maximum of 2 treatments per 24hrs. For Deltamethrin and Cypermethrin a single 6-hour treatment was applied.

Maps and EQS results are presented to illustrate the predicted footprint of bath treatment medicines. The results of the bath modelling found that the medicine amounts summarised in table 1 complied with all EQS standards. An assessment of the proposed treatment quantities on identified sensitive marine features was completed. This shows minimum interactions between treatment plumes and sensitive marine features.

Table 1. Summary of site details and bath treatment results

Stocking details	
Maximum biomass (Tonnes)	1,410
Pen Layout	
No. pens	16
layout	2 x 8
Circumference (m)	100
Orientation (°)	36
Bath Treatments	
Azamethiphos	
Consent mass – 3hr	180g
Consent mass – 24hr	600g
Cypermethrin	

Consent mass – 6hr (Adjusted)	0.0936g
Deltamethrin	
Consent mass – 6hr	10g

1. Introduction

This report details the results of the simulation of bath treatments within a coupled hydrodynamic and particle tracking model. The description of the hydrodynamic model, the calibration and validation and the methods of simulating bath treatments are presented in the Modelling Methods Statement. The measurement of the dispersion coefficient that is used within the particle tracking model is described in detail within the Dye and Drogue Release report. The results of the bath treatment modelling are used to determine EQS compliance with the latest SEPA standards (SEPA, 2023)

1.1 Site description

Meil Bay is an existing, consented site (CAR/L/1003888) operated by Cooke Aquaculture Scotland. The site is located off the northeast coastline of the Orkney mainland, within the Bay of Meil, south of Shapinsay Sound (figure 1). The existing site consists of a single group of 10 circular, 100m circumference cages with a net depth of 6m. These are arranged in a 2 x 5 layout with a 60 m separation, housing a maximum consented biomass of 884T at a maximum stocking density of 18.5kg/m^3. The site is aligned with a bearing of 22.5^o (figure 1). The existing licensed site is centred on 348452.07E, 1012342.29N.

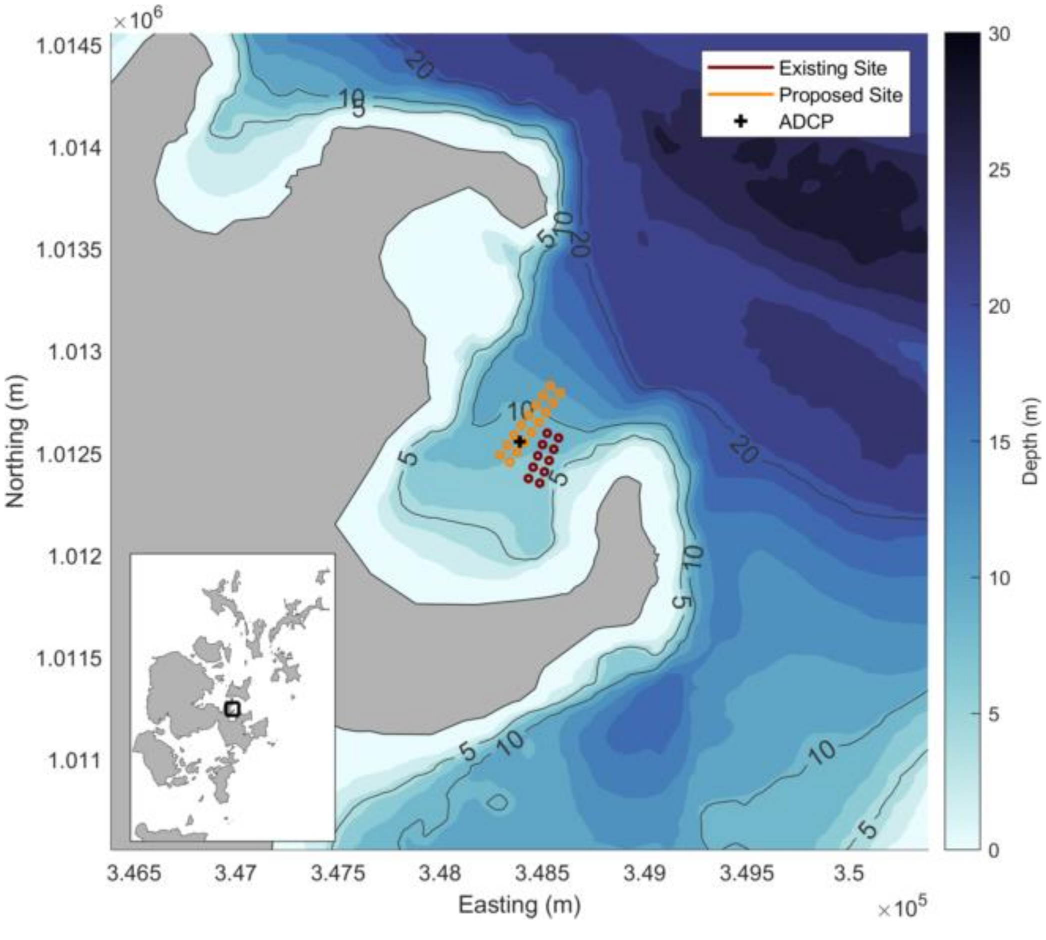

Figure 1. Existing (red) and proposed (orange) Meil Bay site infrastructure, ADCP deployment location ('+') and bathymetry.

The proposed development adds a further six 100m circumference pens to the existing infrastructure, forming a site layout of 2x8 pens on a 60m grid, and repositions the site ~200m to the NW (348439.639E, 1012644.247N) in a deeper, less constrained location closer to the mouth of the bay (figure 1). The proposed site will house a maximum consented biomass of 1410T, providing a maximum stocking density of 18.4kg/m^3. Further information on the existing and proposed site infrastructure and pen layout is presented in table 2.

Table 2 – Existing and proposed site infrastructure and pen layout.

	Meil Bay (Existing)	**Meil Bay (Proposed)**
Consent number	CAR/L/1003888	-
Company	Cooke Aquaculture Scotland	Cooke Aquaculture Scotland
Receiving water	Shapinsay Sound	Shapinsay Sound
Site centre (OSGB36)	348505E, 1012476N	348439.639E, 1012644.247N
Current meter location (OSGB36)/year of deployment	348388E, 1012558N /2021	348388E, 1012558N /2021
Distance to shore (km)	0.35	0.5
Average water depth (m)	9	12
Maximum biomass (t)	884	1410
Total number of pens	10	16
Number of pen groups	1	1
Formation	2x5	2x8
Pen group orientation (°)	22.5	36
Pen shape	Circular	Circular
Pen circumference (m)	100	100
Pen depth (m)	6	6
Mooring grid (m)	60	60

1.2 Sensitive Marine Features

The waters around Shapinsay Sound hosts numerous sensitive marine features. Table 3 outlines the marine features that are assessed within this study. These sites were specified in the Screening and Risk Identification Report (SEPA 2022).

Table 3. Sensitive marine features identified within Shapinsay Sound.

Name	Feature type	Location (OSGB)		Mesh resolution (m^2)
		East (m)	North (m)	
Maerl beds	Marine habitat - Points	346907 347526 350250 351113 349210 349756 349865 351128 350773 351256 351506 352127 352147 352171	1015999 1015671 1015610 1015166 1011840 1012489 1012987 1012514 1012025 1012007 1012036 1011913 1011933 1011960	2000 (45m) - 2500 (50m)
Horse mussel beds	Marine habitat - Area	Shapefile		2000 (45m)
Horse mussel beds	Marine habitat - Points	348810	1015440	2000 (45m) - 4000 (63m)

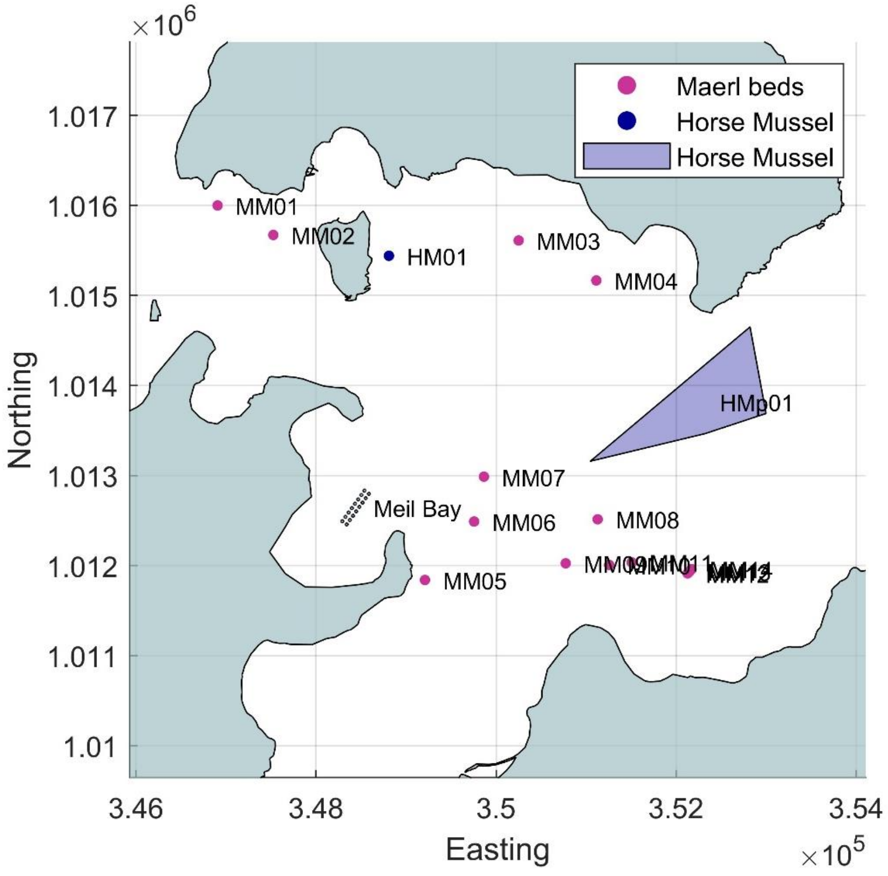

Figure 2. Farm location and sensitive marine features identified within Shapinsay Sound.

2. Model Description

This study uses DHI's MIKE3 flexible mesh model to simulate free-surface flow in a coastal environment. The model uses an unstructured mesh to replicate tidal hydrodynamics, wind and wave driven currents, and storm surges.

2.1 Hydrodynamic model

DHI's MIKE3 flexible mesh model solves the three-dimensional incompressible Reynolds averaged Navier-Stokes equations, using the Boussinesq and hydrostatic pressure assumptions to simulate 3D hydrodynamics over the coastal domain of interest. Continuity of momentum, temperature, salinity and density are applied alongside the k-epsilon turbulent closure scheme. A cell centred finite volume approach is applied for the spatial discretion of the momentum equations over an unstructured triangular mesh.

2.1.1 Model domain

The model domain is created using the cartesian Ordnance Survey of Great Britain 1936 coordinate system (OSGB 1936). Coastline data is imported from Ordnance Survey (2020) and is used to define the land boundaries within the domain. Bathymetry data are taken from the UK Hydrographic Office (UKHO, 2021). The model mesh is unstructured, consisting of non-overlapping triangular elements covering a domain that extends from 229929E to 442733E, and 910599N to 1099869N (figure 3a). An unstructured mesh allows variation in element size, meaning near open boundaries the mesh resolution is relatively coarse (2km) to increase computational efficiency. In areas of specific interest, complex topography or complex bathymetry, the resolution is enhanced so that these features are adequately resolved (figure 3b). Horizontally the mesh comprises 73066 nodes and 139921 elements. In the vertical dimension, the model has 5 terrain following sigma layers, mostly concentrated within the upper part of the water column.

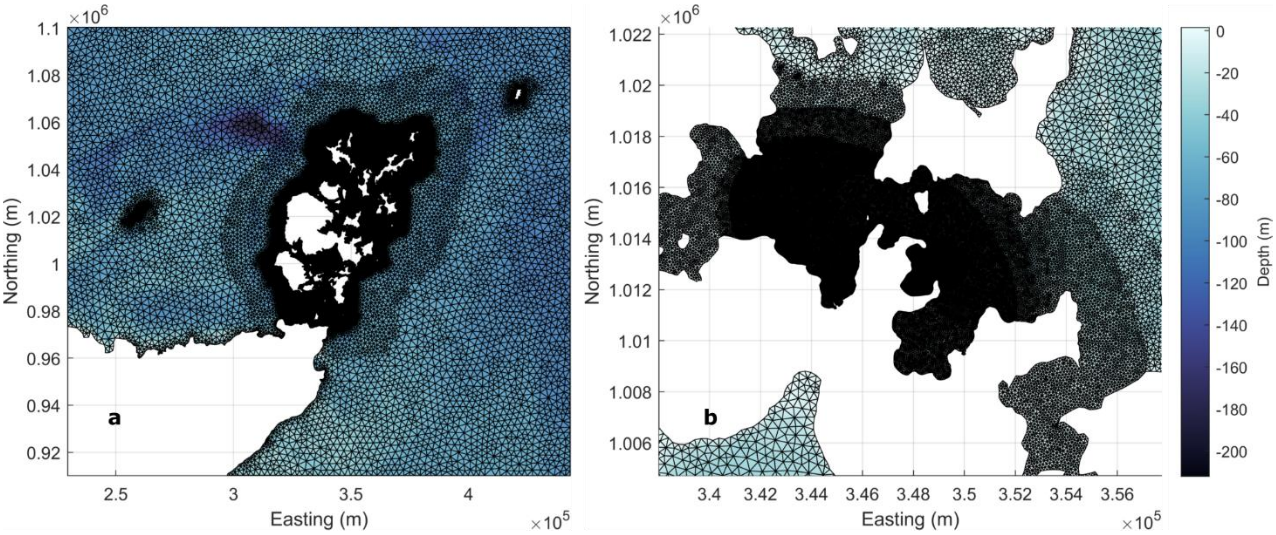

Figure 3. Hydrodynamic model mesh. a) wider computational mesh. b) Computational mesh around the proposed Meil Bay site.

2.1.2 Configuration and boundary forcing

Boundary conditions are taken from DHI's global tidal model, where tidal elevations are calculated from 10 principal astronomical constituents (semidiurnal M2, S2, K2, N2, Diurnal S1, K1, O1, P1, Q1 and Shallow water M4). The global tidal model has a resolution of 0.125°x 0.125° and interpolates data to the nearest boundary element. Temporal resolution outputted elevations every 12 mins. Wind data was taken from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 model (ECMWF, 2023). This provides wind velocity in U and V components, as well as surface pressure with a resolution of 0.25°x. 0.25° at an hourly interval.

A minimum and maximum model time step of 0.01 and 60 seconds was applied, with a critical CFL number of 0.95 ensuring model stability. Point data outputs were produced at 10-minute intervals and area data outputs at 30-minute intervals. Flooding and drying were included, with a drying depth of 0.005m and a wetting depth of 0.1m. The horizontal eddy viscosity applies Smagorinsky's formulation with a constant value of 0.28. Bed roughness in the form of the roughness height is used as the main calibration term. This parameter is adjusted to calibrate the model. The best model performance was achieved using a spatially variable bed roughness. A local (3km radius) bed roughness of 0.025m was applied at

Quanterness and 0.15m at Meil Bay. The background bed roughness across the remainder of the mesh was set to 0.05m.

2.2 Particle tracking model

Particle release is simulated using DHI's MIKE 3 particle tracking model. This is run offline from the hydrodynamic model to reduce computational time. The time step remains identical to that used within the hydrodynamic model. However, simulation start time is located out with the hydrodynamic model warm-up period and coincides with bath treatments finishing on the user-defined spring and neap tides.

2.2.1 Particle Configuration

As treatment chemicals decay when dissolved in aqueous solution, particle decay is included within the model. This decay is specified as the chemical half-life ($t_{1/2}$). This is used to calculate the mean lifetime of the chemical (τ), which is specified within the model as the maximum particle age.

$$\tau = \frac{t_{1/2}}{\ln(2)}$$

To specify the particle decay within the model, the half-life must be converted to decay rate (λ). This is calculated as

$$\lambda = \frac{0.693}{t_{1/2}}.$$

For Azamethiphos, a half-life of 5.6 days is specified. This corresponds to a mean particle lifetime of 8.08 days with a decay rate of 1.43×10^{-6} /s. For Cypermethrin and Deltamethrin, no chemical half-life is available, therefore no chemical decay is simulated for these treatments.

As chemical treatments are dissolved, particle settling within the model was switched off and the erosion critical shear stress was set to 0 N/m^2. The horizontal dispersion coefficients used the measured value of 0.105m^2/s calculated in the Dye and Drogue Release report. The vertical dispersion coefficient used the default value of 0.001m^2/s.

2.2.2 Particle Source

For each bath chemical, a series model runs were carried out using a wellboat-style treatment.

2.2.2.1 Wellboat Release

Particles are emitted from a point source, representative of a wellboat discharge port, at a constant rate for a period of one hour within the particle tracking model. As wellboat locations change frequently, moving from pen to pen to perform treatments, the discharge location will vary. To account for this variability, all treatments will be released from the site centre. Particles are released at a depth of 1.5m below the surface with an output layer thickness that extends from the surface to 5m depth.

2.2.3 Treatments

The maximum number of treatments is restricted to two per working day (9-hour window). This is the maximum number of treatments that could feasibly be conducted during a single representative day. Each treatment within a day is separated by a 3-hour treatment interval. This allows time for treatments to take place, waste medicine discharge and resetting of equipment ready for the next treatment.

Only bath treatments from the Meil Bay are considered within the report as specified within the SEPA Aquaculture Modelling Screening and Risk Identification Report: Meil Bay (BOM1). However cumulative assessment of far-field solids is required and is addressed in a separate report.

For Azamethiphos, the chemical plume area exceeding the EQS threshold for 72 hours after the final treatment was used to explore the site's contribution. For Cypermethrin and Deltamethrin, the chemical plume area exceeding the EQS threshold for 6-hours after the initial treatment was used to explore the site's contribution. To assess the likely most and least dispersive cumulative EQS scenarios, the final treatment for Azamethiphos and the initial treatment for Deltamethrin and Cypermethrin were chosen to coincide with highwater of the smallest neap tide and largest spring tide. This provides a treatment time of 18/07/2021 17:50:00 during a neap tide and 25/07/2021 23:40:00 during a spring tide. Timings of each bath model run are shown in figures 4 and 5 and outlined in table 3.

Table 3. Simulation times for particle tracking model for bath treatments.

	Simulation start date	Last release date	Simulation end date	Time after final treatment (hrs)
Azamethiphos (3hrs)				
Neap	18/07/2021 05:50:00	18/07/2021 17:50:00	19/07/2021 21:50:00	28
Spring	25/07/2021 11:40:00	25/07/2021 23:40:00	27/07/2021 03:40:00	28
Azamethiphos (72hrs)				
Neap	11/07/2021 14:00:00	18/07/2021 17:50:00	22/07/2021 17:50:00	96

Spring	18/07/2021 13:00:00	25/07/2021 23:40:00	29/07/2021 23:40:00	96
Cypermethrin/Deltamethrin				
Neap	18/07/2021 05:50:00	18/07/2021 17:50:00	20/07/2021 00:50:00	31
Spring	25/07/2021 11:40:00	25/07/2021 23:40:00	27/07/2021 06:40:00	31

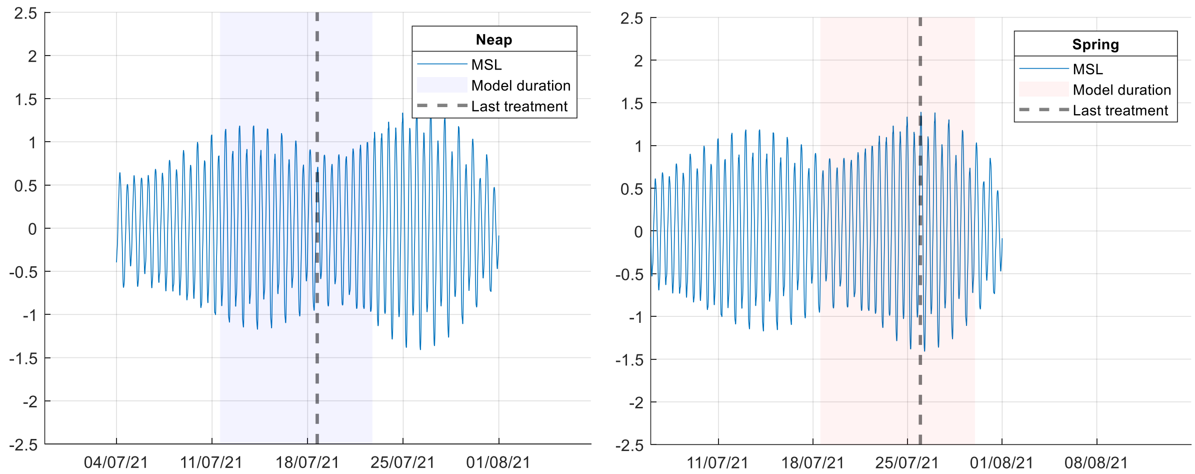

Figure 4. Mean sea level for Neap (left) and Spring (right) tides indicating model simulation duration for Azamethiphos (72hrs) with the final treatment time indicated using the dashed line.

To assess the short-term risk of Azamethiphos, a single release of the 3-hour treatment mass was modelled. The areal extent of the chemical plume captured 3-hours after the first release time was used to determine short-term EQS compliance. To assess long-term risks from Azamethiphos, an entire treatment regime was modelled, encompassing the treatment of all pens within the proposed farm. The maximum chemical concentration and areal extent of the chemical plume captured 72-hours after the final release time was used to determine long-term EQS compliance.

To assess the risk of Deltamethrin and Cypermethrin, a 6-hour treatment mass was modelled. The areal extent of the chemical plume captured 6-hours after the first release time was used to determine EQS compliance.

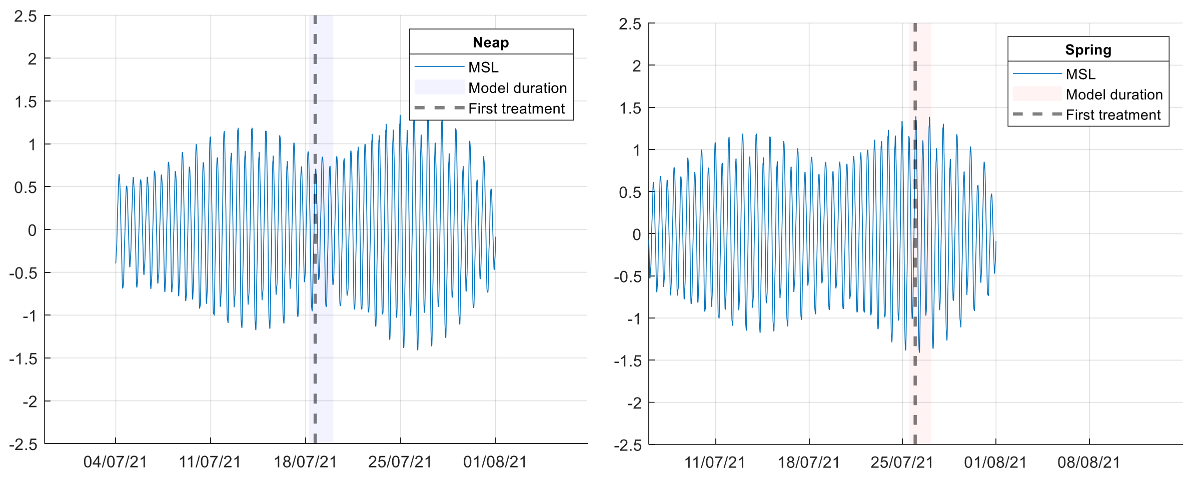

Figure 5. Mean sea level for Neap (a) and Spring (b) tides indicating model simulation duration for Cypermethrin and Deltamethrin with the initial treatment time indicated with the dashed line.

Wind is omitted from the model to ensure the least dispersive conditions are replicated. As wind is not included there is no requirement to select dates in the summer months. For each bath treatment tested, both spring and neap models are required to pass EQS. The particle tracking model will run for the treatment period, plus an additional 24 hours after the last EQS time – i.e., 96 hours after the last treatment for Azamethiphos and 30 hours after the last treatment for Deltamethrin and Cypermethrin. This ensures no further EQS standards are exceeded.

2.2.3.1 Wellboat Treatment

To realistically simulate the treatment process, particle releases were timed to coincide with expected treatment intervals. A treatment plan consisting of two 3-hour wellboat treatments per working day is applied. Within this 3-hour treatment interval, 1 hour is assigned as the wellboat discharge period, whereby the wellboat continually releases the treatment solution into the environment at a constant rate. The number of particles assigned to each treatment is constant, in this case 30,000 particles per treatment are used, providing highly resolved treatment plumes that computes in a reasonable time frame. These are released into the domain continuously over the discharge period. To determine the number of particles released each timestep, the number of particles is divided equally by the number of timesteps within the discharge period. Similarly, the chemical mass assigned to the particles released during the discharge period is defined as the total amount used for the treatment of one wellboat divided by the number of timesteps within the discharge period.

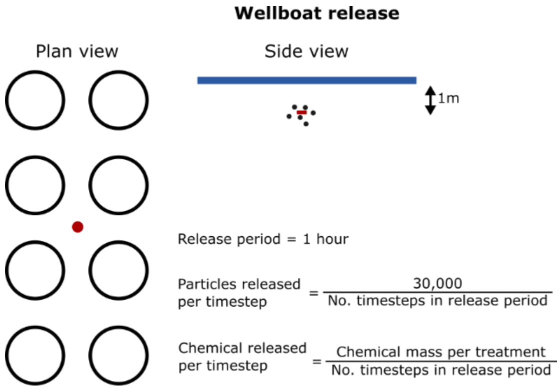

Figure 6. Wellboat release schematic. Open black circles represent pen locations, particle source location is shown in red, the blue line represents the sea surface and small black dots represent particles.

2.2.4 Environmental Standards (EQS)

To determine the quantity of chemical used, a hydrodynamic and particle tracking model simulates the chemical release and plume advection. The area coverage and concentration are then monitored to ensure they remain within acceptable tolerances. These environmental quality standards are outlined in SEPA (2023) for Azamethiphos, Cypermethrin and Deltamethrin treatments (table 4). The EQS determines the concentration of the plume area, that must not exceed a site-specific mixing area (A). For the 3- and 6- hour EQS this area is defined as a function of mean current speed (U), time (t) and the horizontal dispersion coefficient (K_X). Mathematically, this is represented as:

$$A = 2\pi \frac{Ut}{2} \sqrt{(2K_x t)}$$

Signature ADCP deployments for Meil Bay reveal a mean near-surface current speed of 0.0345m/s over the period 15/09/2020 to 05/01/2021, which gives a 3-hour EQS area of 0.0557km^2 and a 6-hour EQS area of 0.1577km^2. The 72-hour EQS area is not site specific and is assigned a constant value of 0.5km^2.

Additionally, for Azamethiphos a Maximum Allowable Concentration (MAC) is applied. This restricts the peak chemical concentration within the domain after the given time interval. This is not required for Cypermethrin and Deltamethrin.

The 3- and 6- hour EQS restrictions are applied to ensure the short-term compliance of a chemical release. Therefore, these times are referenced to the hours after the chemical discharge of a single, initial treatment event. The 72-hour EQS ensures the long-term compliance of bath chemical use, therefore is applied 72 hours after the final treatment of a full site treatment cycle.

Table 4. Environmental standards for chemical treatments.

	EQS (ng/l)			MAC (ng/l)
	3hrs	6hrs	72hrs	72hrs
Azamethiphos	250	-	40	100
Cypermethrin*	-	16	-	-
Deltamethrin	-	6	-	-
*Quantities of Cypermethrin passing EQS, as shown above, will be reduced by a factor of 267 to comply with SEPA (2018).				

3. Results

3.1 Bath Treatments

The simulation of bath treatments from the proposed site was considered. This looks at the release of Azamethiphos, Cypermethrin and Deltamethrin and the dilution of the chemical plume in relation to the EQS standards. The individual EQS parameters are summarised in table 5. This indicates compliance is achieved with all proposed chemical treatments.

Table 5. Environmental standards for bath treatment releases MAC and area EQS for all treatments at Meil Bay.

	Treatment Quantity (g)	**MAC 72 hrs (µg/l)**	**EQS 3hrs - Single Treatment (km^2)**	**EQS 6hrs (km^2)**	**EQS 72hrs (km^2)**
Azamethiphos (3hrs)					
Neap	180	-	0.042 (74.8%)	-	-
Spring	180	-	0.037 (66.2%)	-	-
Azamethiphos (72hrs)					
Neap	300	0.049 (48.5%)	-	-	0.007 (1.5%)
Spring	300	0.069 (69.0%)	-	-	0.02 (4.3%)

Cypermethrin (6hr)					
Neap	25	-	-	0.107 (67.8%)	-
Spring	25	-	-	0.081 (51.5%)	-
Deltamethrin (6hr)					
Neap	10	-	-	0.113 (71.5%)	-
Spring	10	-	-	0.083 (52.7%)	-

3.1.1 Azamethiphos

Compliance was achieved at the proposed Meil Bay site using 180g within a 3hr period and 600g of Azamethiphos within a 24-hour period. This equated to 300g per pen assuming two wellboat treatments per day with a 3-hour interval. This corresponds to a treatable volume of 2992.2 m^3 per 3 hours.

3.1.1.1 Neap tides

To assess the short-term compliance for Azamethiphos, a single release of a 3-hour mass (180g) is modelled in isolation. The size of the 3-hour EQS plume following this initial release (0 hours on the x axis) is shown in figure 7. The size of the chemical plume after a single treatment always remains less than the calculated mixing area of 0.055746km^2.

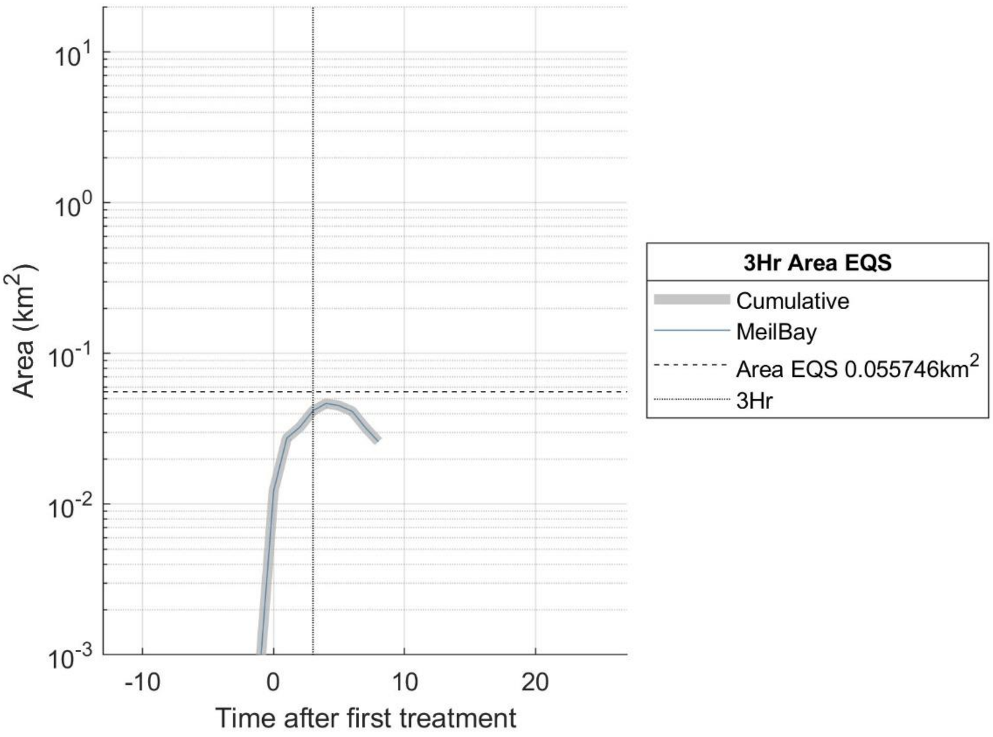

Figure 7. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after the initial 3-hour mass wellboat release of Azamethiphos during neap tides. The size of the 3-hour EQS mixing zone is shown by the horizontal dashed line. 3-hours after the initial treatment is marked by the vertical dotted line.

