23rd July 2024

Bath Modelling Report

Quanterness

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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 Quanterness site. A well boat-based treatment method was applied, using realistic multiple treatment schedules. For Azamethiphos, this simulated a single 3hr treatment mass and 14 treatments with a 3-hour treatment interval and a maximum of 3 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)	1,950
Pen Layout	
No. pens	14
layout	2 x 7
Circumference (m)	120
Orientation (°)	0
Bath Treatments	
Azamethiphos	
Consent mass – 3hr	430g
Consent mass – 24hr	575g

Cypermethrin	
Consent mass – 6hr (Adjusted)	0.112g
Deltamethrin	
Consent mass – 6hr	40g

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

Quanterness is considered a new potential site and would replace the existing West Shargun Shaol (Wide Firth) site (CAR/L/1001931) operated by Cooke Aquaculture Scotland. The site is located off the northeast coastline of the Orkney mainland, within the Bay of Kirkwall, in Wide Firth. The existing site consists of a single group of 8 circular, 90m circumference pens with a net depth of 8m. These are arranged in a 2 x 4 layout with a 50 m separation, housing a maximum consented biomass of 600T at a maximum stocking density of 14.54kg/m^3. The site is aligned with a bearing of ~8^o. The licensed site is centred on 343220.24E, 1013947.6N.

The proposed development relocates the site ~1.1km towards the northwest with a site centre location of 342733E, 1014921N. The infrastructure consists of 14 circular, 120m circumference pens in a 2 x 7 layout (see figure 1). The proposed site will house a maximum consented biomass of 1925T, providing a maximum stocking density of 14.99kg/m^3. Further information on the existing and proposed site infrastructure and pen layout is presented in Table 2.

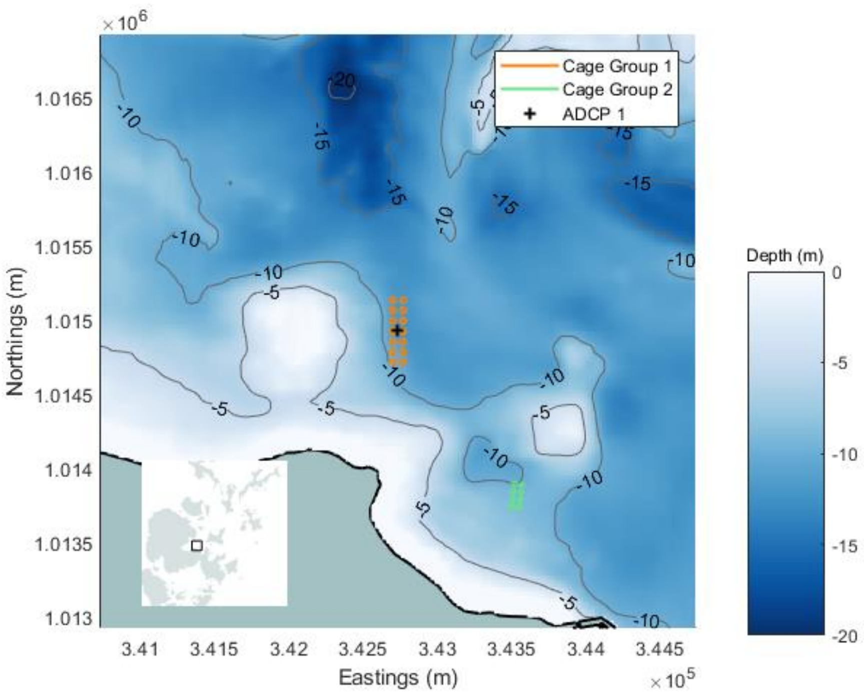

Figure 1. Existing (green) and proposed (orange) Quanterness site infrastructure, ADCP deployment location ('+') and bathymetry.

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

	West Shargun Shaol (Wide Firth)	Quanterness (Proposed)
Consent number	CAR/L/1001931	CAR/L/1001931
Company	Cooke Aquaculture Scotland	Cooke Aquaculture Scotland
Receiving water	Bay of Kirkwall	Wide Firth
Site centre (OSGB36)	343220.24E, 1013947.6N	342733E, 1014921N
Current meter location (OSGB36)/year of deployment		342733E, 1014921N /2021
Distance to shore (km)	0.56	0.9
Average water depth (m)	13.46	15.18
Maximum biomass (t)	600	1925
Total number of pens	8	14
Number of pen groups	1	1
Formation	2 x 4	2 x 7
Pen group orientation (°)	8	0
Pen shape	Circular	Circular
Pen circumference (m)	90	120
Mooring grid (m)	50	70

1.2 Sensitive Marine Features

The waters around Wide Firth and 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 Wide Firth and Shapinsay Sound.

Name	Feature type	Location (OSGB)		Mesh resolution (m^2)
		East (m)	North (m)	
Maerl beds	Marine habitat - Area	Shapefile		10000 (100m) - 2000 (45m)
Maerl beds	Marine habitat - Points	349210 349756 349865 350250 351113 346907 347526 342842 343750	1011840 1012489 1012987 1015610 1015166 1015999 1015671 1016019 1016110	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)
Seagrass beds	Marine habitat – Points	339455 339200 335800 336529	1013313 1018200 1014300 1013628	8000 (89m)
Bay of Firth (Pacific Oysters)	Shellfish water protected area (SWPA) - Area	Shapefile		8000 (89m)
Bay of Firth (Pacific Oysters)	Shellfish water protected area (SWPA) - Points	338966	1015259	8000 (89m)

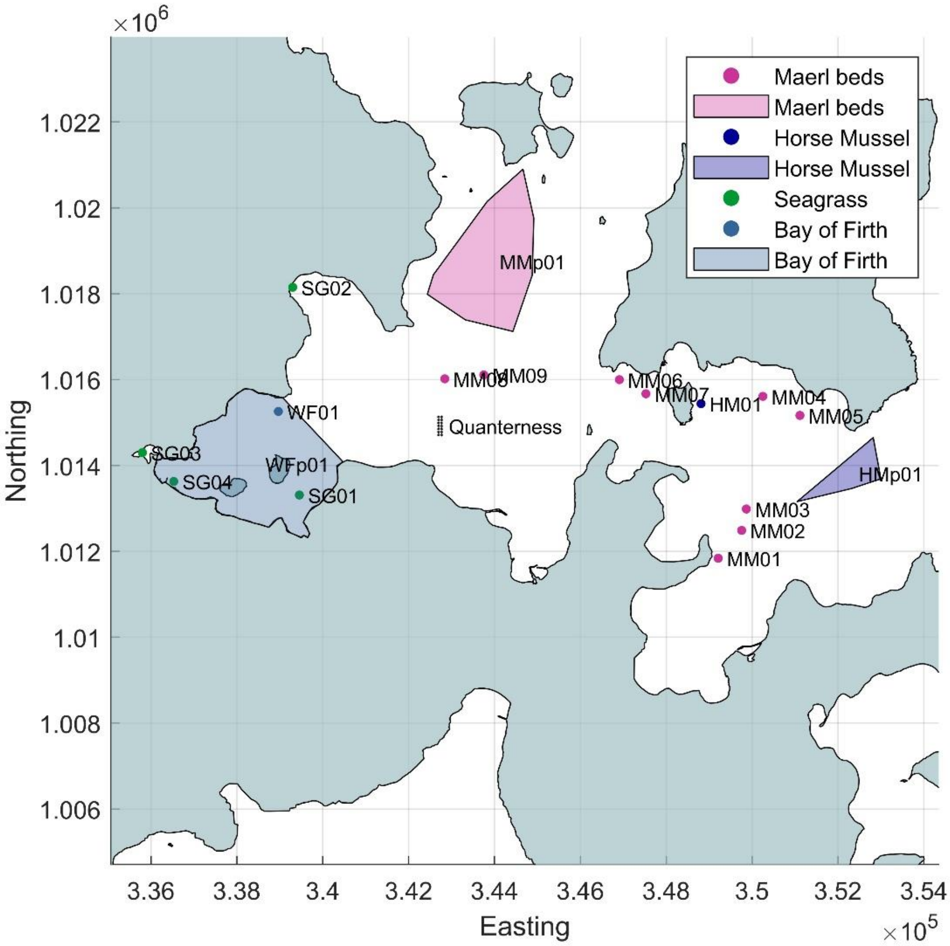

Figure 2. Farm location and sensitive marine features identified within Wide Firth and Shapinsay Sound.

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 2a). 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 2b). 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.

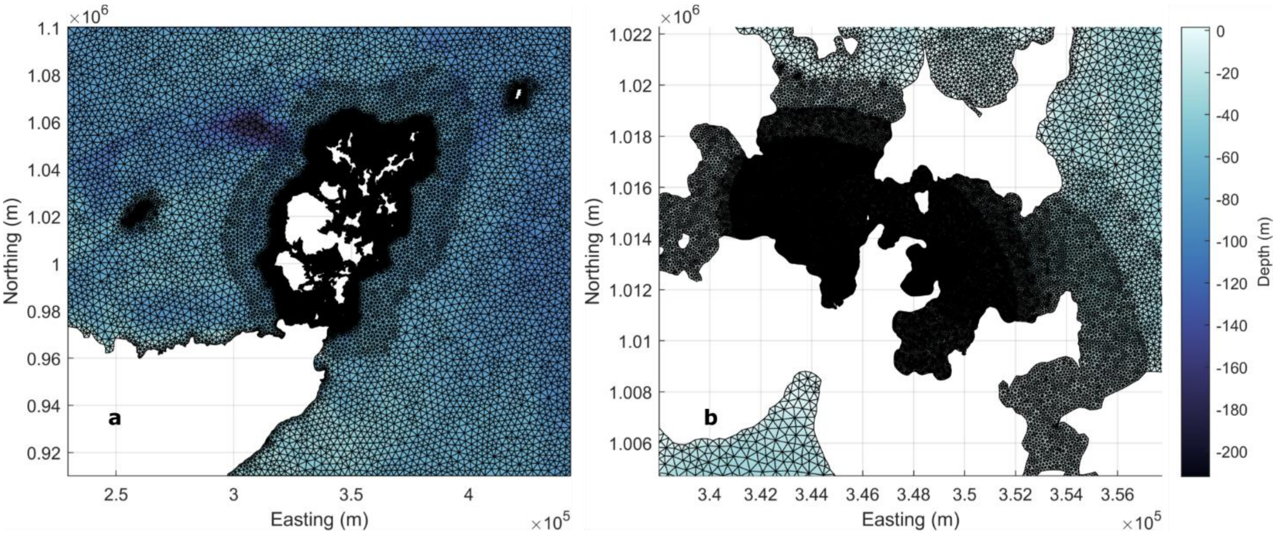

Figure 2. Hydrodynamic model mesh. a) wider computational mesh. b) Computational mesh around the proposed Meil Bay site.

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. A 3D domain is applied with 10 sigma layers in the vertical plane.

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 a layer thickness that extends from the surface to 5m beneath the surface.

2.2.3 Treatments

The maximum number of treatments is restricted to three 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.

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 16:40:00 during a neap tide and 25/07/2021 22:50:00 during a spring tide. Timings of each bath model run are shown in figures 3 and 4 and outlined in table 3.

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

	Simulation start date	Last treatment date	Simulation end date	Time after final treatment (hrs)
Azamethiphos (3hrs)				
Neap	17/07/2021 16:50:00	18/07/2021 16:40:00	22/07/2021 18:40:00	98
Spring	24/07/2021 22:50:00	25/07/2021 22:50:00	30/07/2021 00:50:00	98
Azamethiphos (72hrs)				
Neap	14/07/2021 13:00:00	18/07/2021 15:40:00	22/07/2021 17:40:00	98

Spring	21/07/2021 19:00:00	25/07/2021 21:50:00	29/07/2021 23:50:00	98
Cypermethrin/Deltamethrin				
Neap	17/07/2021 16:40:00	18/07/2021 16:40:00	20/07/2021 00:40:00	32
Spring	24/07/2021 22:50:00	25/07/2021 22:50:00	27/07/2021 06:50:00	32

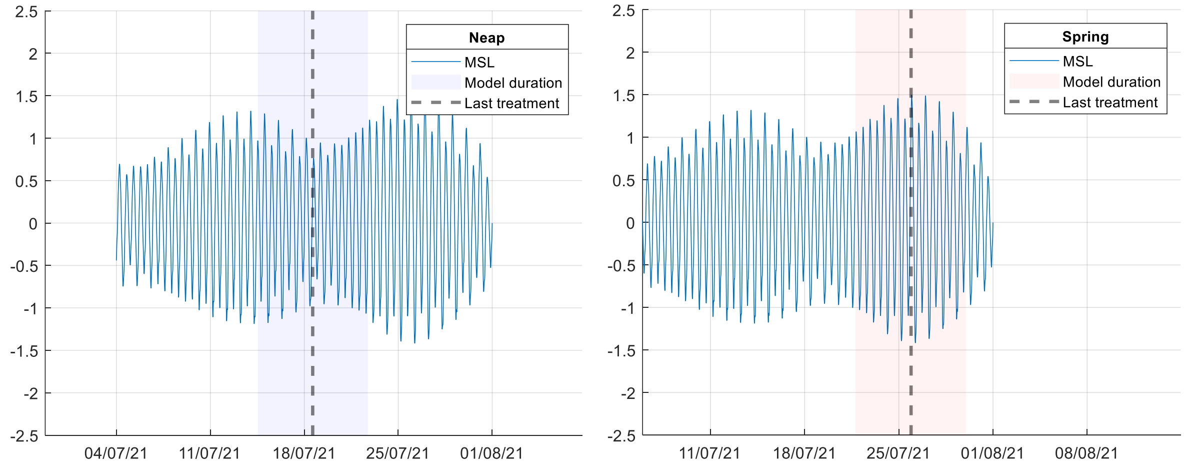

Figure 3. Mean sea level for Neap (left) and Spring (right) tides indicating model simulation duration for Azamethiphos (72hrs) with the final treatment time indicated using the dashed line.

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.

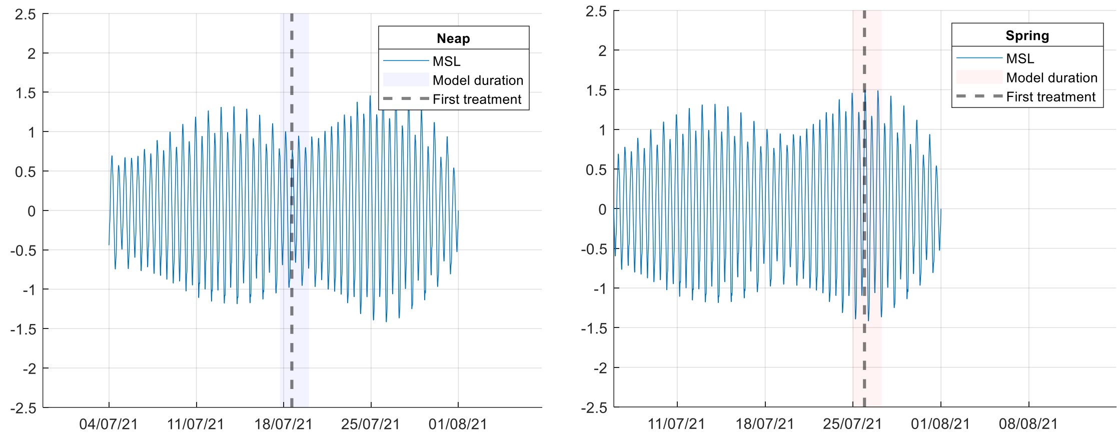

Figure 4. Mean sea level for Neap (a) and Spring (b) tides indicating model simulation duration for Cypermethrin and Deltamethrin with the initial treatment time indicated with the dashed line.

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 wellboat treatment process, particle releases will be timed to coincide with expected treatment intervals. A treatment plan consisting of three 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.

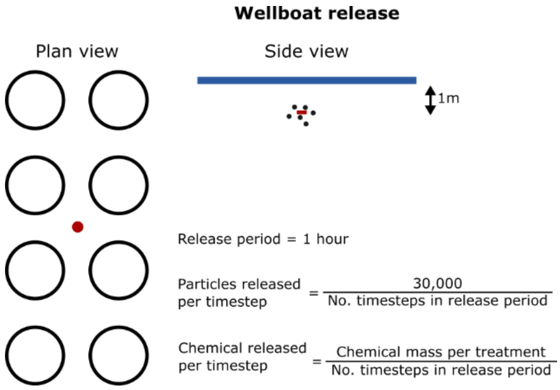

Figure 5. Wellboat release schematic. Open black circles represent pen locations, particle source location is shown in red, the blue line represents the sea surface and small black dots represent particles.

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 wellboat release MAC and area EQS for all treatments at Meil Bay.

	Treatment Quantity (g)	**MAC 72 hrs (µg/l)**	**EQS 3hrs - Single Treatment (km²)**	**EQS 6hrs (km²)**	**EQS 72hrs (km²)**
Azamethiphos (3hrs)					
Neap	430	-	0.093 (43.5%)	-	-
Spring	430	-	0.165 (77.4%)	-	-
Azamethiphos (24hrs)					
Neap	191.7	0.069 (68.7%)	-	-	0.030 (6.00%)
Spring	191.7	0.064 (63.9%)	-	-	0.022 (4.31%)

Cypermethrin					
Neap	30	-	-	0.136 (22.6%)	-
Spring	30	-	-	0.145 (24.0%)	-
Deltamethrin					
Neap	40	-	-	0.207 (34.3%)	-
Spring	40	-	-	0.214 (35.5%)	-

3.1.1 Azamethiphos

Compliance was achieved at the proposed Meil Bay site using 430g of Azamethiphos within a 3-hour period or 575g within a 24-hour. This equated to 108.33g per pen assuming three wellboat treatments per day with a 3-hour interval. This corresponds to a treatable volume of 1080.5 m^3 per 3 hours.

3.1.1.1 Neap tides

3hr Consent Limit
To assess the short-term compliance for Azamethiphos, a single wellboat release of a 3-hour mass (430g) 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 6. The size of the chemical plume after a single treatment always remains less than the calculated mixing area of 0.21329km^2.

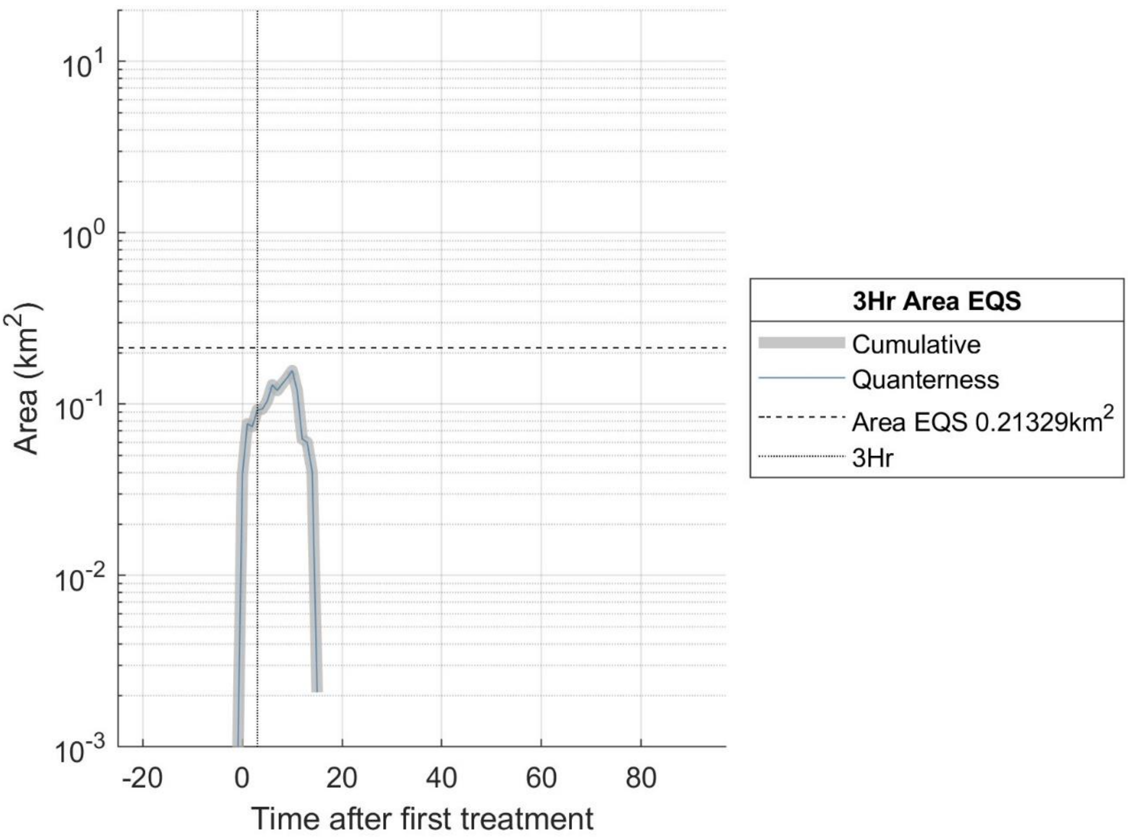

Figure 6. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after the initial 3-hour mass wellboat release of Azamethiphos during neap tides. The size of the 3-hour EQS mixing zone is shown by the horizontal dashed line. 3-hours after the initial treatment is marked by the vertical dotted line.