To assess the longer-term risks from Azamethiphos, a full treatment cycle is simulated. The MAC for the neap tidal cycle is plotted in figure 8. The individual pen treatments are identified by the colour coded site-specific lines. Time, on the x-axis, is referenced as hours since the final treatment event, aiding the interpretation of EQS times. Immediately following the introduction of chemical particles into the model domain decay and dispersion causes a rapid reduction in concentrations, resulting in sharp peaks of chemical quantity as individual pens are treated. If the discharge period coincides with slack water, the peaks become more pronounced, whereas if the discharge period coincides with stronger ebbing/flooding currents the amplitude of the peak is suppressed as the stronger currents are dispersing the released particles more efficiently. At 72 hours after the final treatment the concentration from the proposed Meil Bay site is 0.069µg/l, this is 69.0% of the EQS value. Following this, a general decline in concentration is observed over the remainder of the model run period.

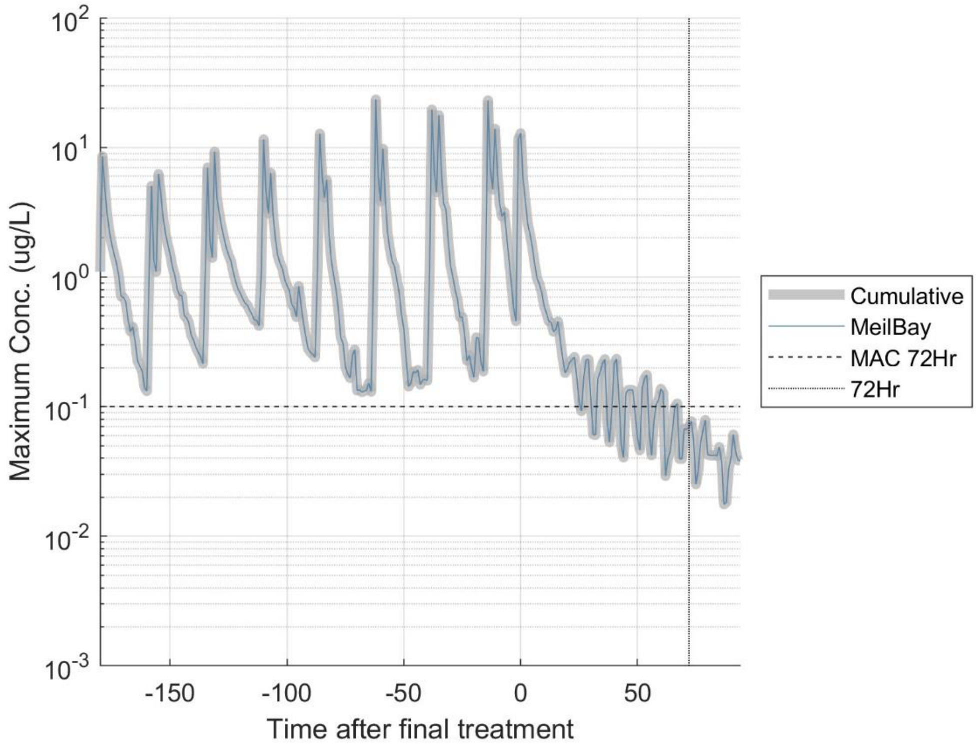

Figure 8. Maximum concentration of Azamethiphos during a neap tide wellboat treatment schedule. Cumulative impact plotted as solid grey line and MAC for the 72-hour EQS (100 ng/l) is indicated by the grey dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The area of the chemical plume exceeding 40ng/l (72-hour EQS) is plotted in figure 9. At the 72-hour EQS time, the area exceeding 40 ng/l is less than 0.5km^2. By this point, the plume is well dispersed and fragmented and decreasingly exceeds the 40ng/l threshold.

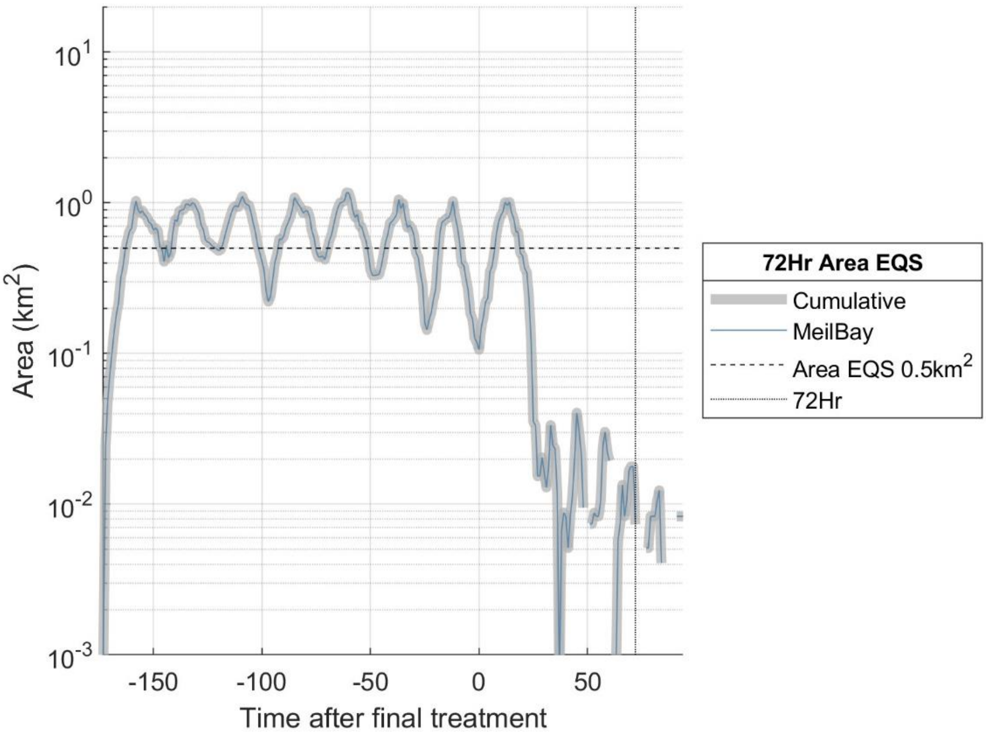

Figure 9. Chemical plume area exceeding the 72-hour (40 ng/l) EQS values after a wellboat treatment cycle using Azamethiphos during neap tides. The size of the 72-hour EQS mixing zone is shown by the horizontal dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The spatial distribution of Azamethiphos after the final release of bath treatment from the proposed site during neap tides is shown in figure 10. The areas where concentrations exceed the 72-hour EQS values are outlined in red. This indicates that the main plume stays relatively local to the site during the ebb tide then during the flood tide the plume is pulled out of the bay. When the tide changes again, this branch of the plume is separated, and is rapidly transported and dispersed in the strong tides of the tidal strait to the north of the site. Aft 48hrs the bulk of the plume is dispersed and by 72hrs no chemical concentrations exceeding the EQS threshold.

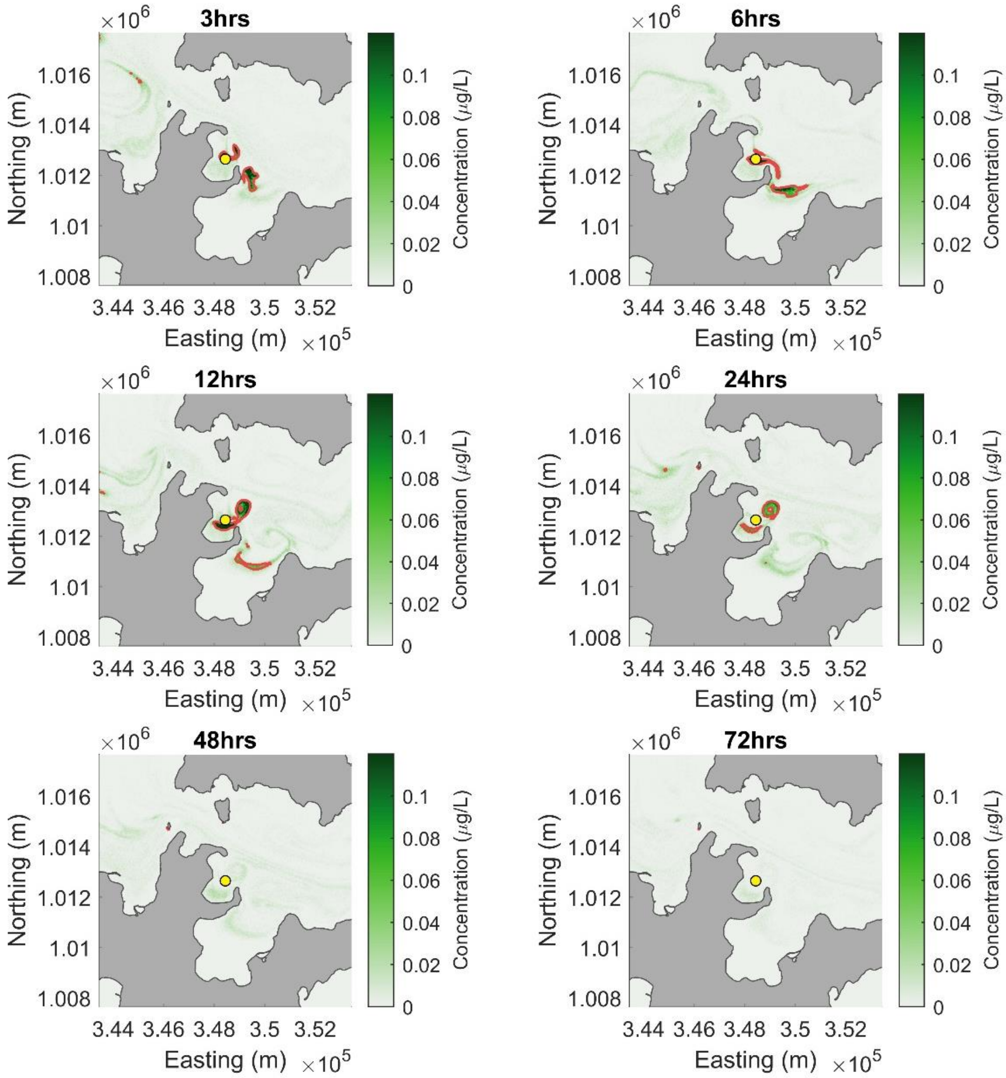

Figure 10. Spatial Azamethiphos distribution for wellboat releases during neap tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour and site location is identified using a yellow marker.

3.1.1.2 Spring tides

To assess the short-term compliance for Azamethiphos, a single release of a 3-hour mass (180g) is modelled in isolation. The size of the 3-hour EQS plume following this initial release (0 hours on the x axis) is shown in figure 11. The size of the chemical plume after a single treatment always remains less than the calculated mixing area of 0.055746km^2. No plumes with concentrations exceeding 250ng/l exist 14 hours after a single treatment event.

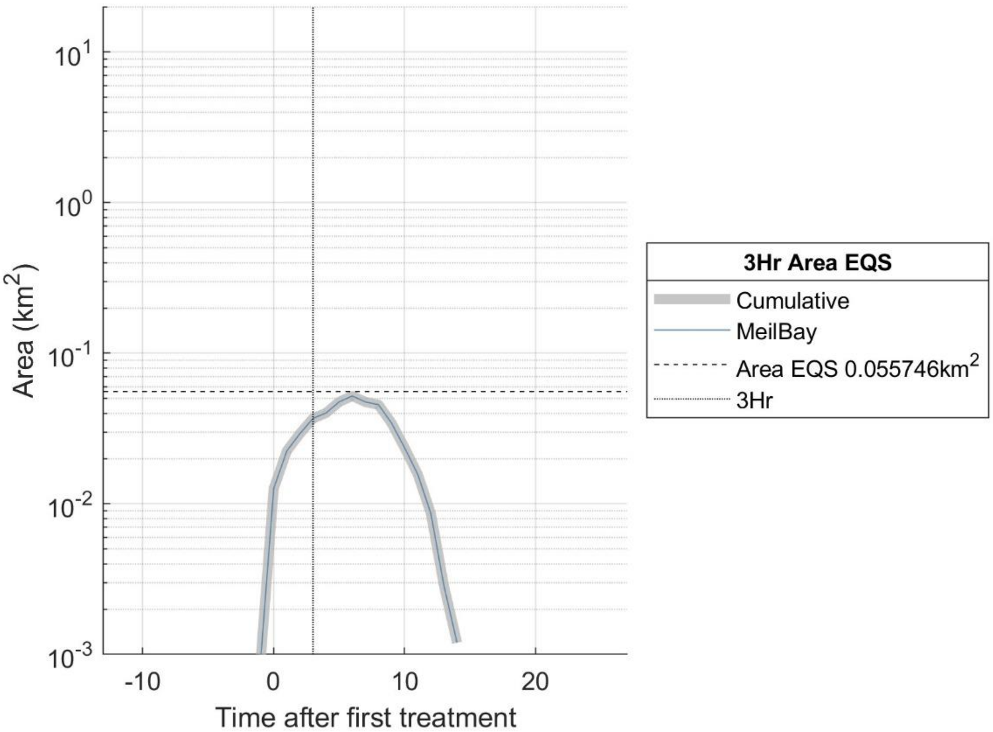

Figure 11. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after the initial 3-hour mass wellboat release of Azamethiphos during spring tides. The size of the 3-hour EQS mixing zone is shown by the horizontal dashed line. 3-hours after the initial treatment is marked by the vertical dotted line.

To assess the longer-term risks from Azamethiphos, the full treatment regime is modelled. The MAC for the spring tidal cycle is plotted in figure 12. Again, particle decay and dispersion provide a rapid reduction in concentrations. The decrease in maximum concentration is more rapid during spring tides than during neap tides due to greater spring velocities providing a more efficient mechanism for chemical advection. This is particularly true for discharge periods that coincide with peak tidal velocities, for these treatments, no peak in maximum concentration is observed as chemical mass is dispersed as quickly as it is released from the wellboat. At 72 hours after the final treatment, the concentration from the Meil Bay site is 0.069µg/l, this is 69.0% of the EQS value. A general decline, interspersed with higher frequency fluctuations, in the maximum concentration is observed for the remainder of the model run with no values exceeding 0.1 µg/l.

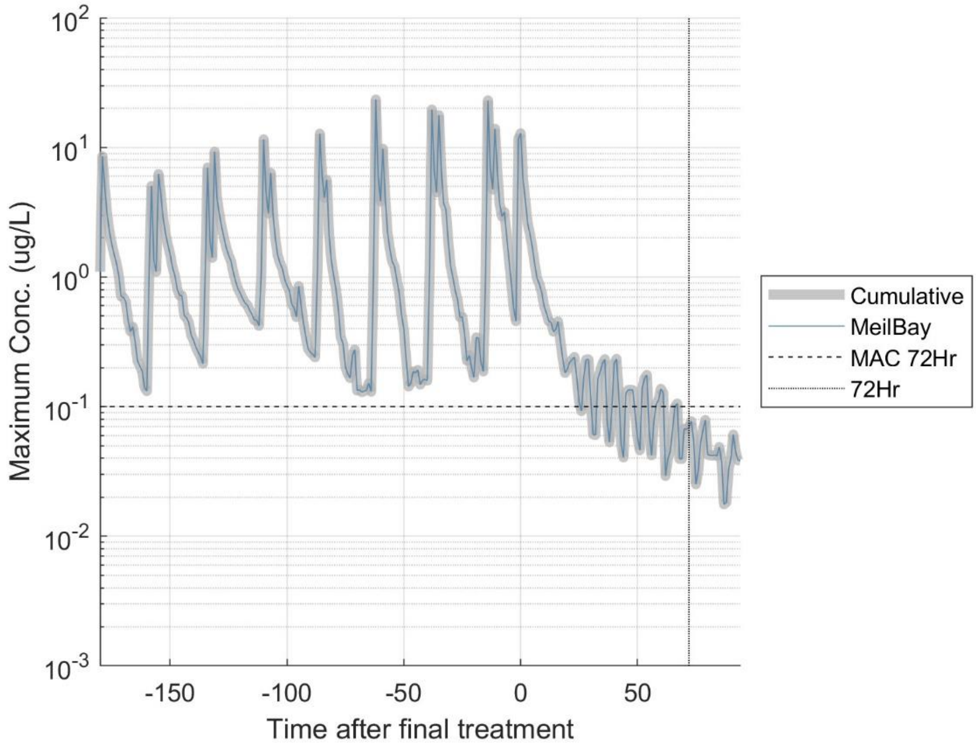

Figure 12. Maximum concentration of Azamethiphos during spring tide wellboat releases. Cumulative impact plotted as solid grey line and MAC for the 72-hour EQS (100 ng/l) is indicated by the grey dotted line. 72-hours after the final treatment is marked by the vertical dotted line.

The area exceeding the 72hr EQS value is plotted in figure 13 for the spring tide. The results show a similar dispersion of plumes where the 72hr area EQS is achieved and maintained after 25 hrs.

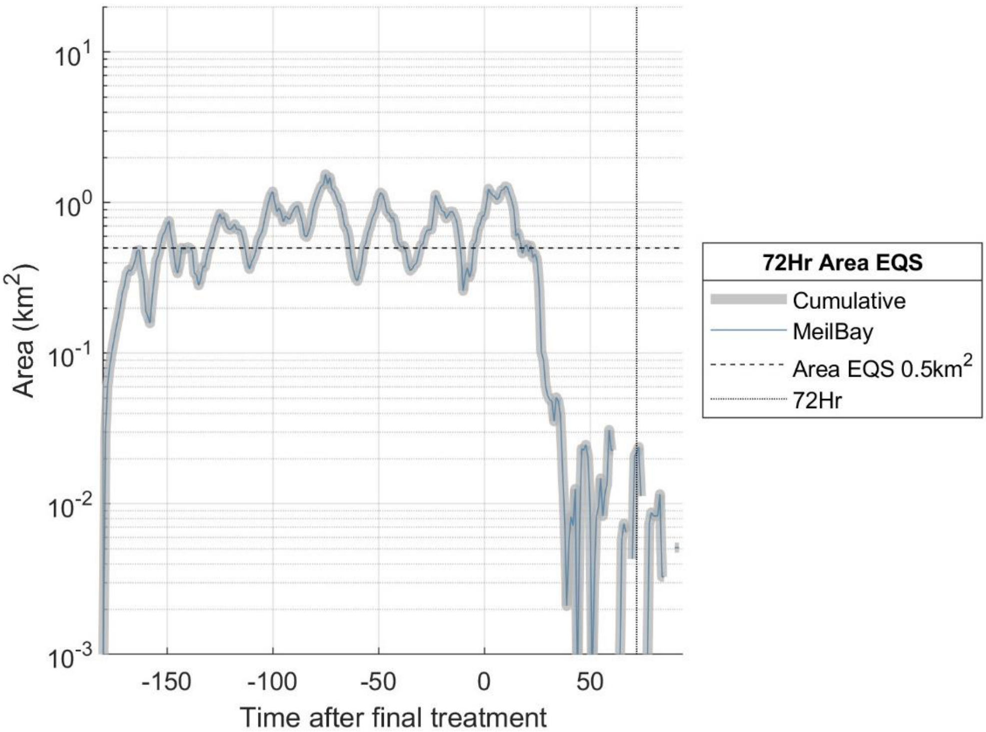

Figure 13. The chemical plume area exceeding the 72-hour (40 ng/l) EQS values after wellboat release of Azamethiphos during spring tides. The size of the 72-hour EQS mixing zone is shown by the horizontal dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The spatial distribution of Azamethiphos during spring tides is shown in figure 14. Following a single treatment release, the 3hr EQS shows a small, confined area coverage above the EQS threshold localized to the region close to the releasing farm. The 72-hour EQS shows chemical plumes from the site to have been entirely dissipated, forming very low concentrations across the model domain 72 hours after the final wellboat release.

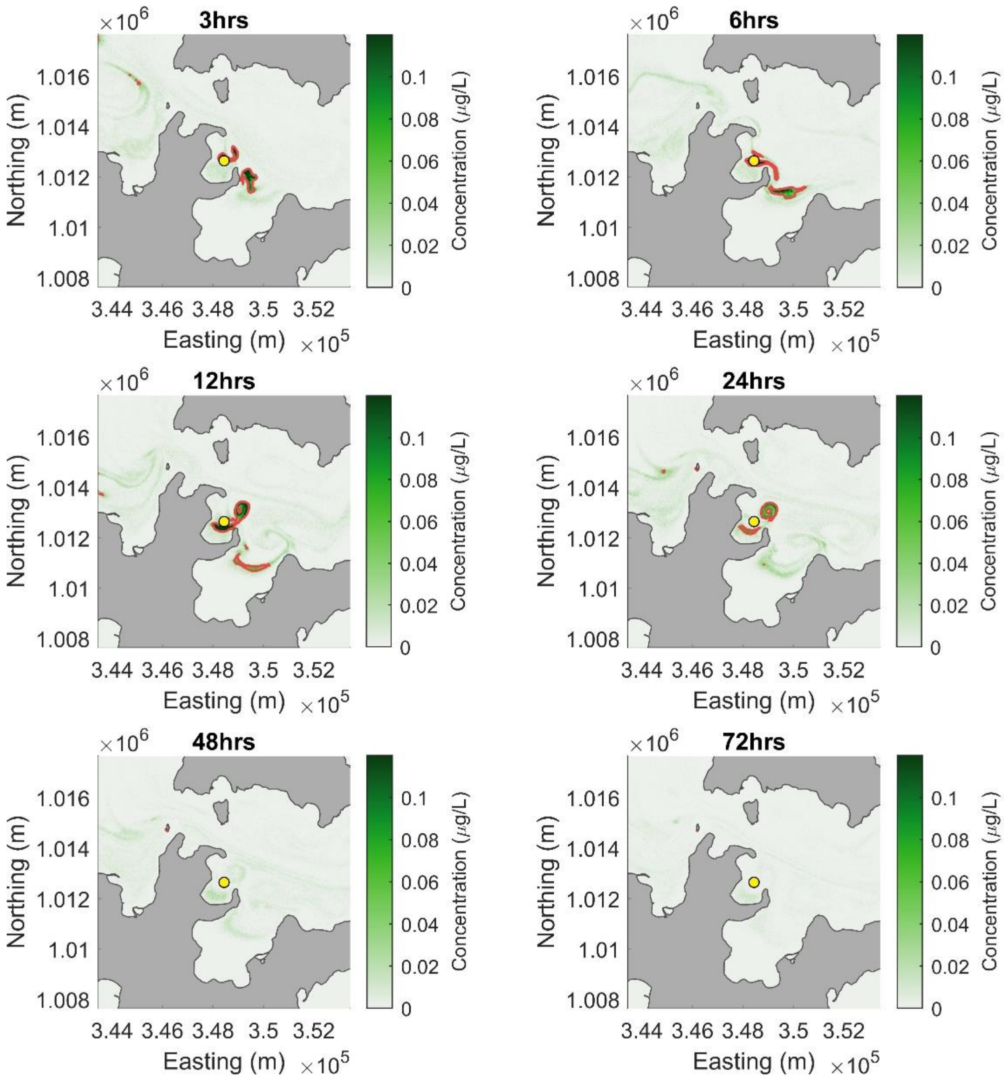

Figure 14. Spatial Azamethiphos distribution for wellboat releases during spring tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour and site location is identified using a yellow marker.

3.1.2 Cypermethrin

Environmental compliance was achieved at the proposed Meil Bay site using 25g of Cypermethrin in a single wellboat treatment. A reduction factor of 267 is applied to the compliant chemical quantity to achieve the actual consent mass. This provides a recommended consent mass of 0.0936g. This provides a treatment volume of 37.46 m^3 per 6 hours.

3.1.2.1 Neap tides

The area of the chemical plume, 6 hours after the single treatment release period, that exceeds a concentration of 16ng/l (6hr EQS threshold) is plotted in figure 15. The 6-hour EQS time is applied relative to the first chemical release and is illustrated in the figure by the vertical dotted line. The size of the chemical plume originating from Meil Bay after a 6-hour mass treatment release remains less than the calculated mixing area of 0.15767km^2 throughout the model run.

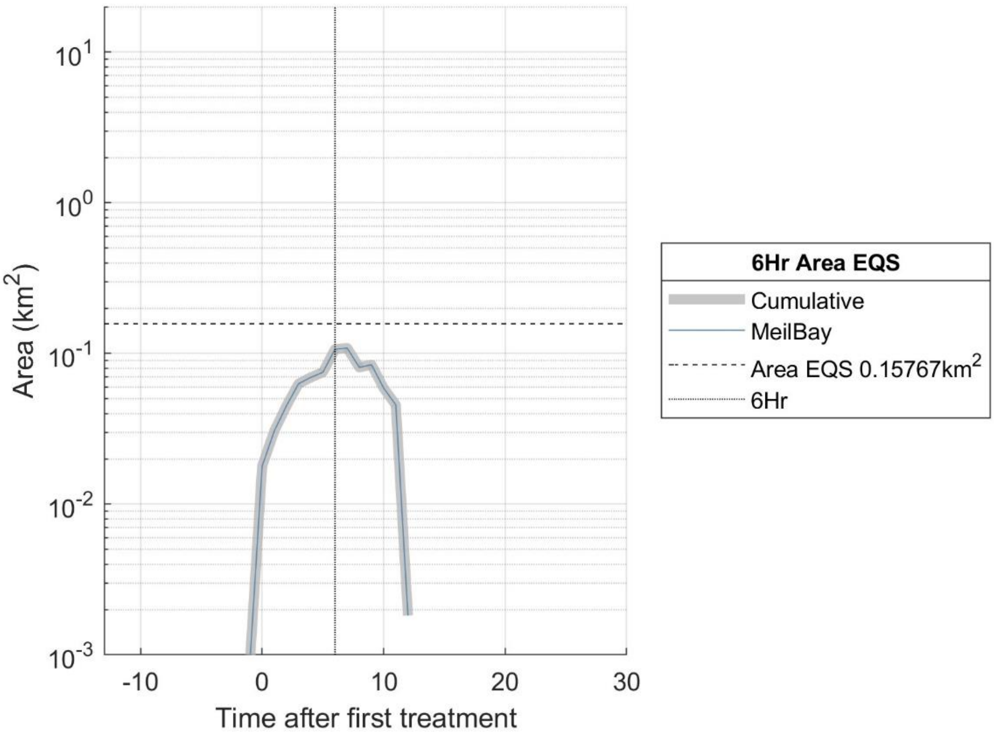

Figure 15. Chemical plume area exceeding the 6-hour (16 ng/l) EQS value after the initial 6-hour mass (25g) wellboat release of Cypermethrin during neap tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The spatial distribution of Cypermethrin 6 hours after the first simultaneous release of bath treatments from the site during a neap tide is shown in figure 16. The areas where concentrations exceed the 6-hour EQS concentration are outlined in red. After 6-hours, the chemical plume is dispersed out of the bay to the south east, where only a few cells exceed 16ng/l.

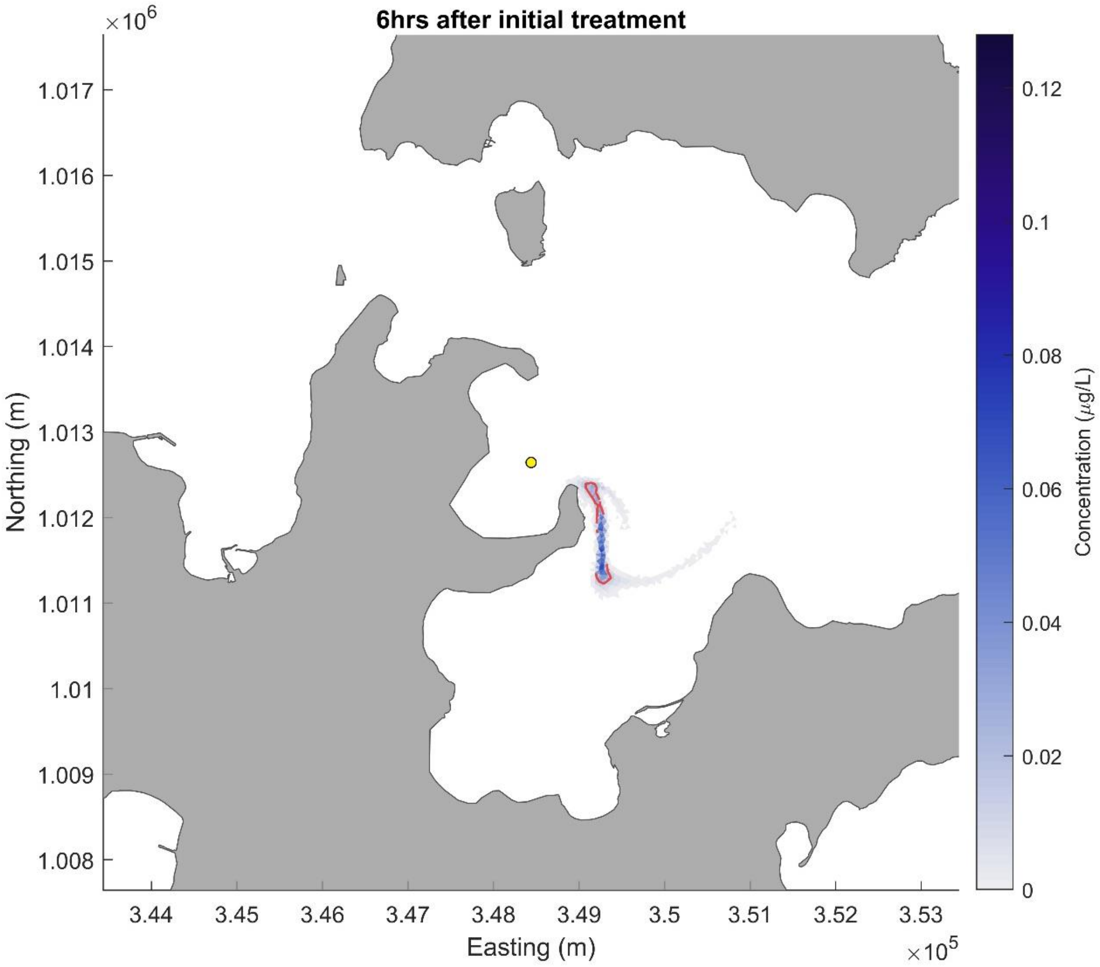

Figure 16. Spatial Cypermethrin distribution for a wellboat release during neap tides 6hr after the treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

3.1.2.2 Spring tides

The area of the chemical plume, 6 hours after the treatment release period, that exceeds a concentration of 16ng/l (6hr EQS threshold) is plotted in figure 17. The 6-hour EQS time is applied relative to the chemical release and is illustrated in the figure by the vertical dotted line. The size of the chemical plume originating from Meil Bay is 0.081km^2 (51.4%) 6 hours after the last treatment release.

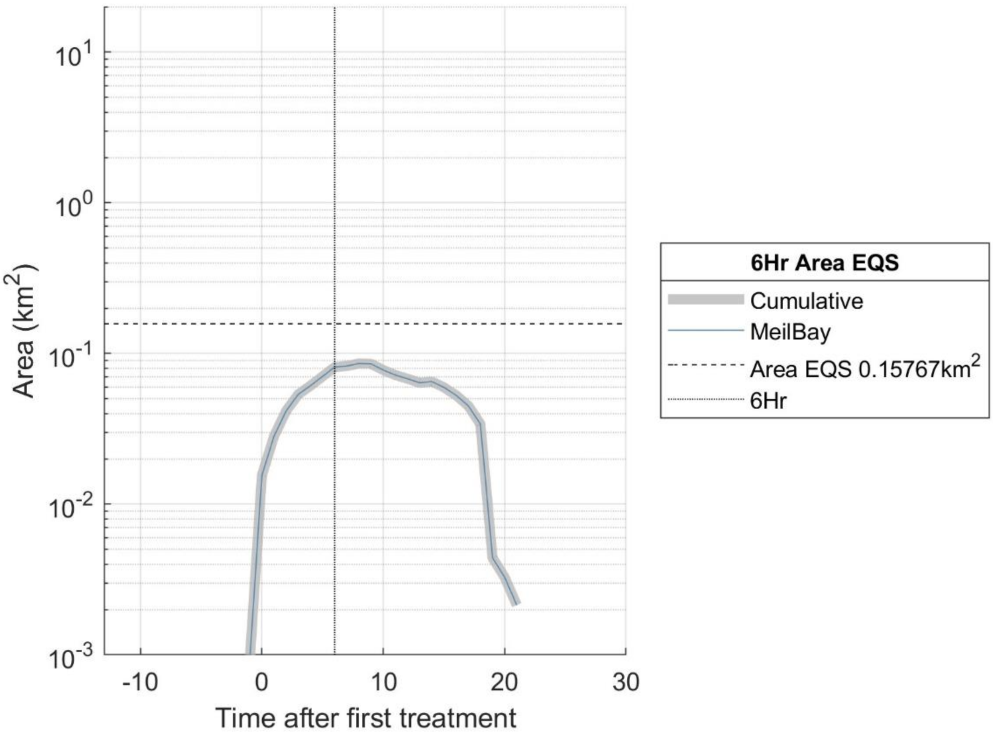

Figure 17. Chemical plume area exceeding the 6-hour (16 ng/l) EQS value after the initial 6-hour mass (25g) wellboat release of Cypermethrin during spring tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The spatial distribution of Cypermethrin 6 hours after the first simultaneous release of the 6-hour treatment mass from all sites during a spring tide is shown in figure 18. The treatment plume is shown to be located near the site centre with a trail of diluted plume heading out of the embayment.

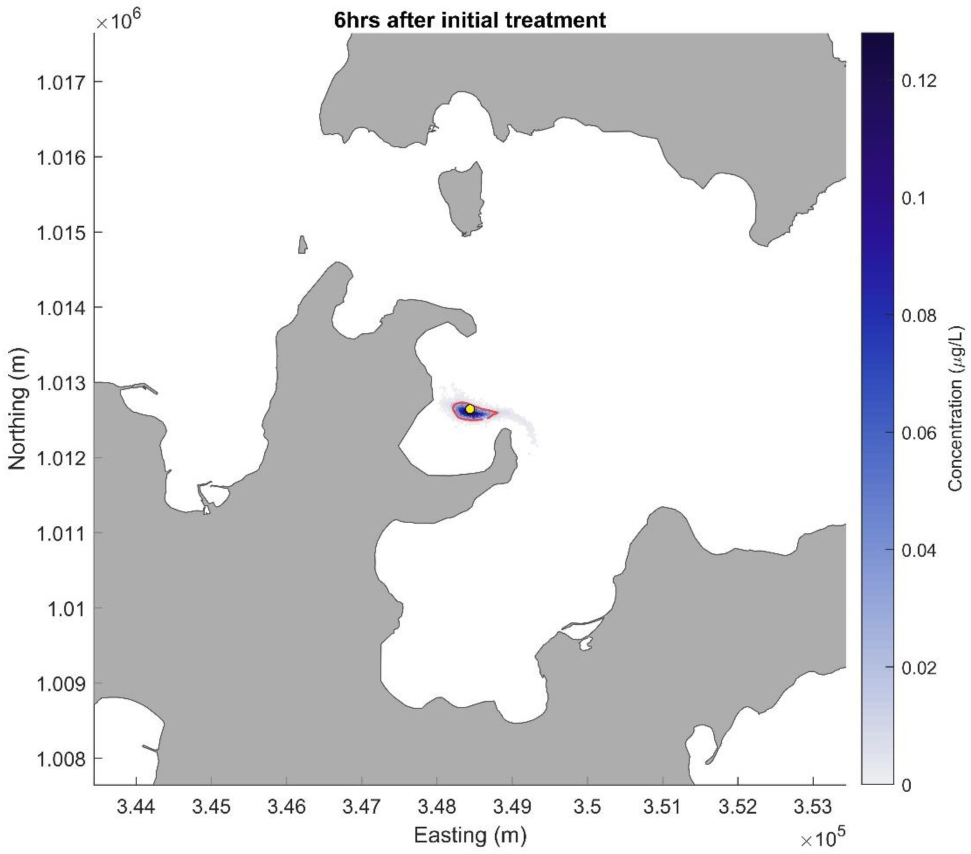

Figure 18. Spatial Cypermethrin distribution for wellboat releases during spring tides 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

3.1.3 Deltamethrin

Compliance was achieved at the proposed Meil Bay site using 10g of Deltamethrin in a treatment plan involving a single wellboat treatment. This provides a treatable volume of 10,000 m^3 per 6-hour period.

3.1.3.1 Neap tides

The area of the chemical plume, 6 hours after the first treatment release period, that exceeds a concentration of 6ng/l (6hr EQS threshold) is plotted in figure 19. The 6-hour EQS time is applied relative to the first chemical release and is illustrated in the figure by the vertical dotted line. The size of the chemical plume originating from Meil Bay after a 6-hour mass treatment release remains less than the calculated mixing area of 0.15767km^2

throughout the model run.

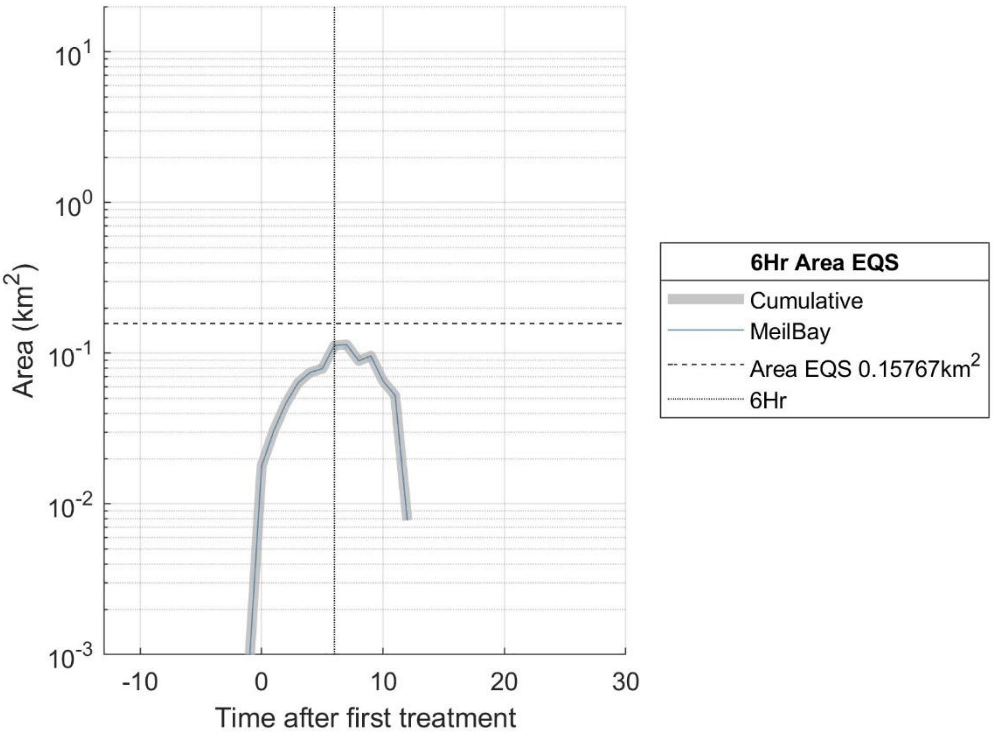

Figure 19. Chemical plume area exceeding the 6-hour (6 ng/l) EQS value after the initial 6-hour mass wellboat release of Deltamethrin during neap tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The spatial distribution of Deltamethrin 6 hours after the first release of bath treatments from the site during a neap tide is shown in figure 20. Regions with chemical concentration exceeding the EQS threshold are illustrated by the red contour. This shows at the 6hr EQS the plume is distributed to the east of the site.

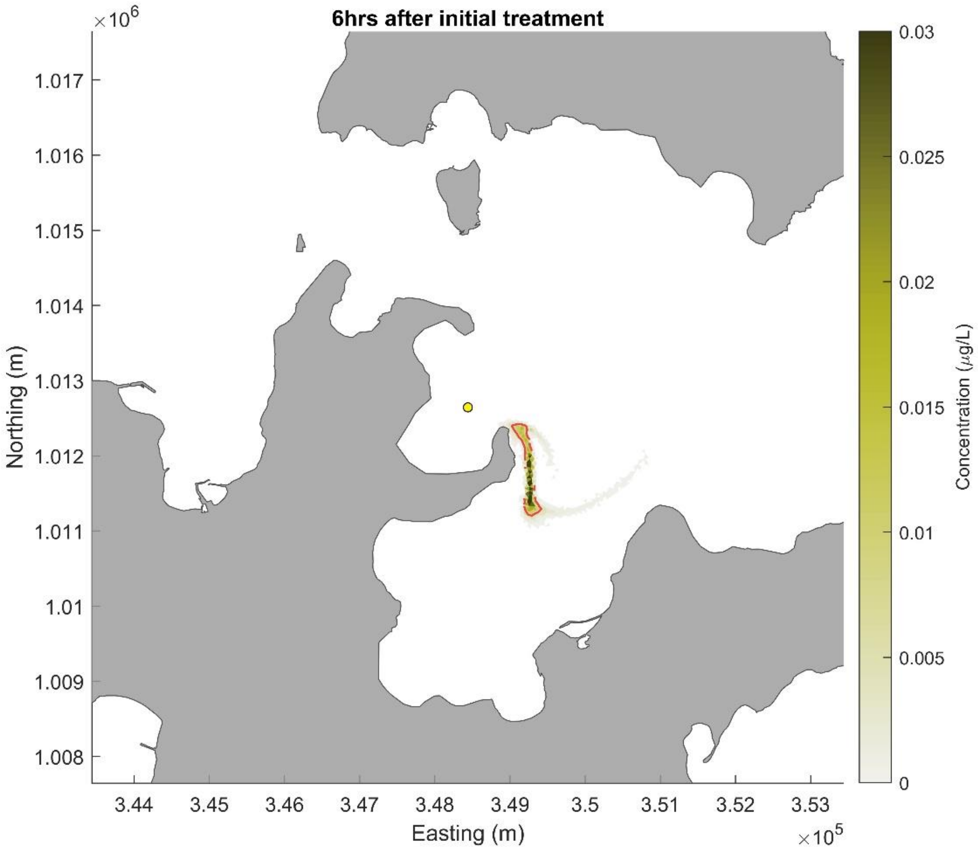

Figure 20. Spatial Deltamethrin distribution for wellboat releases during neap tides, 6 hours after the last treatment event. Areas above EQS values are indicated within the red contour and site location is identified using a yellow marker.

3.1.3.2 Spring tides

The area of the chemical plume, 6 hours after the first treatment release period, that exceeds a concentration of 16ng/l (6hr EQS threshold) is plotted in figure 21. The 6-hour EQS time is applied relative to the first chemical release and is illustrated in the figure by the vertical dotted line. The size of the chemical plume originating from Meil Bay after a 6-hour mass treatment release remains less than the calculated mixing area of 0.15767km^2 throughout the model run.

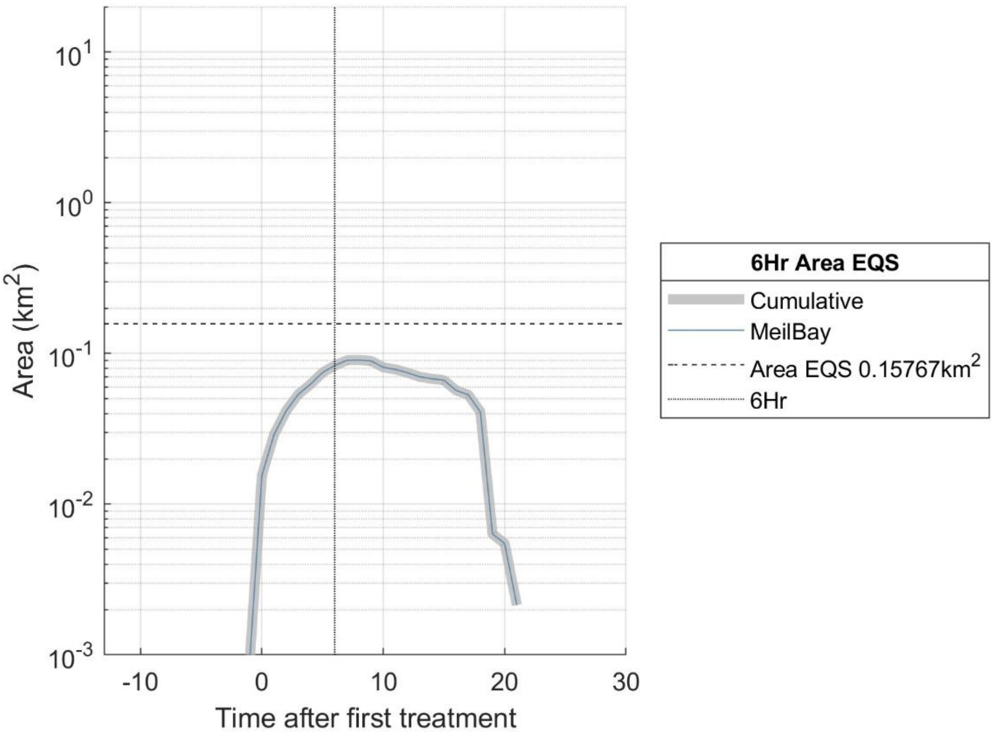

Figure 21. Chemical plume area exceeding the 6-hour (6 ng/l) EQS value after the initial 6-hour mass wellboat release of Deltamethrin during spring tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The spatial distribution of Deltamethrin 6 hours after the first release of the 6-hour treatment mass from the site during a spring tide is shown in figure 22. The regions in which chemical concentration exceeds the EQS threshold are illustrated by the red contour. After 6hrs the treatment plume is shown to be close to the site centre, with a diluted trail exiting the bay near the southern headland.

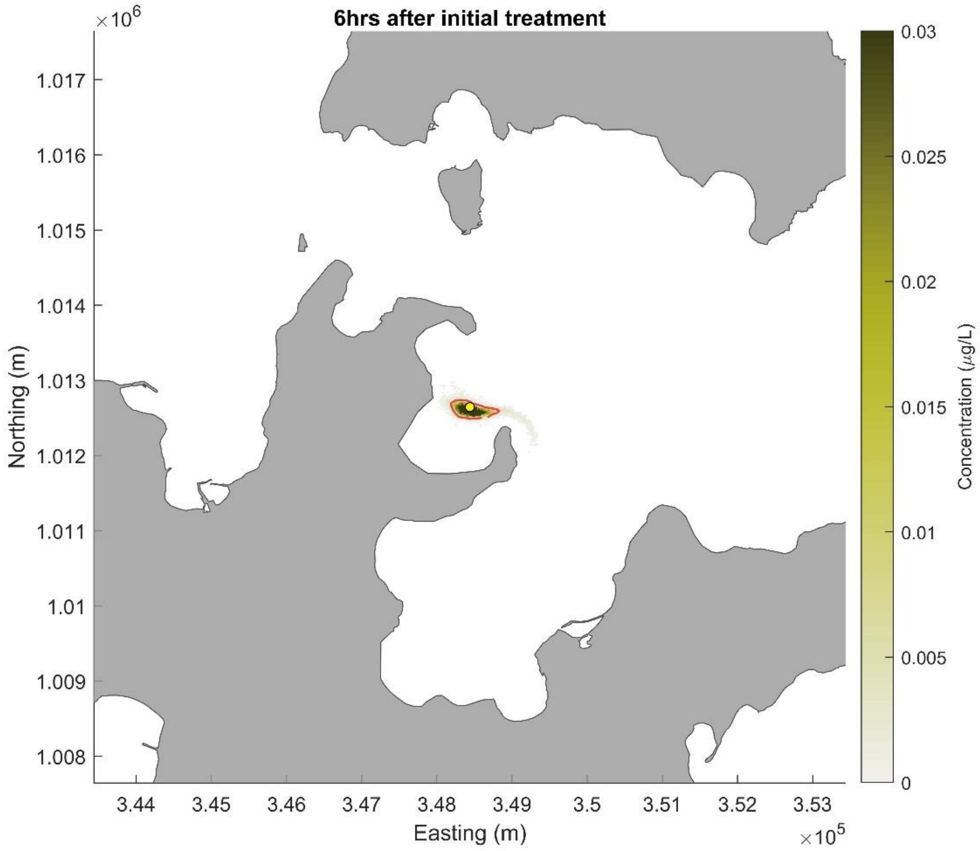

Figure 22. Spatial Deltamethrin distribution for wellboat releases during spring tides, 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site location is identified using a yellow marker.

4. Interactions with Sensitive Marine Features

The results of the modelled distribution of the bath treatments are used to assess potential interactions with identified sensitive marine features. Treatment specific EQS parameters are used to determine potential risk to each feature. As there are currently no environmental standards for bath treatment exposure to sensitive marine features, the treatment specific EQS parameters are used as a guide. It should be noted that the EQS parameters used are area-based measurements and not MACs and therefore any exceedance in these values is permitted within a reasonable magnitude.

4.1 Spatial Features

Clusters of similar nearby point sensitive features have been combined to form area-based features for specific receptors. The assessment of bath treatments on these features uses chemical specific concentrations to determine the spatial scale of any suspended and deposited treatments. Concentrations over the entire water column are used as any interaction with the seabed will require treatment plumes to be well mixed within the water column. It should be noted that this represents a precautionary approach as the majority of treatments will remain suspended and will not interact with the seabed.

4.1.1 Azamethiphos

3hr Consent Limit

4.1.1.1 Neap tides

Results from the Azamethiphos 3hr consent limit simulation during the neap tide are used to determine deposited concentrations within HMp01 (figure 23). HMp01 show no treatment concentrations exceeding 250 ng/l or 1 ng/l. This shows 0% of the feature area exposed to either of these treatment concentrations.

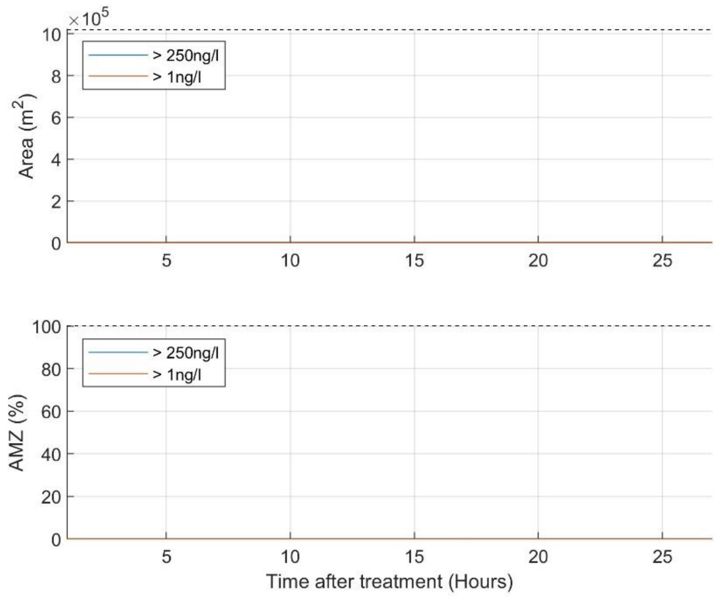

Figure 23 Upper: Area within HMp01 polygon exceeding 3hr EQS concentration with the total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon concentration with the total area indicated by the dashed black line

4.1.1.2 Spring tides

Results from the Azamethiphos 3hr consent limit simulation during the spring tide are used to determine deposited concentrations within HMp01 (figure 24). HMp01 shows no treatment concentrations exceeding 250 ng/l or 1 ng/l. This shows 0% of the feature area exposed to either of these treatment concentrations.

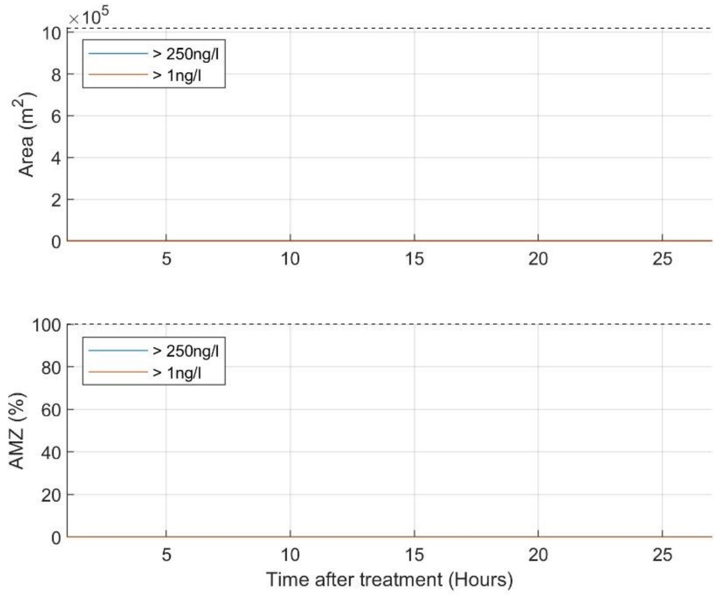

Figure 24 Upper: Area within HMp01 polygon exceeding 250 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 250 and 1 ng/l with the total area indicated by the dashed black line

72hr EQS

4.1.1.1 Neap tides

Results from the Azamethiphos 24hr consent limit simulation during the neap tide are used to determine deposited concentrations within HMp01 (figure 25). HMp01 shows no treatment concentrations exceeding 40 ng/l or 1 ng/l. This shows 0% of the feature area exposed to either of these treatment concentrations.

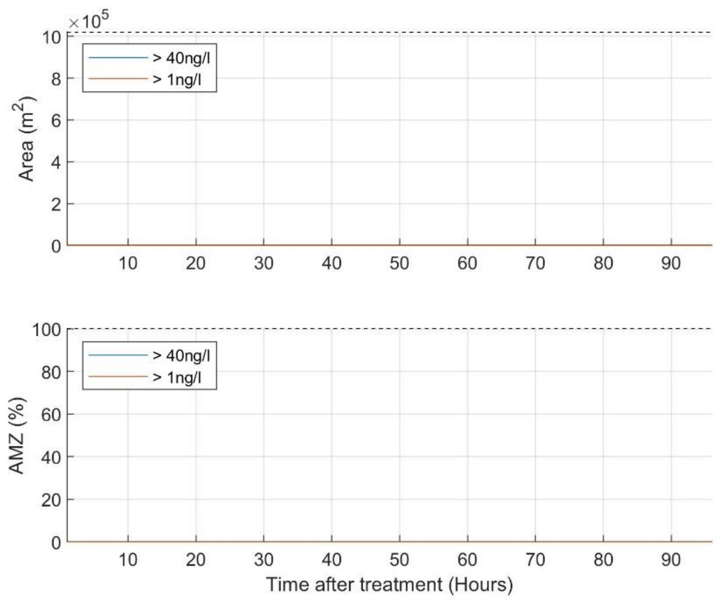

Figure 25 Upper: Area within HMp01 polygon exceeding 40 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 40 and 1 ng/l with the total area indicated by the dashed black line

4.1.1.2 Spring tides

Results from the Azamethiphos 24hr consent limit simulation during the spring tide are used to determine deposited concentrations within HMp01 (figure 26). HMp01 shows no treatment concentrations exceeding 40 ng/l or 1 ng/l. This shows 0% of the feature area exposed to either of these treatment concentrations.

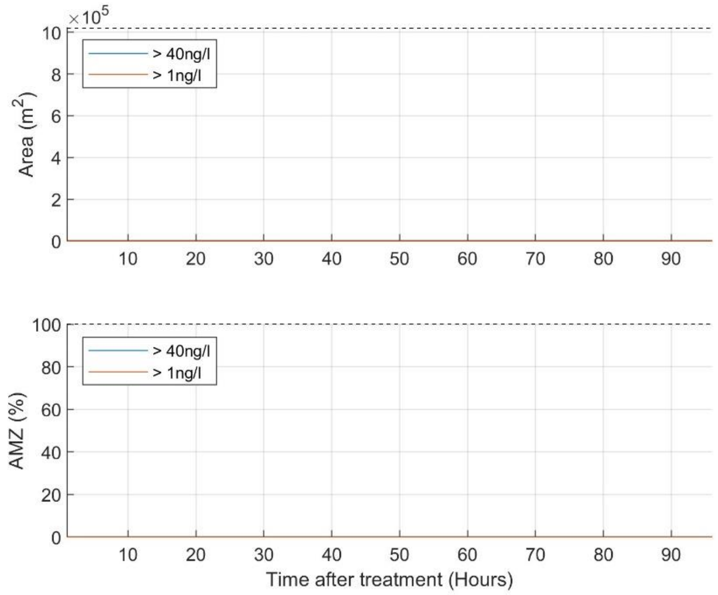

Figure 26 Upper: Area within HMp01 polygon exceeding 40 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 40 and 1 ng/l with the total area indicated by the dashed black line

4.1.2 Cypermethrin

4.1.2.1 Neap tide

Results from the Cypermethrin simulation during the neap tide are used to determine deposited concentrations within HMp01 (figure 27). HMp01 shows no treatment concentrations exceeding 16 ng/l or 1 ng/l. This shows 0% of the feature area exposed to either of these treatment concentrations.

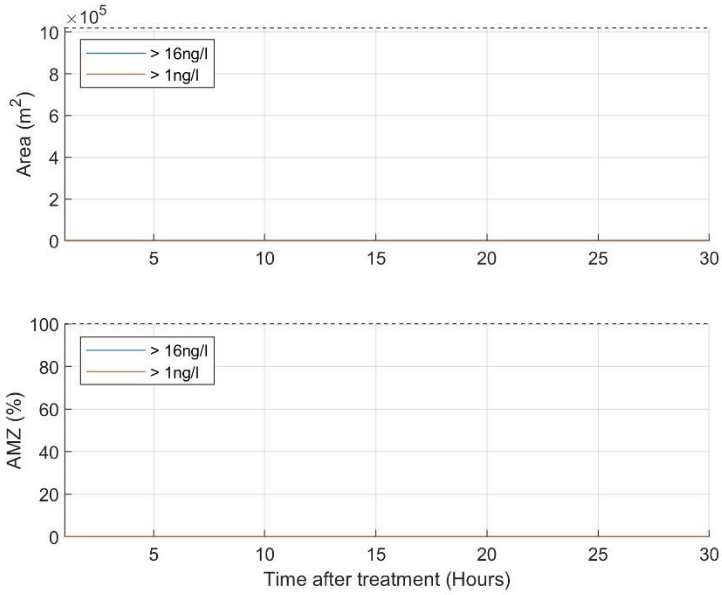

Figure 27 Upper: Area within HMp01 polygon exceeding 16 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 16 and 1 ng/l with the total area indicated by the dashed black line

4.1.2.2 Spring tide

Results from the Cypermethrin simulation during the spring tide are used to determine deposited concentrations within HMp01 (figure 28). HMp01 shows no treatment concentrations exceeding 16 ng/l or 1 ng/l. This shows 0% of the feature area exposed to either of these treatment concentrations.

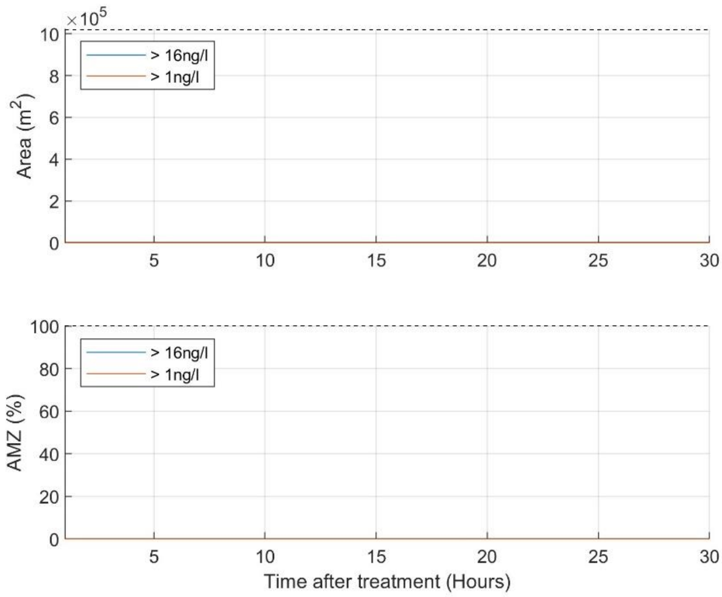

Figure 28 Upper: Area within HMp01 polygon exceeding 16 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 16 and 1 ng/l with the total area indicated by the dashed black line

4.1.3 Deltamethrin

4.1.3.1 Neap tide

Results from the Deltamethrin simulation during the neap tide are used to determine deposited concentrations within HMp01 (figure 29). HMp01 show no treatment concentrations exceeding 6 ng/l or 1 ng/l. This shows 0% of the feature area exposed to either of these treatment concentrations.

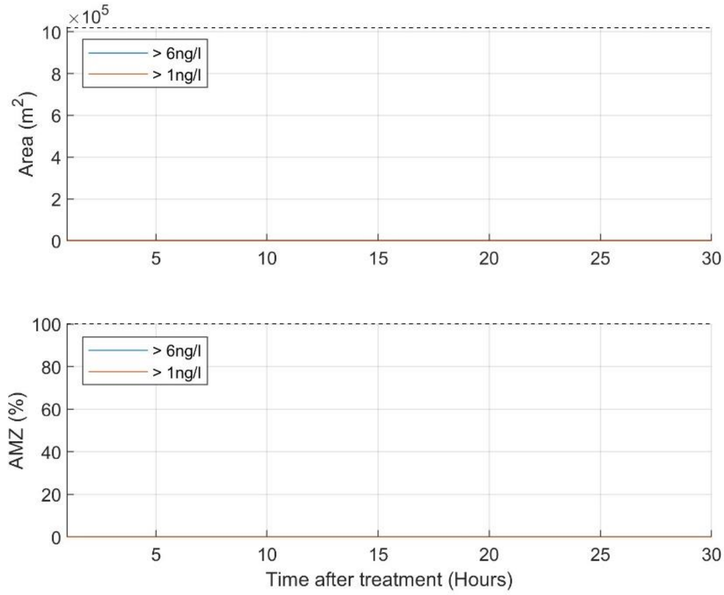

Figure 29 Upper: Area within HMp01 polygon exceeding 6 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 6 and 1 ng/l with the total area indicated by the dashed black line

4.1.3.2 Spring tide

Results from the Deltamethrin simulation during the spring tide are used to determine deposited concentrations within HMp01 (figure 30). HMp01 show no treatment concentrations exceeding 6 ng/l or 1 ng/l. This shows 0% of the feature area exposed to either of these treatment concentrations.

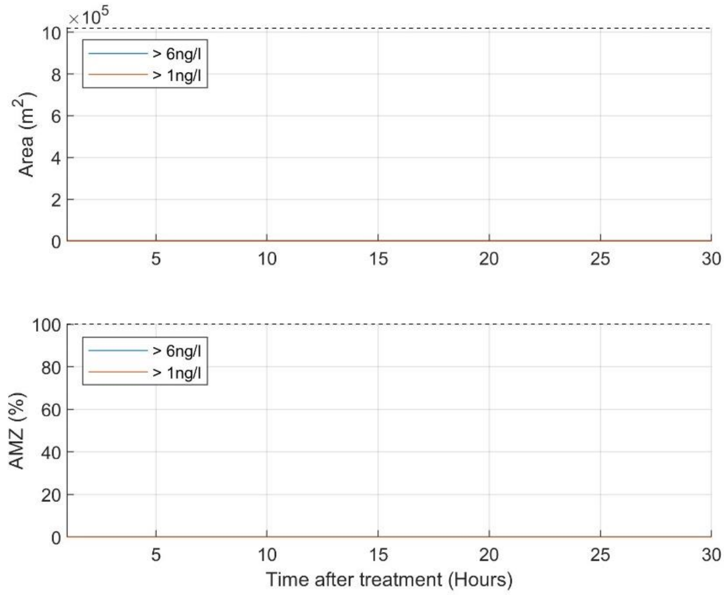

Figure 30 Upper: Area within HMp01 polygon exceeding 6 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 6 and 1 ng/l with the total area indicated by the dashed black line

4.2 Point Features

4.2.1 Azamethiphos

4.2.1.1 Neap tides

3hr EQS

Short-term exposure during the neap tide is assessed using a single release of the 3hr treatment mass, 180g of Azamethiphos. Treatment concentration at sensitive features is identified in figure 31. For the majority of features no observable treatment concentrations are shown. Features MM05 show a minor residue of treatments within 5-6 after the treatment with a short exposure time.