24hr Consent Limit

To determine the 24-hr treatment mass (575g), repeated treatments are considered using a realistic treatment pattern where compliance is assessed against the 72hr MAC and area EQS. This uses an individual treatment mass of 191.7g. The MAC for the neap tidal cycle is plotted in figure 7. 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 wellboat 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 Quanterness site is 0.069µg/l, this is 68.7% of the EQS value. Following this, the concentration increases slightly, peaking after 79 hours at 0.081µg/l, as the chemical is transported and concentrated within eddy systems. A general decline in concentration is observed over the remainder of the model run period.

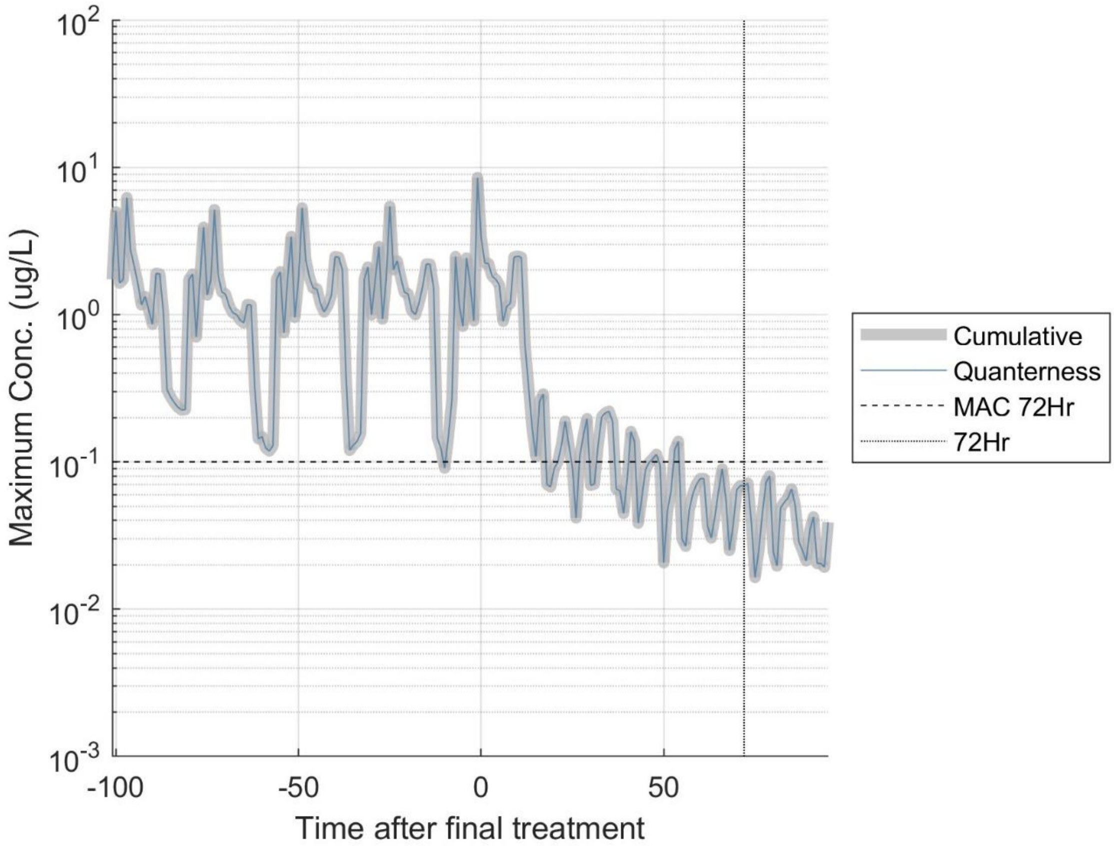

Figure 7. Maximum concentration of Azamethiphos during a neap tide wellboat treatment schedule. Cumulative impact plotted as solid grey line and MAC for the 72-hour EQS (100 ng/l) is indicated by the grey dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The area of the chemical plume exceeding 40ng/l (72-hour EQS) is plotted in figure 8. At the 72-hour EQS time, no concentrations exceed 40 ng/l. By this point, the plume is well dispersed and fragmented and decreasingly exceeds the 40ng/l threshold.

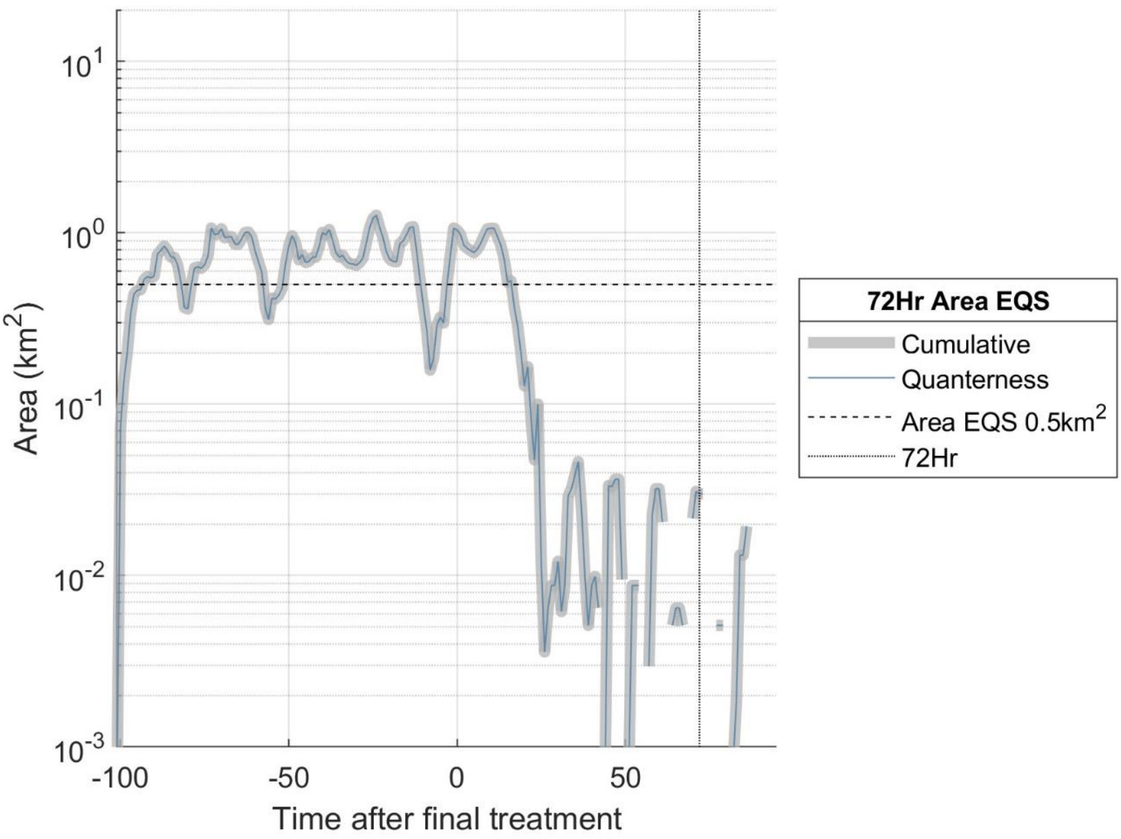

Figure 8. Chemical plume area exceeding the 72-hour (40 ng/l) EQS values after a wellboat treatment cycle using Azamethiphos during neap tides. The size of the 72-hour EQS mixing zone is shown by the horizontal dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The spatial distribution of Azamethiphos after the final release of bath treatment from the proposed site during neap tides is shown in figure 9. The areas where concentrations exceed the 72-hour EQS values are outlined in red. This indicates that the main plume is transported away from the site rapidly and dispersed within Wide Firth and flushed through the tidal straight to the east. Aft 24 hrs the bulk of the plume is dispersed and by 48hrs no chemical concentrations exceeding the EQS threshold are present.

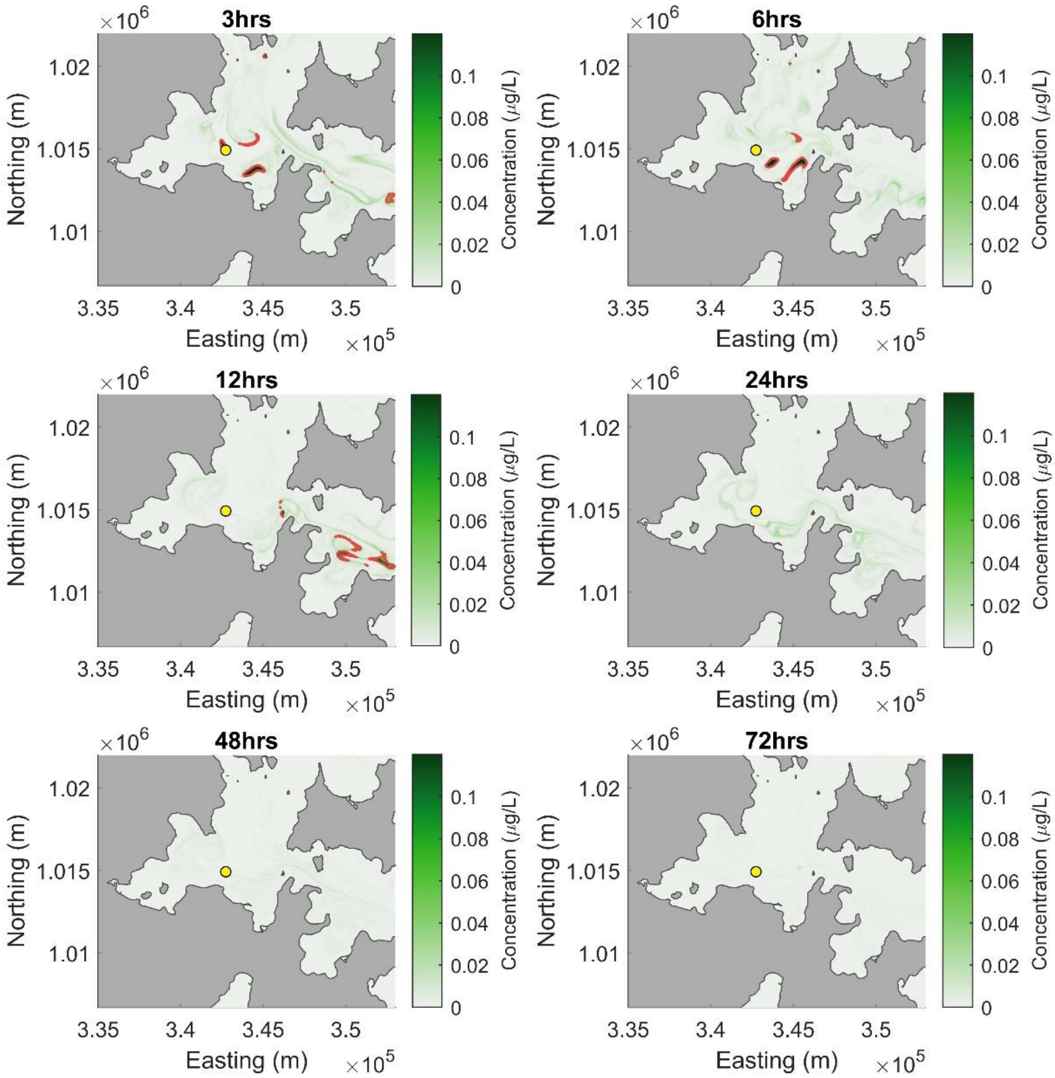

Figure 9. Spatial Azamethiphos distribution for wellboat releases during neap tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour and site location is identified using a yellow marker.

3.1.1.2 Spring tides

3hr Consent Limit

To assess the short-term compliance for Azamethiphos, a single wellboat release of a 3-hour mass (430g) 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 10. The size of the chemical plume after a single treatment always remains less than the calculated mixing area of 0.21329km^2.

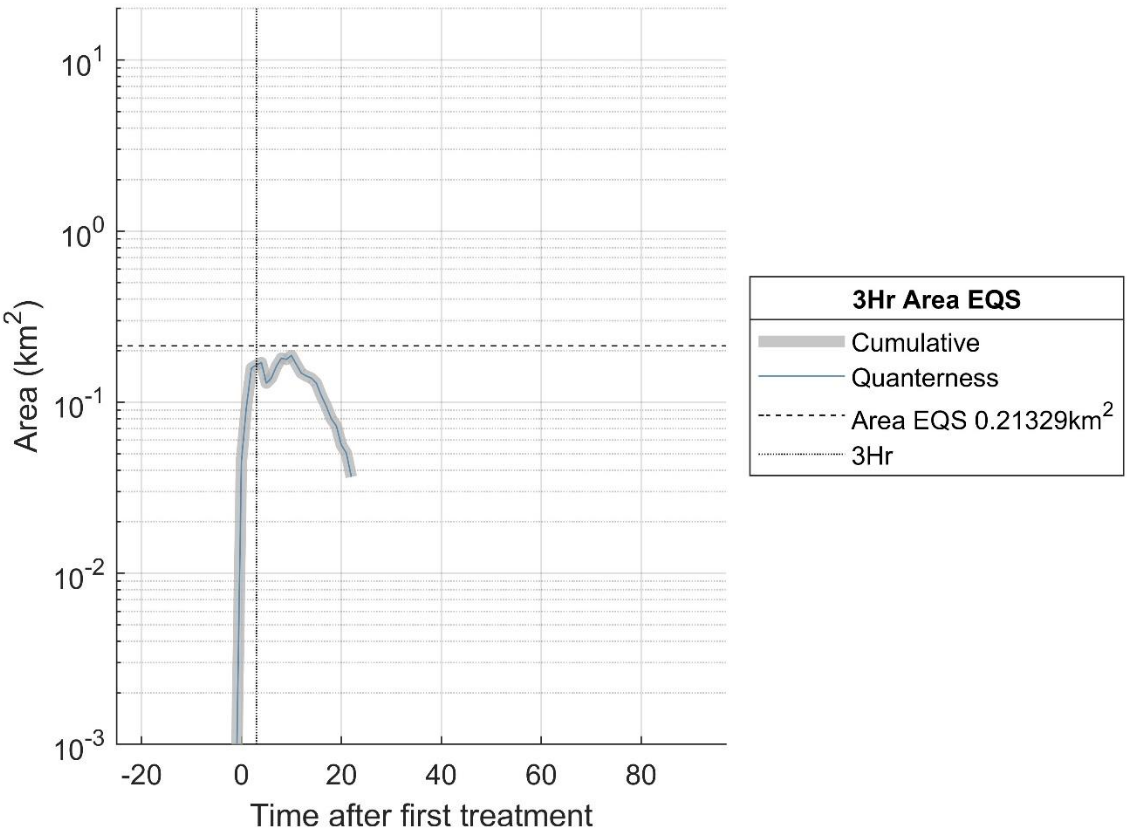

Figure 10. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after the initial 3-hour mass wellboat release of Azamethiphos during spring tides. The size of the 3-hour EQS mixing zone is shown by the horizontal dashed line. 3-hours after the initial treatment is marked by the vertical dotted line.

24hr Consent Limit

To determine the 24-hr treatment mass (575g), repeated treatments are considered using a realistic treatment pattern where compliance is assessed against the 72hr MAC and area EQS. This uses an individual treatment mass of 191.7g. The MAC for the neap tidal cycle is plotted in figure 11. 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 wellboat 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 Quanterness site is 0.064µg/l, this is 63.9% of the EQS value. Following this, the concentration increases slightly, peaking after 80 hours at 0.086µg/l, as the chemical is transported and concentrated within eddy systems. A general decline in concentration is observed over the remainder of the model run period.

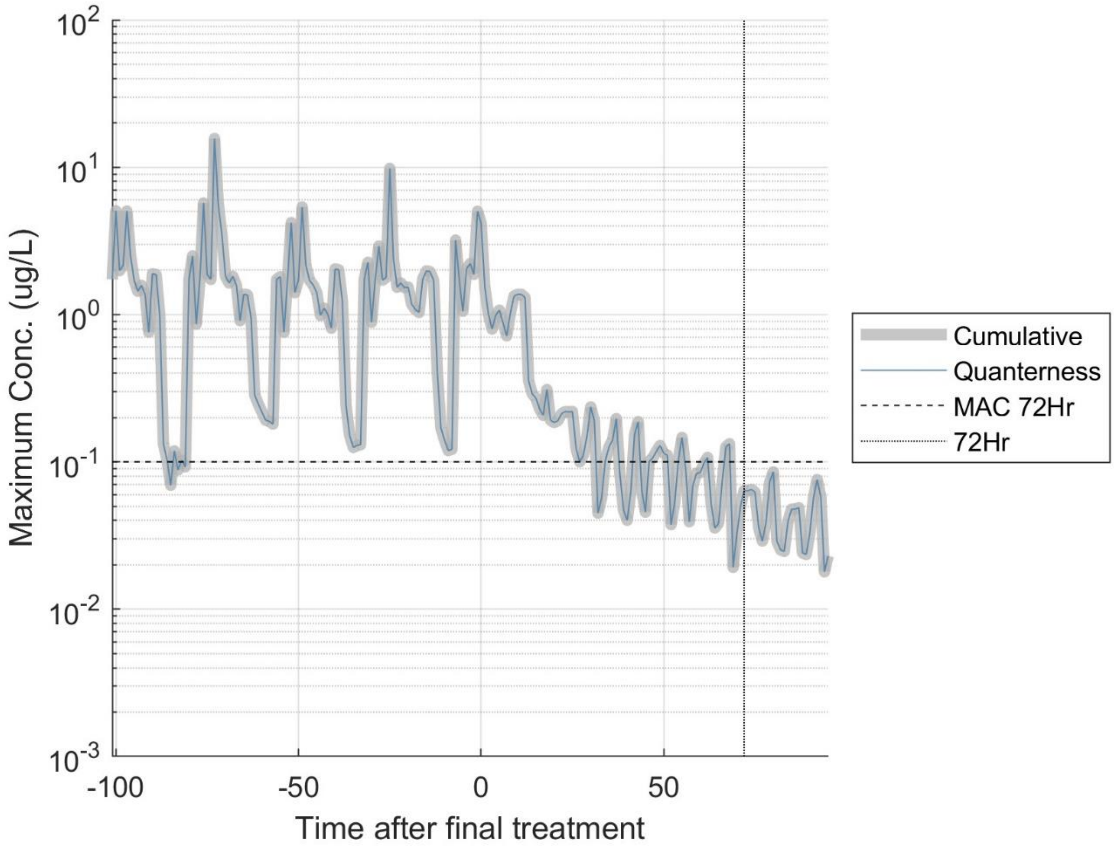

Figure 11. Maximum concentration of Azamethiphos during spring tide wellboat releases. Cumulative impact plotted as solid grey line and MAC for the 72-hour EQS (100 ng/l) is indicated by the grey dotted line. 72-hours after the final treatment is marked by the vertical dotted line.

The area of the chemical plume exceeding 40ng/l (72-hour EQS) is plotted in figure 12. At the 72-hour EQS time, no concentrations exceed 40 ng/l. By this point, the plume is well dispersed and fragmented and decreasingly exceeds the 40ng/l threshold.

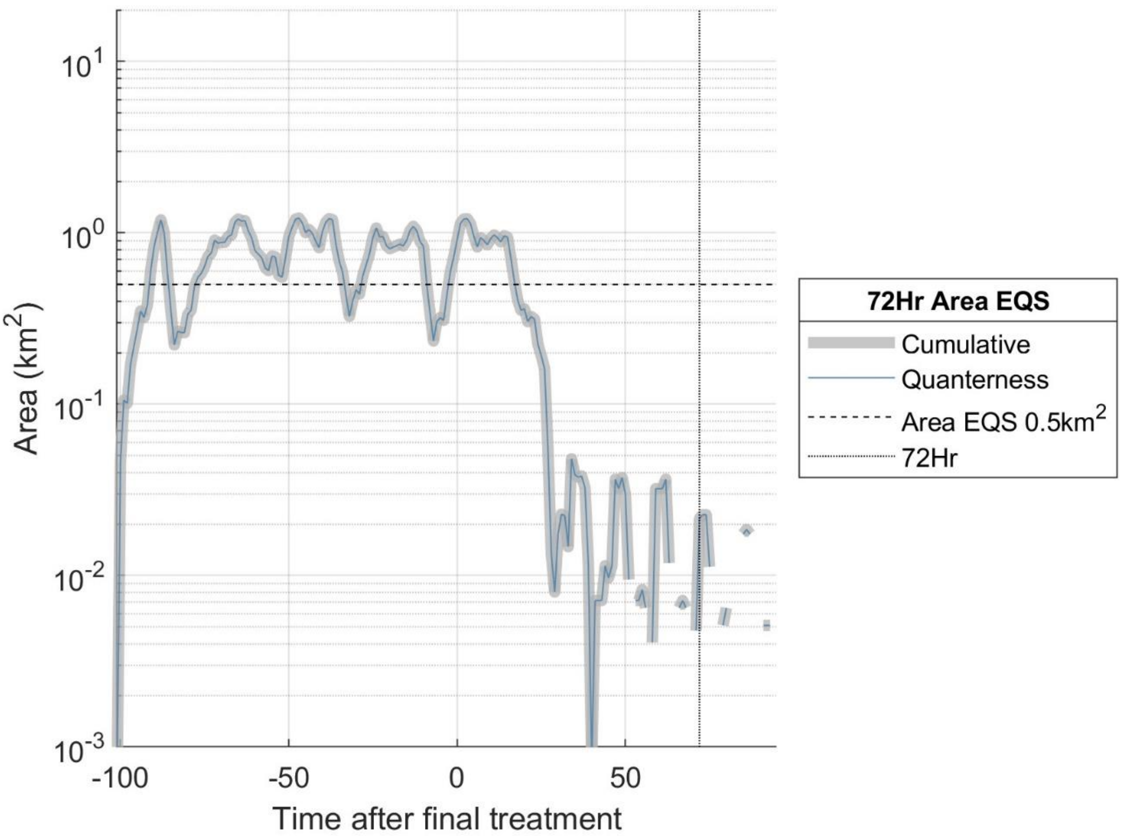

Figure 12. The chemical plume area exceeding the 72-hour (40 ng/l) EQS values after wellboat release of Azamethiphos during spring tides. The size of the 72-hour EQS mixing zone is shown by the horizontal dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The spatial distribution of Azamethiphos during spring tides is shown in figure 13. After 3hrs the final treatment plume and previous treatment plumes are visible in acceptable concentration and area in the surrounding waterbody. Treatment plumes are quickly dispersed and by 24hrs very small concentrations exceed the area based EQS threshold. Following a treatment release, the 3hr EQS shows a small, confined area coverage above the EQS threshold localized to the region close to the releasing farms. 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.