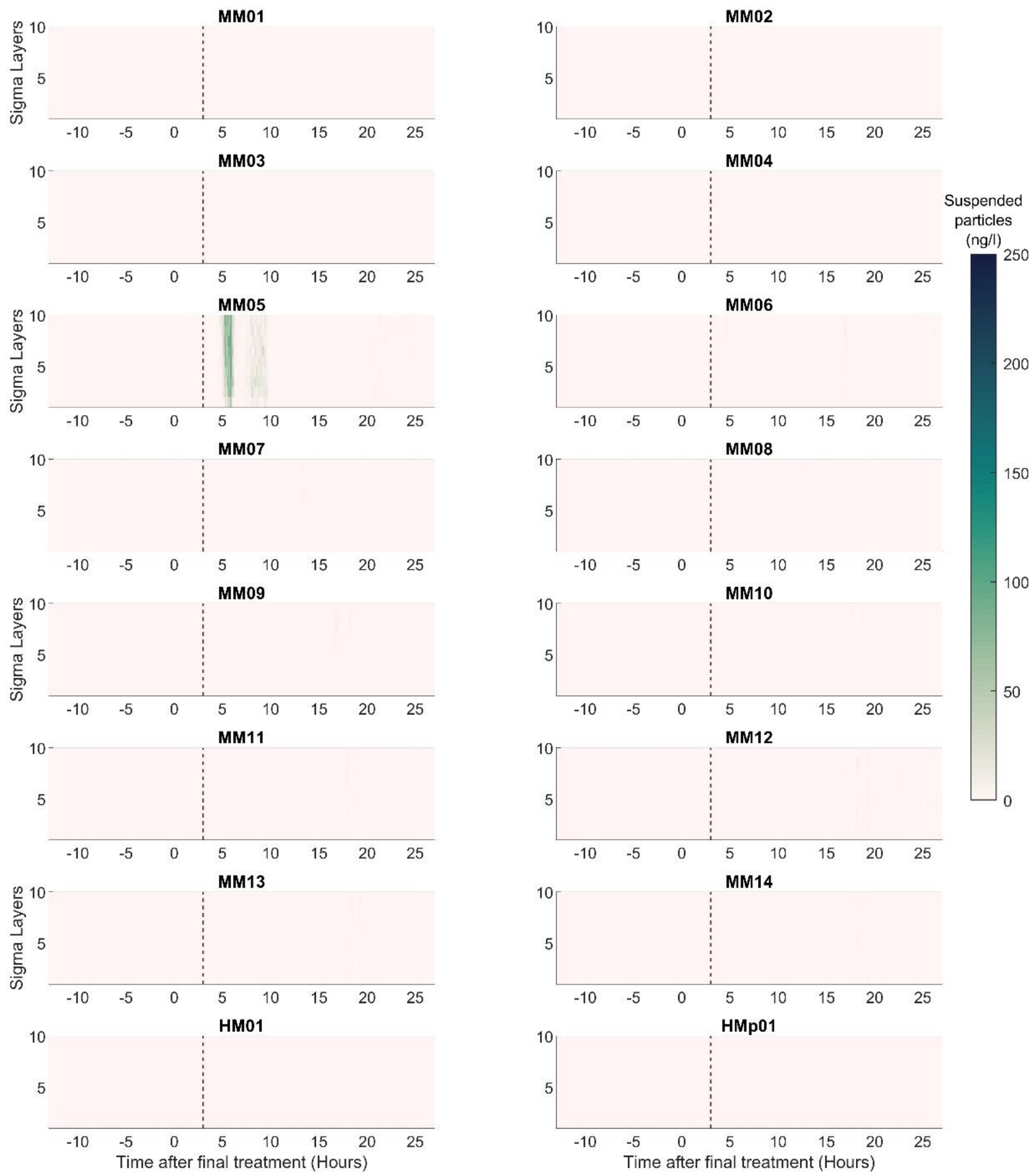

Figure 31. Neap tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

Vertical concentration profiles for each feature are shown in figure 32 for the 3hr EQS time. After 3hrs of a single treatment, all features show no concentration increase.

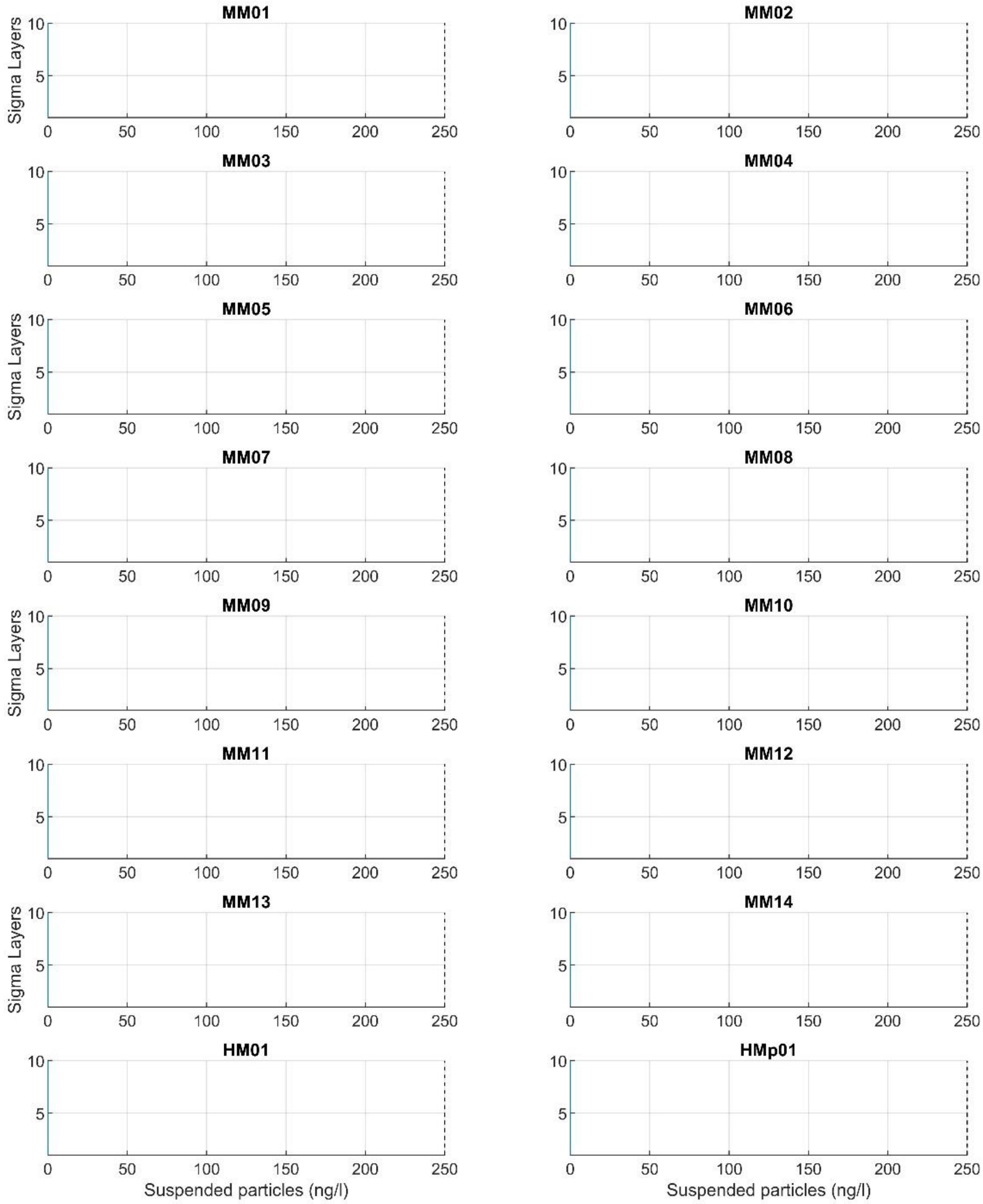

Figure 32. Neap tide vertical concentration profile of Azamethiphos after the single treatment at the 3hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

72hr EQS

Bath treatment exposure during the neap tide is assessed using a 24-hr treatment mass of 600g of Azamethiphos. Treatment concentrations at sensitive features are identified in figure 33, where the concentration scale is adjusted to 40ng/l, in line with the 72hr EQS value. Plume concentration at sensitive feature locations remain at very low levels. Feature MM05 shows more visible variations in passing plume concentrations as concentrations exceed the 72hr 40ng/l EQS during the treatment cycle. These small increases in concentration have a short duration and generally weaken in strength nearer the seabed. After 6hrs the majority of treatment plumes has dissipated and no longer exceeds the 72 hr 40ng/l threshold. Beyond this, concentrations of any chemical plume at sensitive feature locations is shown to be very dilute.

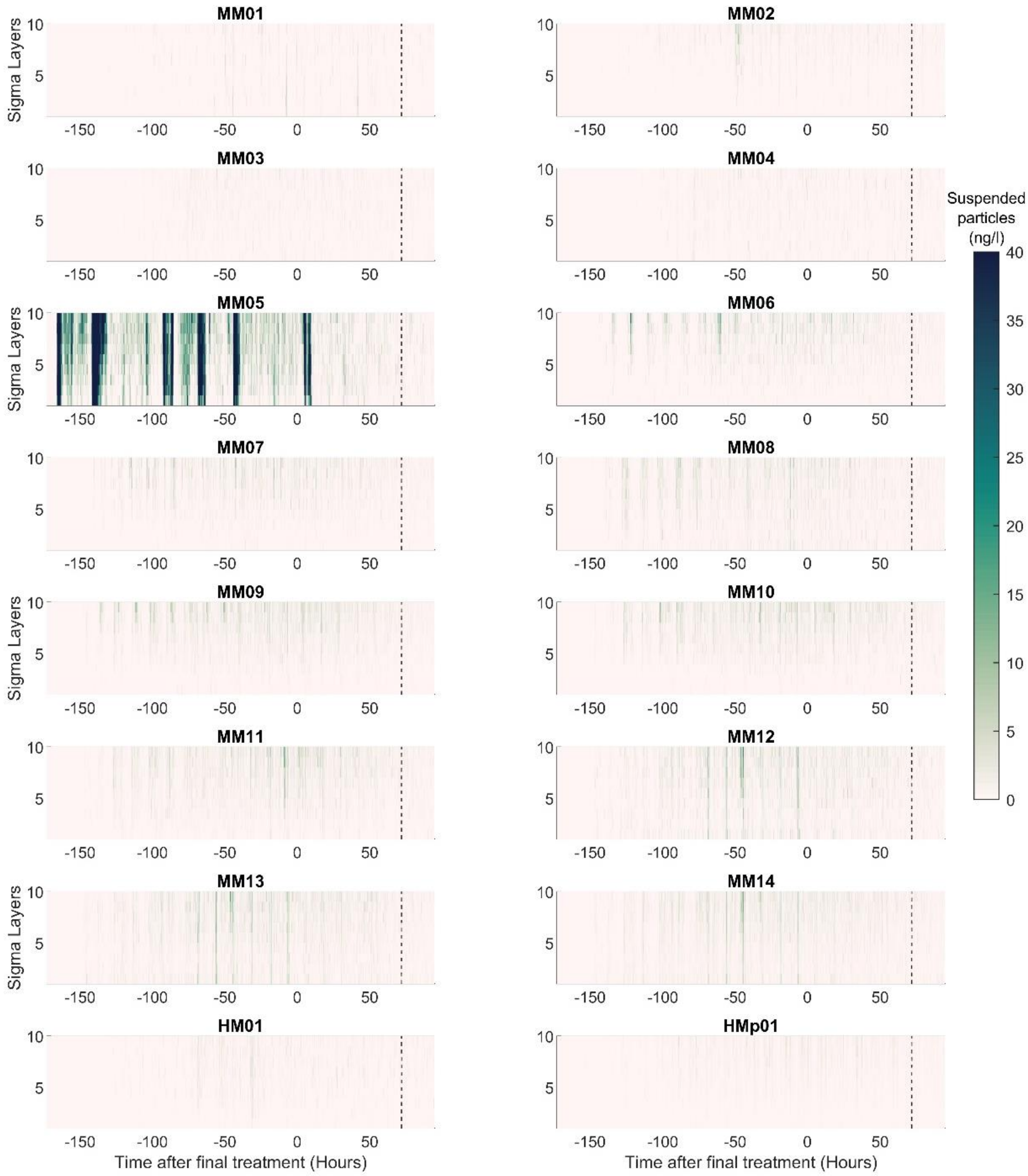

Figure 33. Neap tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

After 72hrs the concentration of Azamethiphos is less than 40ng/l for all features, with most locations recording concentrations between 0 and 5ng/l. Due to the increased time duration and dispersion plumes show more varied vertical distribution.

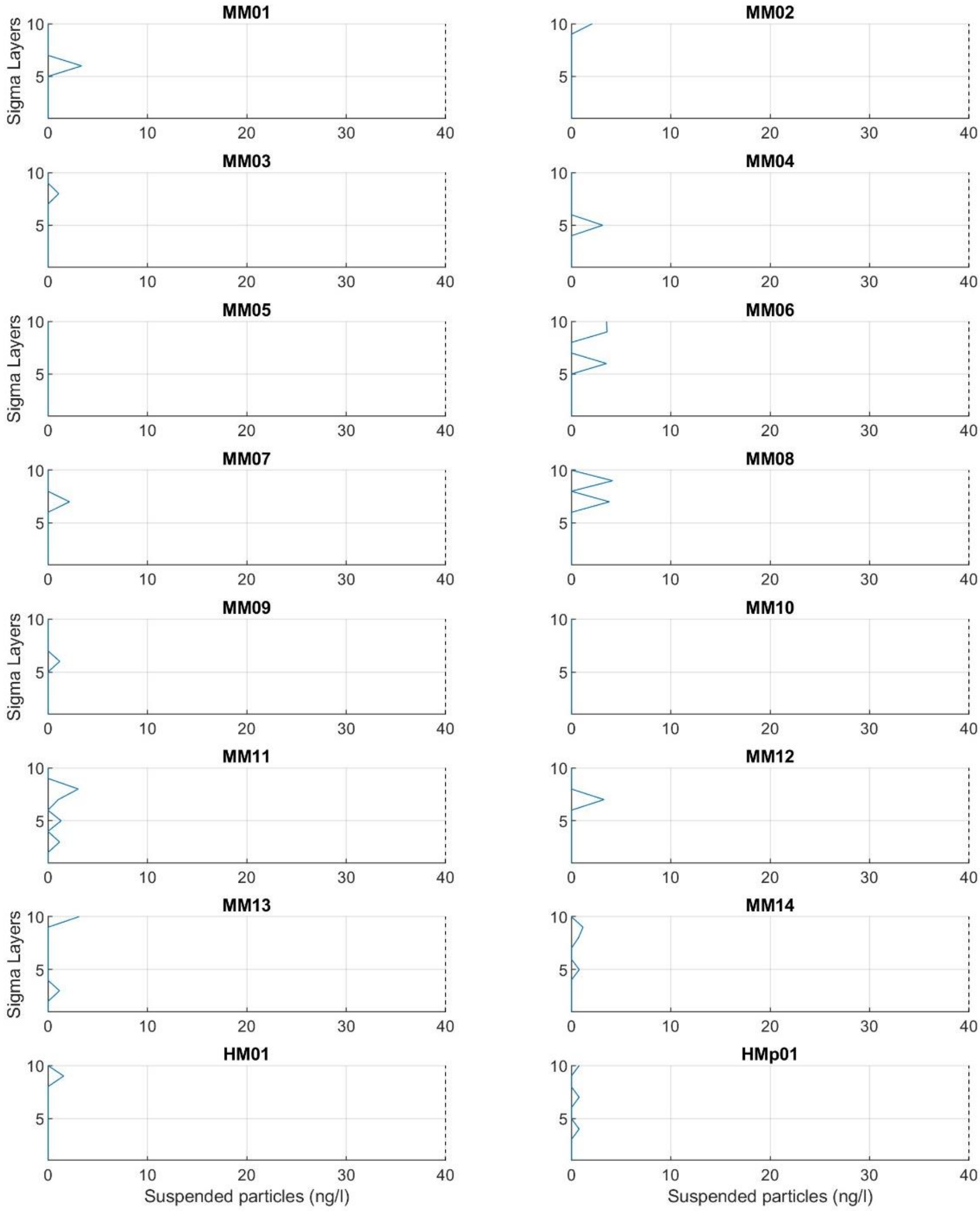

Figure 34. Neap tide vertical concentration profile of Azamethiphos after a treatment plan with a 24-hr treatment mass of 600g at the 72hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Azamethiphos is shown relative to the sensitive feature locations in figure 35. Several time steps are shown ranging from 3 to 72hrs, red contour lines are shown for treatment concentrations of 100 ng/l. Treatments are shown to be widely and quickly distributed with no accumulations. Interactions with sensitive features are uncommon and occur only with very diluted plumes. The largest concentration occurs between 3 and 6hrs after the final treatment at MM05, due to strong currents through the straight these plumes are pulled aways from the site and feature locations and distributed.

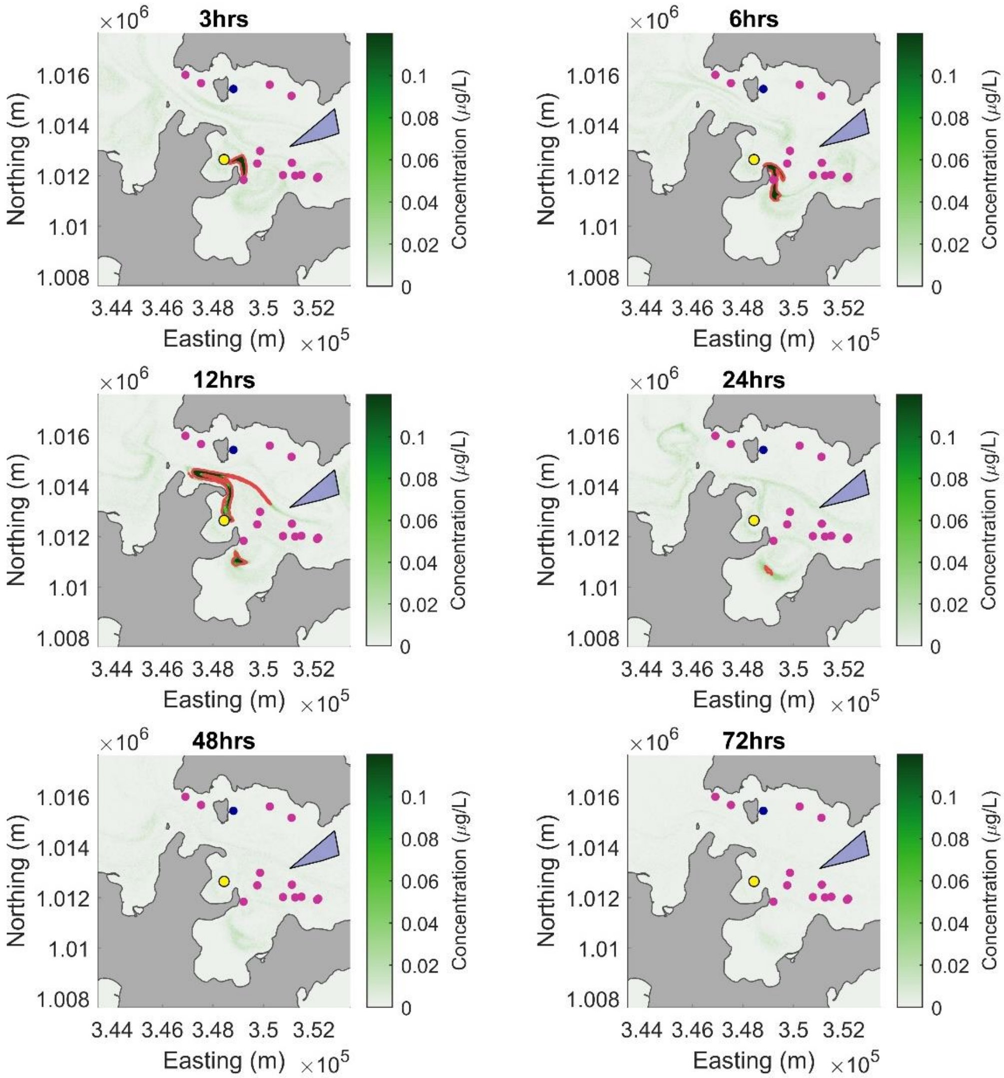

Figure 35. Spatial Azamethiphos distribution for bath treatment releases during neap tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.1.2 Spring tides

3hr EQS

Short-term exposure during the spring tide is assessed using a single release of the 3hr treatment mass, 180g of Azamethiphos. Treatment concentration at sensitive features is identified in figure 36. Very weak plume concentrations are shown at MM05 around 20hrs after the final treatment.

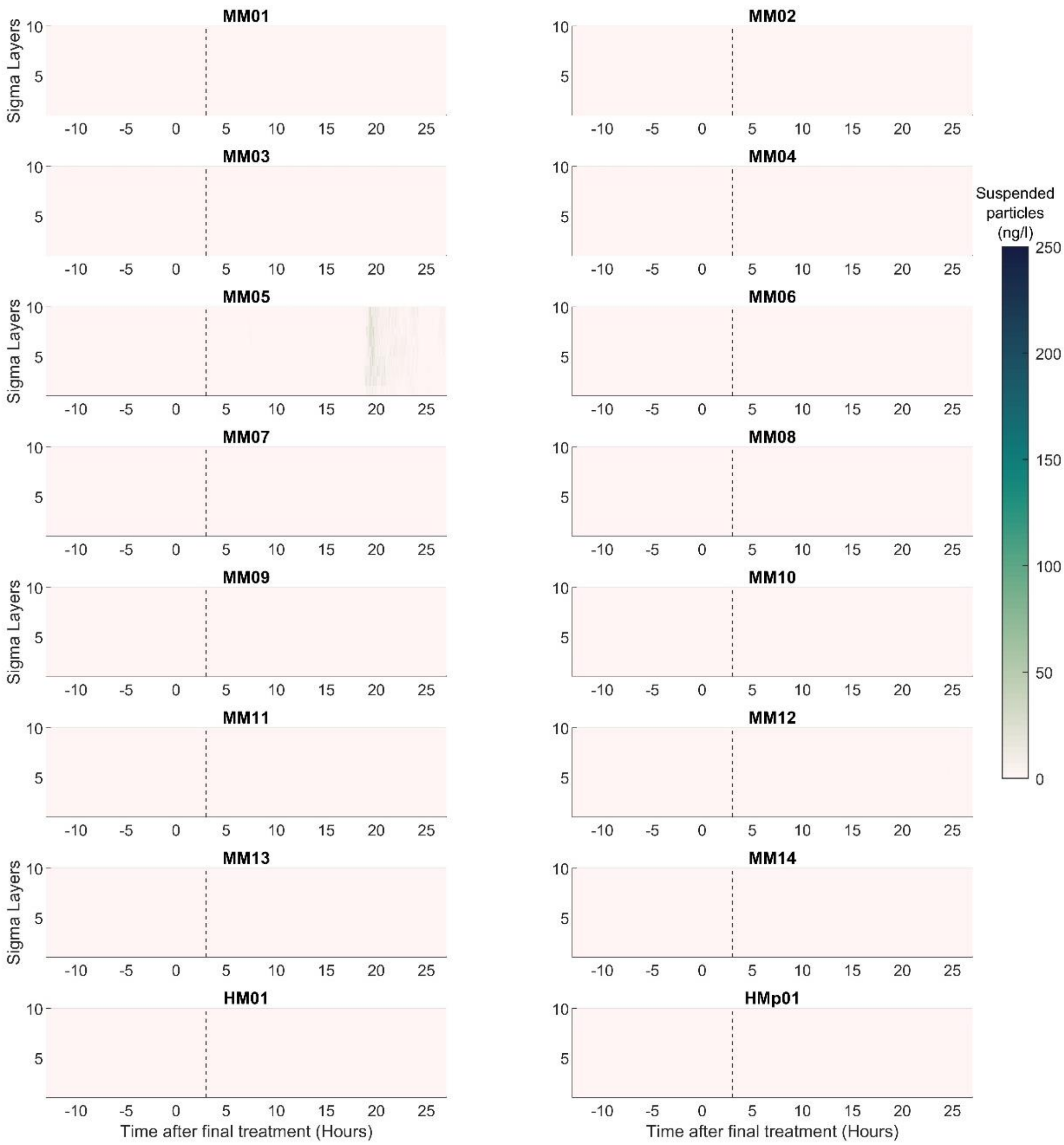

Figure 36. Spring tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

Vertical concentration profiles for each feature are shown in figure 37 for the 3hr EQS time. After 3hrs no treatment concentrations are shown for any of the identified sensitive marine features.

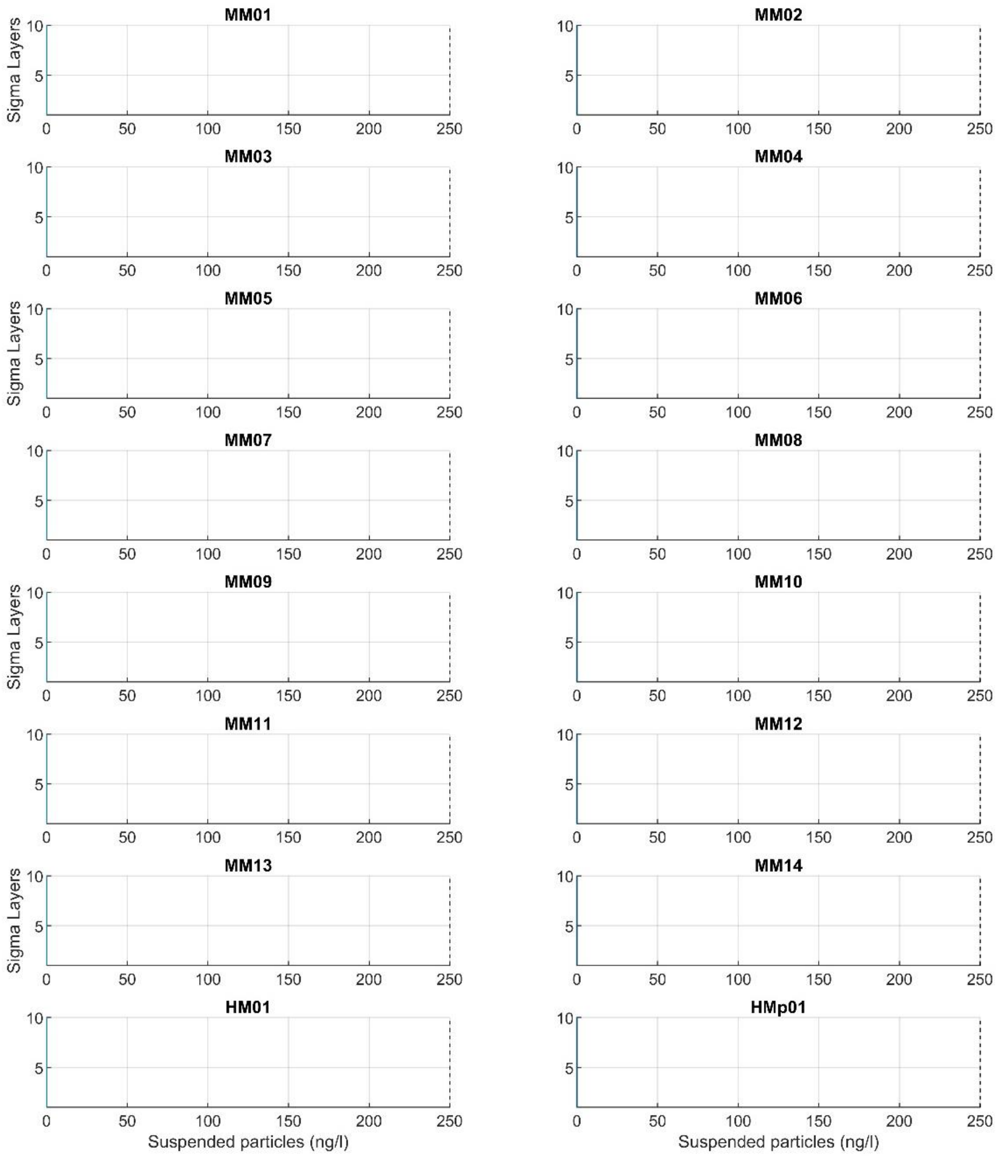

Figure 37. Spring tide vertical concentration profile of Azamethiphos after the single treatment at the 3hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

72hr EQS

Bath treatment exposure during the spring tide is assessed using a 24-hr treatment mass of 600g of Azamethiphos. Treatment concentrations at sensitive features are identified in figure 38, where the concentration scale is adjusted to 40ng/l, in line with the 72hr EQS value. Plume concentration at sensitive feature locations remain at very low levels. Features MM05 show more visible variations in passing plume concentrations. These elevated concentrations are shown to be infrequent and occur for a short duration.

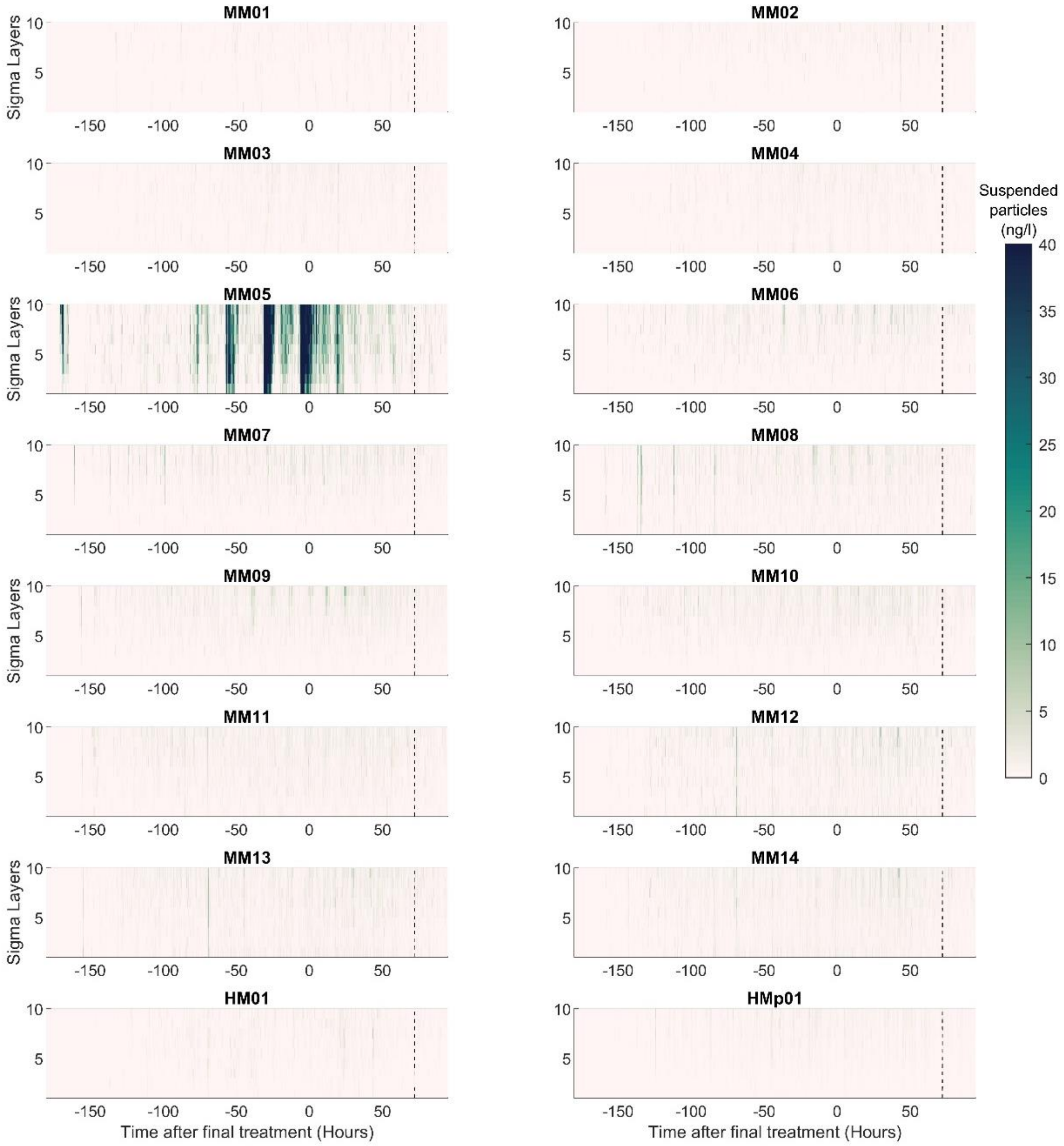

Figure 38. Spring tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

Vertical concentration profiles for each feature are shown in figure 39 for the 72hr EQS time. After 72hrs treatment concentrations are shown to remain less than 4ng/l at all sensitive marine features.

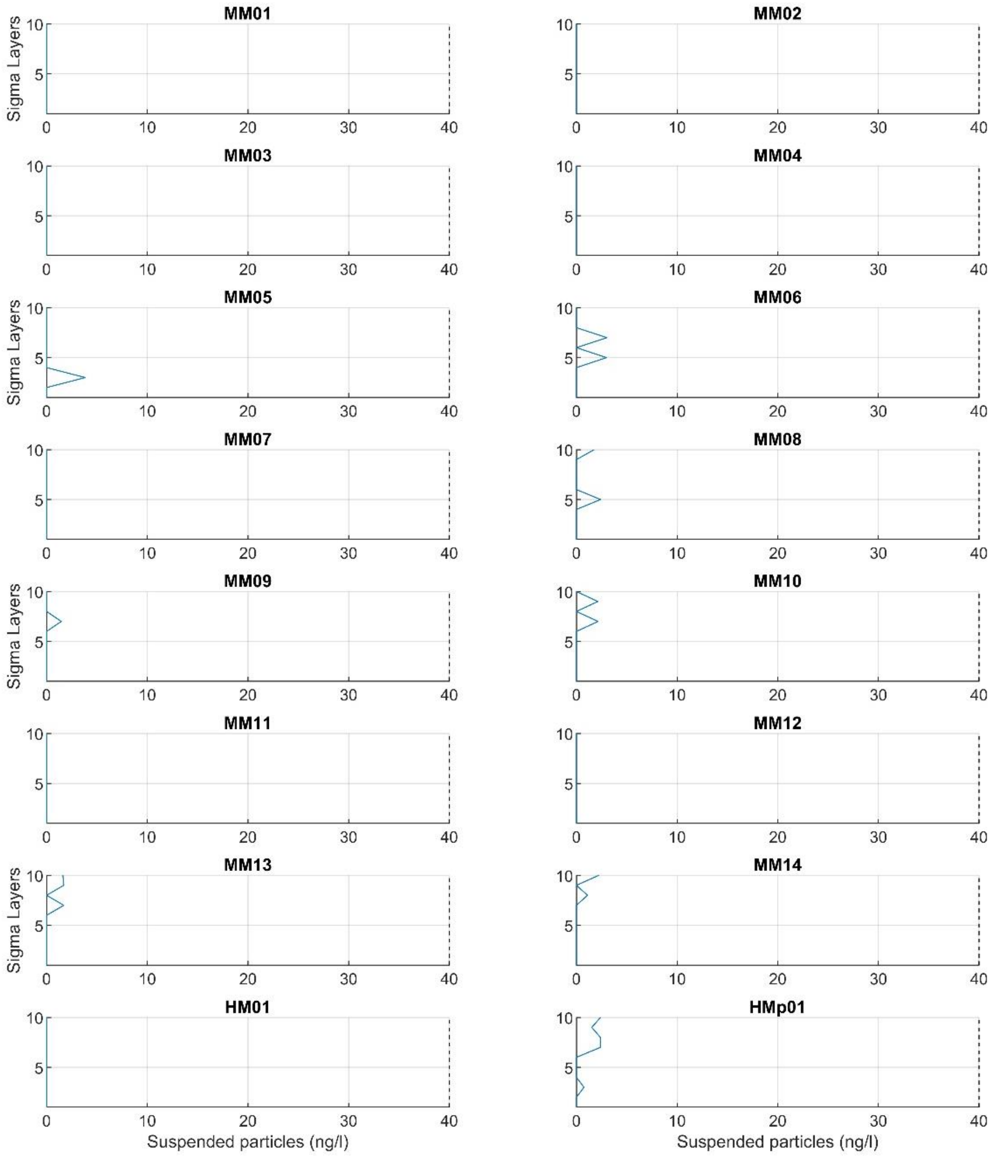

Figure 39. Spring tide vertical concentration profile of Azamethiphos after a treatment plan with a 24-hr treatment mass of 600g at the 72hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Azamethiphos is shown relative to the sensitive feature locations in figure 40. Several time steps are shown ranging from 3 to 72hrs, red contour lines are shown for treatment concentrations of 100 ng/l. Treatments are shown to be widely distributed and separated into fragmented plumes with no accumulations. After 24hrs treatments are highly diluted and dispersed from the region.

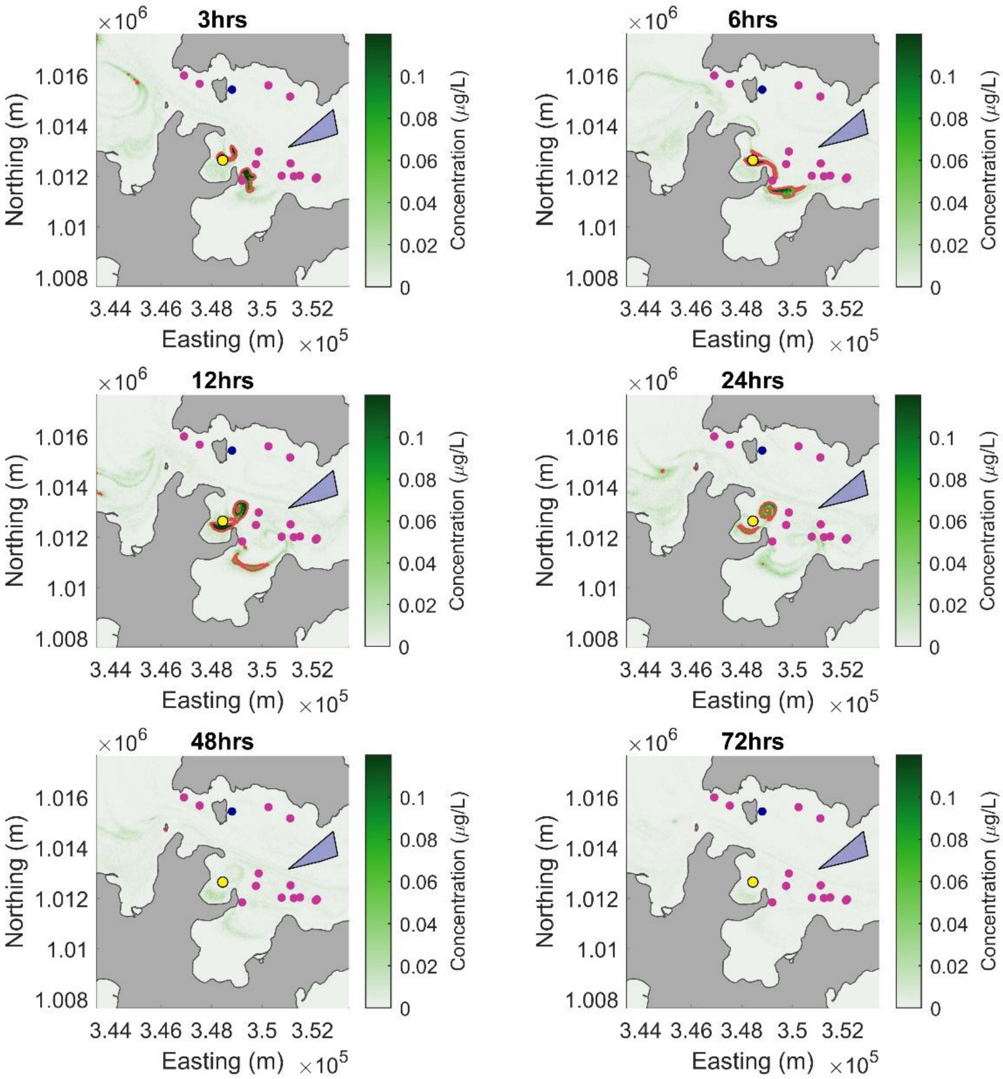

Figure 40. Spatial Azamethiphos distribution for bath treatment releases during spring tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.2 Cypermethrin

4.2.2.1 Neap tides

Short-term exposure during the neap tide is assessed using a single release of 25g of Cypermethrin. Treatment concentration at sensitive features is identified in figure 41. For the majority of features no observable treatment concentrations are shown. Features MM05 shows a minor treatment concentration with a short exposure time.

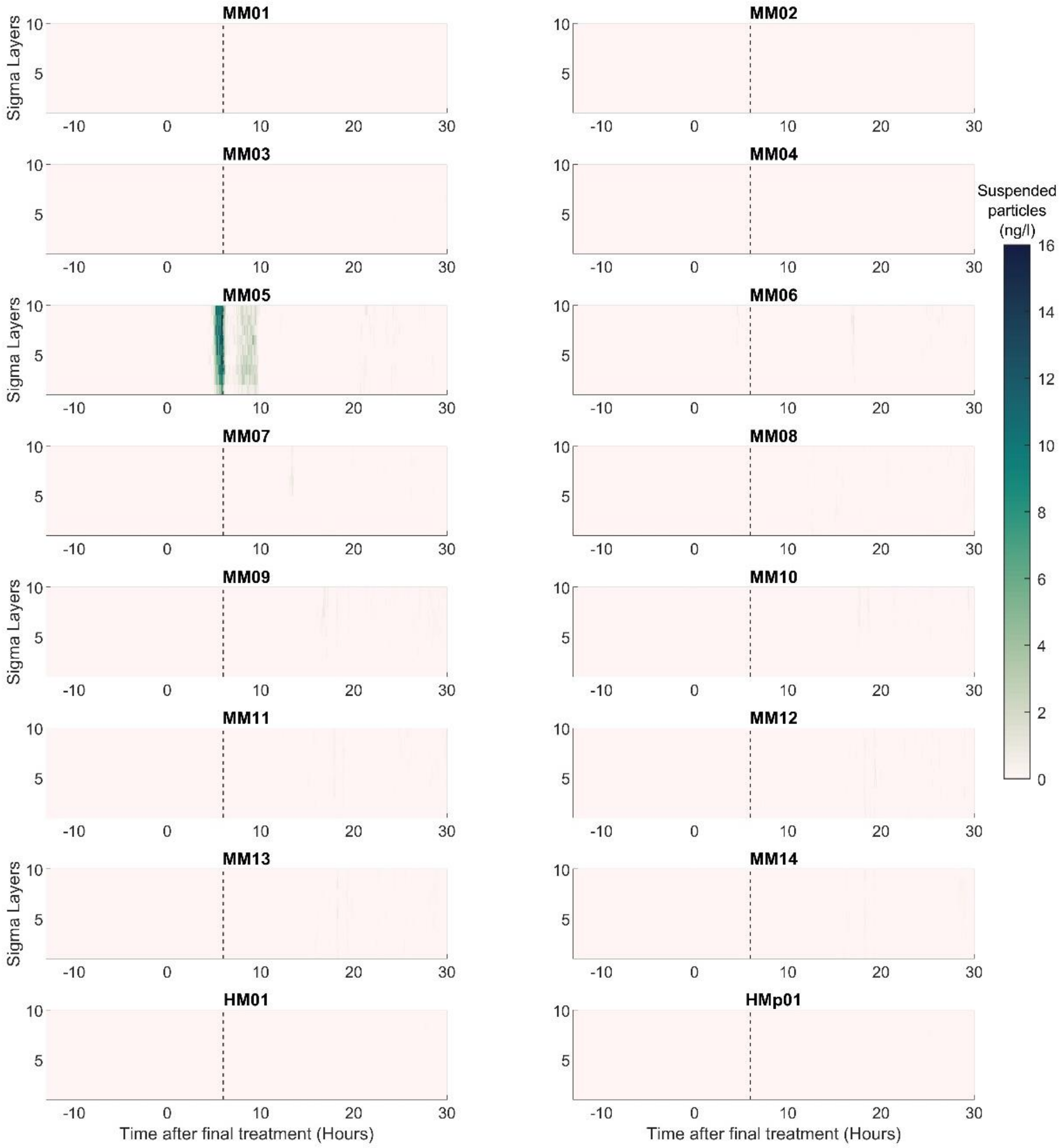

Figure 41. Neap tide Cypermethrin concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

Vertical concentration profiles for each feature are shown in figure 42 for the 6hr EQS time. Only sensitive feature MM05 shows treatment present at low concentrations.

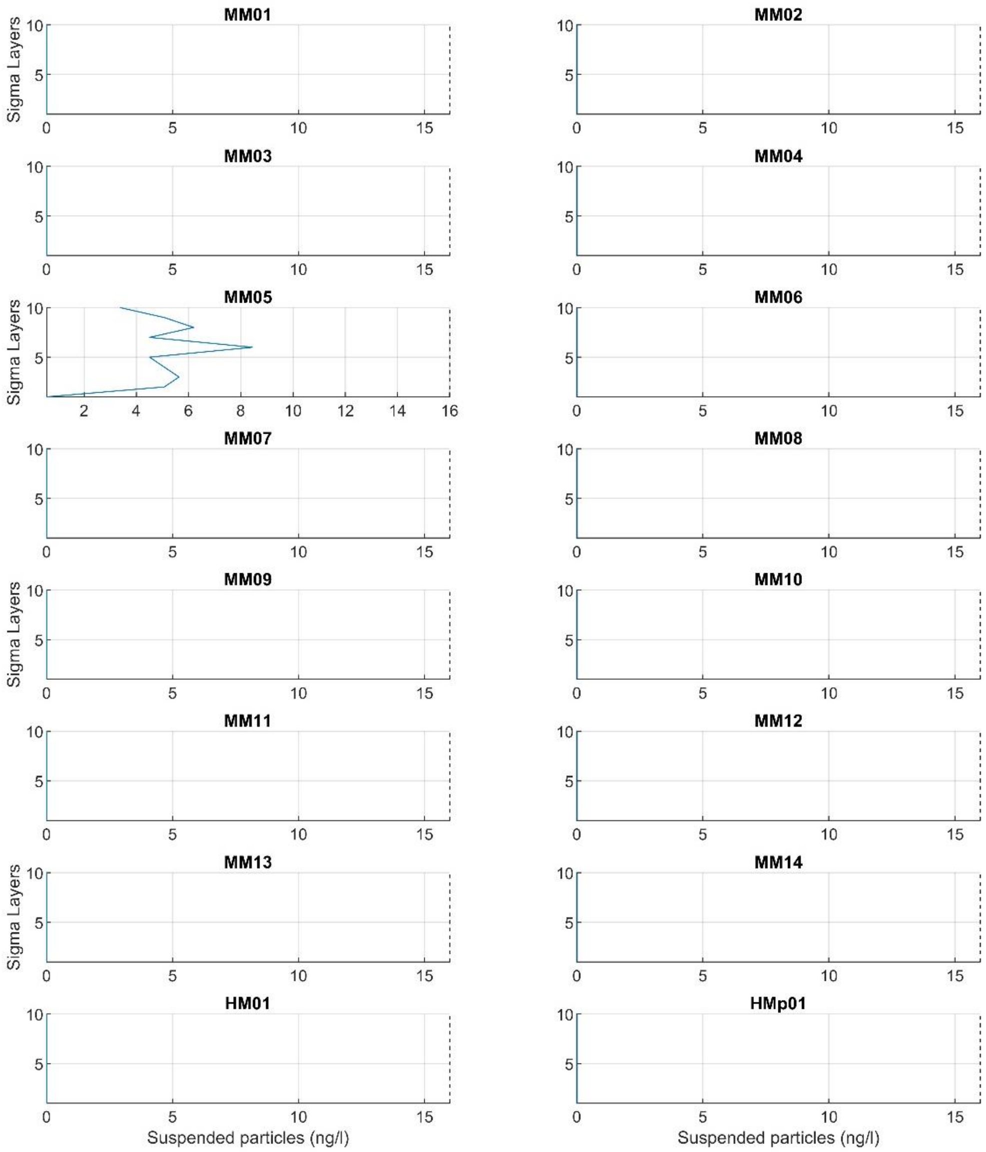

Figure 42. Neap tide vertical concentration profile of Cypermethrin after the single treatment at the 6 hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Cypermethrin is shown relative to the sensitive feature locations in figure 43. Red contour lines are shown for treatment concentrations of 16 ng/l. Treatment plume is shown to be distributed to the southeast away from sensitive feature locations.

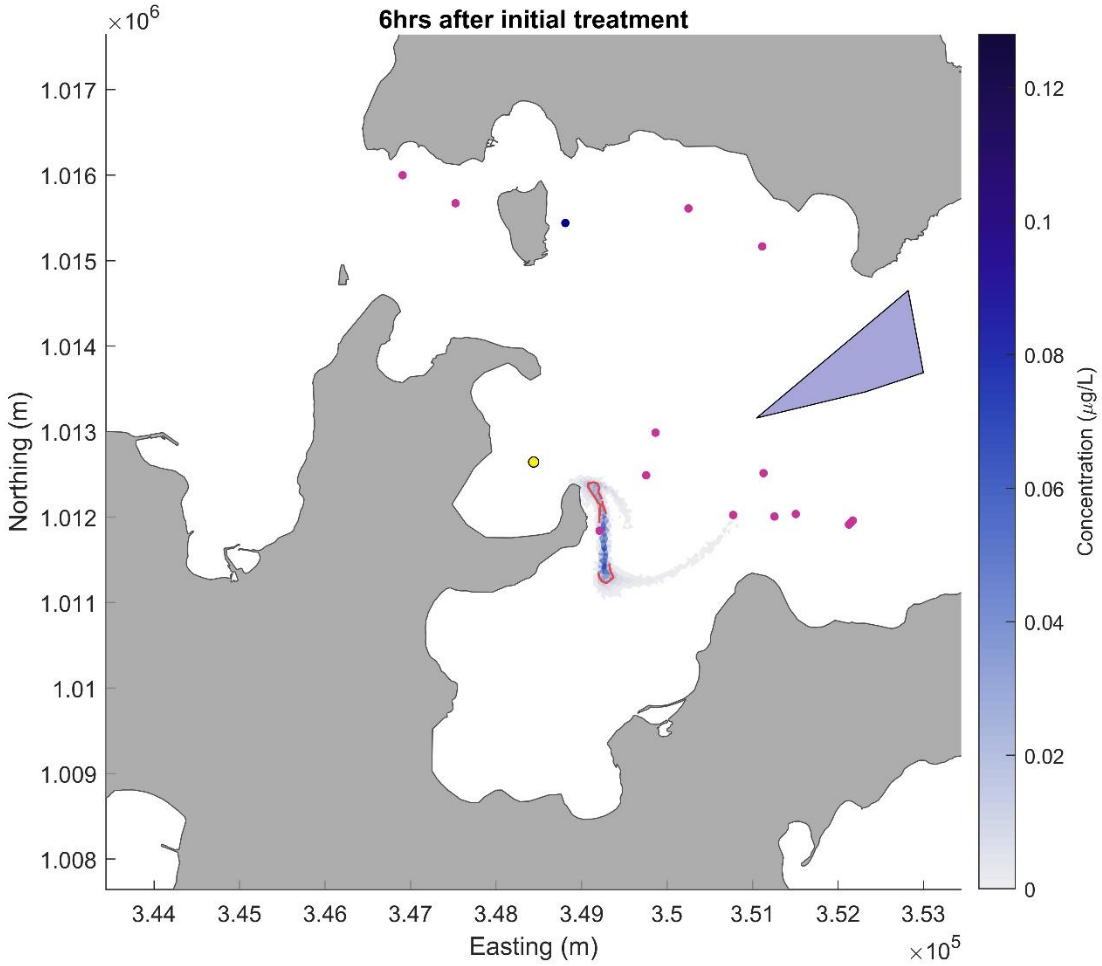

Figure 43. Spatial Cypermethrin distribution for bath treatment releases during neap tides 6hrs after treatment. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.2.2 Spring tides

Short-term exposure during the spring tide is assessed using a single release of 25g of Cypermethrin. Treatment concentration at sensitive features is identified in figure 44. MM05 shows weak traces of the plume around 20hrs after treatment. All other features showing no observable treatment concentrations.

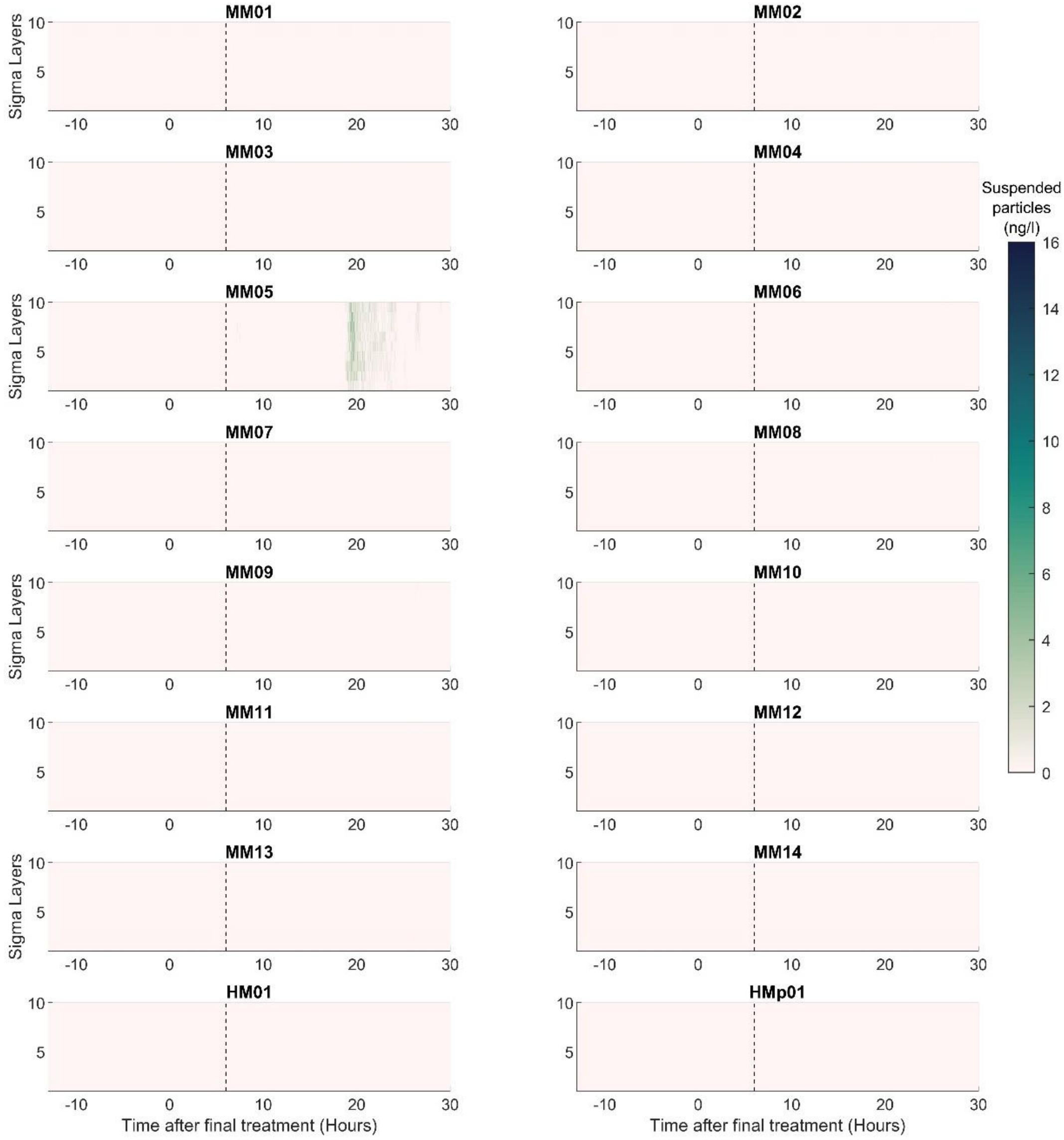

Figure 44. Spring tide Cypermethrin concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

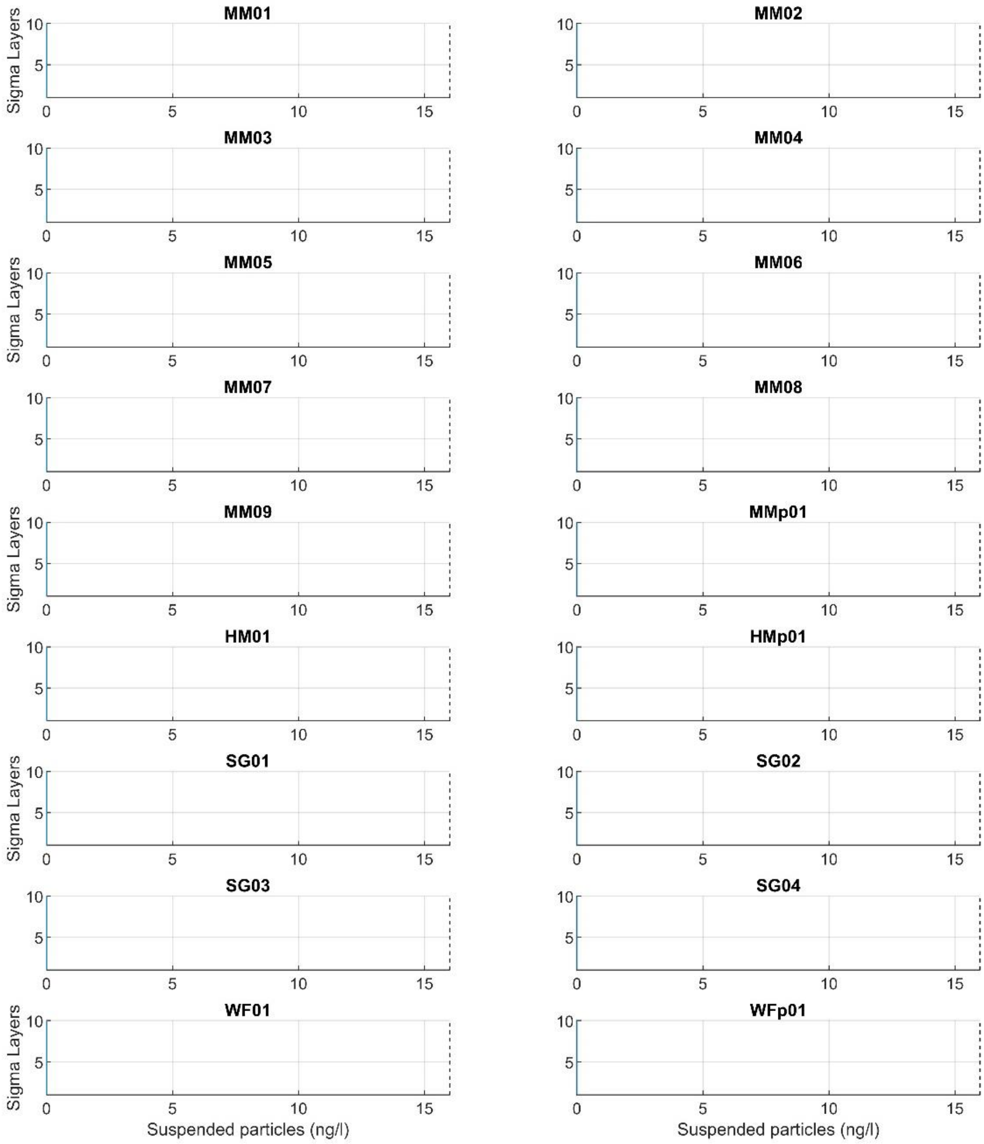

Figure 45. Spring tide vertical concentration profile of Cypermethrin after the single treatment at the 6 hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Cypermethrin is shown relative to the sensitive feature locations in figure 46. Red contour lines are shown for treatment concentrations of 16 ng/l.

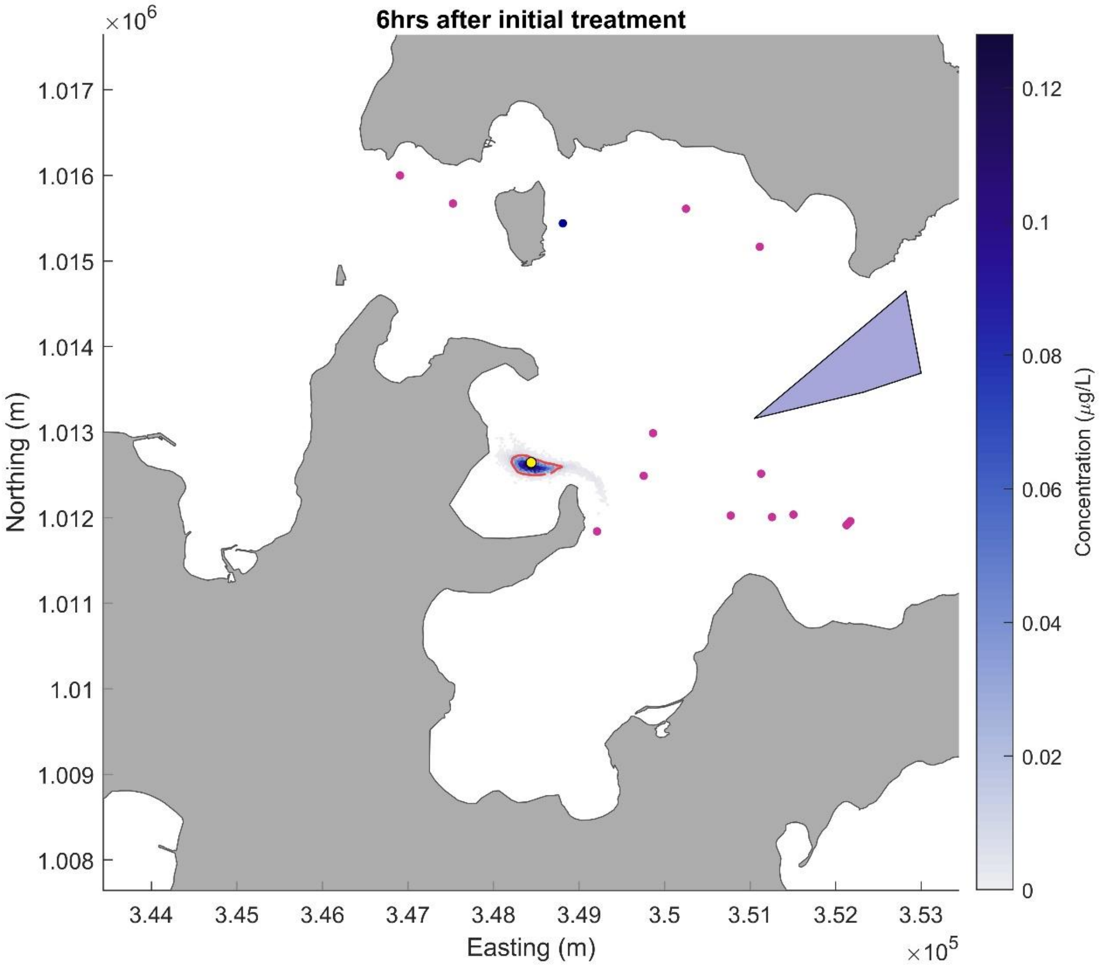

Figure 46. Spatial Cypermethrin distribution for bath treatment releases during spring tides 6hrs after treatment. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.3 Deltamethrin

4.2.3.1 Neap tides

Short-term exposure during the neap tide is assessed using a single release of 10g of Deltamethrin. Treatment concentration at sensitive features is identified in figure 47. For the majority of features no observable treatment concentrations are shown. Features MM05 show an increase in treatment concentration after the treatment as it is dispersed.