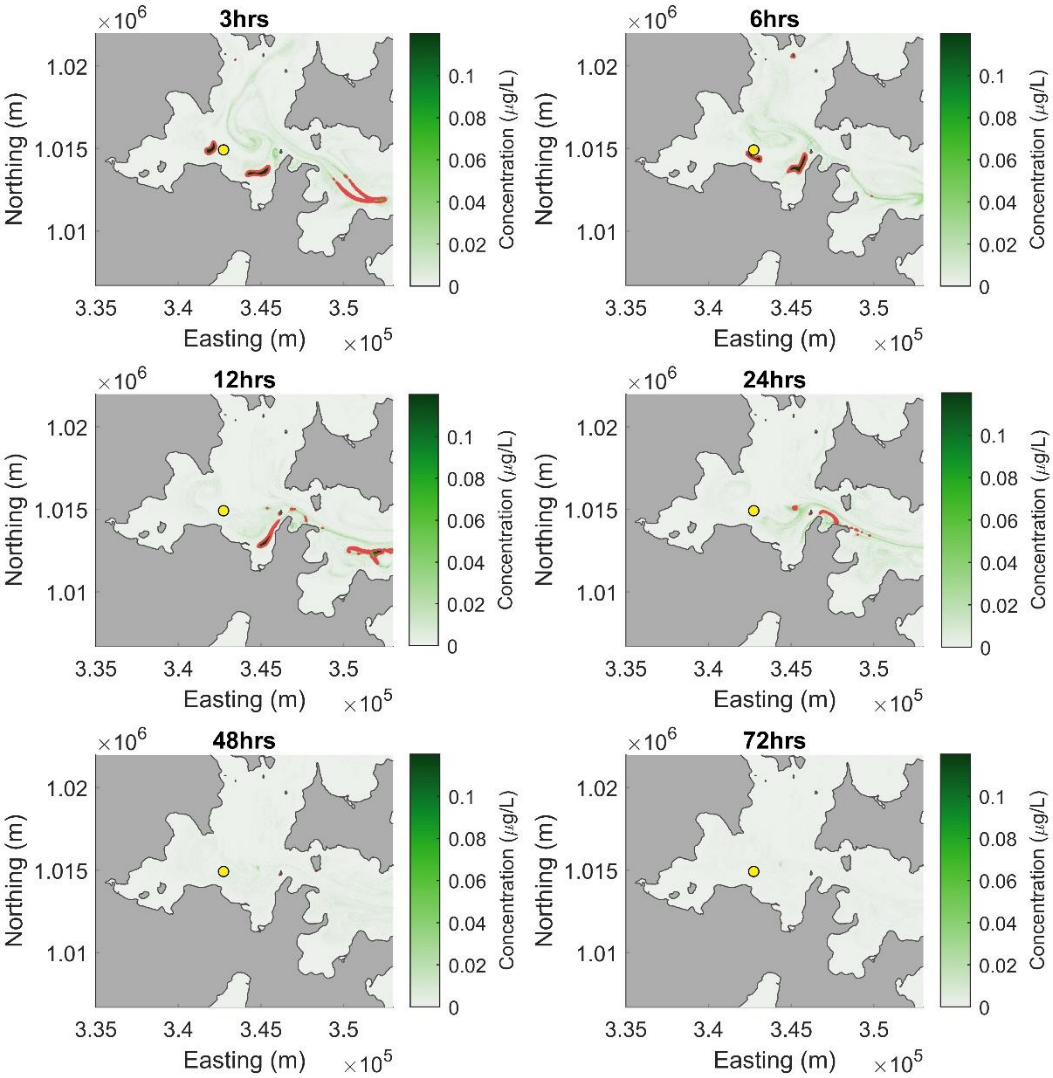

Figure 13. Spatial Azamethiphos distribution for wellboat releases during spring tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour and site location is identified using a yellow marker.

3.1.2 Cypermethrin

Environmental compliance was achieved at the proposed Quanterness site using 30g 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 0.112g. This provides a treatment volume of 22.48 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 14. 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 Quanterness after a 6-hour mass treatment release remains less than the calculated mixing area 0.60327km^2 throughout the model run.

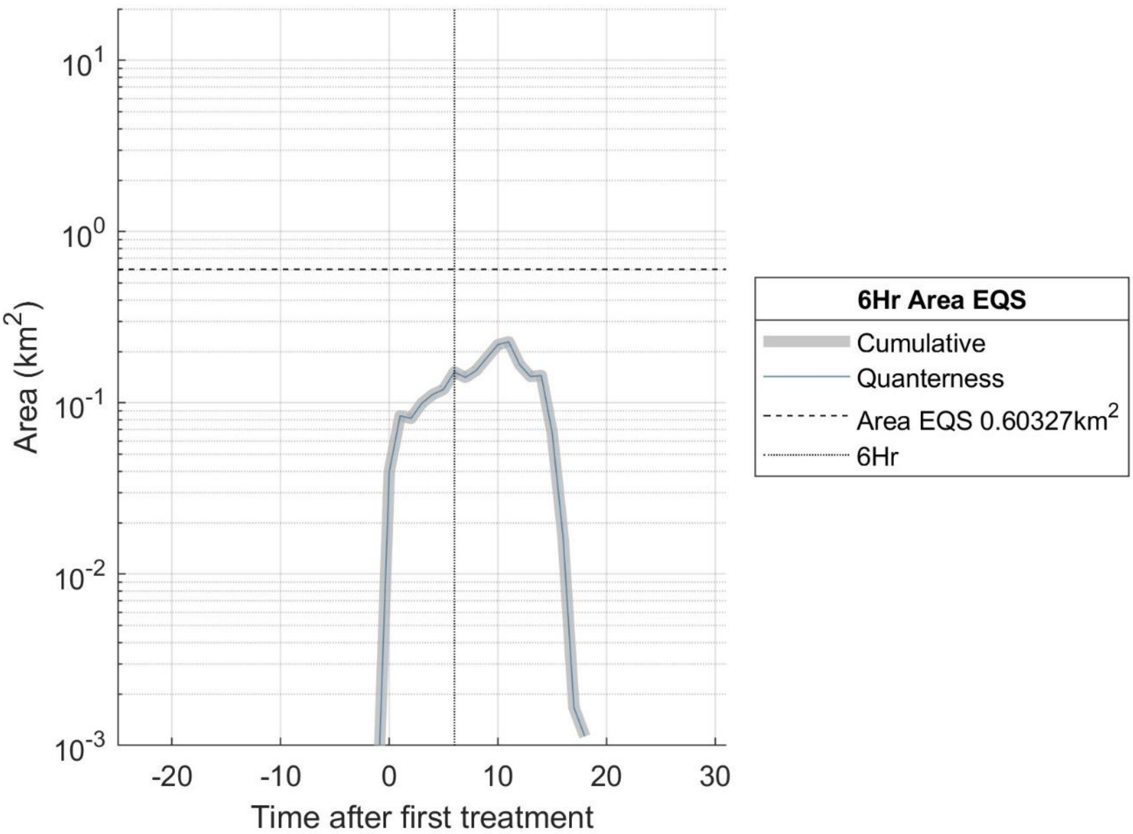

Figure 14. Chemical plume area exceeding the 6-hour (16 ng/l) EQS value after the initial 6-hour mass (30g) wellboat release of Cypermethrin during neap tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The spatial distribution of Cypermethrin 6 hours after the first simultaneous release of bath treatments from all sites during a neap tide is shown in figure 15. The areas where concentrations exceed the 6-hour EQS concentration are outlined in red. After 6-hours, the chemical plume appears elongated and is distributed towards the south.

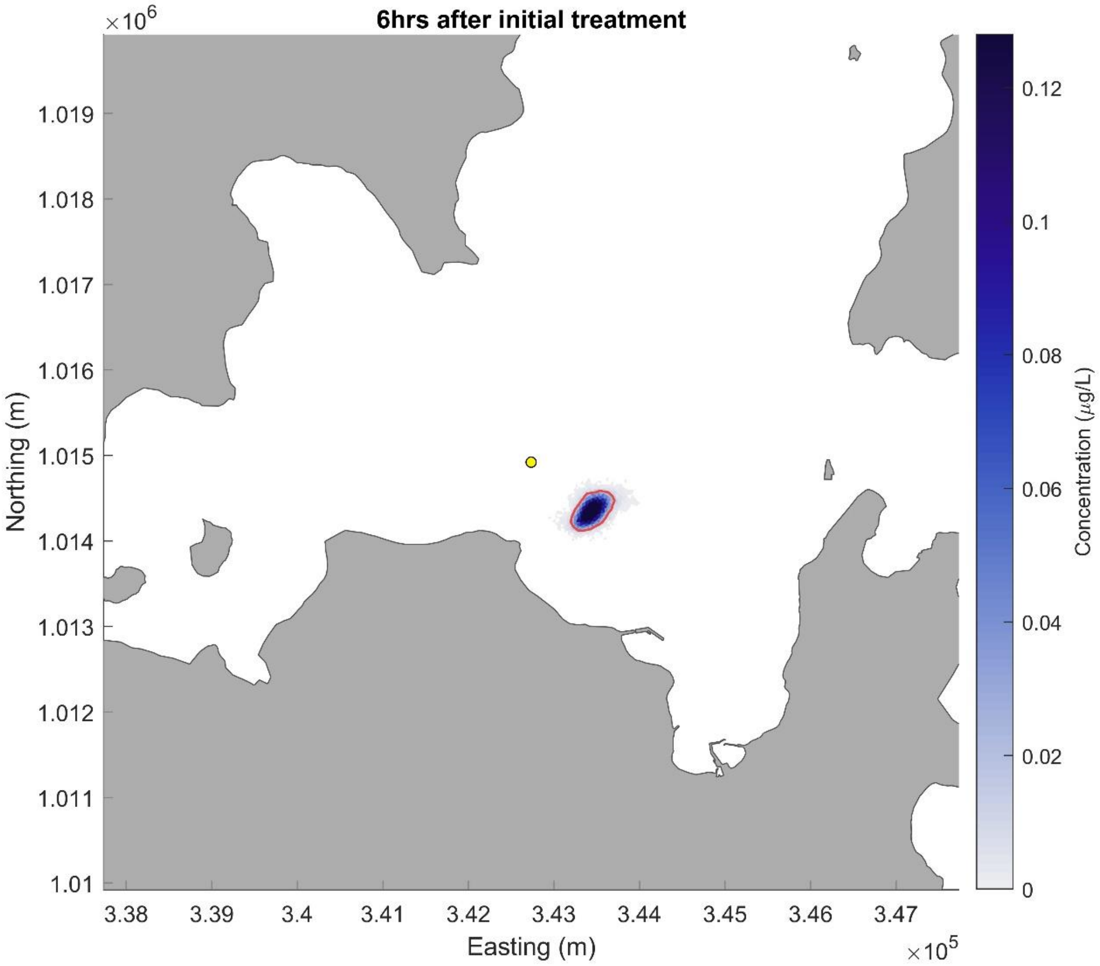

Figure 15. Spatial Cypermethrin distribution for a wellboat release during neap tides 6hr after the treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

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 16. 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 Quanterness peaks at 0.415km^2 21 hours after the first treatment release period.

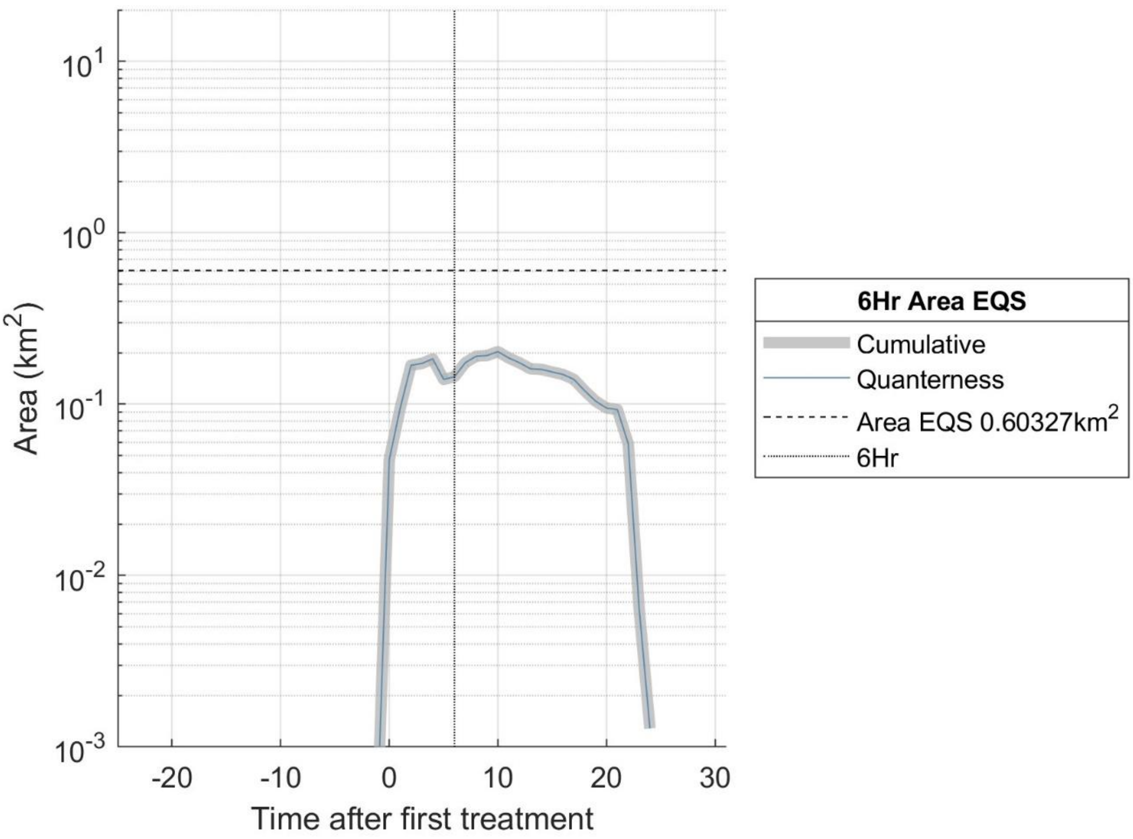

Figure 16. Chemical plume area exceeding the 6-hour (16 ng/l) EQS value after the initial 6-hour mass (30g) wellboat release of Cypermethrin during spring tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical 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 17. The areas where concentrations exceed the 6-hour EQS concentration are outlined in red. In comparison to the neap tide, the spring tide chemical plumes passes closer to the site centre and experiences a slightly higher concentration at the EQS time. After 20 hours the plume is fragmented and is rapidly dispersed.

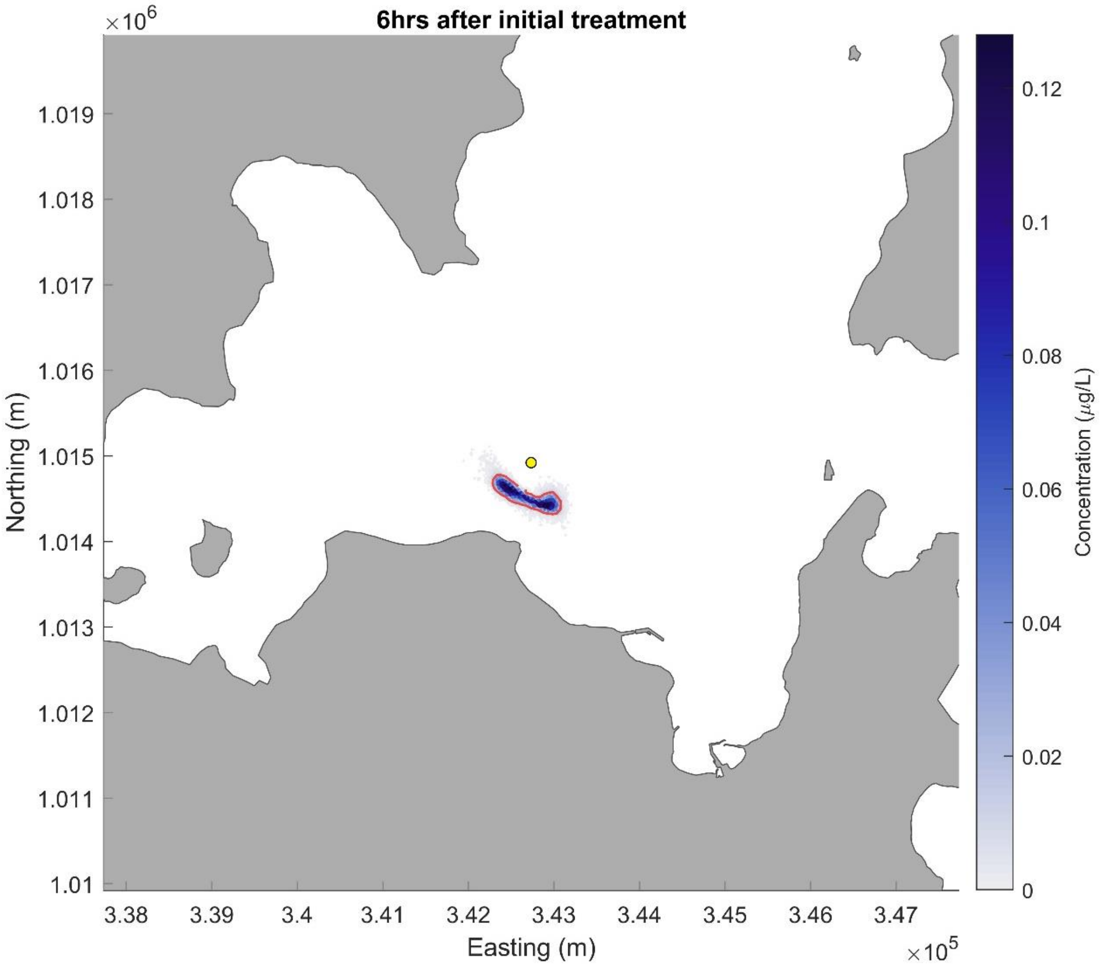

Figure 17. Spatial Cypermethrin distribution for wellboat releases during spring tides 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

3.1.3 Deltamethrin

Compliance was achieved at the proposed Quanterness site using 40 g of Deltamethrin in a treatment plan involving a single wellboat treatment. This provides a treatable volume of 20,000 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 16ng/l (6hr EQS threshold) is plotted in figure 18. 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 Quanterness after a 6-hour mass treatment release remains less than the calculated mixing area of 0.60327km^2 throughout the model run.