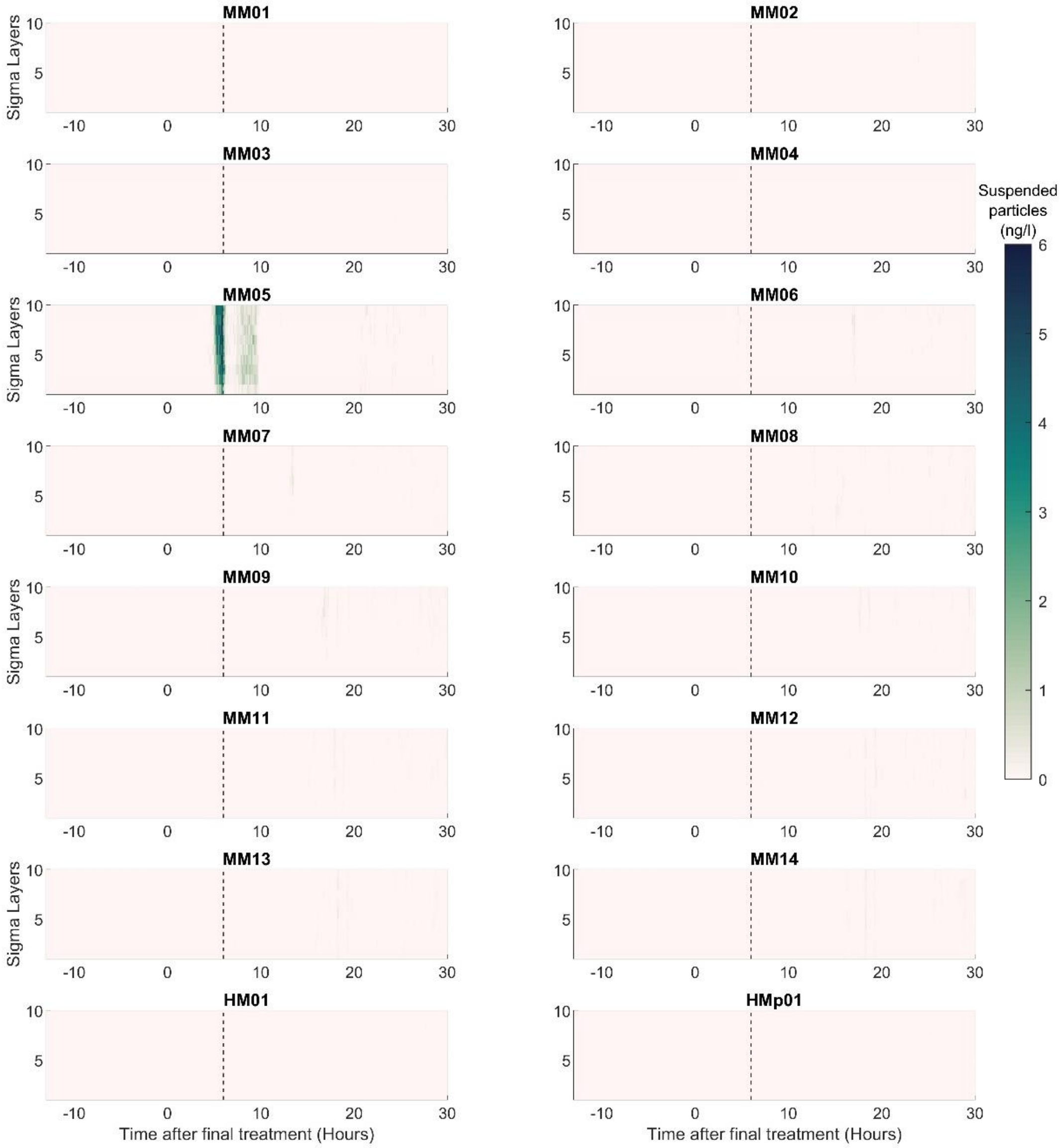

Figure 47. Neap tide Deltamethrin concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

Vertical concentration profiles for each feature are shown in figure 48 for the 6hr EQS time. After 6hrs low concentrations of deltamethrin are observed at MM05, with no other features showing treatment concentrations present.

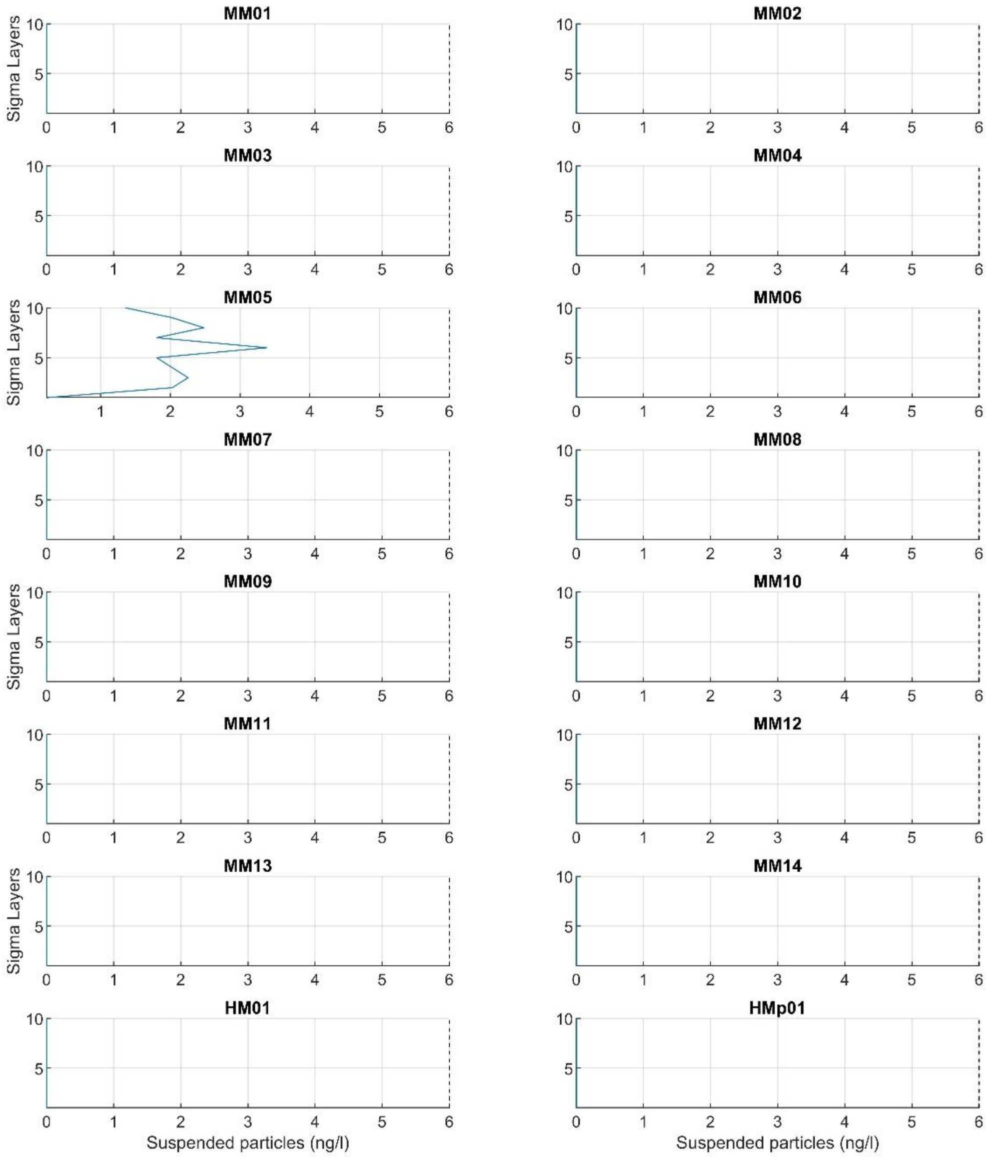

Figure 48. Neap tide vertical concentration profile of Deltamethrin after the single treatment at the 6 hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Deltamethrin is shown relative to the sensitive feature locations in figure 49. Red contour lines are shown for treatment concentrations of 6 ng/l.

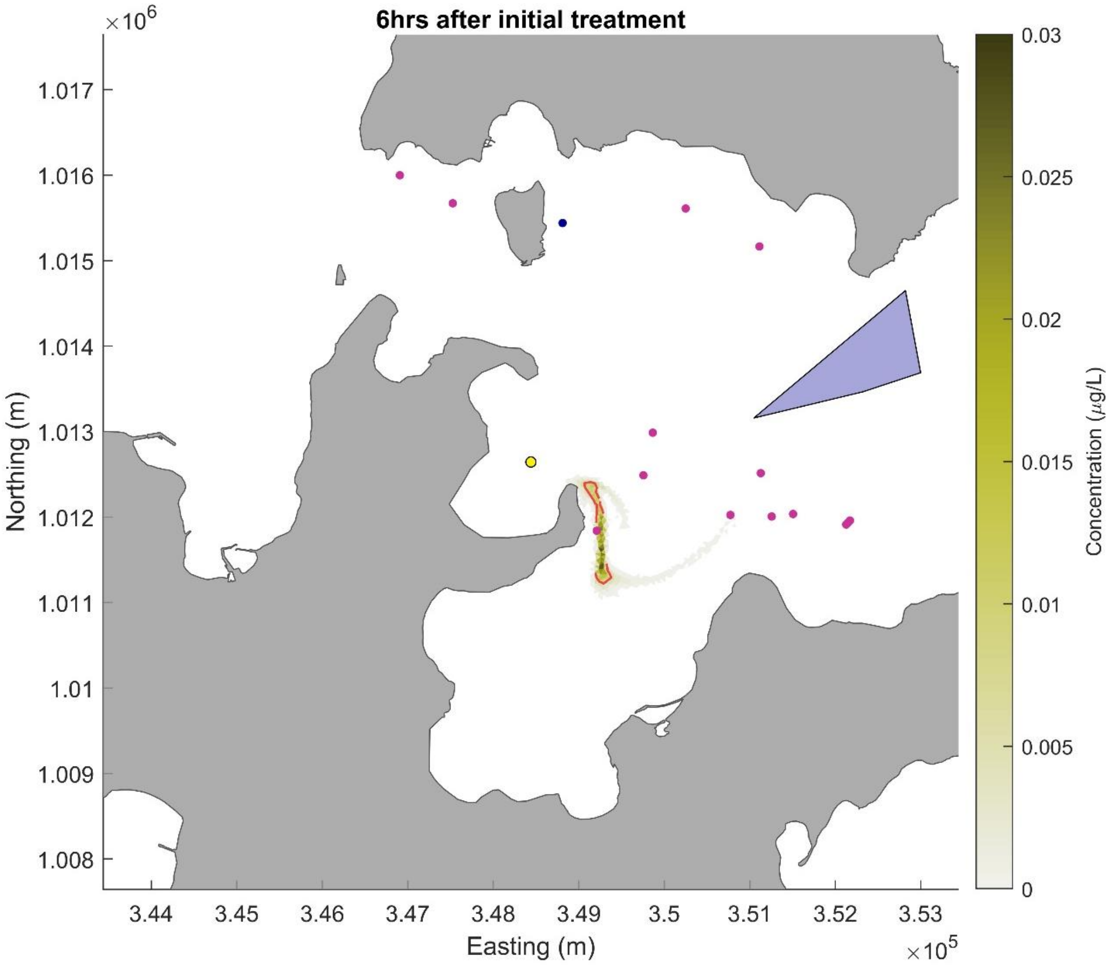

Figure 49. Spatial Deltamethrin distribution for bath treatment releases during neap tides 6hrs after treatment. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.3.2 Spring tides

Short-term exposure during the spring tide is assessed using a single release of 10g of Deltamethrin. Treatment concentration at sensitive features is identified in figure 50. Feature MM05 shows a very diluted plume passing after 20hrs. No other features record observable treatment residues.

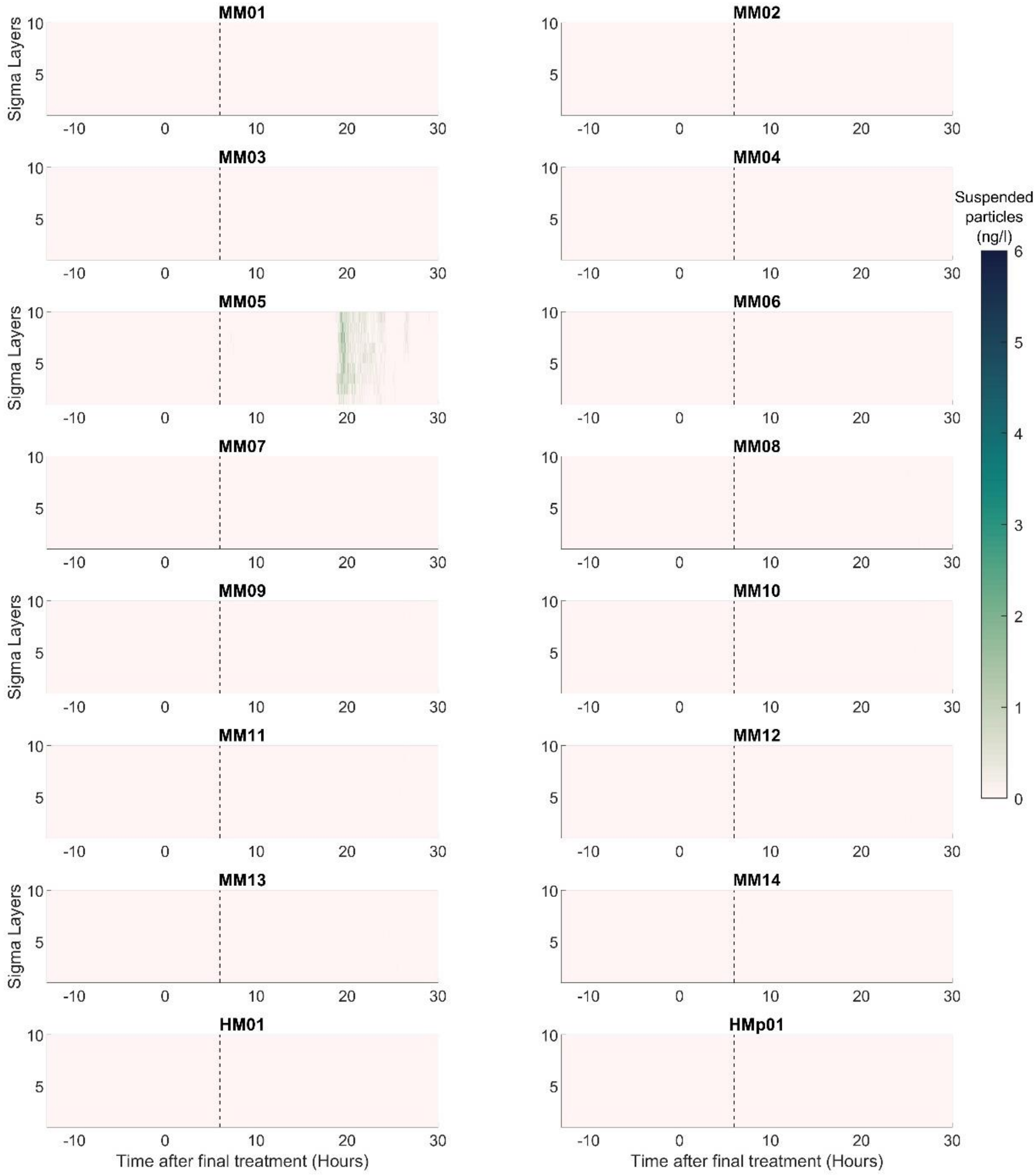

Figure 50. Neap tide Deltamethrin concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

Vertical concentration profiles for each feature are shown in figure 51 for the 6hr EQS time. No treatment concentrations are shown for any of the identified sensitive marine features.

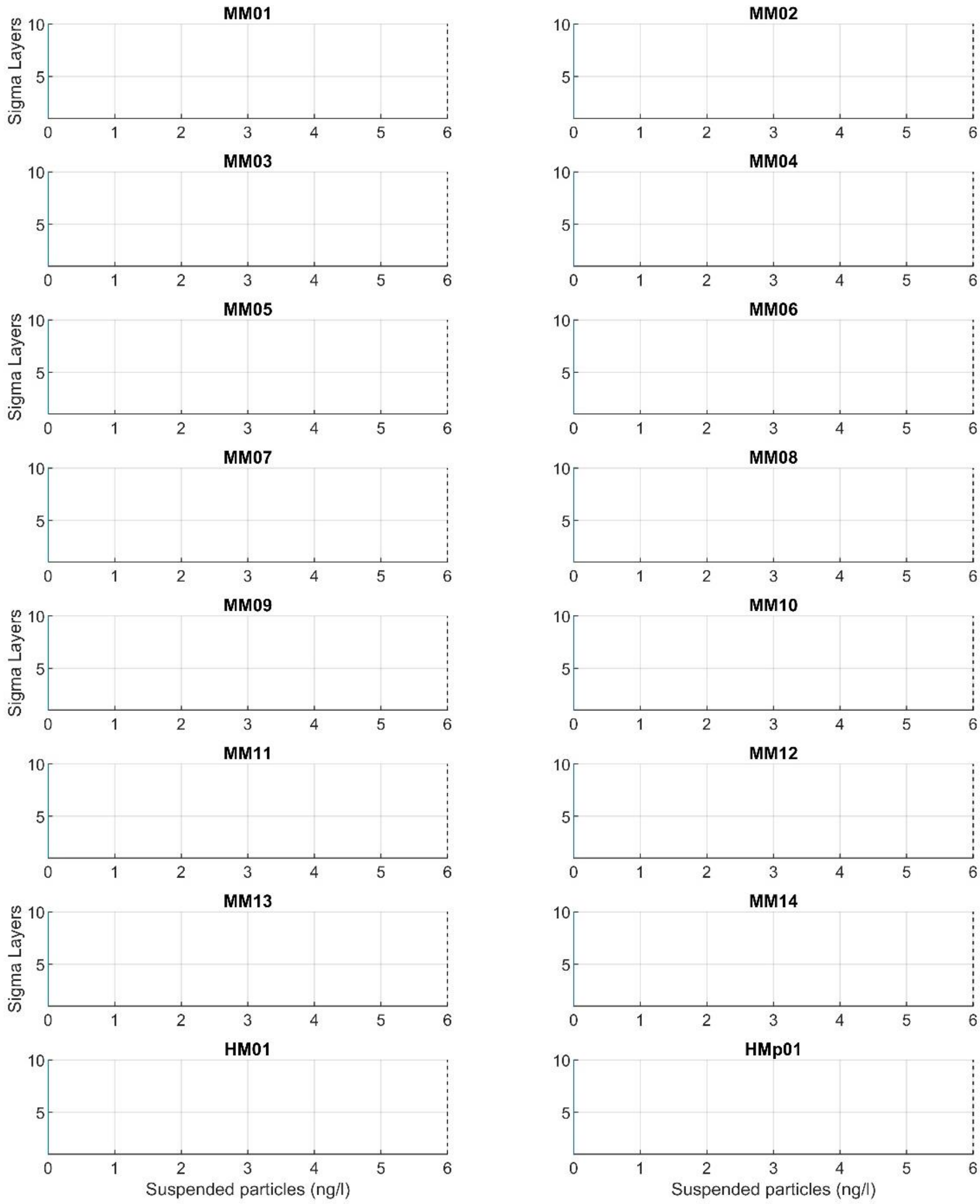

Figure 51. Spring tide vertical concentration profile of Deltamethrin after the single treatment at the 6 hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Deltamethrin is shown relative to the sensitive feature locations in figure 52. Red contour lines are shown for treatment concentrations of 6 ng/l. Treatment plume is shown to be distributed around the site with a trailing plume to the east.

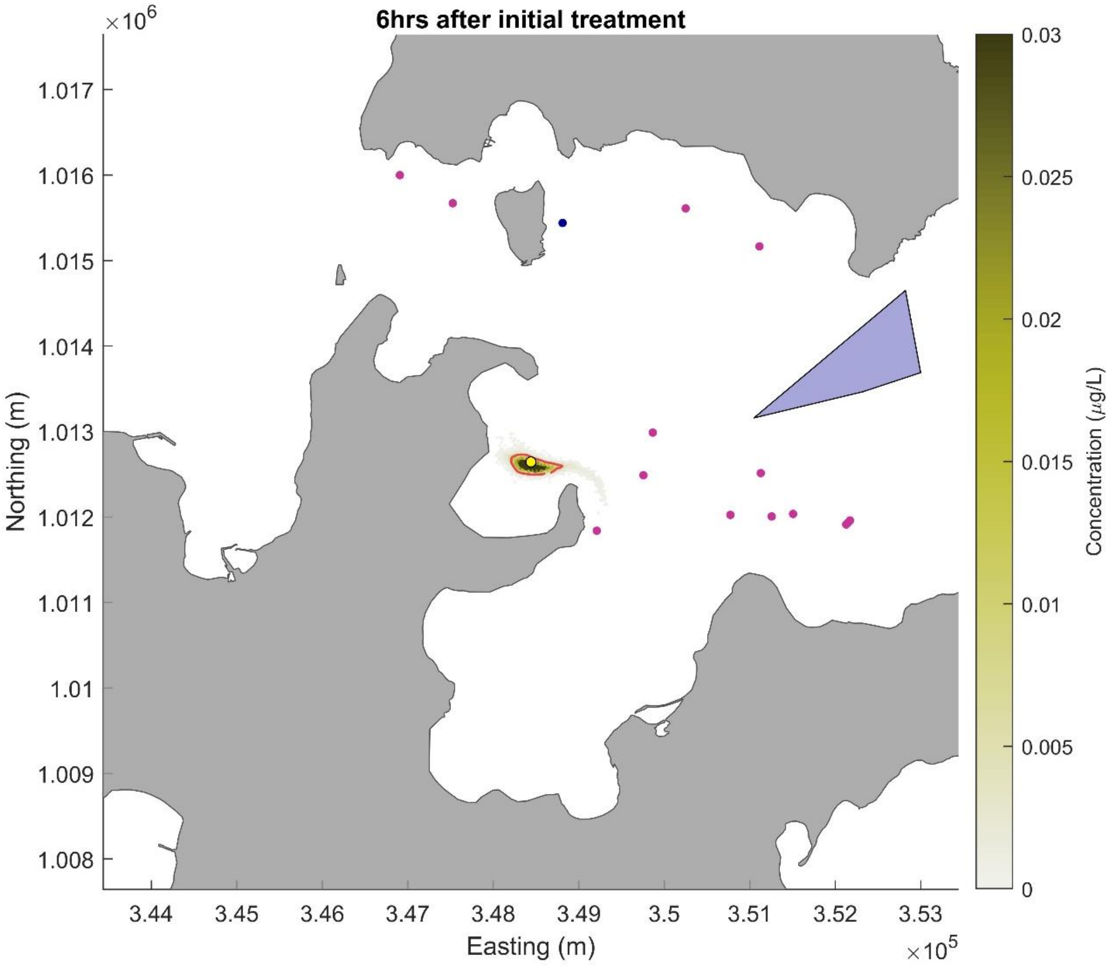

Figure 52. Spatial Deltamethrin distribution for bath treatment releases during spring tides 6hrs after treatment. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4. Conclusions

This report outlines the methodology and results for the simulation of bath treatment chemicals at the proposed Meil Bay site. This informs of the safe quantities of treatment chemicals that may be used on site in the event of a sea lice outbreak.

To explore the impacts and determine environmental compliance under a realistic bath treatment plan, bath medicines were released in particle tracking models driven by the calibrated and validated hydrodynamic model. Treatments were split into working days with a maximum of 2 treatments per day with a treatment interval of 3hrs. For Azamethiphos, modelling of the entire treatment cycle revealed a recommended consent mass of 600g per 24-hour period or 180g per 3-hour window was shown to be compliant with EQS. This equates to a treatment volume of 2.99 wellboat treatments (1,000m^3 capacity) per 3 hours. For Cypermethrin, modelling of the 6-hour treatment mass revealed an adjusted consent mass of 0.0936g. This chemical quantity is not viable for the effective treatment of sea lice. For Deltamethrin, modelling of the 6-hour treatment mass provided a recommended consent mass of 10g, while maintaining EQS compliance. This provides a treatable volume of 10,000m^3, equal to 6.66 wellboat treatments (1,500m^3 capacity) per 6-hours.

Azamethiphos, Cypermethrin and Deltamethrin have been assessed at 15 sensitive feature locations and 1 area-based features. As there are no compliant standards for sensitive marine features, EQS time and concentrations were used as a point of reference. It should be noted that EQS concentrations are used for area assessment and not maximum allowable concentration, therefore it is permitted for EQS concentrations to be exceeded. The results indicate that the majority of identified sensitive marine features experience no interaction with bath chemical treatments. Features MM05 is shown to have infrequent and diluted interaction with bath treatment plumes that are rapidly dispersed. Interactions with large extents of the area-based sensitive features show no exceedance of EQS or lower treatment concentration thresholds and therefore poses no risk to these features

The numerical simulation of bath treatments has revealed multiple feasible treatment options for Meil Bay using Azamethiphos and/or Deltamethrin. The treatment of sea lice however is not restricted to medicinal approaches, thermal or mechanical treatment options can also be used if required. This flexibility provides a diverse range of sea lice treatment options that can be called upon if required, allowing specific treatment plans to be chosen that are best suited for the welfare of the farmed fish, wild salmonids and the wider environment.

5. References

Ordnance Survey (2020) “Data Downloads” (Accessed September 2020) Available at: https://osdatahub.os.uk/downloads/open

SEPA (2018) “Supporting Guidance (WAT-SG-53): Environmental quality standards and standards for discharges to surface waters”.

SEPA (2022) “Aquaculture Modelling Screening &Risk Identification Report: Meil Bay (BOM1) May, 2022

SEPA (2023) “Interim Marine Modelling Guidance for Aquaculture Applications” December 2023.

UK Hydrographic Office (2021) Marine Data Portal (Accessed May 2021) Available at: https://datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal

6. Appendices

A. Tarpaulin based treatment method

The current modelling simulates the release of bath treatments using wellboat treatment options. While this is the preferred method and offers a more modern approach of administering treatments it is necessary to consider alternative or traditional treatment methods to ensure the most flexibility when considering farm management. This section looks at the difference in release mechanisms and particle fate when considering wellboat and tarpaulin treatment options at the proposed Meil Bay fish farm.

A.1 Methodology

To realistically simulate the tarpaulin treatment process, particles were released instantaneously from a volume source within the particle tracking model. The particle source is located at depths between 1.5m to 5m and is representative of a hypothetical pen at the site centre location, a diagram of this is shown in figure A-1. For the assessment of the long-term treatment program where multiple treatments are considered, particle releases were simulated at a 3hr interval with a maximum of 2 treatments per day. At the end of each treatment, the treatment solution is instantaneously released into the environment over a single model timestep. The number of particles assigned to each treatment is constant, this uses 30,000 particles per treatment. Outputs of particle concentration are assessed using particles within the top 5m of the water column.

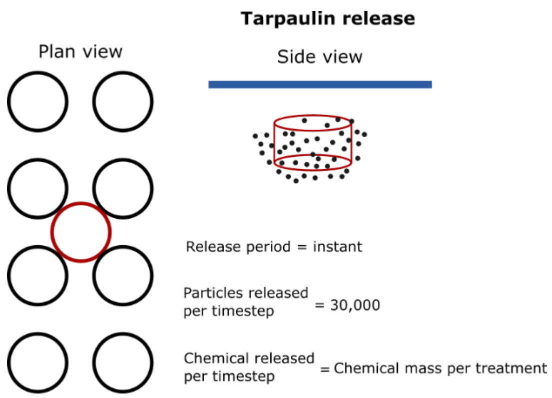

Figure A-1. Tarpaulin release schematic. Open black circles represent pen locations, particle source location is shown in red, the blue line represents the sea surface, and small black dots represent particles.

The simulation of wellboat treatments uses a gradual discharge as opposed to the instantaneous release of the tarp treatment method. Wellboat treatment discharge is completed over 3600s from a single point source at the farm centre at a depth of 1.5m. The number of particles per treatment remains at 30,000 and are equally distributed through the release. Treatment intervals match the tarp-based method where a maximum of two 3-hour treatments per day are simulated. Outputs of particle concentration are assessed using particles within the top 5m of the water column.

Wellboat and tarp treatment were simulated using 180g of Azamethiphos within a 3-hour period and 600g within a 24-hour for both spring and neap tidal cycles. The maximum concentration and plume area extent for respective EQS values are compared to assess differences in particle fate relevant to EQS parameters.

A.2 Results

A.2.1 Azamethiphos

Neap Tides

3hr Consent Time

A single release of 180g of Azamethiphos was simulated for both treatment methods. Within the first 9hrs the plume area exceeding 250ng/l shows almost identical distribution between wellboat and tarp treatment options. After 9hrs concentrations of both treatment plumes drop below 250ng/l and no further area is plotted.

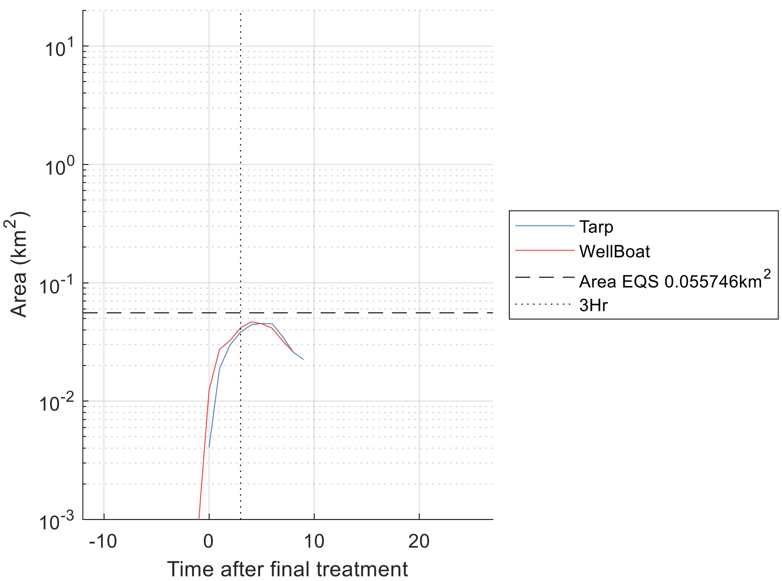

Figure A-2. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after the initial 3-hour mass tarp and wellboat release of Azamethiphos during neap tides. The size of the 3-hour EQS mixing zone is shown by the horizontal dashed line. 3-hours after the initial treatment is marked by the vertical dotted line.

24hr Consent Time

Multiple pen treatments are simulated using the 24hr consent method. Initial treatments using tarps show a slightly higher concentration, where the release times are visible in figure A-3. Immediately after each treatment, wellboat and tarp plume concentrations rapidly drop and show very similar values, this persists for the remainder of the model duration.

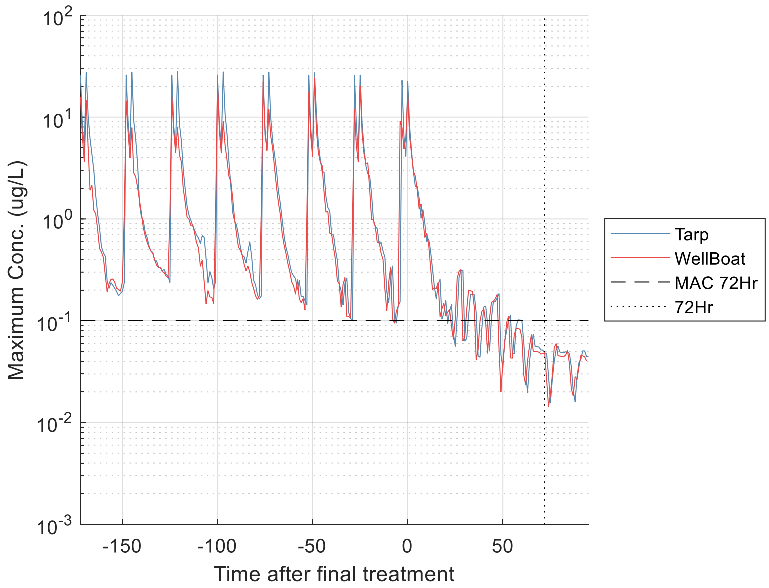

Figure A-3. Maximum concentration of Azamethiphos during neap tide from tarp and wellboat based treatments. MAC for the 72-hour EQS (100 ng/l) is indicated by the grey horizontal dotted line. 72-hours after the final treatment is marked by the vertical dotted line.

Quantification of the area extent between tarp and wellboat treatment methods for plume concentrations exceeding 40ng/l are shown in figure A-4. During the treatment window, wellboat treatments tend to show larger plume areas. After the final treatment, plume area is shown to dissipate at very similar rates.

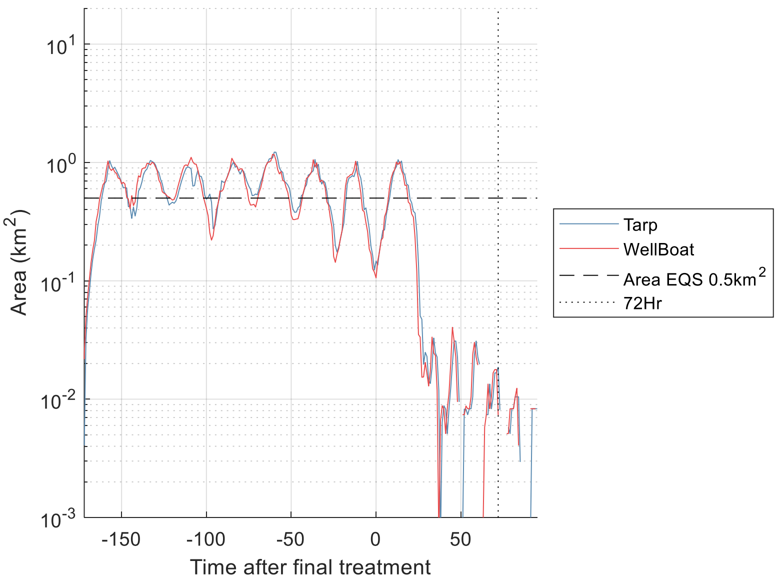

Figure A-4. Chemical plume area exceeding the 72-hour (40 ng/l) EQS values after a tarp and wellboat treatment cycle using Azamethiphos during neap tides. The size of the 72-hour EQS mixing zone is shown by the horizontal dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

Spring Tides

3hr Consent Time

During the spring tide, the difference between the plume area for wellboat and tarp treatment is shown to be minimal. After the peak in plume area at around 7hrs, both tarp- and wellboat-based treatments show a very similar dispersion, which drops below 250ng/l at 15hrs.

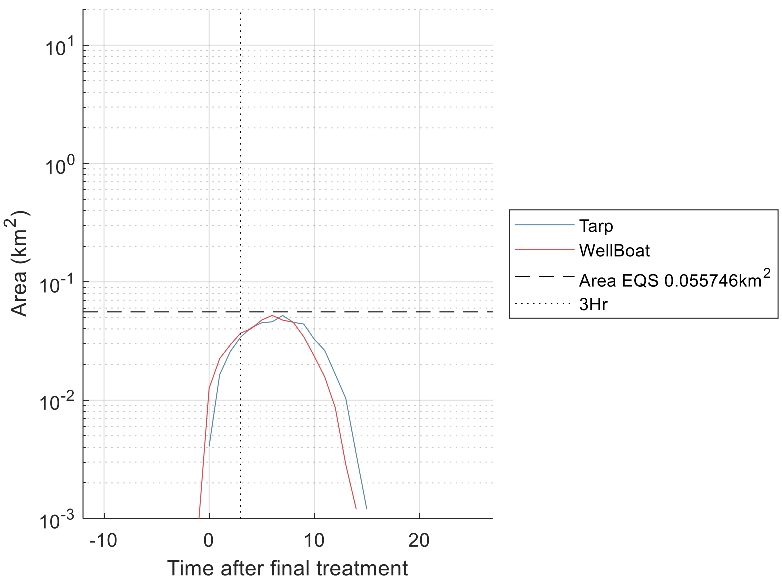

Figure B-5. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after the initial 3-hour mass wellboat release of Azamethiphos during Spring tides. The size of the 3-hour EQS mixing zone is shown by the horizontal dashed line. 3-hours after the initial treatment is marked by the vertical dotted line.

24hr Consent Time

Similar to the neap tidal phase, the difference between wellboat and tarp treatment methods is mainly visible during the few hours surrounding the treatments. After this, both treatment methods show very similar dispersion rates with very similar values recorded for both general dispersion and higher frequency plume concentration.

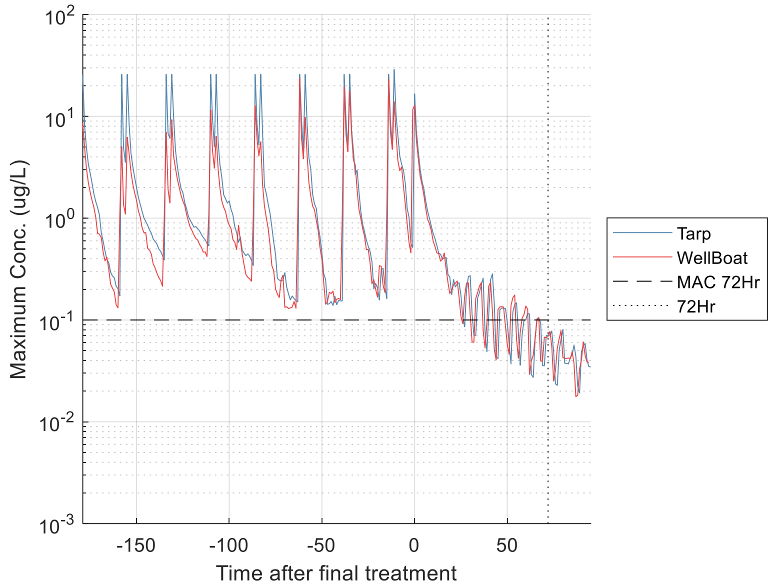

Figure A-6. Maximum concentration of Azamethiphos during spring tide from tarp and wellboat based treatments. MAC for the 72-hour EQS (100 ng/l) is indicated by the grey horizontal dotted line. 72-hours after the final treatment is marked by the vertical dotted line.

The initial plume area exceeding the 72hr EQS shows large variations. At this stage wellboat plume area often exceeds tarp-based methods. At the final treatment time, plume sizes are very similar with wellboat treatment options showing a fractionally earlier dispersion.

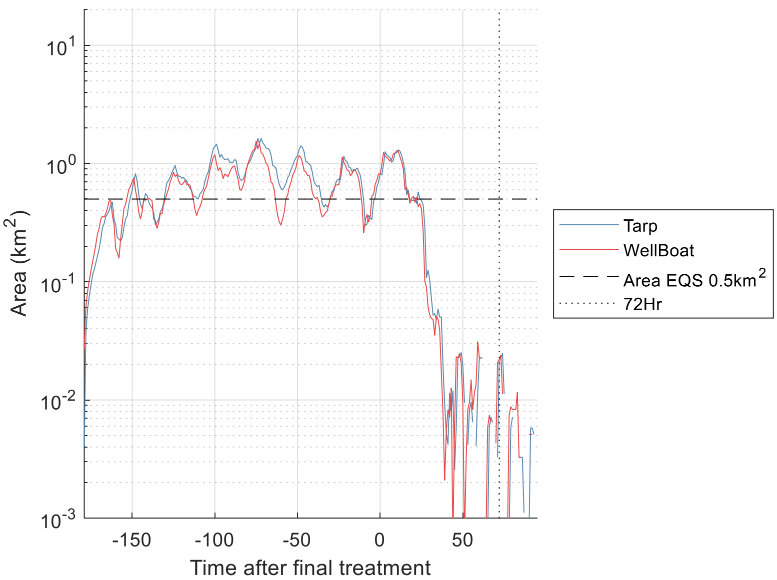

Figure A-7. Chemical plume area exceeding the 72-hour (40 ng/l) EQS values after a tarp and wellboat treatment cycle using Azamethiphos during spring tides. The size of the 72-hour

EQS mixing zone is shown by the horizontal dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

A.3 Discussion

The simulation of wellboat and tarp-based treatment options in spring and neap tides have illustrated the difference in dispersion mechanisms associated with each process. This highlights that the main difference in treatment concentrations is observed during the initial treatment cycle. In this phase, wellboat treatment concentrations are shown to be lower but occur over a wider area. After each treatment, both treatment options show very similar plume concentration and area dissipation. This provides very similar results for both treatments for the EQS parameters.

Comparisons of treatment plume area and concentrations at EQS times is shown in table A-1. This shows all treatment options passing EQS criteria. Comparison between wellboat and tarp treatment methods for the 3hr EQS shows wellboat treatments having a slightly higher percentage of the area EQS allowance. The 72hrs parameters very similar concentration and plume extents.

Table A-1. EQS parameters for wellboat and bath treatment options.

		3hr - Max area (km^2)	72hr EQS- MAC (ug/l)	72hr EQS Area (km^2)
Neap	Tarp	0.038 (68.4%)	0.048 (48.4%)	0.019 (3.7%)
	Wellboat	0.042 (74.8%)	0.049 (48.5%)	0.007 (1.5%)
Spring	Tarp	0.034 (61.3%)	0.071 (71.0%)	0.022 (4.4%)
	Wellboat	0.037 (66.2%)	0.069 (69.0%)	0.022 (4.4%)

A.4 Conclusion

A diverse range of lice management options is required to protect stocked and wild fish for potential outbreaks from parasitic sea lice. This report considers two treatment methods for administering these treatments and assesses the dispersion and assimilation into the environment. Treatment releases are considered for spring and neap tides and monitored for up to 96hrs. The results show that during the treatment cycle, tarp-based treatments have a marginally higher concentration. Once the treatment cycle is completed and the plumes are dispersed, concentration and plume area are shown to be very similar between treatment options. This suggests that any difference in plume concentration between treatment methods will occur at the farm or in very close proximity and will quickly fade once the treatment has stopped. At the Meil Bay farm location, this results in a negligible change in environmental risk when considering wellboat or tarp options

B. Existing Sites Interactions with Sensitive Marine Features

Existing bath treatment concentrations from the current consented Meil Bay site are shown to help illustrate the changes in the particle fate and the potential interactions of marine sensitive features. The modelling methods used to simulate the plume treatment uses the same methods as outlined above. The particle release location has been changed to the existing site centre location and the chemical quantities specified in table B-1 are released and monitored. As the proposed site changes result in lower treatment quantities for Cypermethrin and Deltamethrin, these treatment methods are not included in the assessment as there is a clear reduction in environmental risk.

Table B-1. Existing bath treatment consent

Azamethiphos	**Existing**	**Proposed**
Consent mass – 3hr	126.71g	180g
Consent mass – 24hr	318.29g	600g
Cypermethrin		
Consent mass – 6hr (Adjusted)	45.88 (2x 3hr mass)	0.0936g
Deltamethrin		
Consent mass – 6hr	17.2g (2x 3hr mass)	10g

B.1 Azamethiphos

Neap tides

3hr Consent Time

Short-term exposure during the neap tide is assessed using a single release of the 3hr treatment mass, 126.71g of Azamethiphos. Treatment concentration at sensitive features for the existing site is identified in figure B-1. For the majority of features no observable treatment concentrations are shown. Feature MM05 show a minor residue of treatments around 5-6hrs after the last treatment, this has a short exposure time and is quickly dispersed.

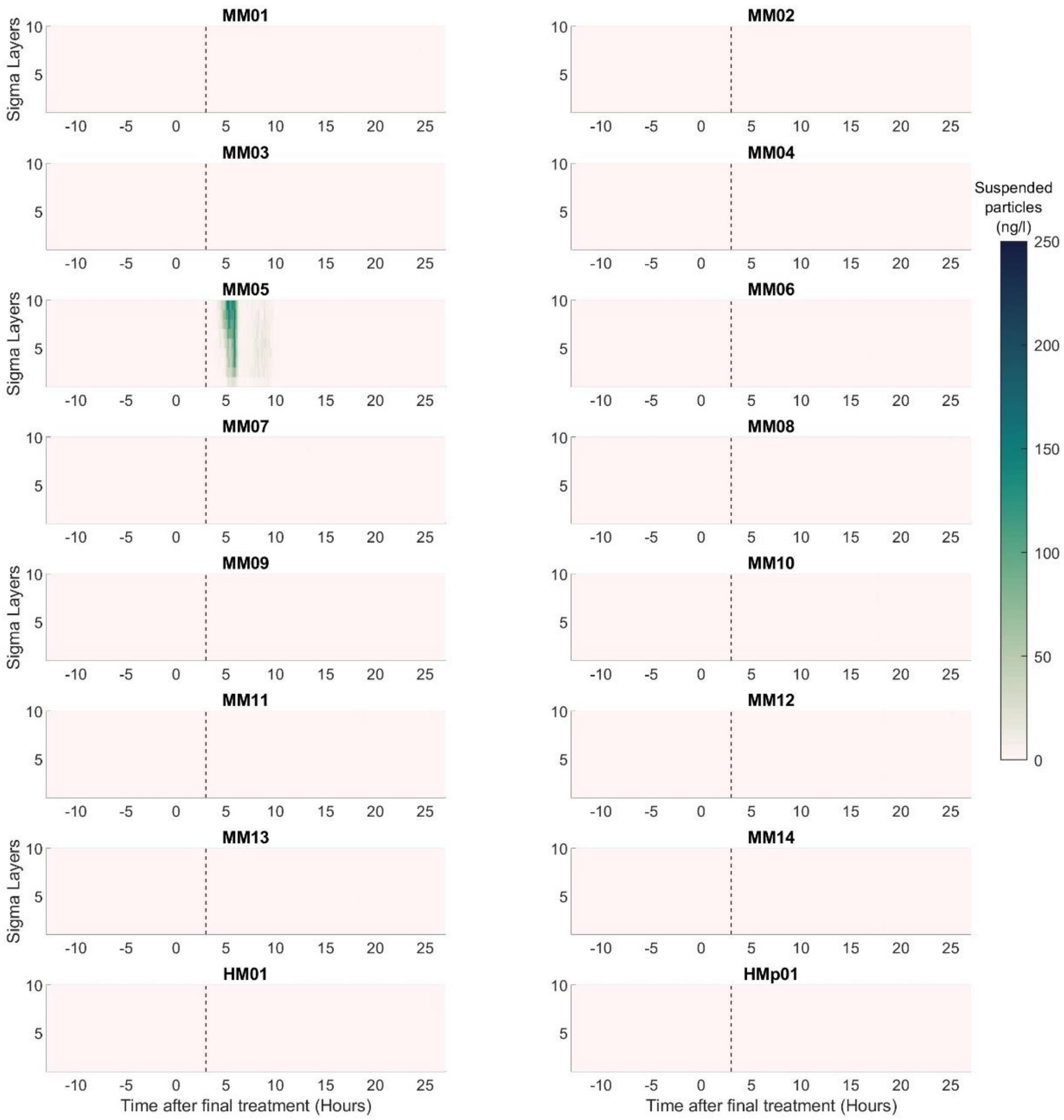

Figure B-1. Neap tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

Vertical concentration profiles for each feature are shown in figure B-2 for the 3hr EQS time. After 3hrs of a single treatment, all features show no concentration increase.

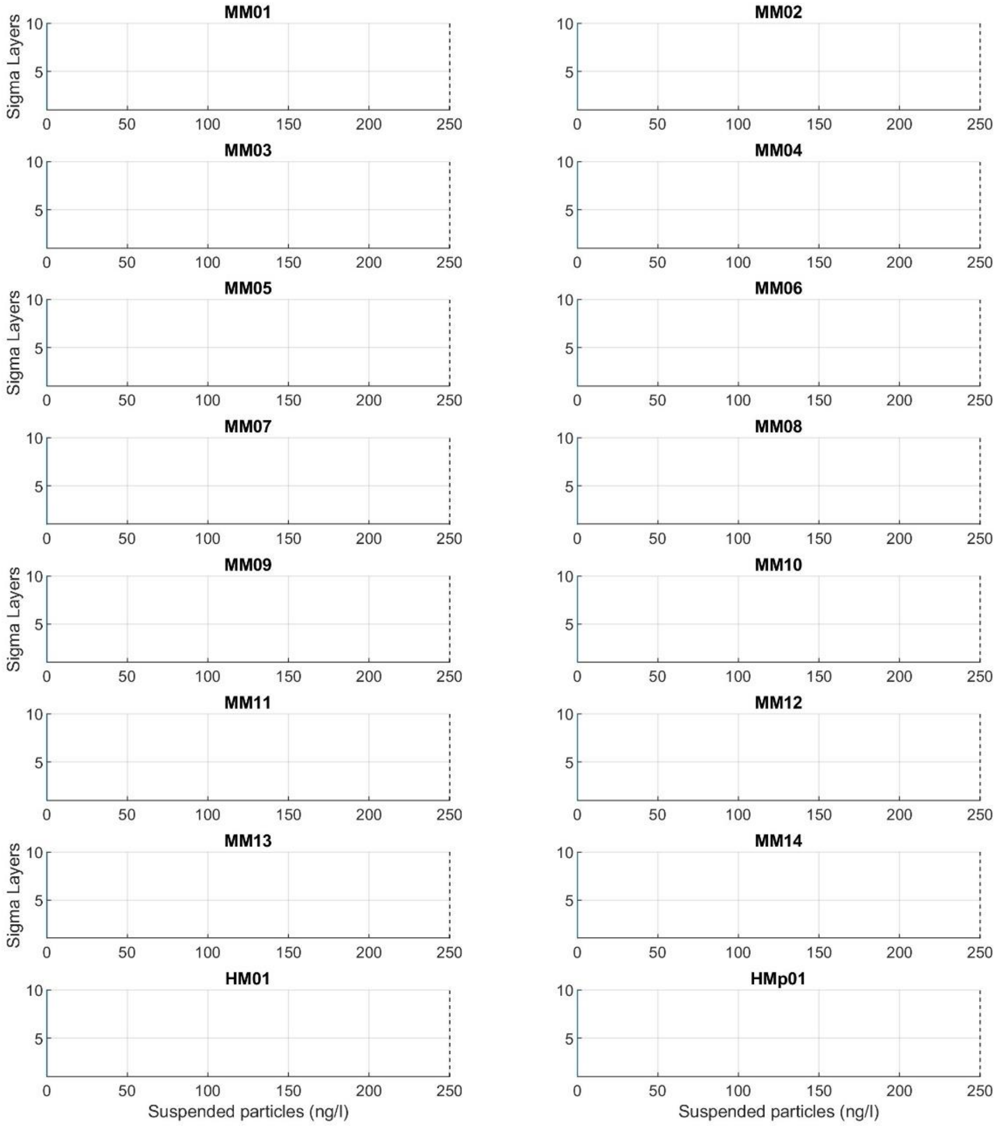

Figure B-2. Neap tide vertical concentration profile of Azamethiphos after the single treatment at the 3hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

72hr Consent time

Existing site bath treatment exposure during the neap tide is assessed using the 24-hr consented treatment mass of 318.29g of Azamethiphos. Treatment concentrations at sensitive features are identified in figure B-3, where the concentration scale is adjusted to 40ng/l, in line with the 72hr EQS value. Plume concentration at sensitive feature locations remain at very low levels. Feature MM05 shows more visible variations in passing plume concentrations as concentrations exceed the 72hr 40ng/l EQS during the treatment cycle. These increases in concentration have a short duration and generally weaken in strength nearer the seabed. After 6hrs the majority of treatment plumes have dissipated and no longer exceeds the 72 hr 40ng/l threshold. Beyond this, concentrations of any chemical plume at sensitive feature locations are shown to be very dilute.

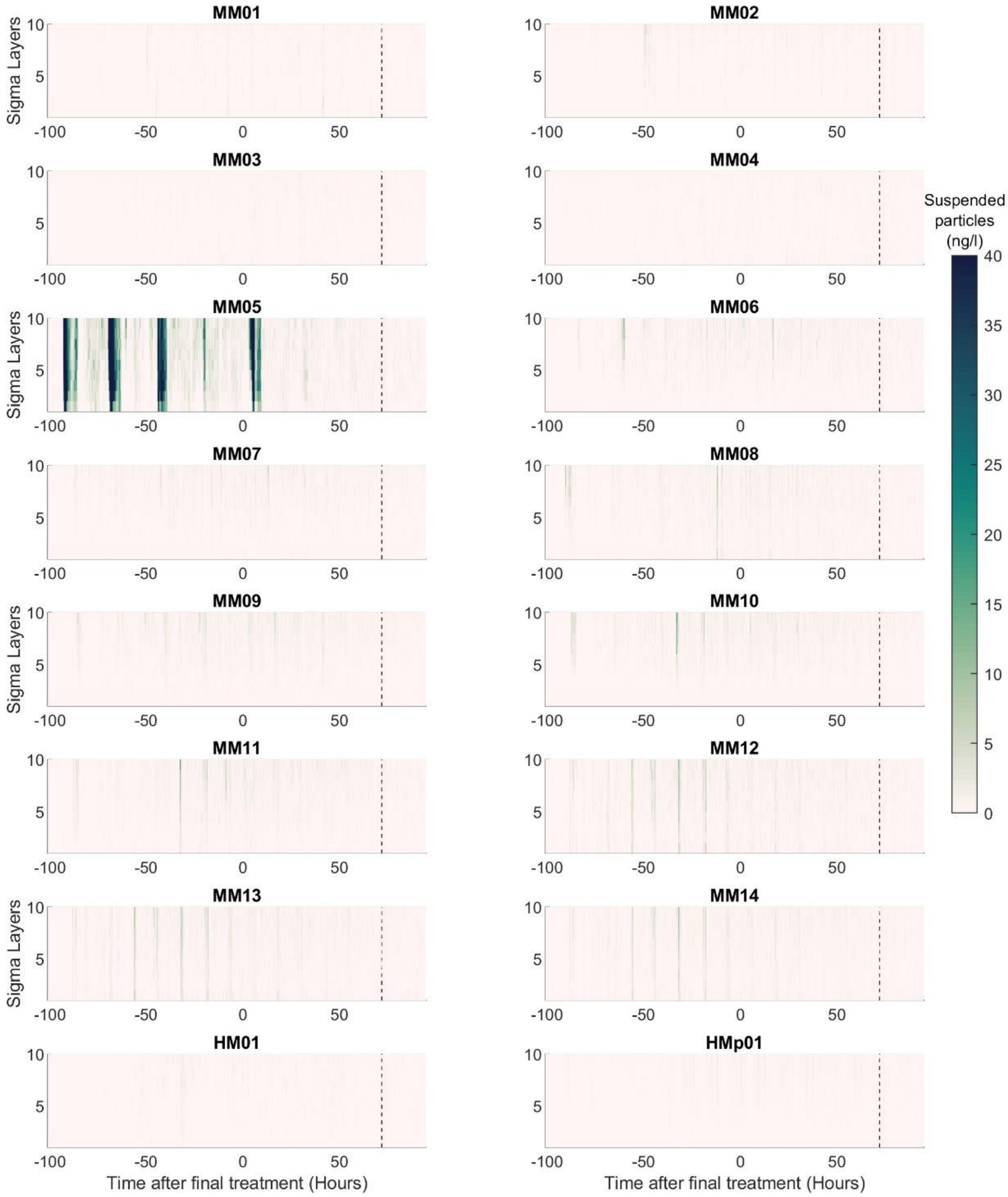

Figure B-3. Neap tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.

Vertical concentration profiles for each feature are shown in figure B-4 for the 72hr EQS time. All features show no or very low concentration increase.

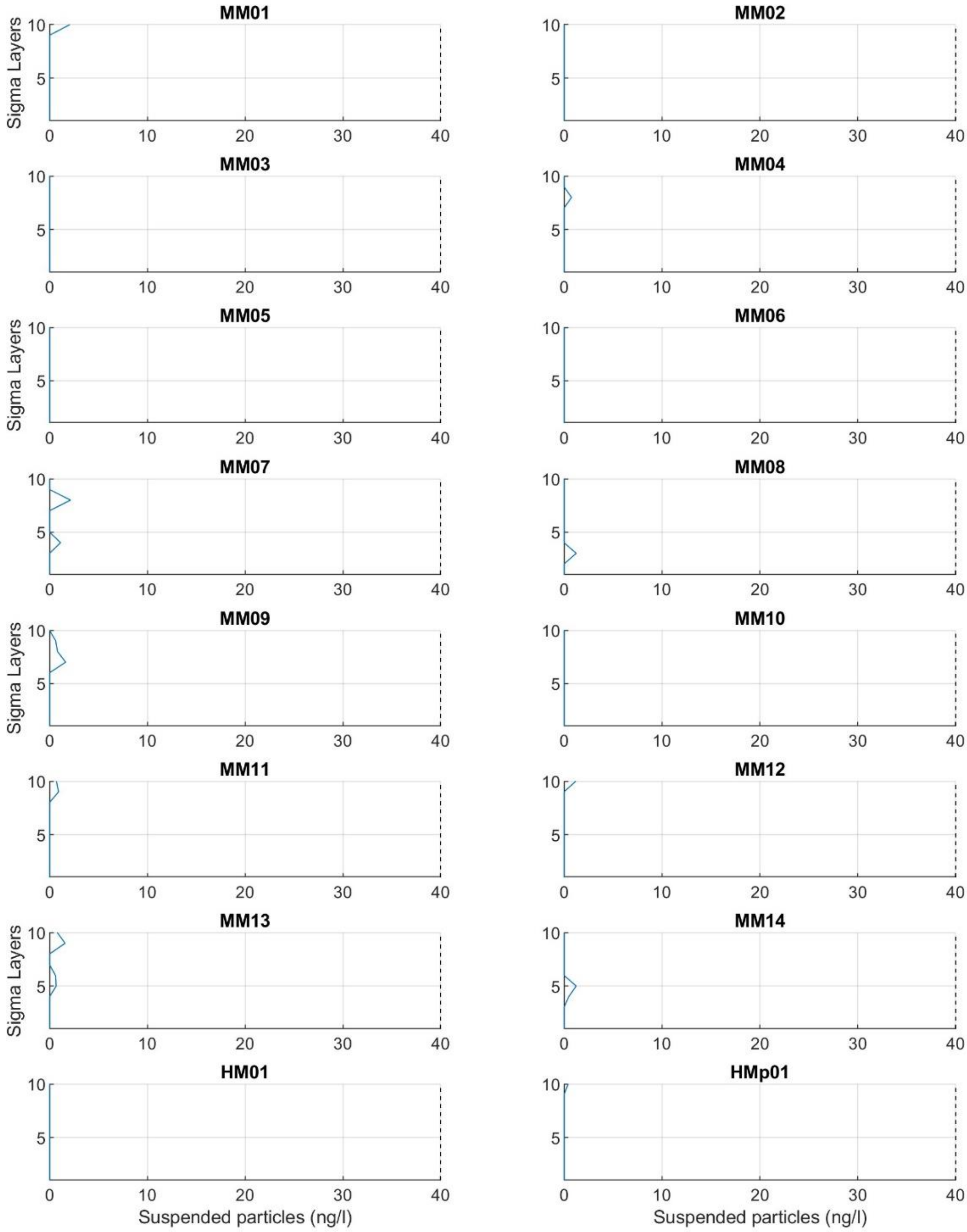

Figure B-4. Neap tide vertical concentration profile of Azamethiphos after the single treatment at the 72hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Azamethiphos is shown relative to the sensitive feature locations in figure B-5. Several time steps are shown ranging from 3 to 72hrs, red contour lines are shown for treatment concentrations of 100 ng/l. Treatments are shown to be widely and quickly distributed with no accumulations. Interactions with sensitive features are uncommon and occur only with very diluted plumes. The largest concentration occurs between 3 and 6hrs after the final treatment at MM05, due to strong currents through the straight, these plumes are pulled away from the site and sensitive feature locations and distributed.

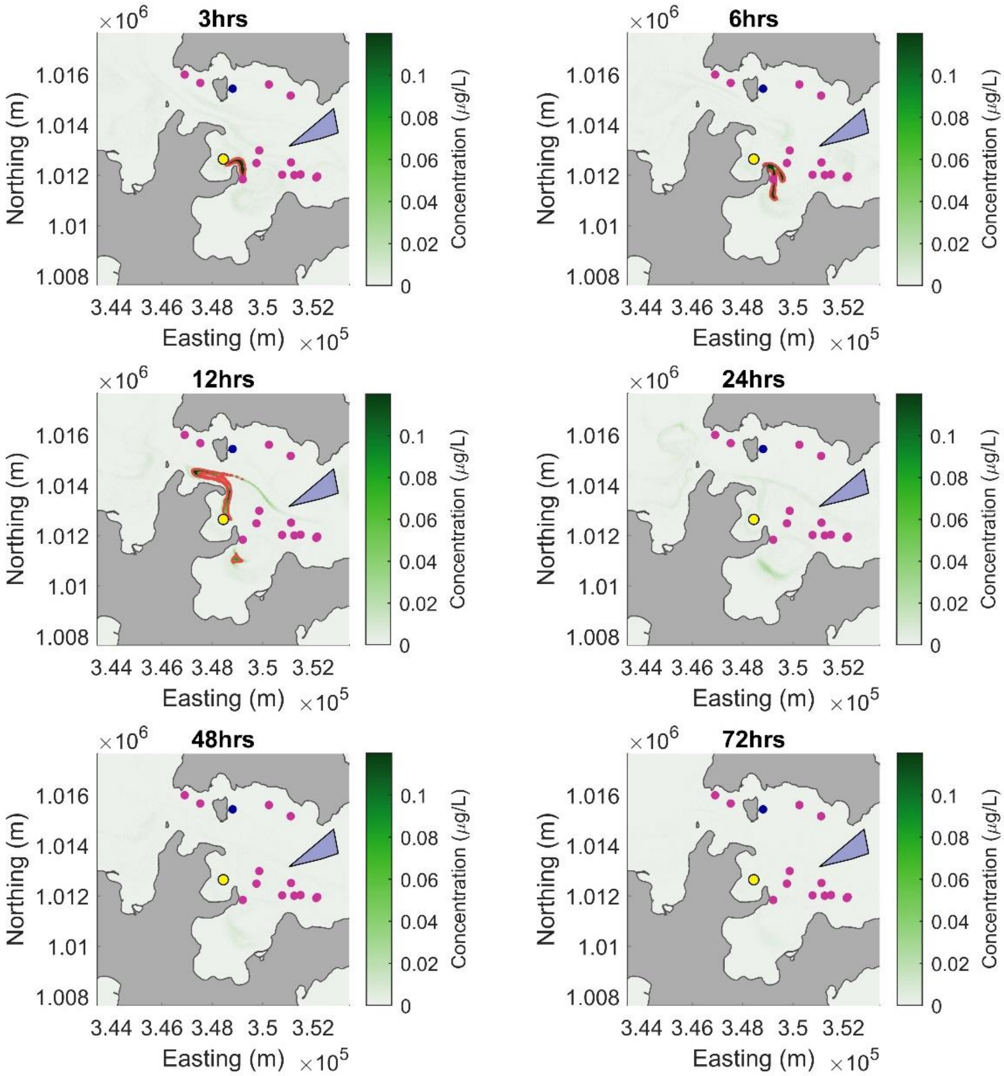

Figure B-5. Spatial Azamethiphos distribution for bath treatment releases during neap tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

Spring tides

3hr Consent Time

Short-term exposure during the spring tide is assessed using a single release of the 3hr treatment mass, 126.71g of Azamethiphos. Treatment concentration at sensitive features is identified in figure B-6. Weak plume concentrations are shown at MM05 around 7hrs after the final treatment.