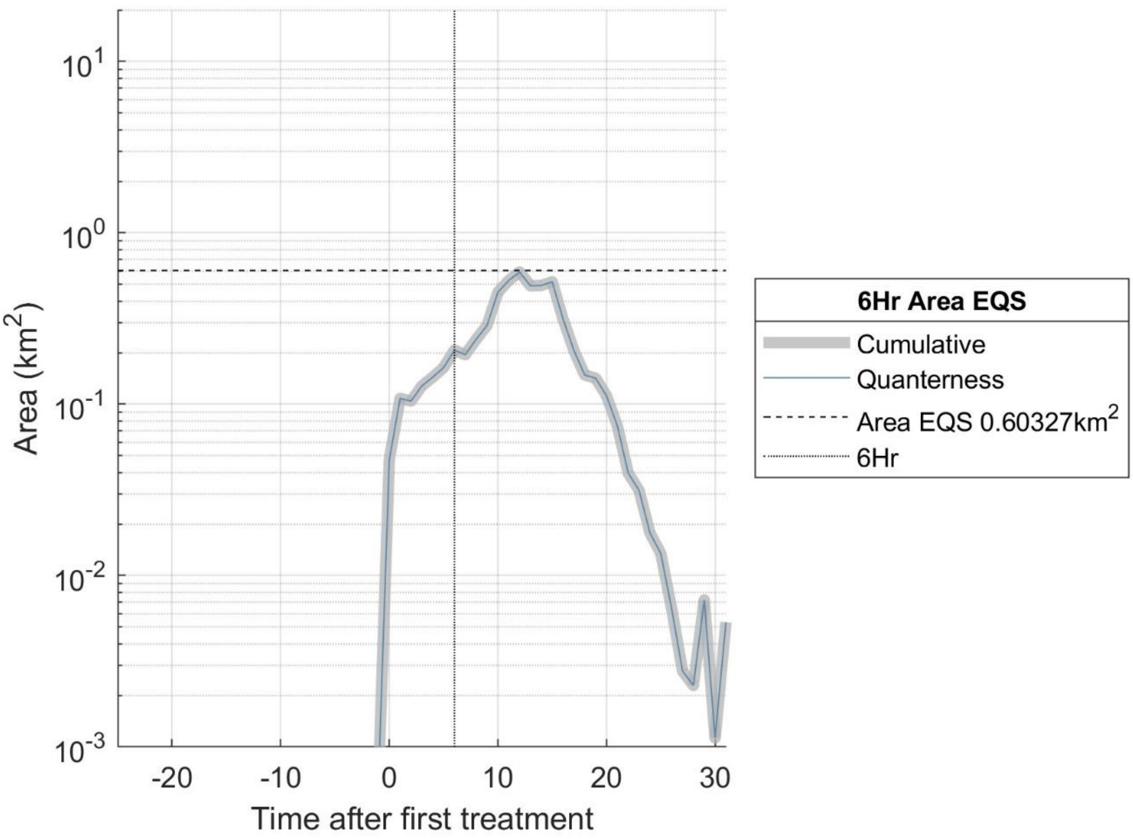

Figure 18. Chemical plume area exceeding the 6-hour (6 ng/l) EQS value after the initial 6-hour mass wellboat release of Deltamethrin during neap tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted 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 19. Regions with chemical concentration exceeding the EQS threshold are illustrated by the red contour. This shows at the 6hr EQS the plume remains close to the site.

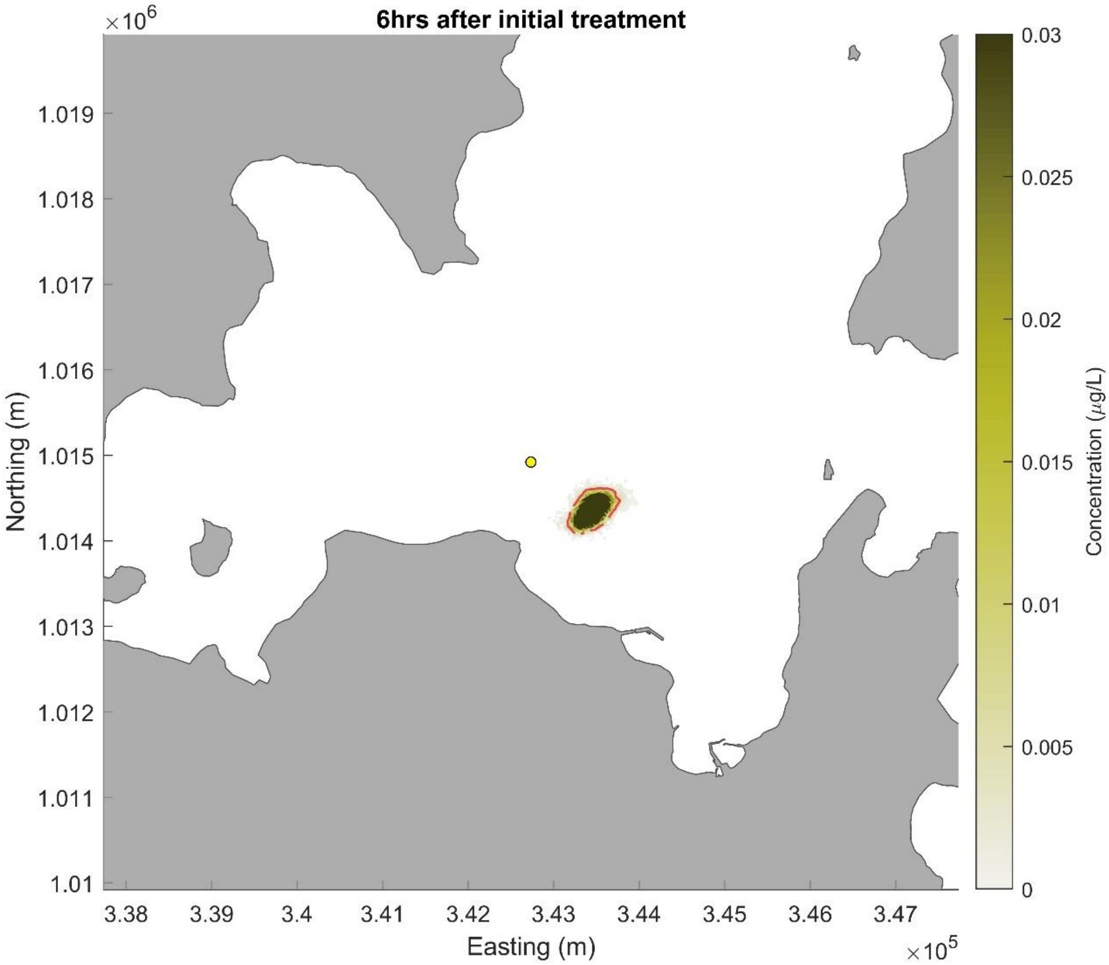

Figure 19. Spatial Deltamethrin distribution for wellboat releases during neap tides, 6 hours after the last treatment event. Areas above EQS values are indicated within the red contour and site location is identified using a yellow marker.

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 20. 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 Quanterness after a 6-hour mass treatment release remains less than the calculated mixing area of 0.60327km^2 throughout the model run.

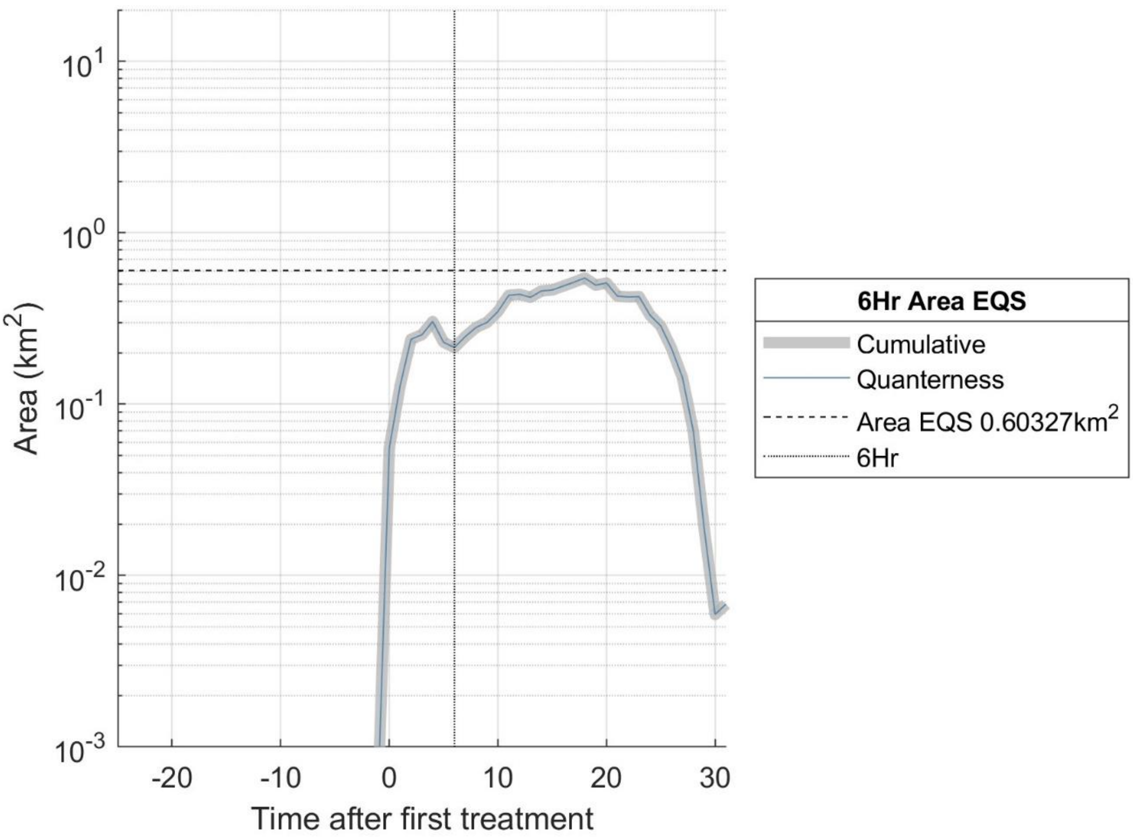

Figure 20. Chemical plume area exceeding the 6-hour (6 ng/l) EQS value after the initial 6-hour mass wellboat release of Deltamethrin during spring tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted 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 21. The regions in which chemical concentration exceeds the EQS threshold are illustrated by the red contour. This shows an area extent less than the permitted EQS area. Initially the plume is dispersed to the west of the site and then pulled back over the site at the 6hr EQS time. After 6hr, the plume is dispersed within the Wide Firth waterbody and further distributed out the tidal strait in the east.

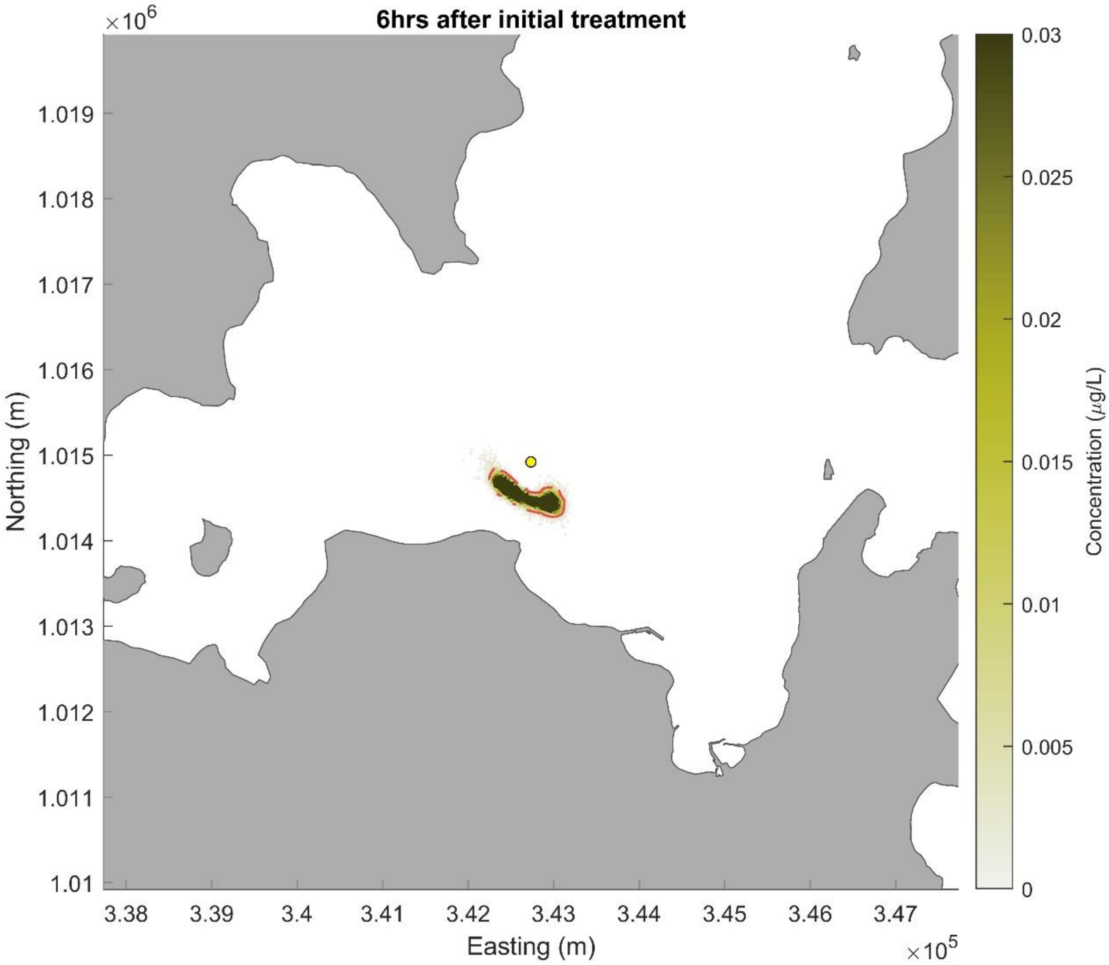

Figure 21. Spatial Deltamethrin distribution for wellboat releases during spring tides, 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site location is identified using a yellow marker.

4. Interactions with Sensitive Marine Features

The results of the modelled distribution of the bath treatment plumes 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 MMp01 (figure 22) and HMp01 (figure 23). Both MMp01 and 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.

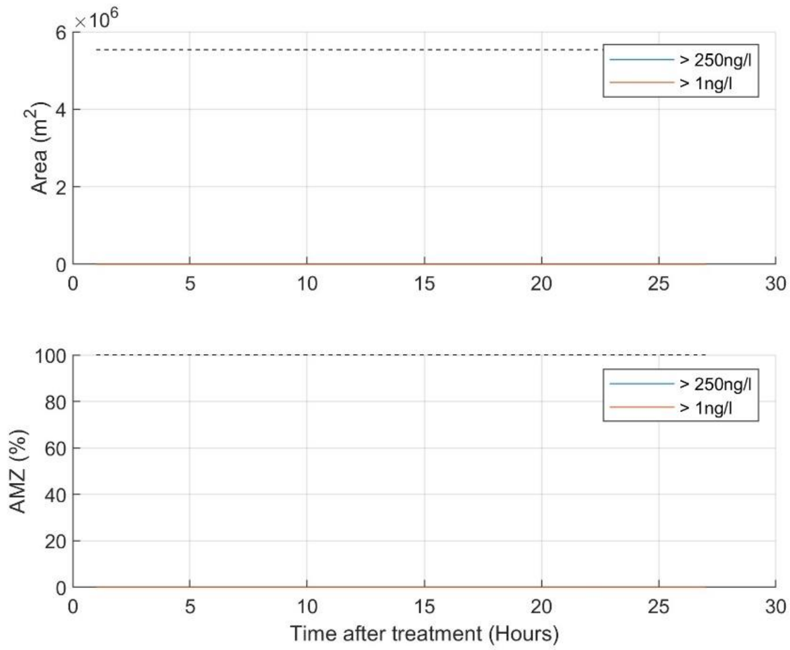

Figure 22 Upper: Area within MMp01 polygon exceeding 3hr EQS concentration with the total area indicated by the dashed black line. Lower: Percentage area of the MM01p polygon concentration with the total area indicated by the dashed black line

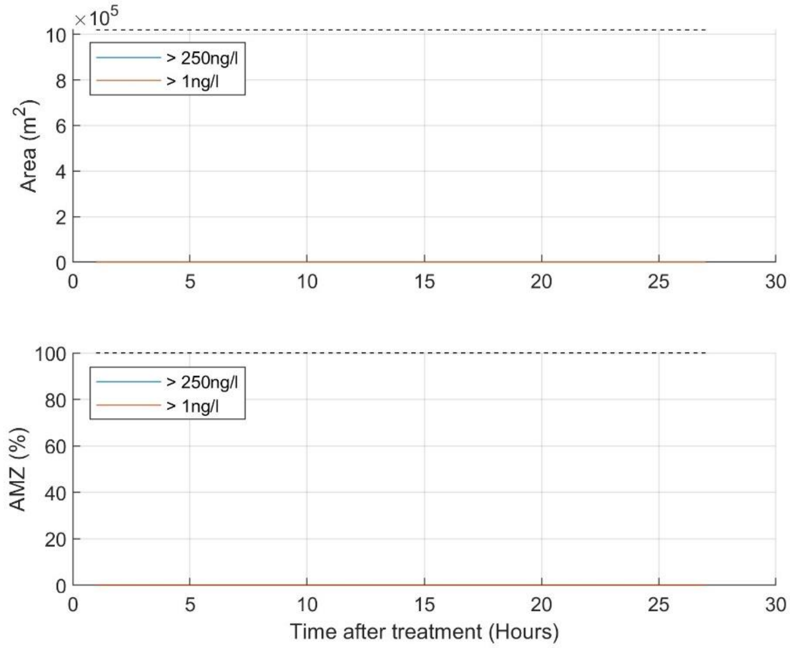

Figure 23 Upper: Area within HMp01 polygon exceeding 3hr EQS concentration with the total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon concentration with the total area indicated by the dashed black line

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 MMp01 (figure 24) and HMp01 (figure 25). Both MMp01 and 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.

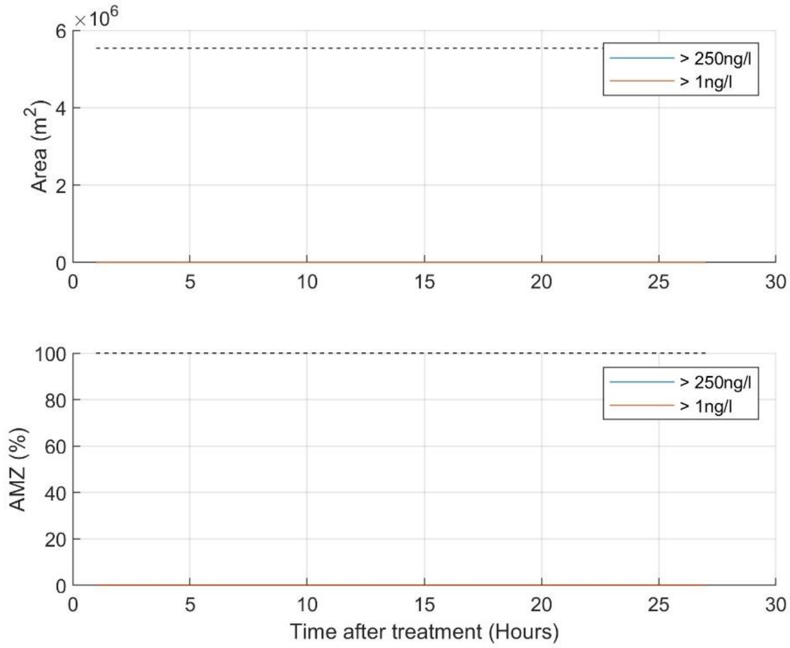

Figure 24 Upper: Area within MMp01 polygon exceeding 250 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the MM01p polygon exceeding 250 and 1 ng/l with the total area indicated by the dashed black line

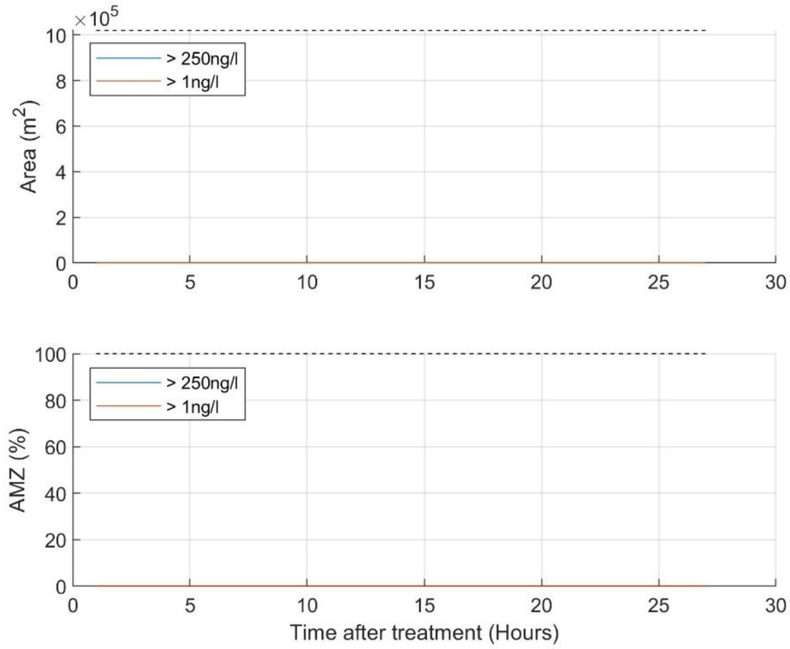

Figure 25 Upper: Area within HMp01 polygon exceeding 250 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 250 and 1 ng/l with the total area indicated by the dashed black line

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 MMp01 (figure 26) and HMp01 (figure 27). Both MMp01 and HMp01 show 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.

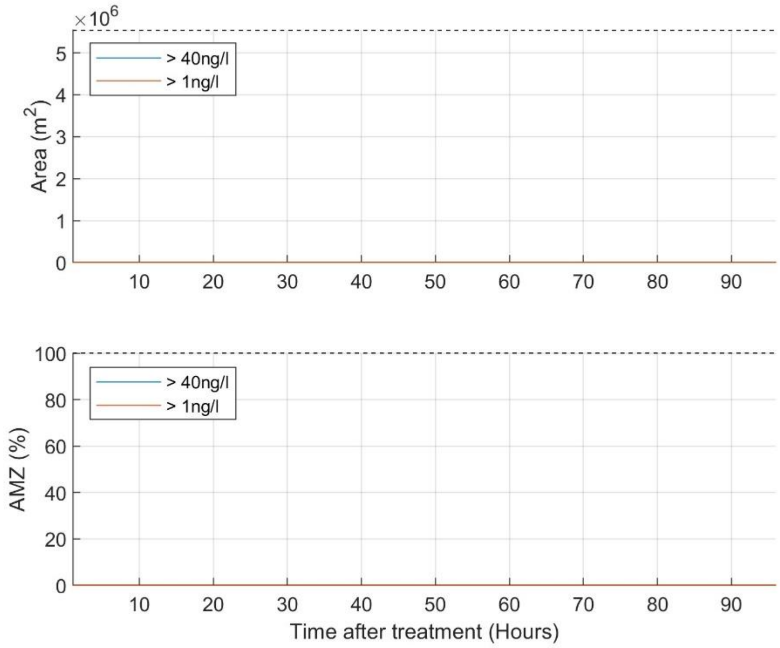

Figure 26 Upper: Area within MMp01 polygon exceeding 40 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the MM01p polygon exceeding 40 and 1 ng/l with the total area indicated by the dashed black line

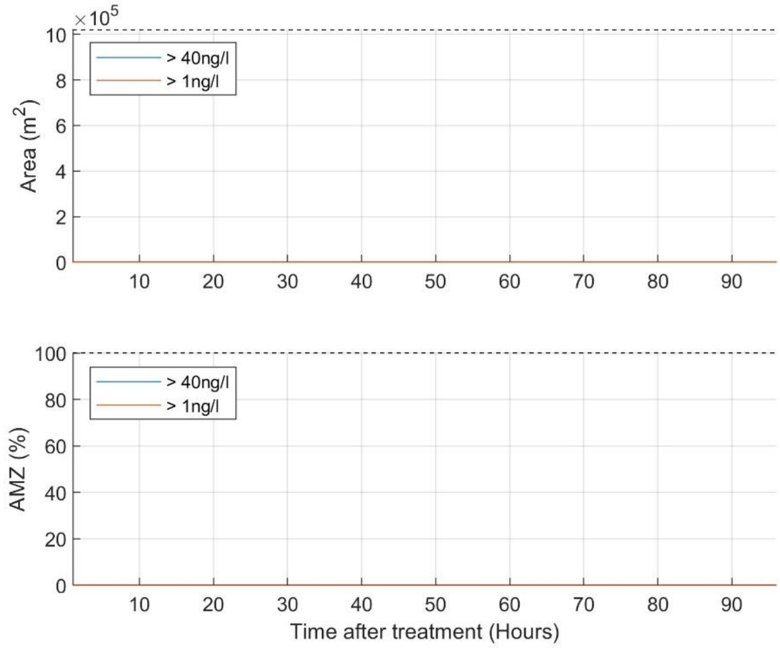

Figure 27 Upper: Area within HMp01 polygon exceeding 40 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 40 and 1 ng/l with the total area indicated by the dashed black line

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 MMp01 (figure 28) and HMp01 (figure 29). Both MMp01 and HMp01 show 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.

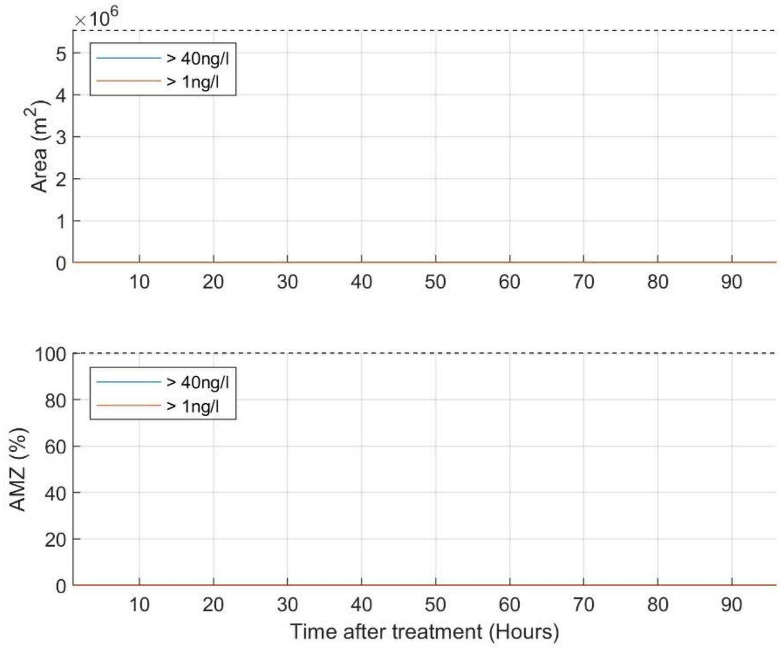

Figure 28 Upper: Area within MMp01 polygon exceeding 40 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the MM01p polygon exceeding 40 and 1 ng/l with the total area indicated by the dashed black line

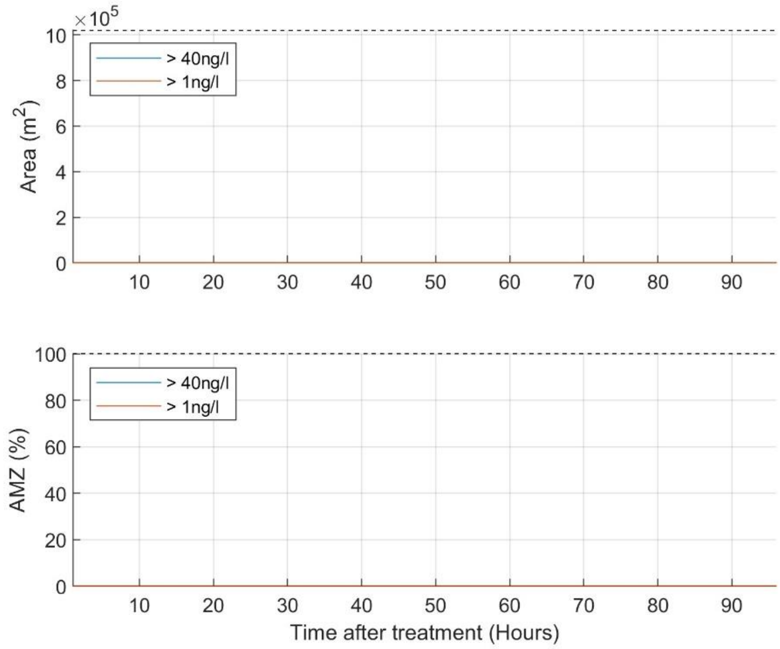

Figure 29 Upper: Area within HMp01 polygon exceeding 40 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 40 and 1 ng/l with the total area indicated by the dashed black line

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 MMp01 (figure 30) and HMp01 (figure 31). Both MMp01 and HMp01 show 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.

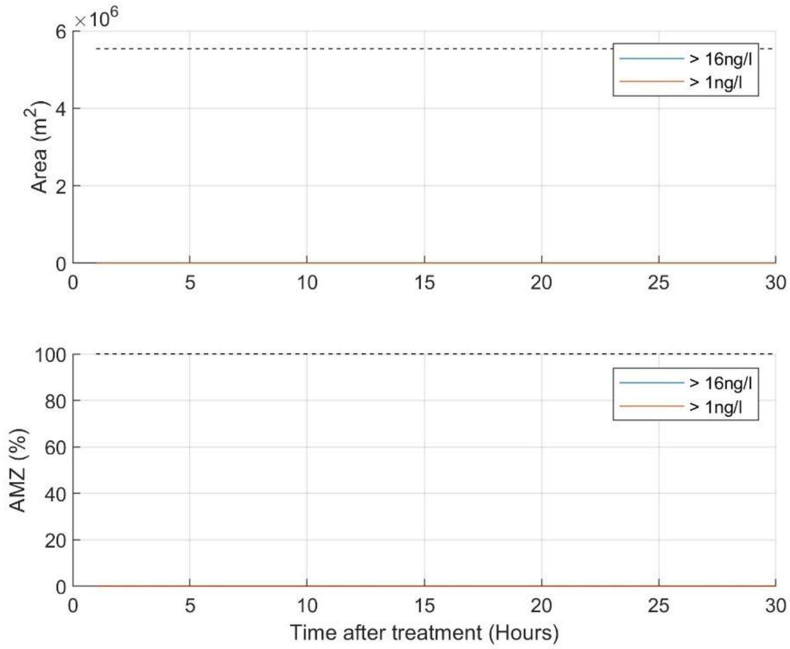

Figure 30 Upper: Area within MMp01 polygon exceeding 16 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the MM01p polygon exceeding 16 and 1 ng/l with the total area indicated by the dashed black line

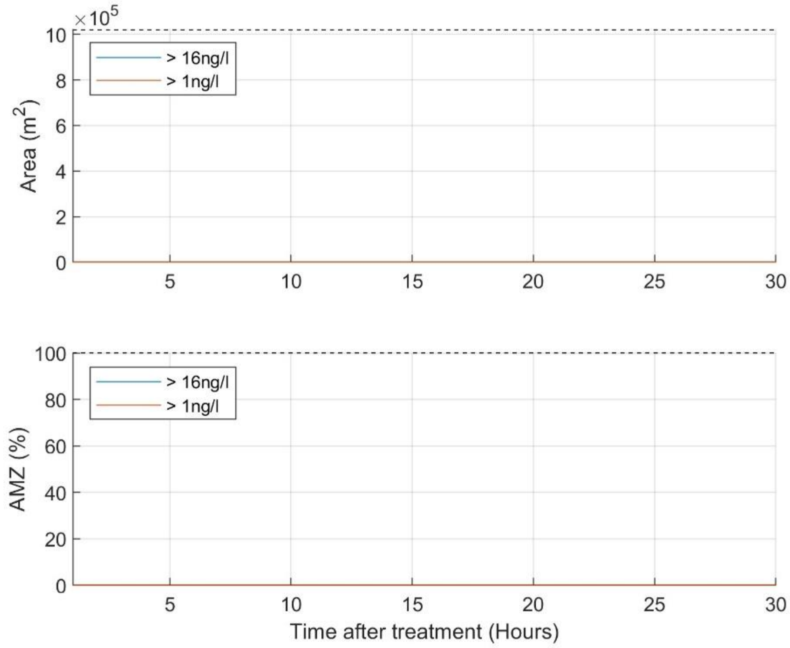

Figure 31 Upper: Area within HMp01 polygon exceeding 16 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 16 and 1 ng/l with the total area indicated by the dashed black line

4.1.2.2 Spring tide

Results from the Cypermethrin simulation during the spring tide are used to determine deposited concentrations within MMp01 (figure 32) and HMp01 (figure 33). Both MMp01 and HMp01 show 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.

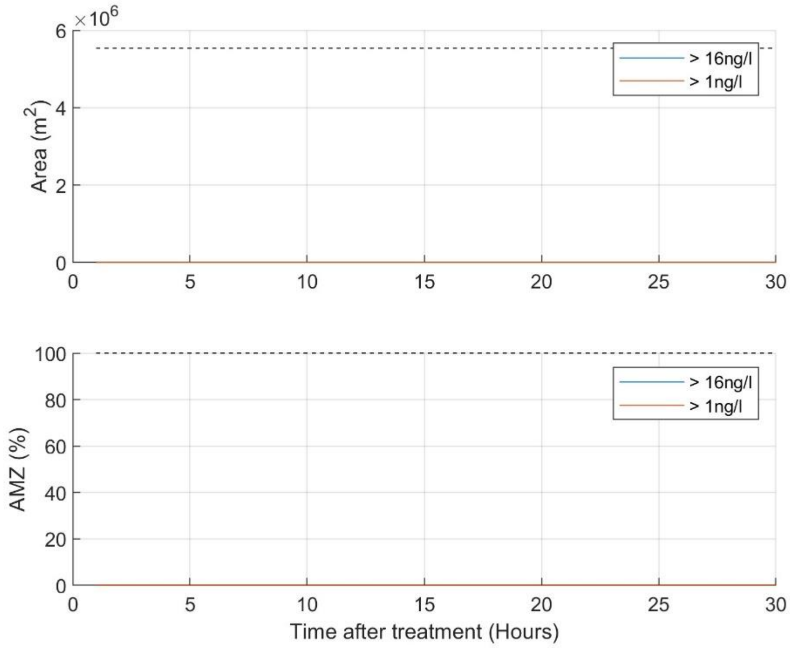

Figure 32 Upper: Area within MMp01 polygon exceeding 16 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the MM01p polygon exceeding 16 and 1 ng/l with the total area indicated by the dashed black line

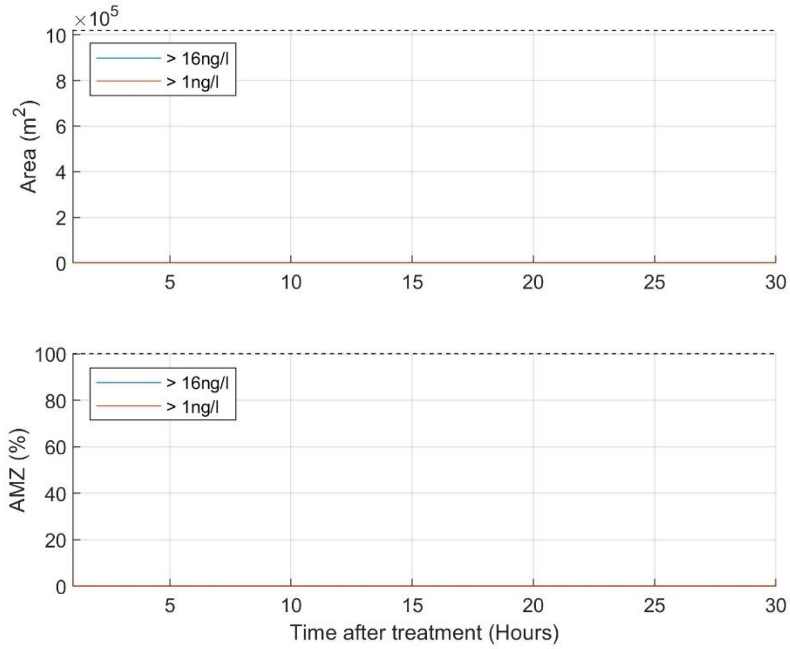

Figure 33 Upper: Area within HMp01 polygon exceeding 16 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 16 and 1 ng/l with the total area indicated by the dashed black line

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 MMp01 (figure 34) and HMp01 (figure 35). Both MMp01 and 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.

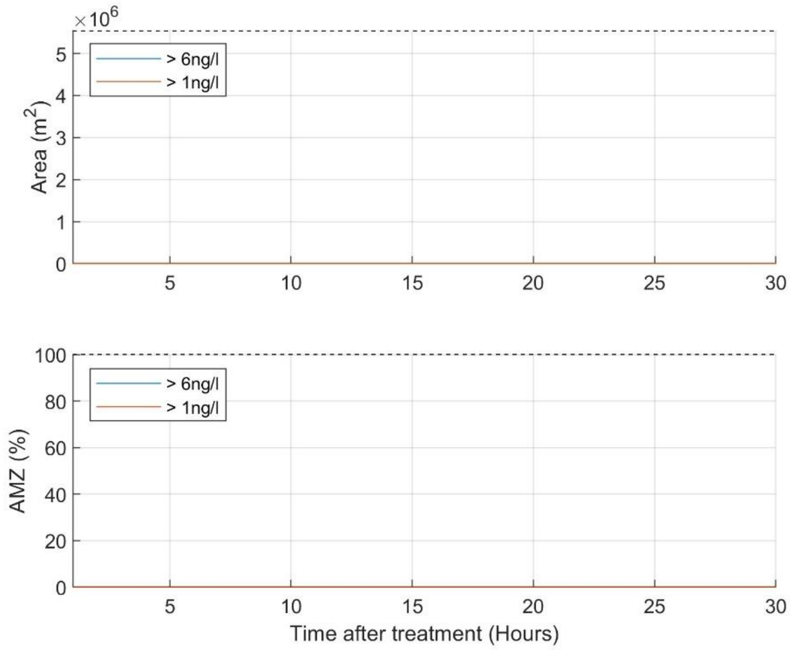

Figure 34 Upper: Area within MMp01 polygon exceeding 6 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the MM01p polygon exceeding 6 and 1 ng/l with the total area indicated by the dashed black line

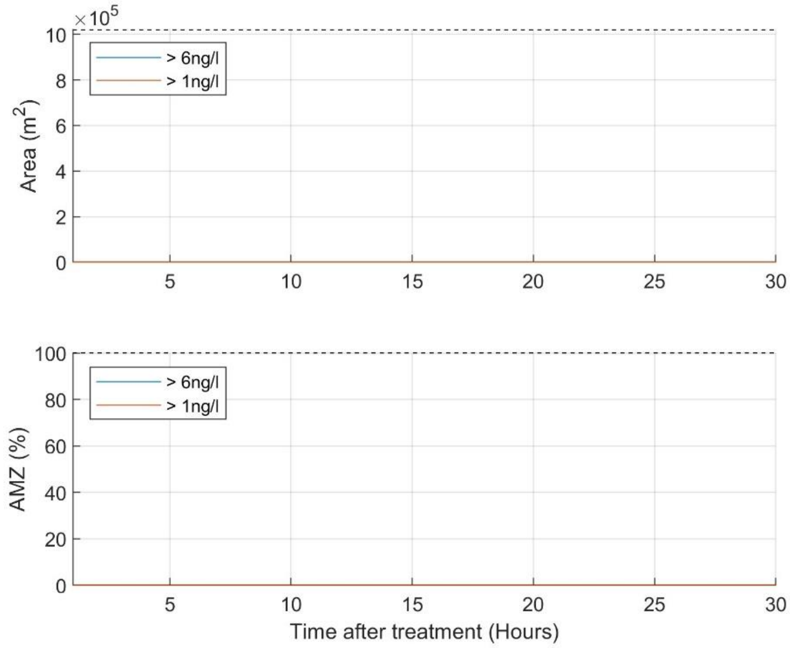

Figure 35 Upper: Area within HMp01 polygon exceeding 6 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 6 and 1 ng/l with the total area indicated by the dashed black line

4.1.3.2 Spring tide

Results from the Deltamethrin simulation during the spring tide are used to determine deposited concentrations within MMp01 (figure 36) and HMp01 (figure 37). Both MMp01 and 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.

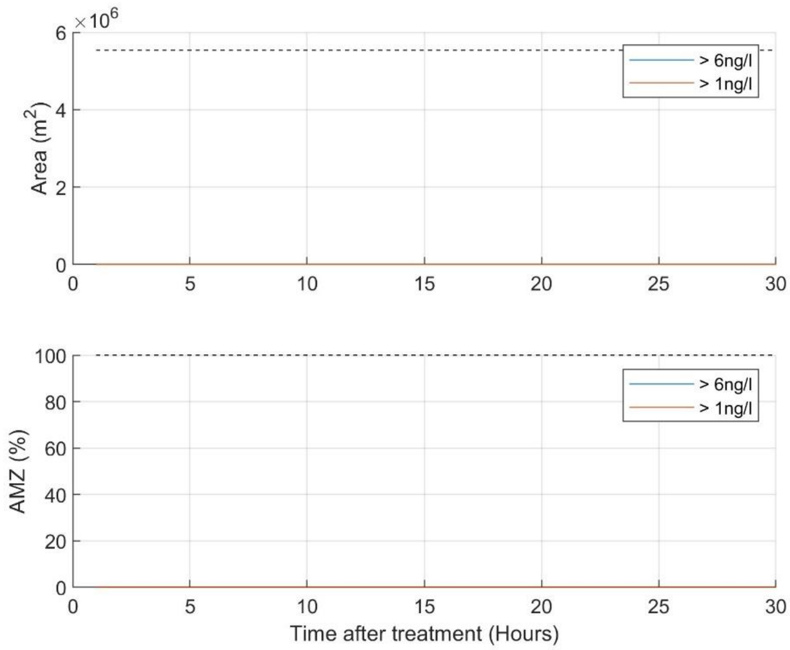

Figure 36 Upper: Area within MMp01 polygon exceeding 6 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the MM01p polygon exceeding 6 and 1 ng/l with the total area indicated by the dashed black line

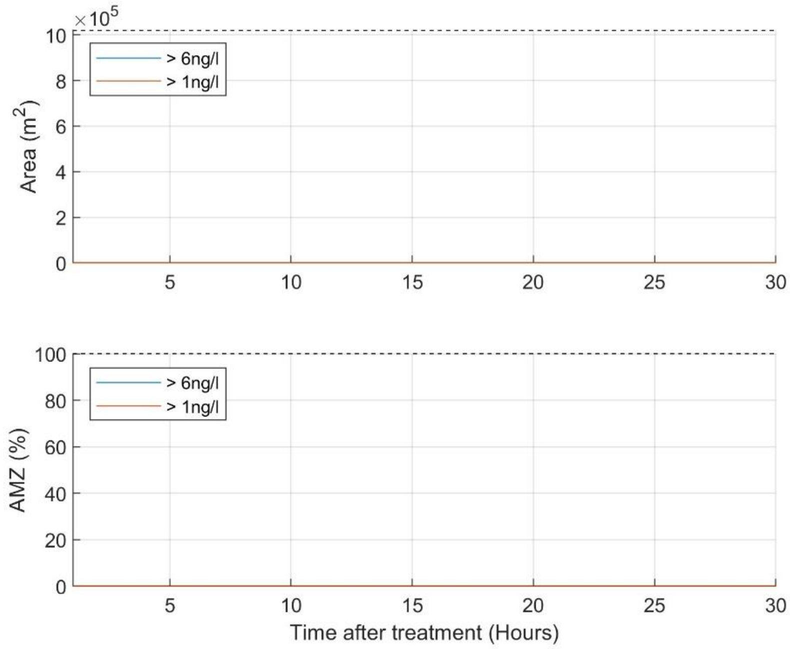

Figure 37 Upper: Area within HMp01 polygon exceeding 6 and 1 ng/l. Total area indicated by the dashed black line. Lower: Percentage area of the HM01p polygon exceeding 6 and 1 ng/l with the total area indicated by the dashed black line

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, 430g of Azamethiphos. Treatment concentration at sensitive features is identified in figure 38. For the majority of features no observable treatment concentrations are shown. Features MM01, MM02 and MMp01 show a minor residue of treatments with a short exposure time.