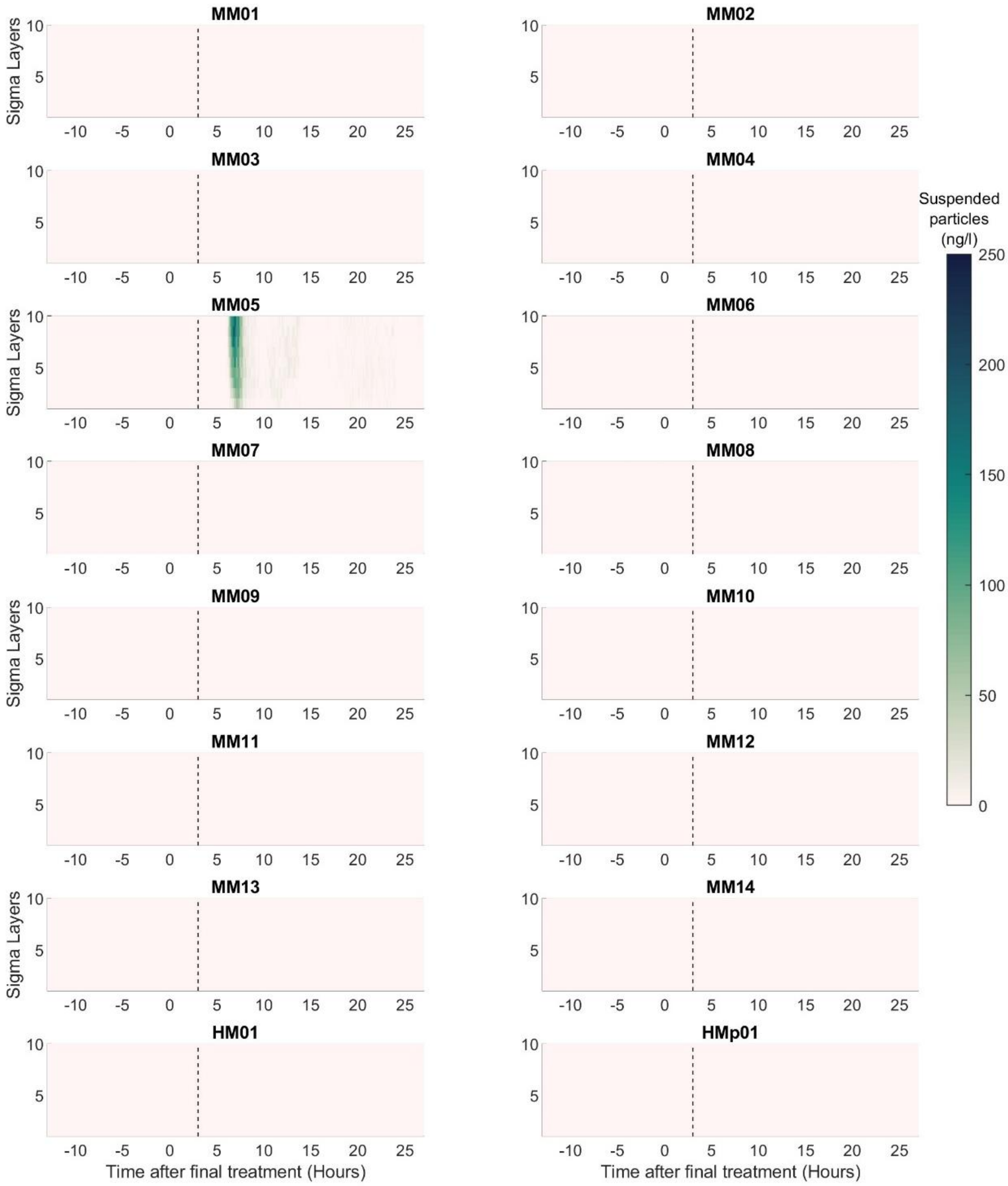

Figure B-6. Spring tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water *depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.*

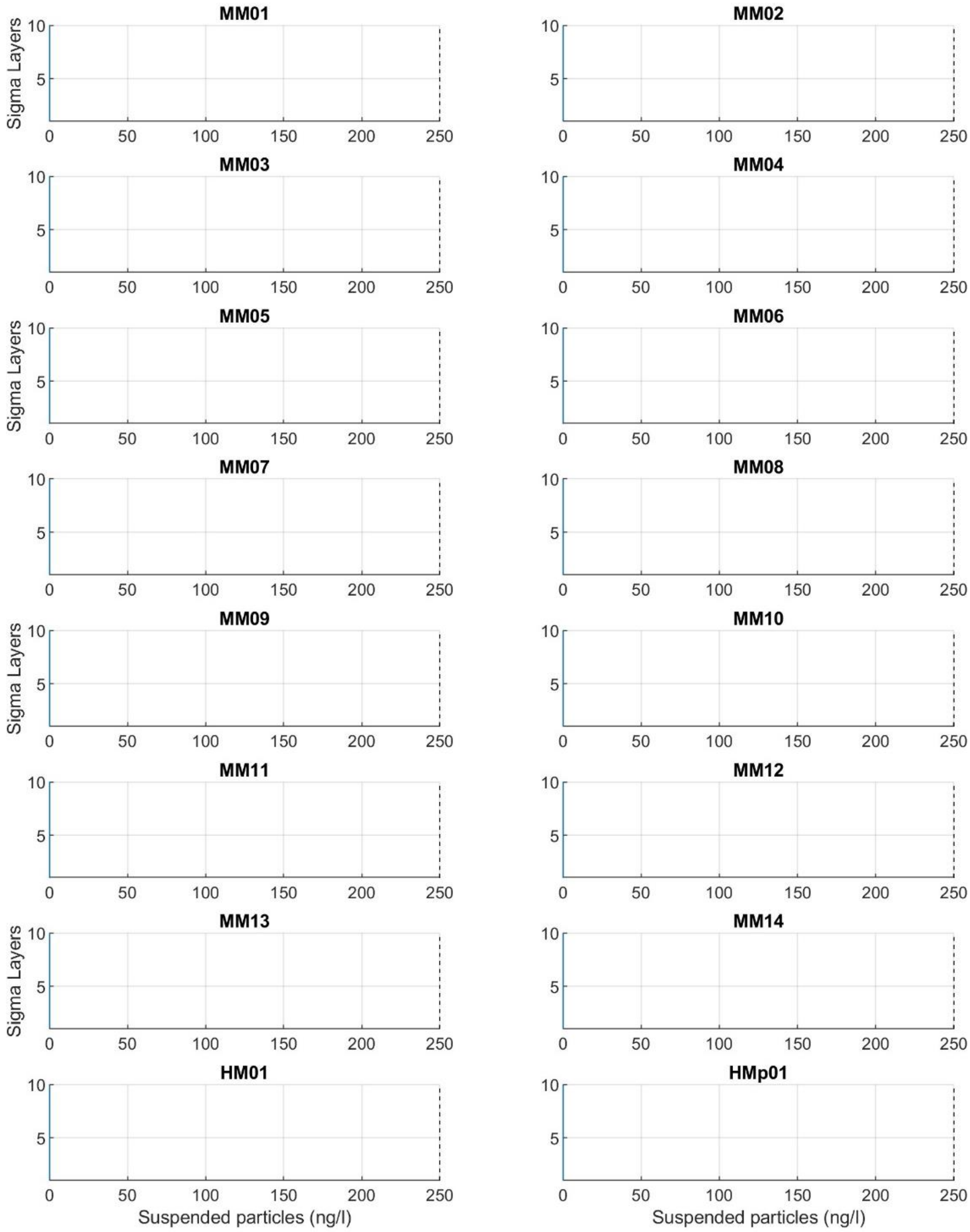

Figure B-7. Spring tide vertical concentration profile of Azamethiphos after the single treatment at the 3hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

72hr Consent Time

Longer term exposure during the spring tide is assessed using multiple treatments of 318.29g of Azamethiphos within a 24hr period. Treatment concentration at sensitive features is identified in figure B-8. The majority of sensitive features show no or very weak concentrations of treatments. Feature MM05 shows the highest concentration throughout the treatment process that quickly dissipates after the final treatment. By the 72hr EQS time period, concentration levels at all features show no or only trace levels of any treatment.

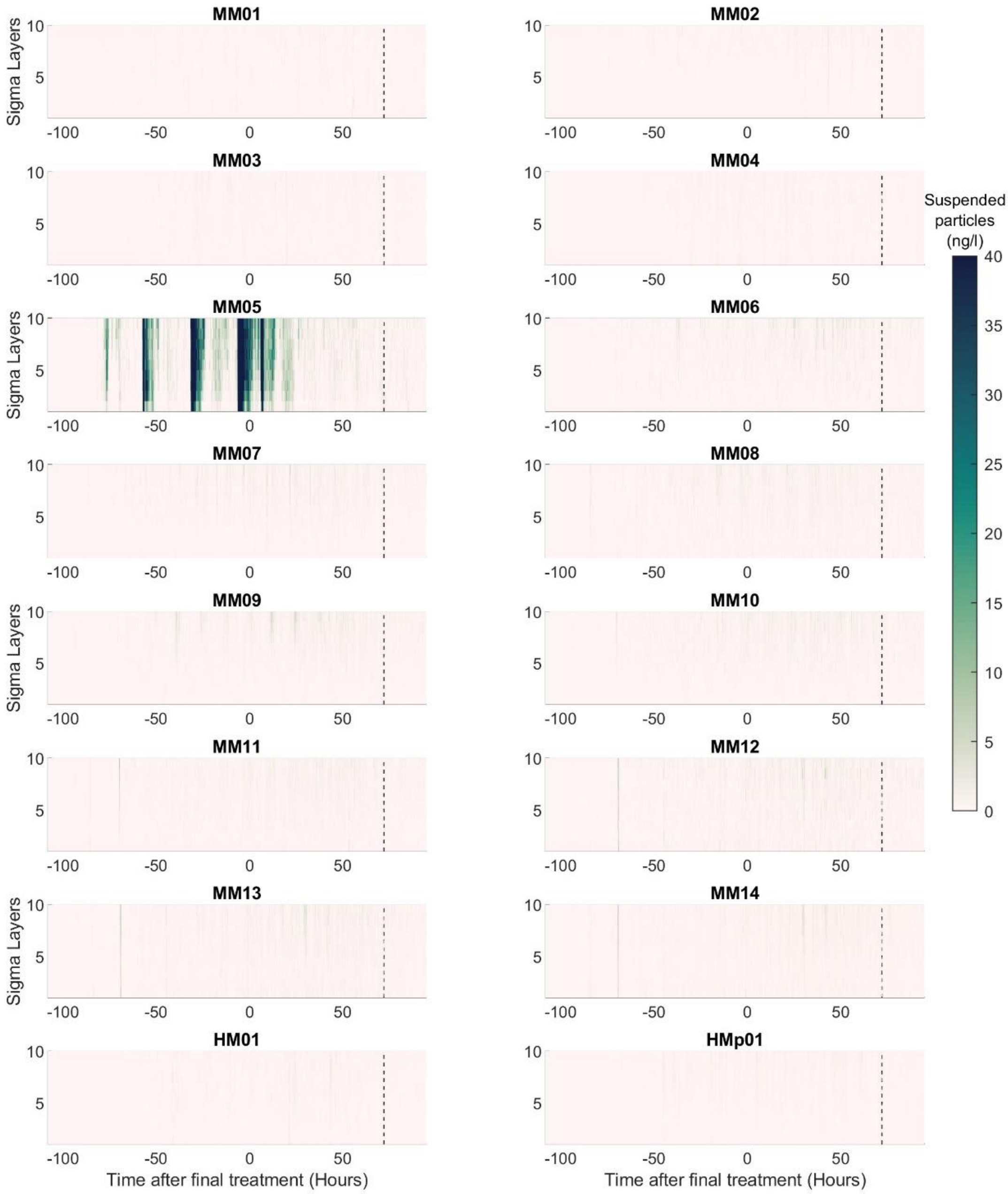

Figure B-8. Spring tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar. Water *depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment.*

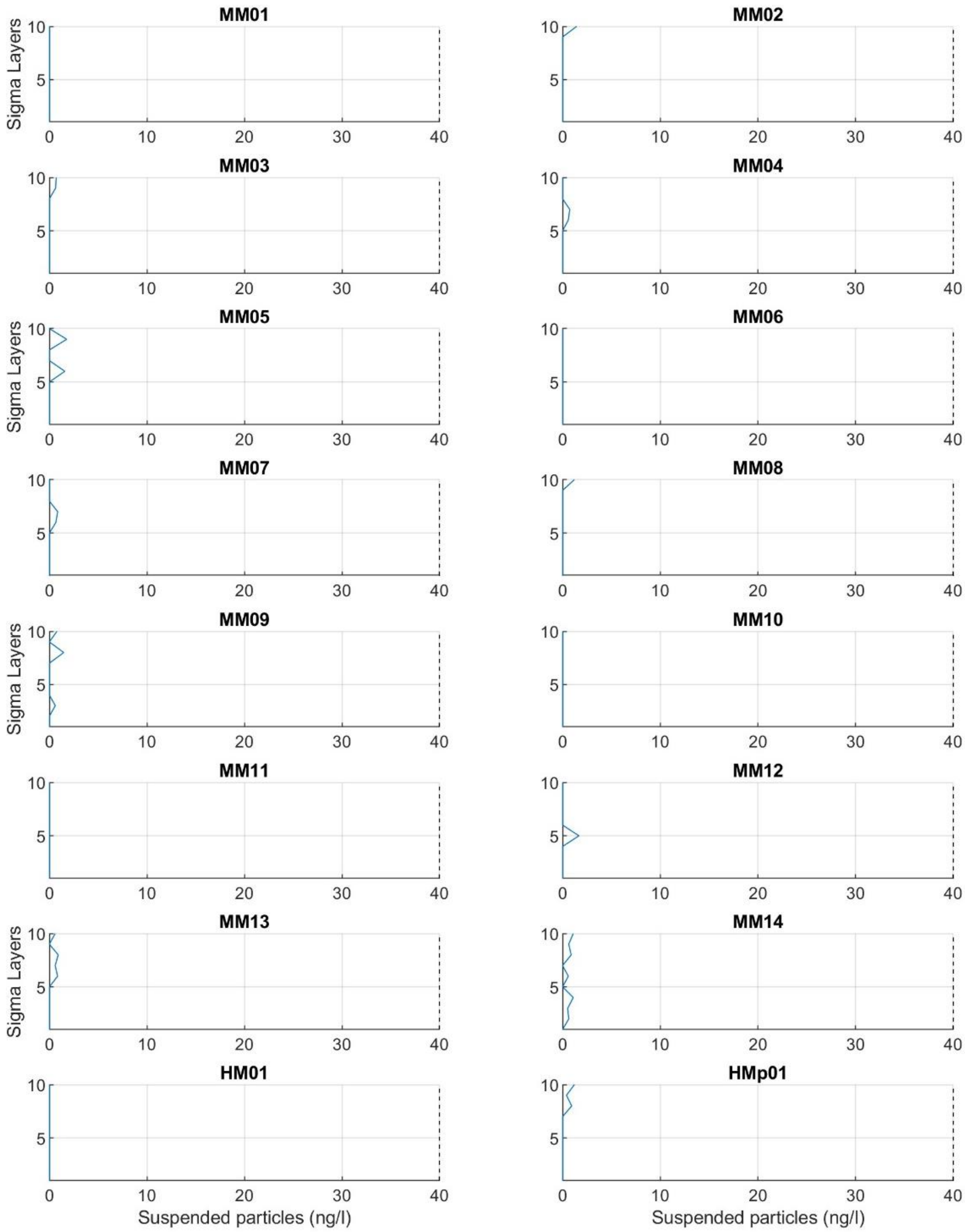

Figure B-9. Spring tide vertical concentration profile of Azamethiphos after the single treatment at the 72hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Azamethiphos during spring tides is shown relative to the sensitive feature locations in figure B-10. Several time steps are shown ranging from 3 to

72hrs, red contour lines are shown for treatment concentrations of 100 ng/l. Treatments are shown to be widely and quickly distributed with no accumulations. Interactions with sensitive features are uncommon and occur only with very diluted plumes.

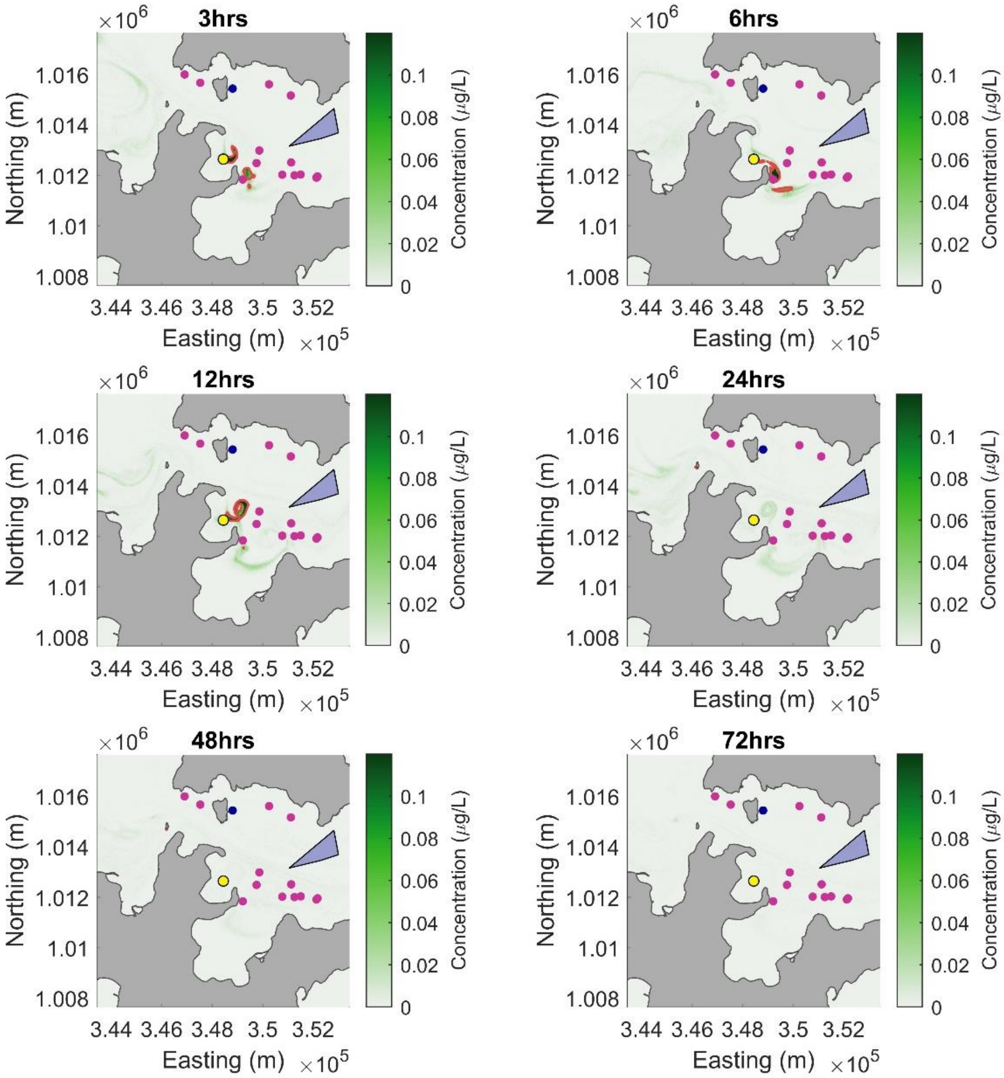

Figure B-10. Spatial Azamethiphos distribution for bath treatment releases during spring tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

C. Proposed Tarpaulin Treatment Interactions with Sensitive Marine Feature MM05

Modelling methods and results have been described for the simulation of bath treatments using tarps and wellboats. These have shown very similar performance with respect to EQS values but have not considered the wider changes in plume dispersion and interaction with sensitive features. As the majority of sensitive features have little or no interaction with plume dispersion, these are considered very low risk and are not considered when assessing the variation in treatment exposure with respect to treatment methods. However, for the closest proximity sensitive feature MM05, additional data is provided in this section to ensure treatment concentration is maintained at an acceptable level.

Wellboat and tarp treatments were simulated using 180g of Azamethiphos within a 3-hour period and 600g within a 24-hour period for both spring and neap tidal cycles. Particle sources and output methods are consistent with the models previously described.

C.1 Azamethiphos

Neap tides

3hr Consent Time

Treatment plumes for both wellboat and tarps are shown to occur at similar low quantities and duration. Two visible plumes occur, the first at 5-6hrs, followed by a second much weaker plume at 8-10hrs. Tarp-based treatment methods show similar intensity in plume strength.

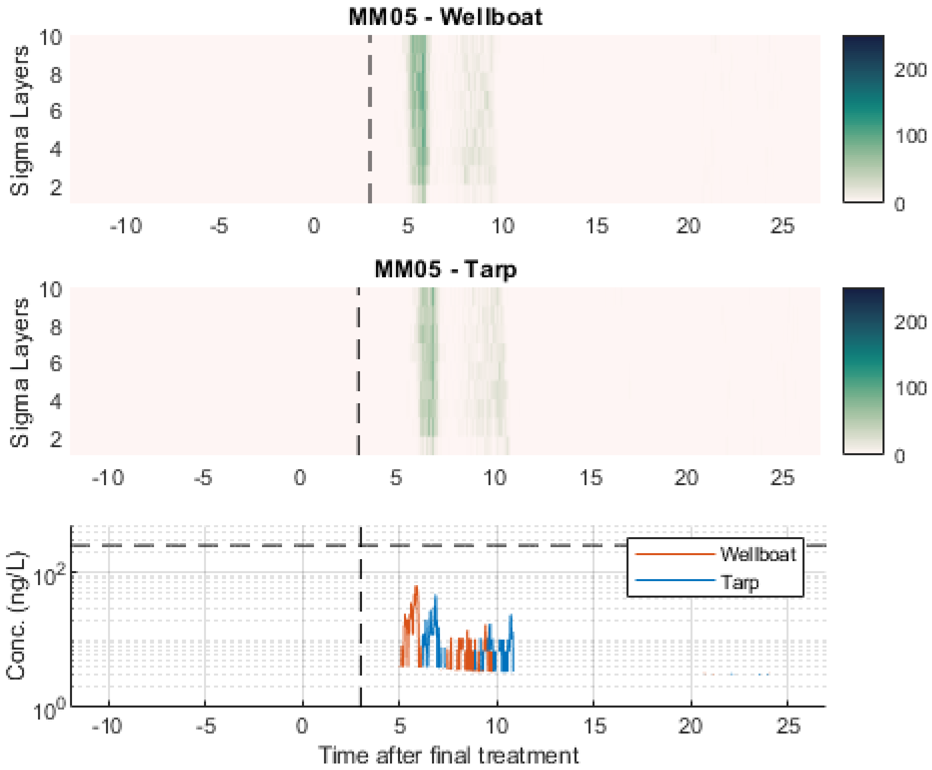

Figure C-1. Top/Middle: Neap tide Azamethiphos concentration in the water column at MM05. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment. Bottom: time series of Azamethiphos concentration at MM05 *for wellboat and tarp treatments. Dashed lines indicate EQS time (vertical) and concentration (horizontal).*

24hr Consent Time

The longer duration model treatment plan shows multiple peaks in plume concentration during the treatment process. Once the treatment plan has ended, plume concentration reduces rapidly. The comparison of the wellboat and tarp treatment plumes shows very similar values with very similar exposure duration. By the 72hr EQS time both treatment mechanisms have fully dispersed to very low levels.

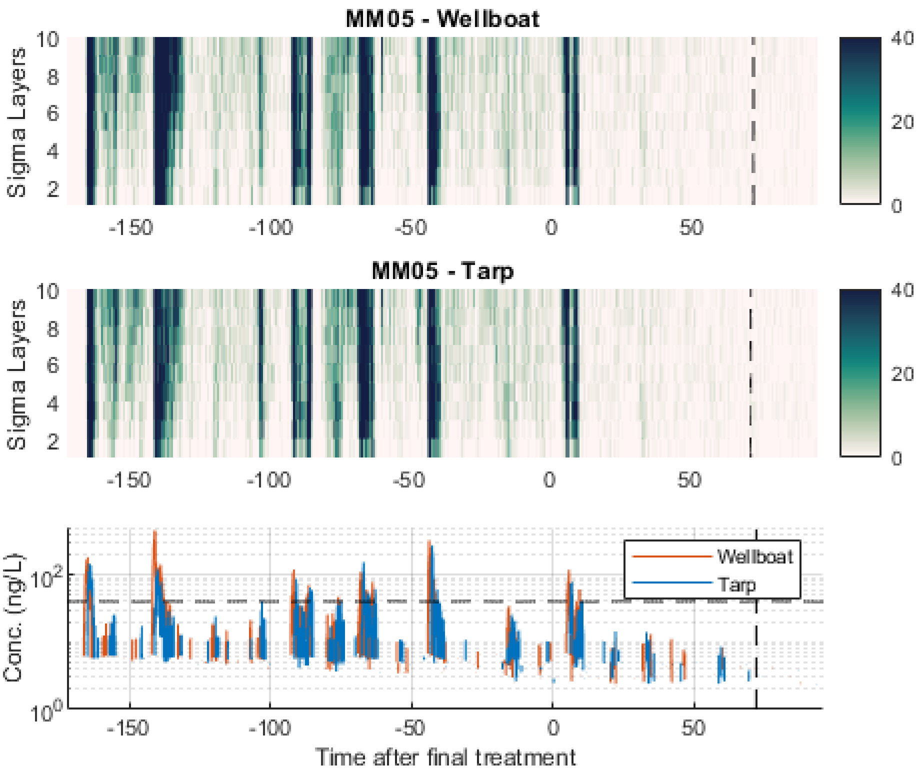

Figure C-2. Top/Middle: Neap tide Azamethiphos concentration in the water column at MM05. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment. Bottom: time series of Azamethiphos concentration at MM05 for wellboat and tarp treatments. Dashed lines indicate EQS time (vertical) and concentration (horizontal).

Spring tides

3hr Consent Time

Spring tides show increased dispersion where only very diluted plumes interact with MM05 after 20hrs. Both treatment options continue to have similar values.

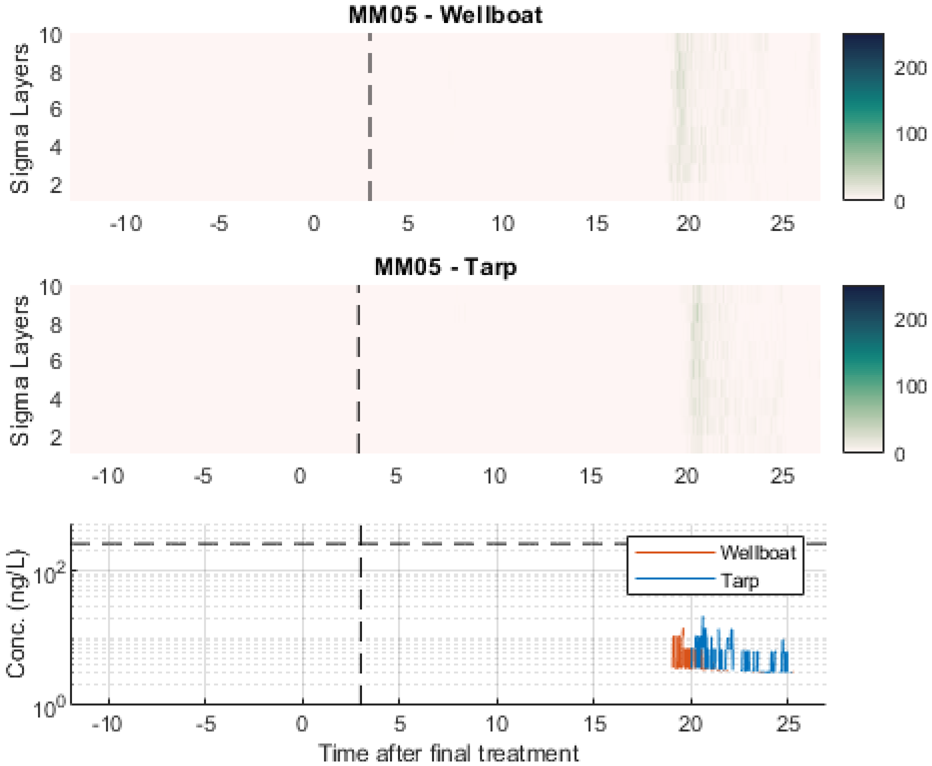

Figure C-3. Top/Middle: Spring tide Azamethiphos concentration in the water column at MM05. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment. Bottom: time series of Azamethiphos concentration at MM05 for wellboat and tarp treatments. Dashed lines indicate EQS time (vertical) and concentration (horizontal).

24hr Consent Time

Similar to the neap tides the comparison of the wellboat and tarp treatments shows very little difference throughout the plume dispersion.

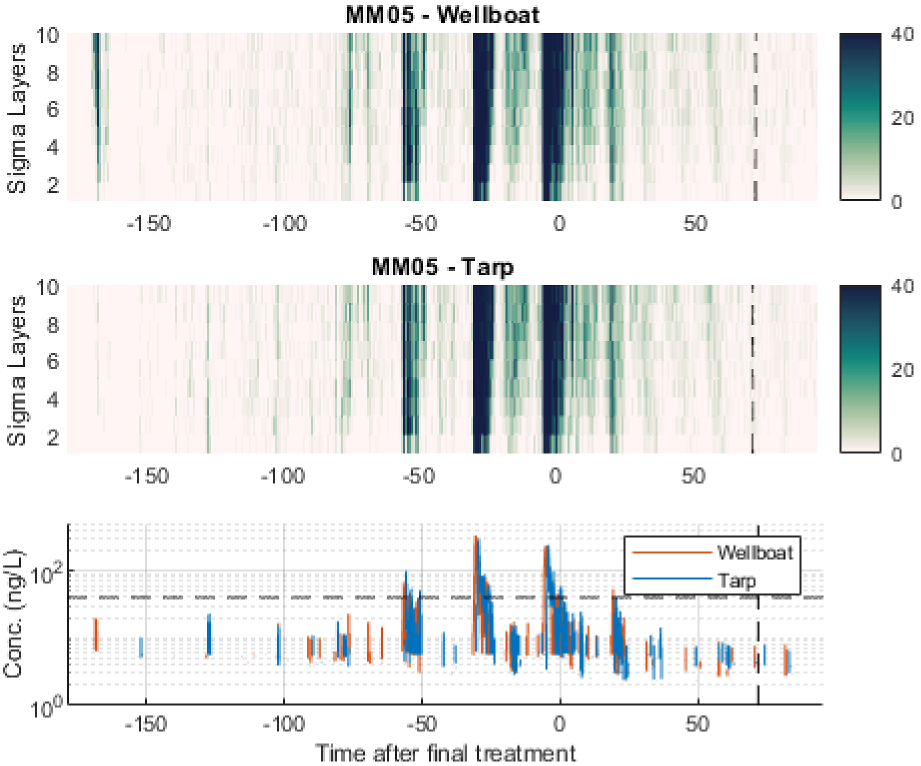

Figure C-4. Top/Middle: Spring tide Azamethiphos concentration in the water column at MM05. Concentration in ng/l is shown in the colour bar. Water depth is defined in model sigma layers where 1 is the bed cell and 10 is the surface cell and time is shown in hours from the last/single treatment. Bottom: time series of Azamethiphos concentration at MM05 for wellboat and tarp treatments. Dashed lines indicate EQS time (vertical) and concentration (horizontal).

C.2 Discussion

The treatment concentration at the remote MM05 sensitive feature has been shown for different treatment options. Throughout the treatment cycle and during treatment dispersion, both options indicate very similar concentrations and interaction times. Therefore, it is very unlikely that treatments administered using a tarp-based method would result in any difference in adverse treatment exposure when compared to a wellboat equivilent.