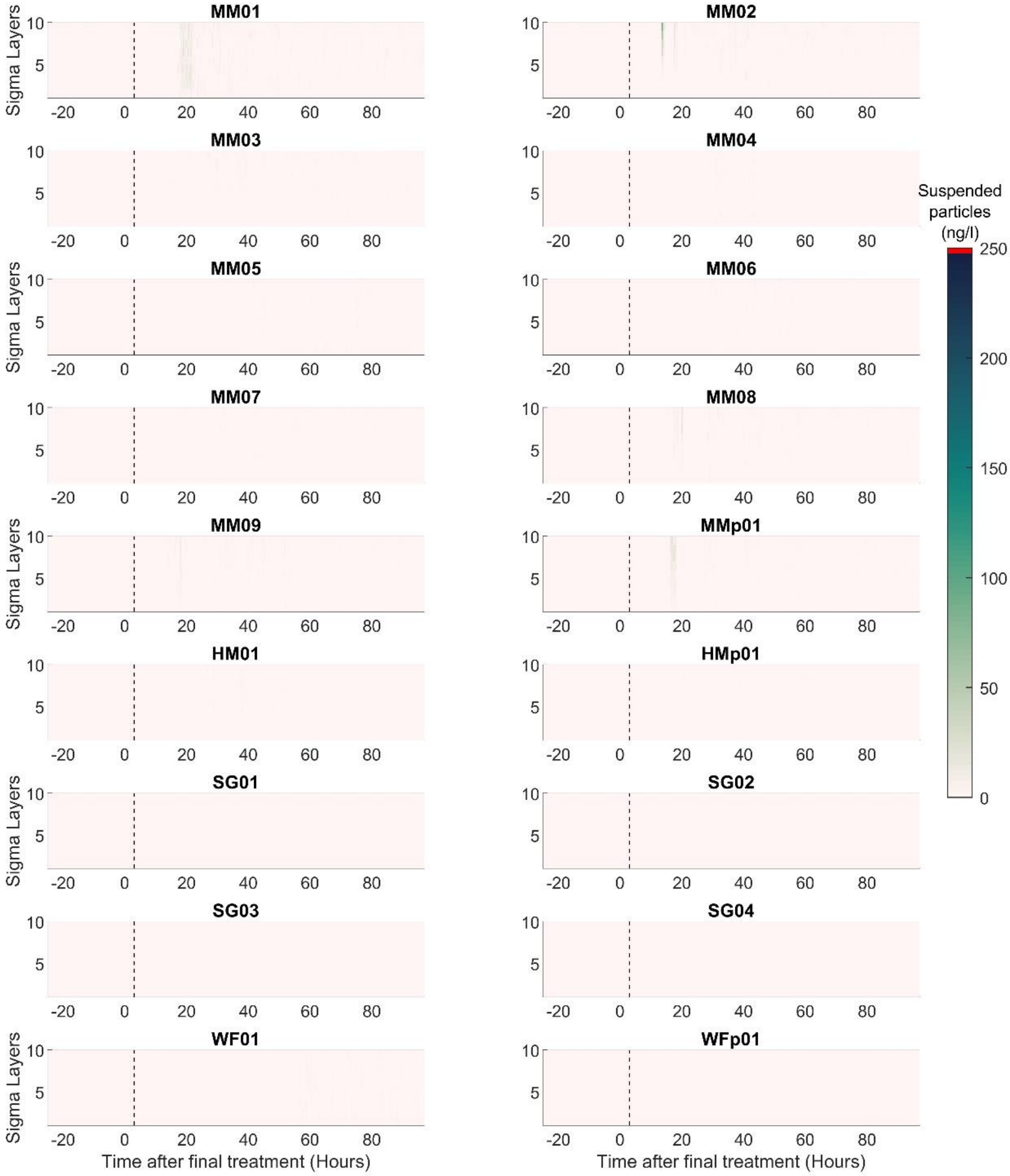

Figure 38. Neap tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar with any values indicated in red that exceed the 3hr EQS value. Water depth is defined in model sigma layers where 1 is the bed cell and 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 3hr EQS time. After 3hrs of a single treatment, most feature show no concentration of the plume.

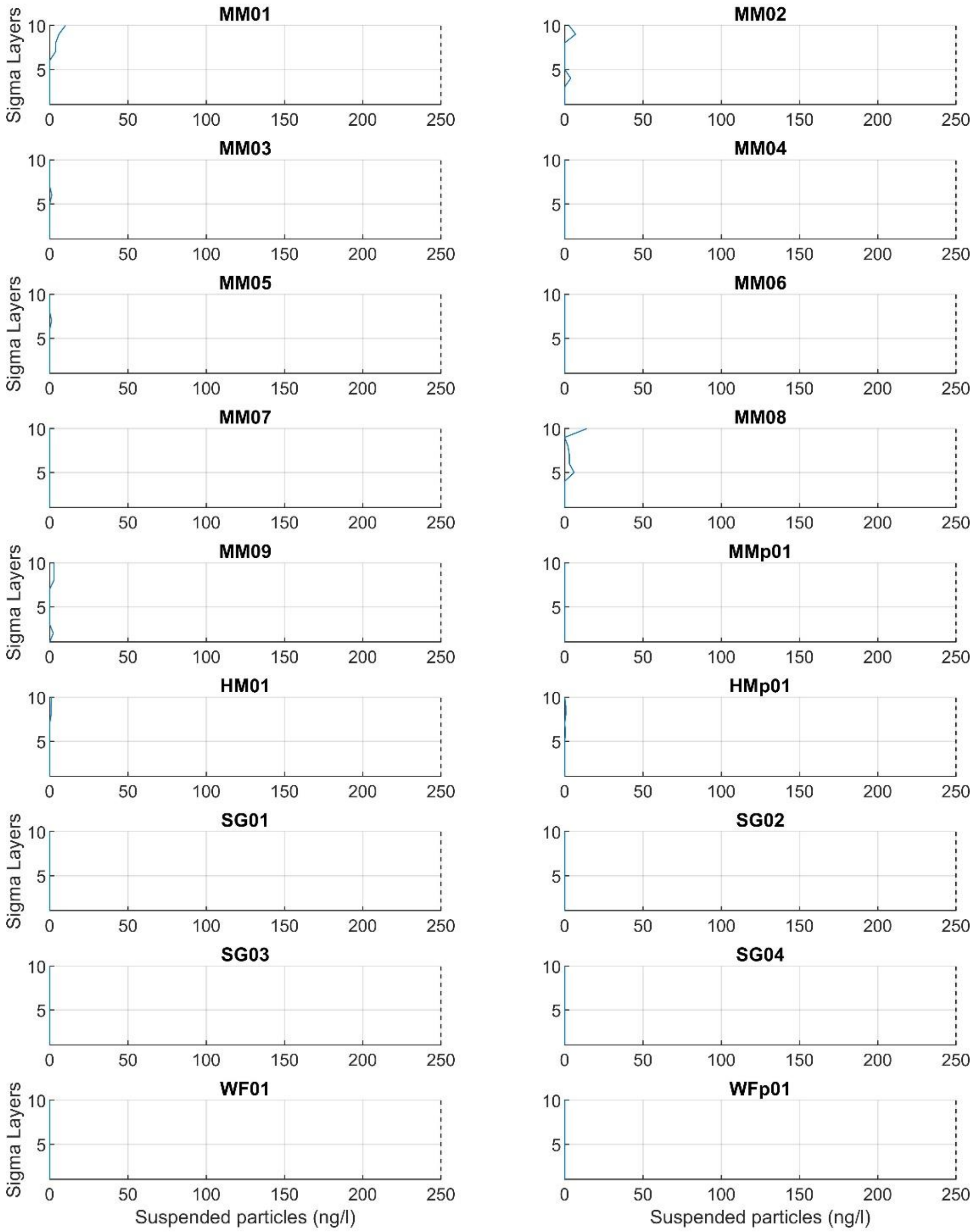

Figure 39. Neap tide vertical concentration profile of Azamethiphos after the single treatment at the 3hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

72hr EQS

Bath treatment exposure during the neap tide is assessed using a 24-hr treatment mass of 575g of Azamethiphos. Treatment concentrations at sensitive features are identified in figure 40, where the concentration scale is adjusted to 40ng/l, in line with the 72hr EQS value. Plume concentration at sensitive feature locations all remain at very low levels. Features MM01, MM02, MM08, MM09 and MMp01 show more visible variations in passing plume concentrations. These small increases in concentration have a short duration and generally weaken in strength nearer the seabed. After 40hrs the concentration of any chemical plume interacting with the sensitive feature location have been largely diluted and are no longer observed at the identified locations.

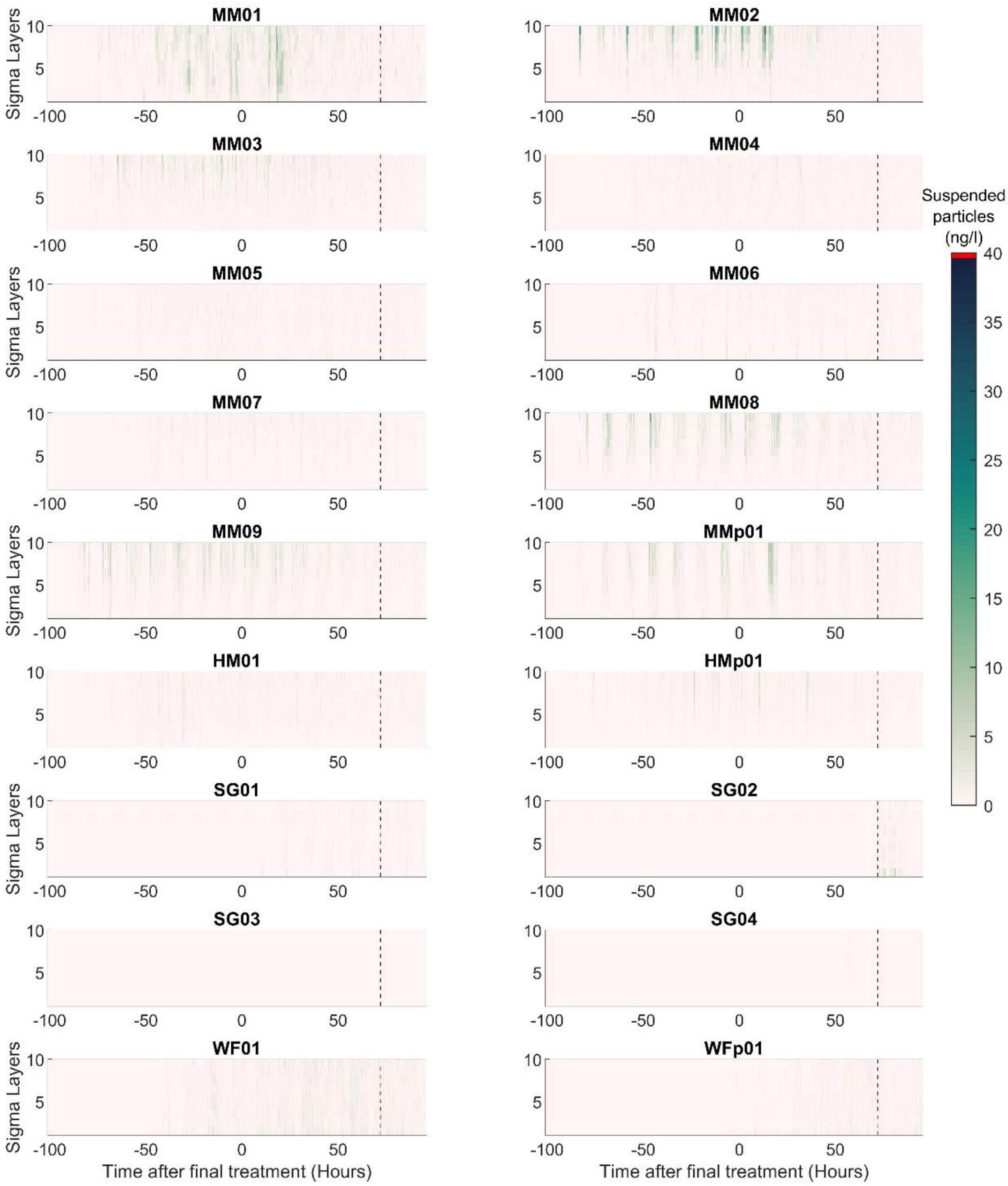

Figure 40. Neap tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar with any values indicated in red that exceed the 72hr EQS value. Water depth is defined in model sigma layers where 1 is the bed cell 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 4ng/l for all features, with most locations recording concentrations of 0ng/l. Due to the increased time duration and dispersion plumes show more varied vertical distribution.

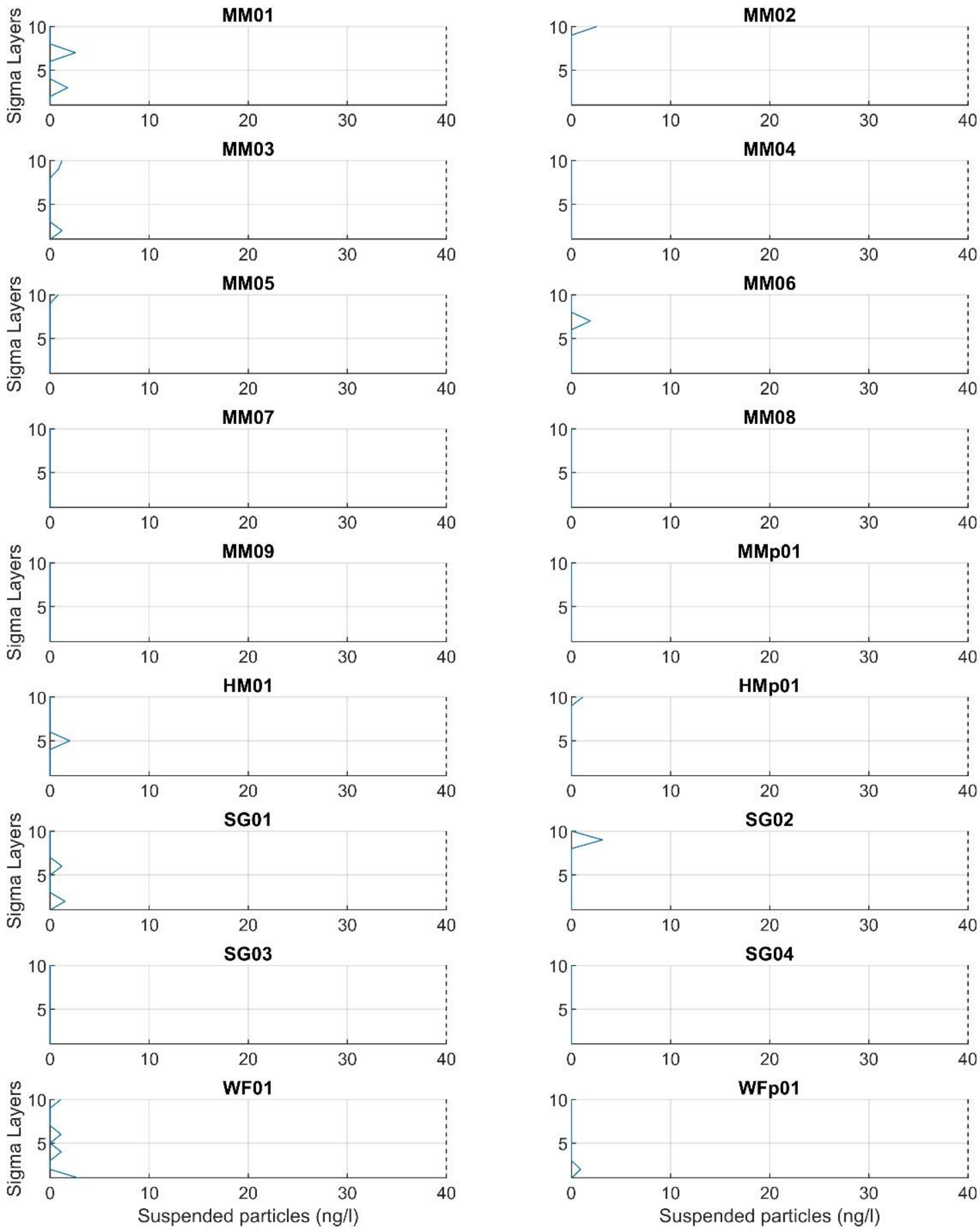

Figure 41. Neap tide vertical concentration profile of Azamethiphos after a treatment plan with a 24-hr treatment mass of 575g at the 72hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Azamethiphos is shown relative to the sensitive feature locations in figure 42. 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 in to fragmented plumes with no accumulations, with a net travel towards the east. Interactions with sensitive features are uncommon and occur only with very diluted plumes. The largest concentration occurs around 12hrs after the final treatment at MM01 and MM02 located off the Head of Holland near Ingerness Bay. However, these remain low in concentration are shown in figure 40 to occur near the surface.

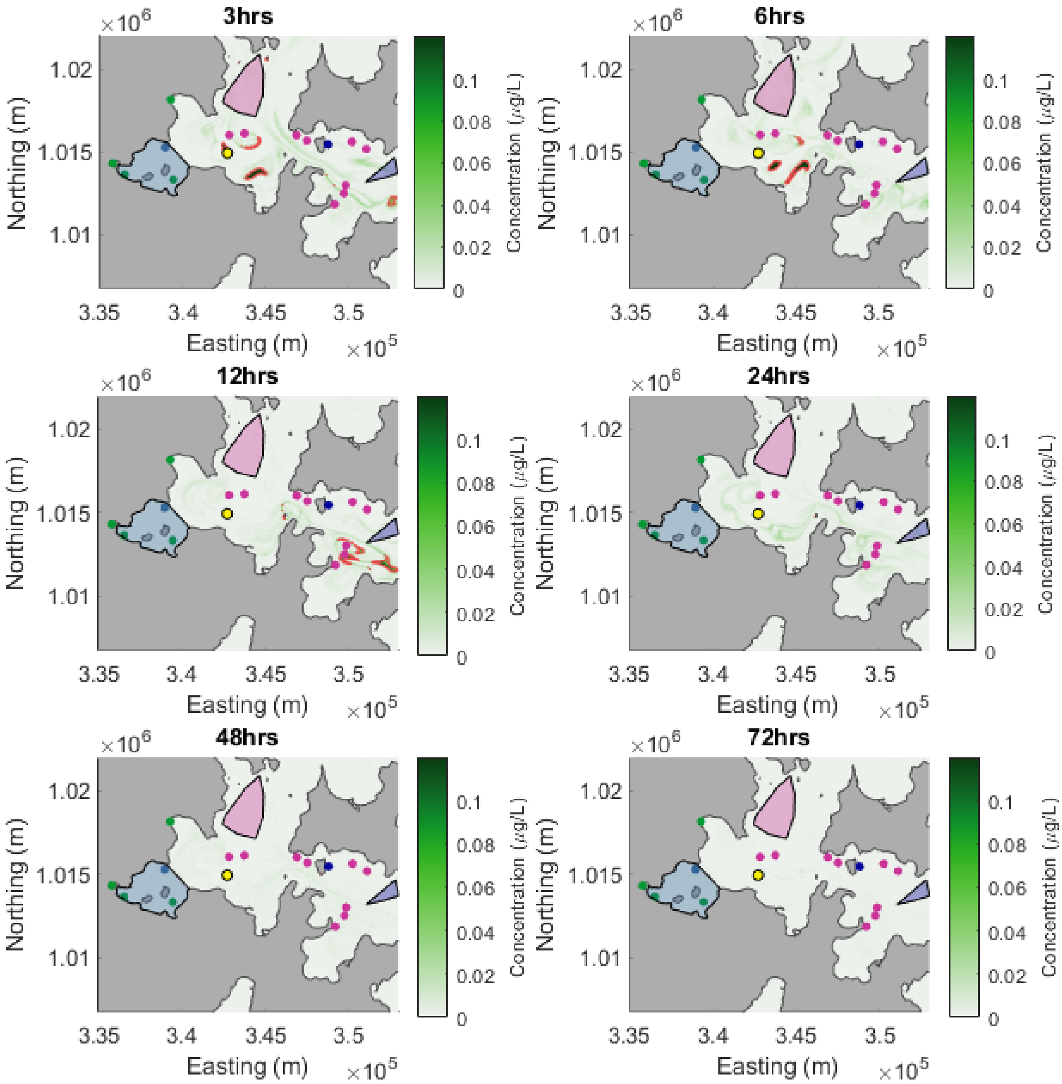

Figure 42. Spatial Azamethiphos distribution for bath treatment releases during neap tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

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, 430g of Azamethiphos. Treatment concentration at sensitive features is identified in figure 43. No observable treatment concentrations are shown for any sensitive feature.

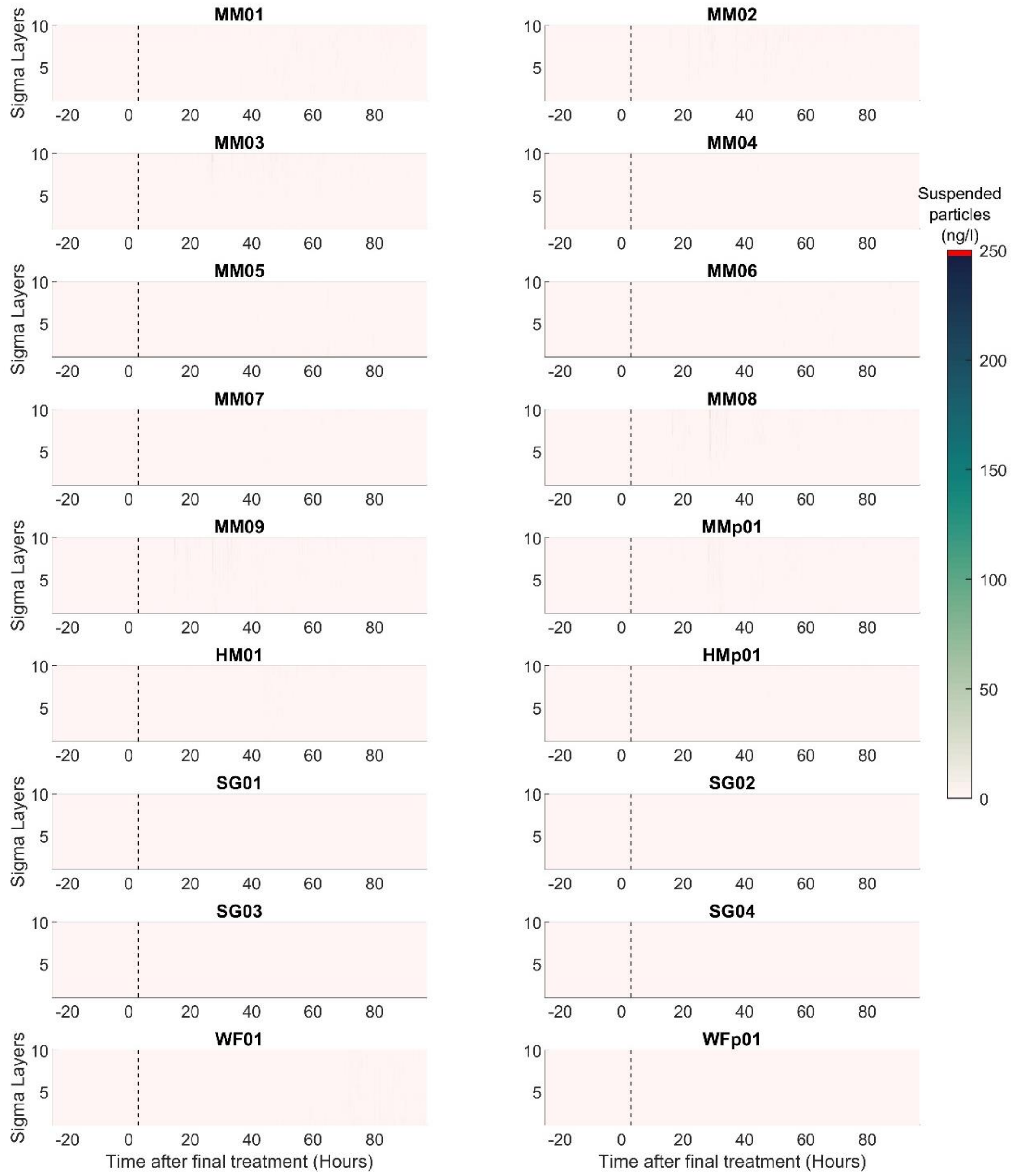

Figure 43. Spring tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar with any

values indicated in red that exceed the 72hr EQS value. 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 44 for the 3hr EQS time. After 3hrs no treatment concentrations are shown for any of the identified sensitive marine features.

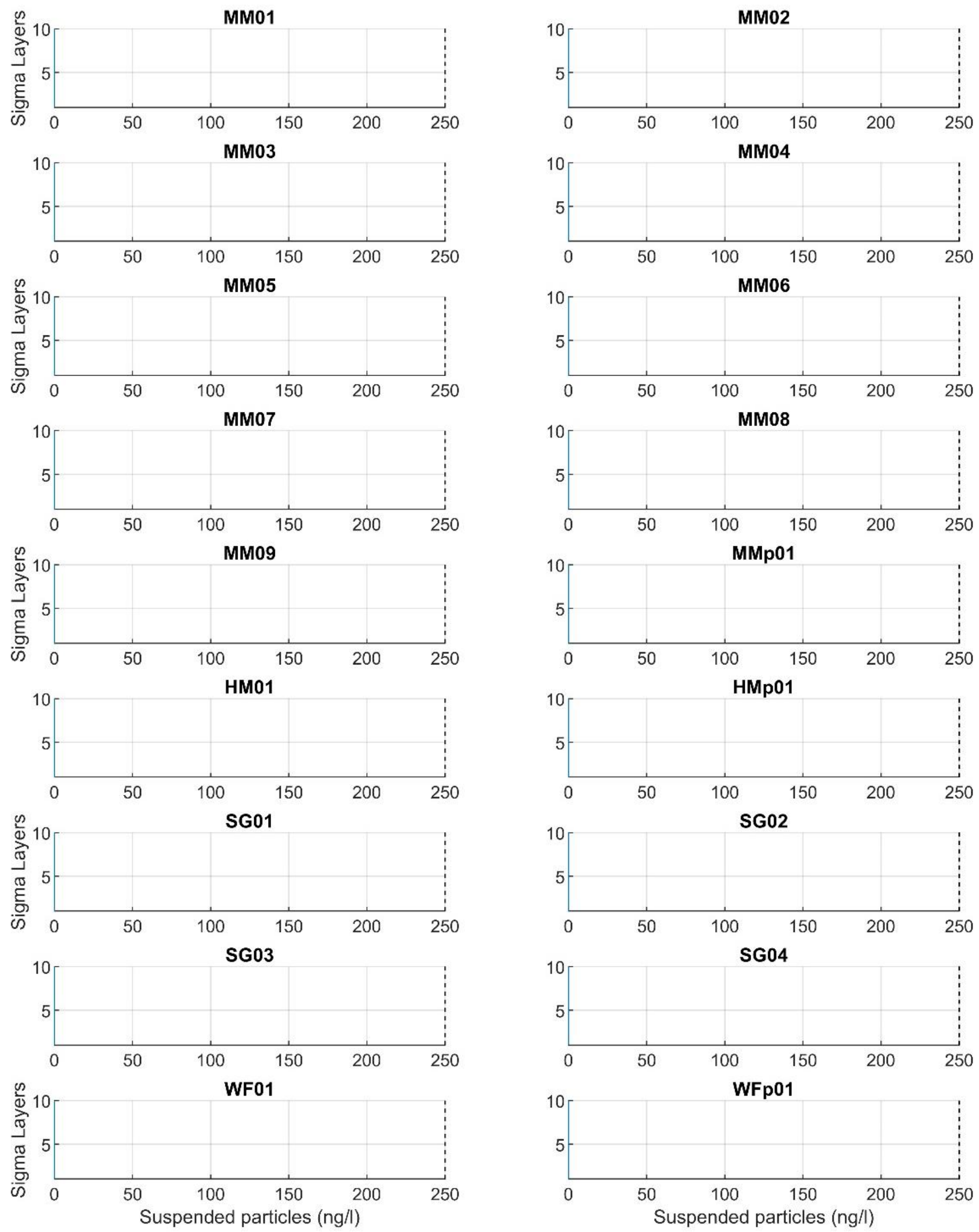

Figure 44. Spring tide vertical concentration profile of Azamethiphos after the single treatment at the 3hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

72hr EQS

Bath treatment exposure during the spring tide is assessed using a 24-hr treatment mass of 575g of Azamethiphos. Treatment concentrations at sensitive features are identified in figure 45, where the concentration scale is adjusted to 40ng/l, in line with the 72hr EQS value. Plume concentration at sensitive feature locations all remain at very low levels. Features MM01, MM02, MM03, MM08, MM09 and MMp01 show more visible variations in passing plume concentrations. These small increases in concentration have a short duration and generally weaken in strength nearer the seabed. After 50hrs the concentration of any chemical plume interacting with the sensitive feature location have been largely diluted.

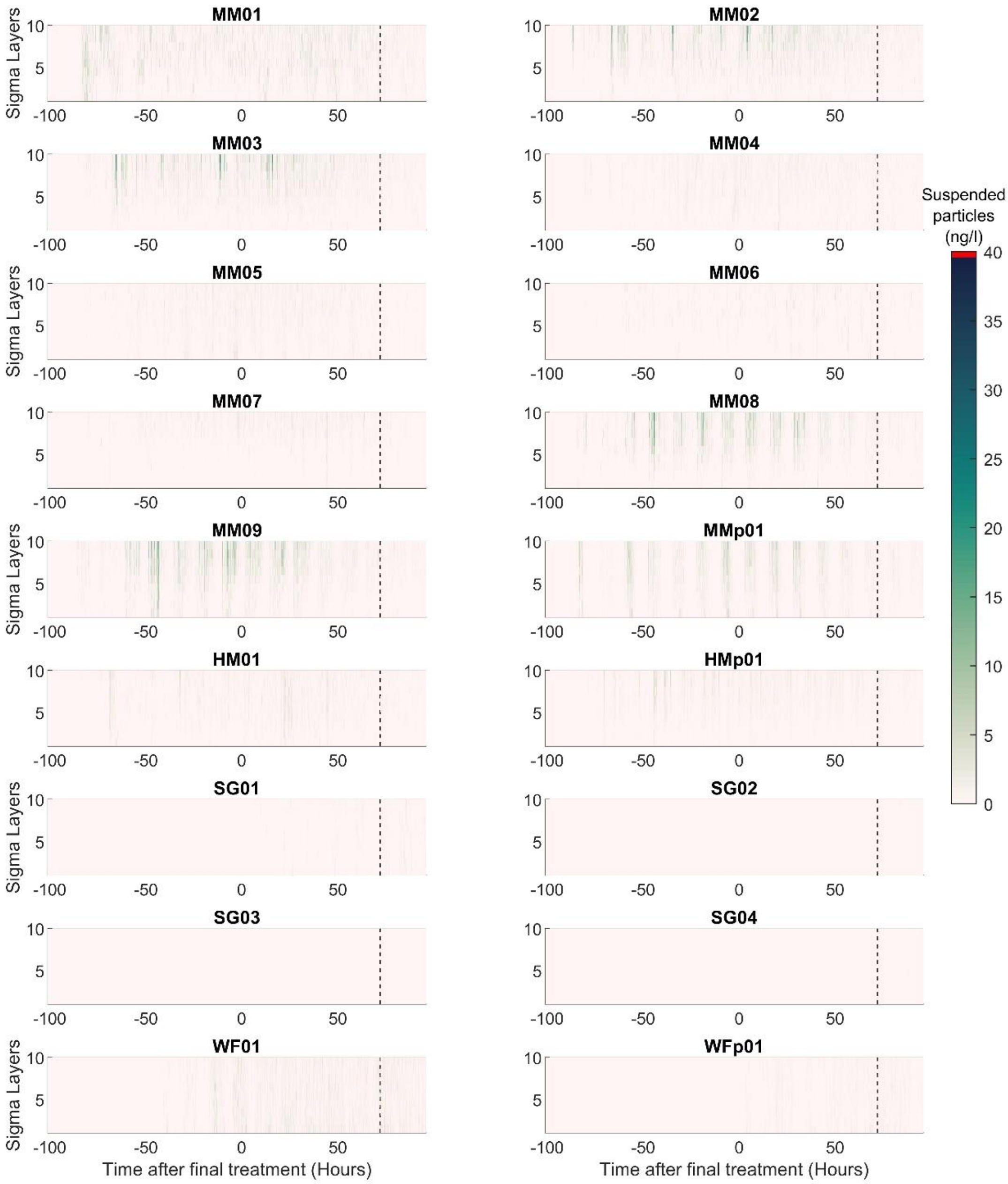

Figure 45. Spring tide Azamethiphos concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar with any values indicated in red that exceed the 72hr EQS value. Water depth is defined in model sigma layers where 1 is the bed cell 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 46 for the 72hr EQS time. After 72hrs treatment concentrations are shown to remain less than 3ng/l at all sensitive marine features.

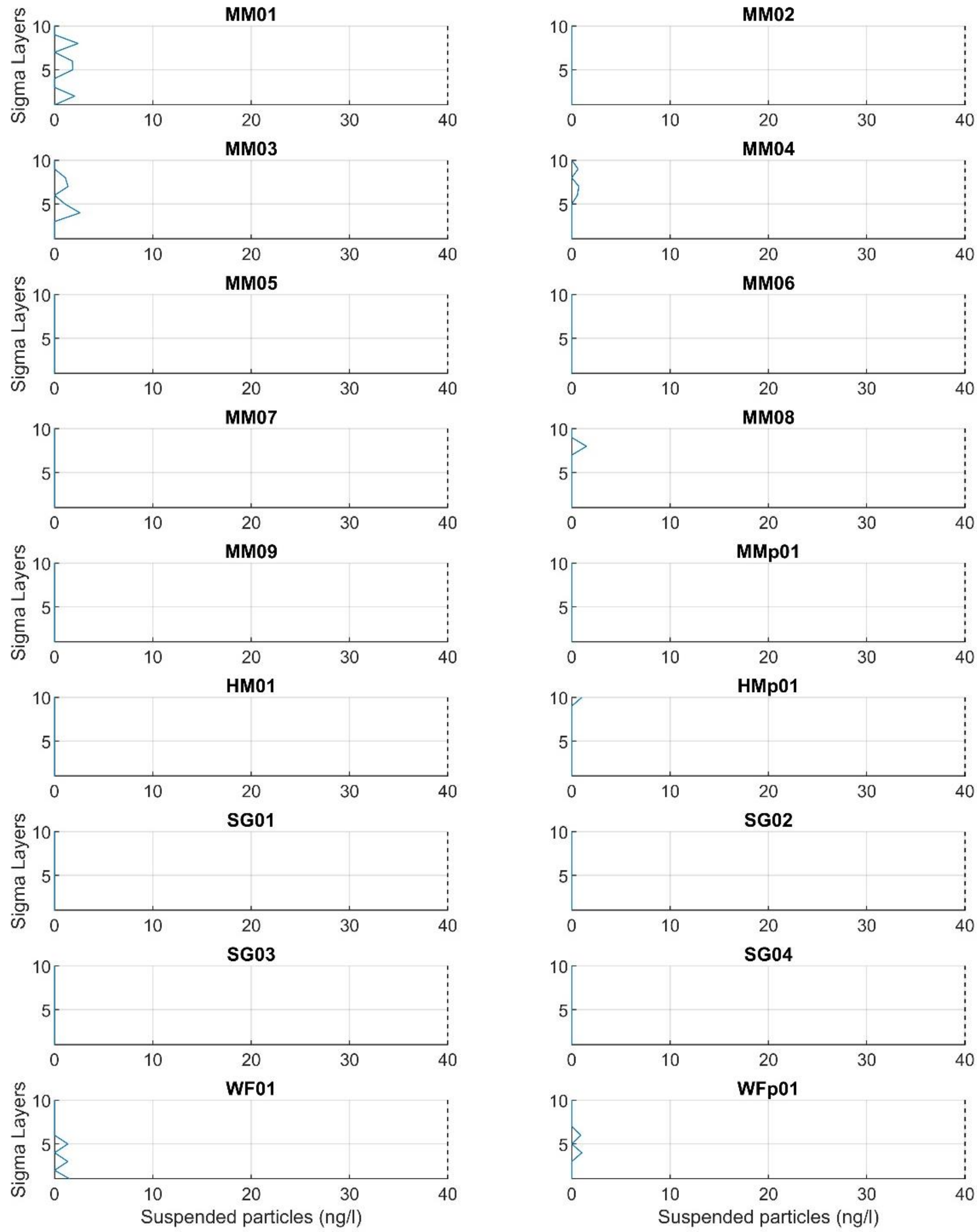

Figure 46. Spring tide vertical concentration profile of Azamethiphos after a treatment plan with a 24-hr treatment mass of 575g at the 72hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Azamethiphos is shown relative to the sensitive feature locations in figure 47. 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 in to fragmented plumes with no accumulations, with a net travel towards the east. Interactions with sensitive features are uncommon and occur only with very diluted plumes.

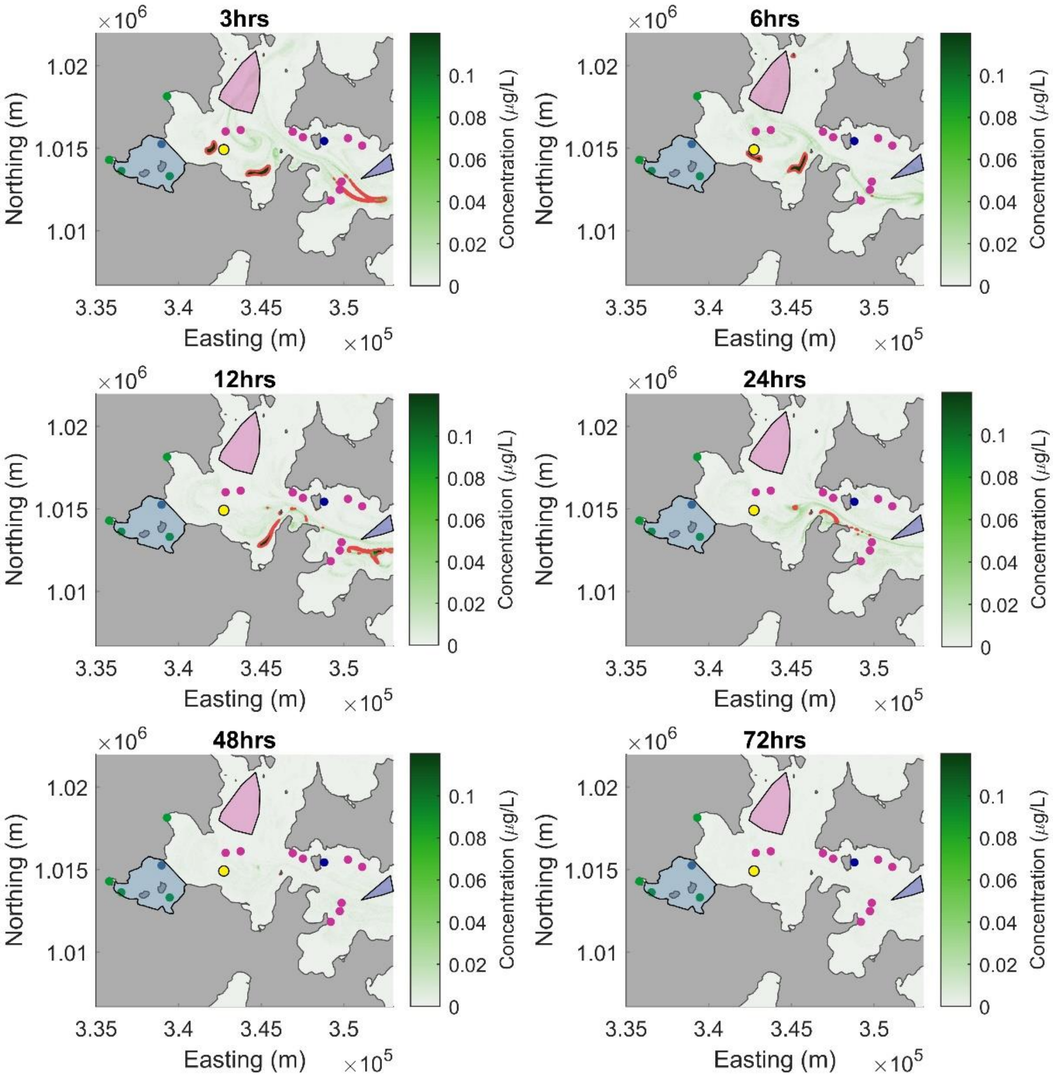

Figure 47. Spatial Azamethiphos distribution for bath treatment releases during spring tides 3hrs to 72 hrs after the last treatment event. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.2 Cypermethrin

4.2.2.1 Neap tides

Short-term exposure during the neap tide is assessed using a single release of 30g of Cypermethrin. Treatment concentration at sensitive features is identified in figure 48. For the majority of features no observable treatment concentrations are shown. Features MM01, MM08 and MMp01 show a minor residue of treatments with a short exposure time. Slightly larger concentrations are shown at MM02, however, this occurs in 2 plumes that quick pass the location and only occur in the upper water column.

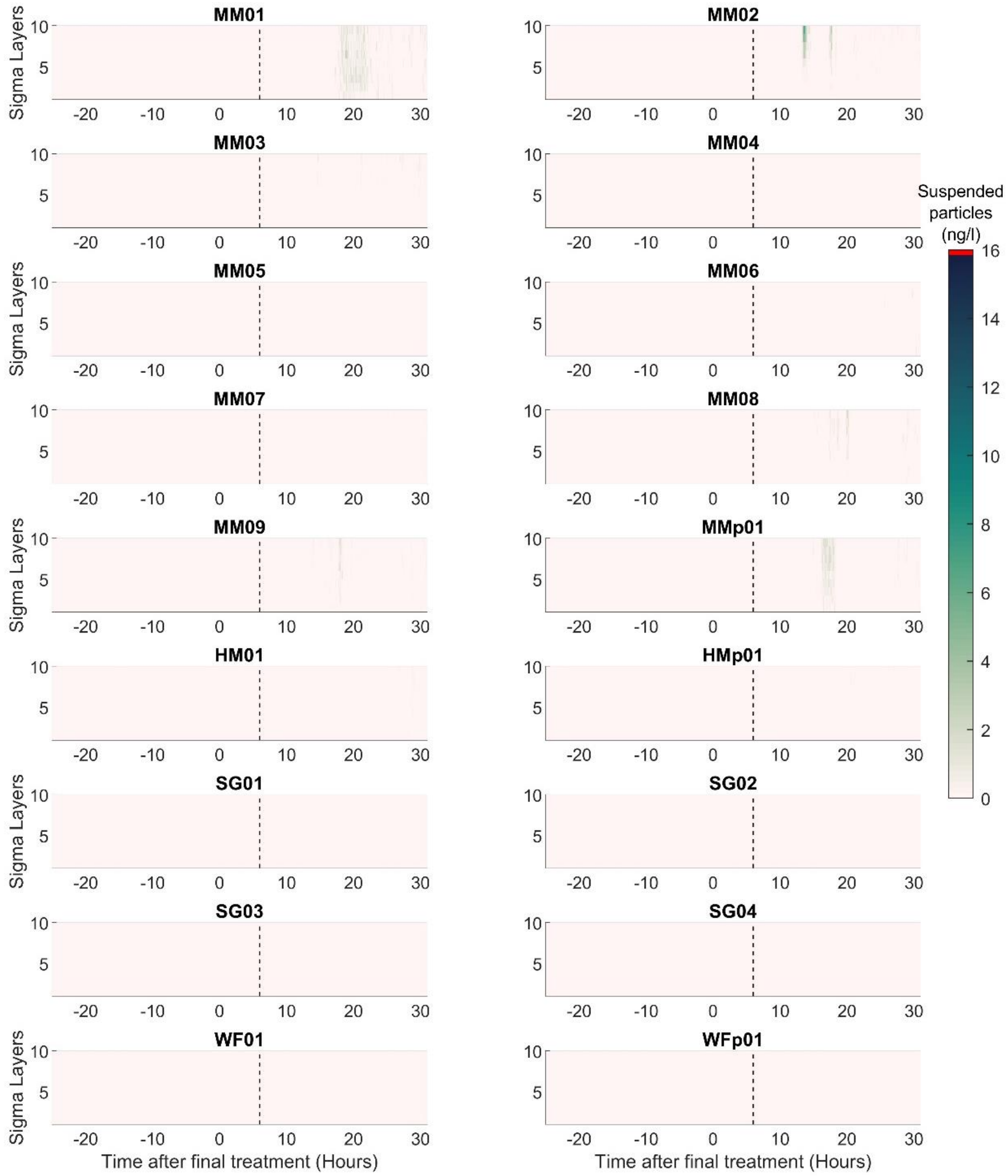

Figure 48. Neap tide Cypermethrin concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar with any values indicated in red that exceed the 6hr EQS value. Water depth is defined in model sigma layers where 1 is the bed cell and 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 49 for the 6hr EQS time. After 6hrs no treatment concentrations are shown for any of the identified sensitive marine features.

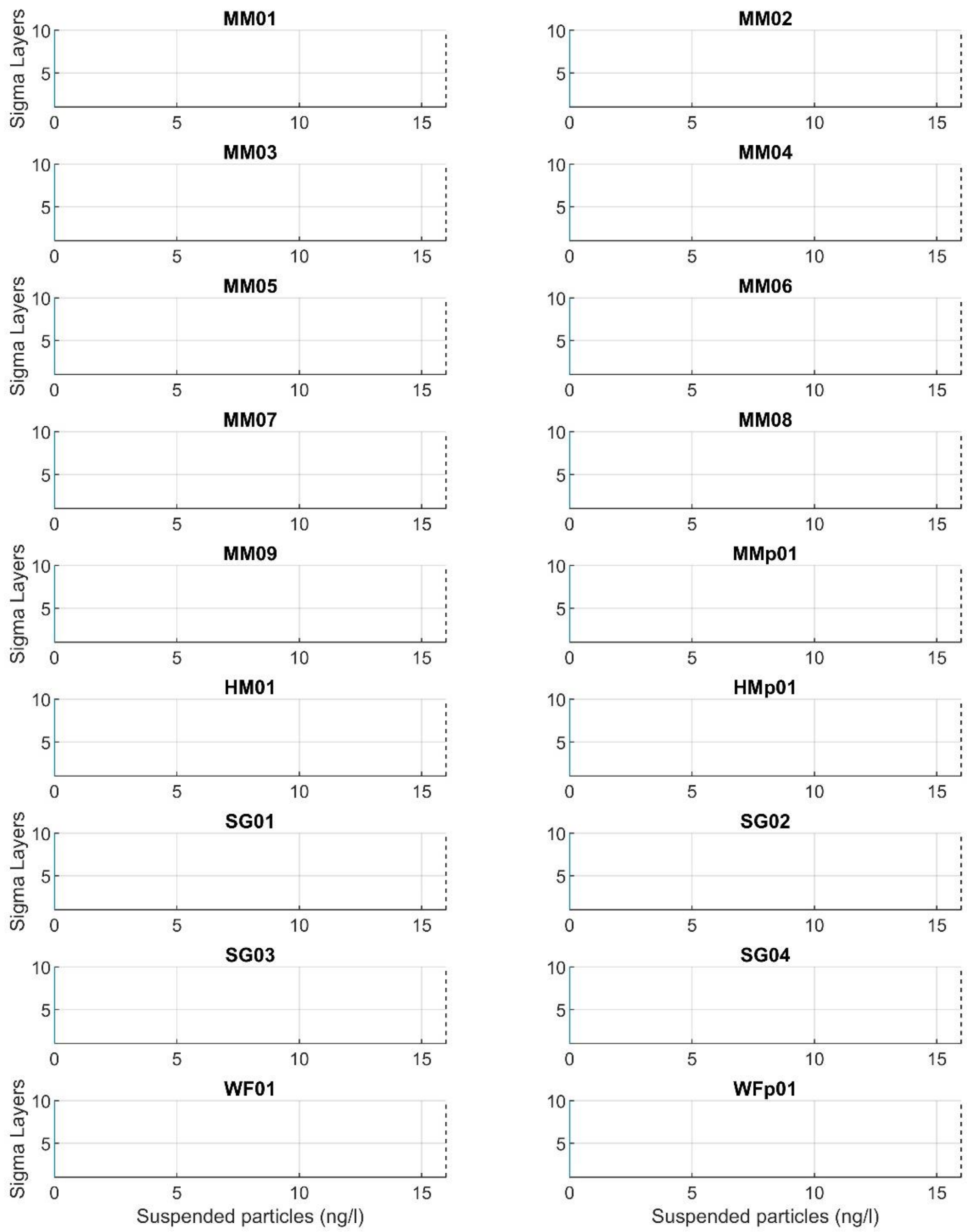

Figure 49. Neap tide vertical concentration profile of Cypermethrin after the single treatment at the 6 hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Cypermethrin is shown relative to the sensitive feature locations in figure 50. 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.

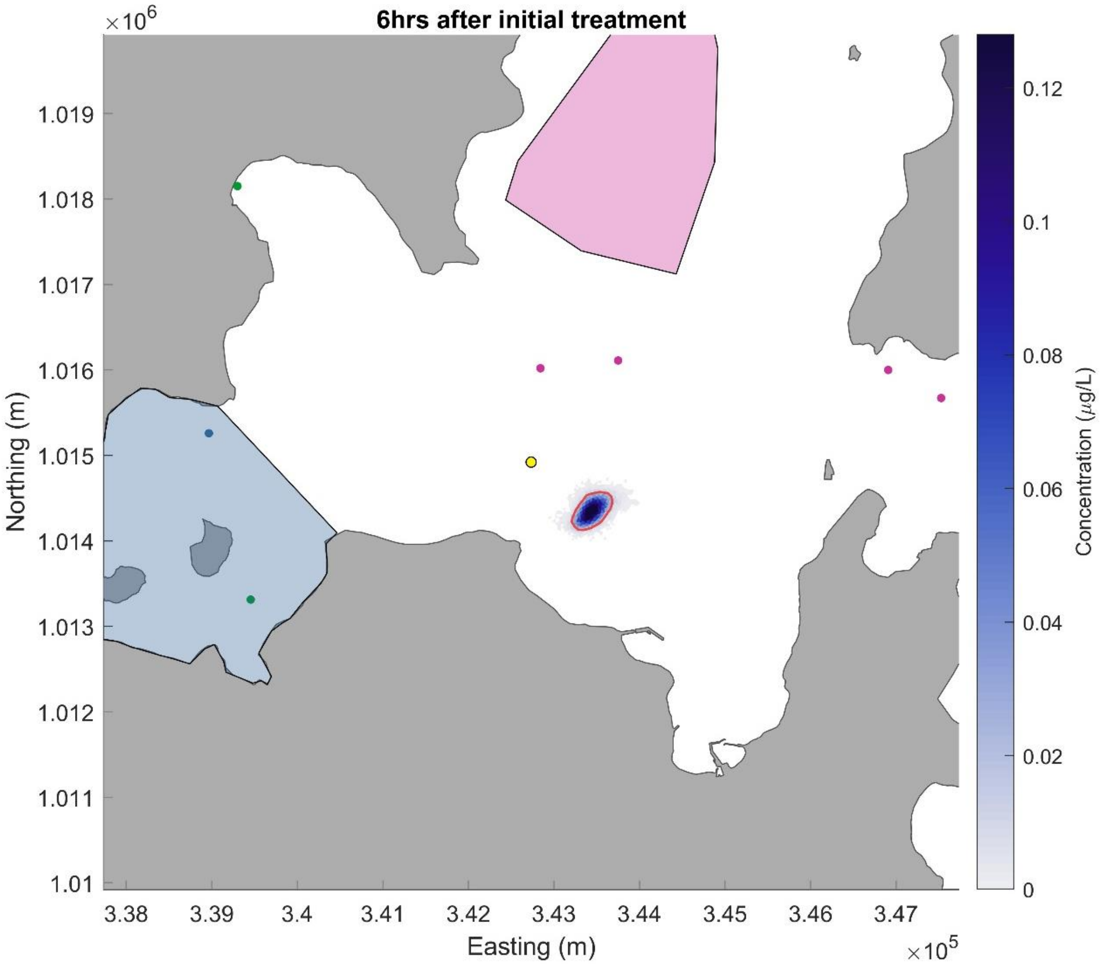

Figure 50. Spatial Cypermethrin distribution for bath treatment releases during neap tides 6hrs after treatment. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.2.2 Spring tides

Short-term exposure during the spring tide is assessed using a single release of 30g of Cypermethrin. Treatment concentration at sensitive features is identified in figure 51. No observable treatment concentrations are shown for any sensitive feature.

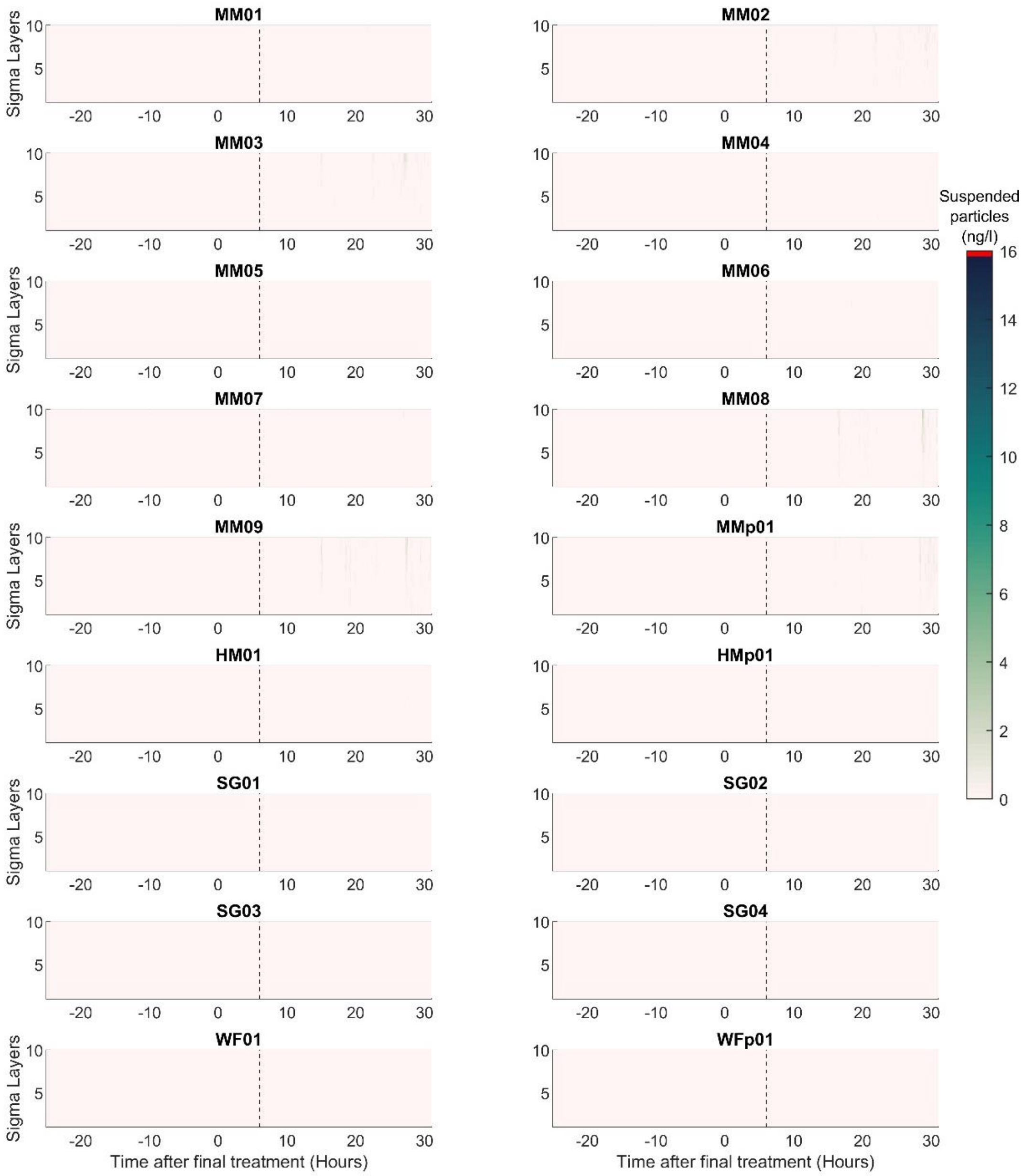

Figure 51. Spring tide Cypermethrin concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar with any values indicated in red that exceed the 6hr EQS value. Water depth is defined in model sigma layers where 1 is the bed cell 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 52 for the 6hr EQS time. After 6hrs no treatment concentrations are shown for any of the identified sensitive marine features.

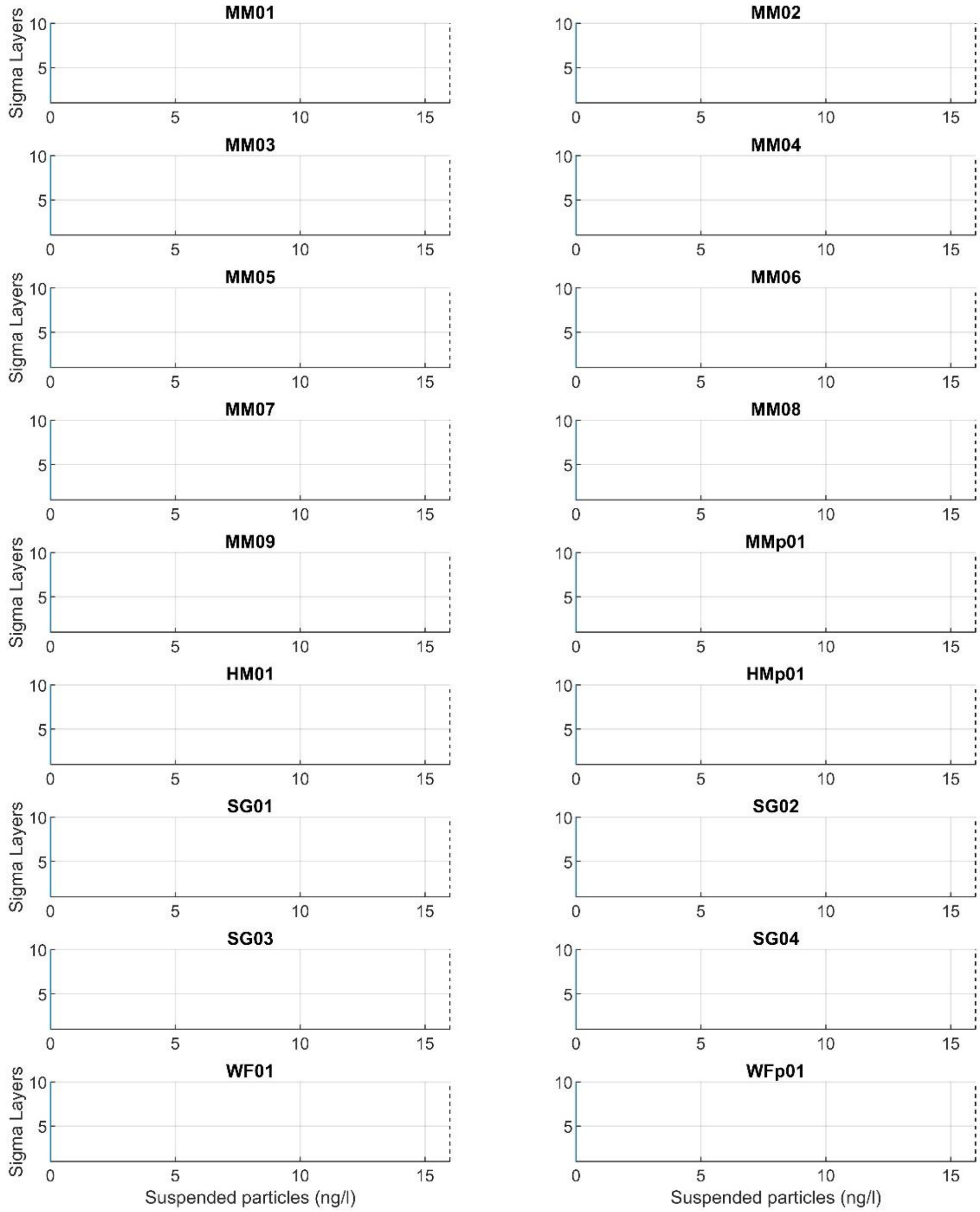

Figure 52. Spring tide vertical concentration profile of Cypermethrin after the single treatment at the 6 hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Cypermethrin is shown relative to the sensitive feature locations in figure 53. Red contour lines are shown for treatment concentrations of 16 ng/l. Treatment plume is shown to be distributed to the south, away from sensitive feature locations.

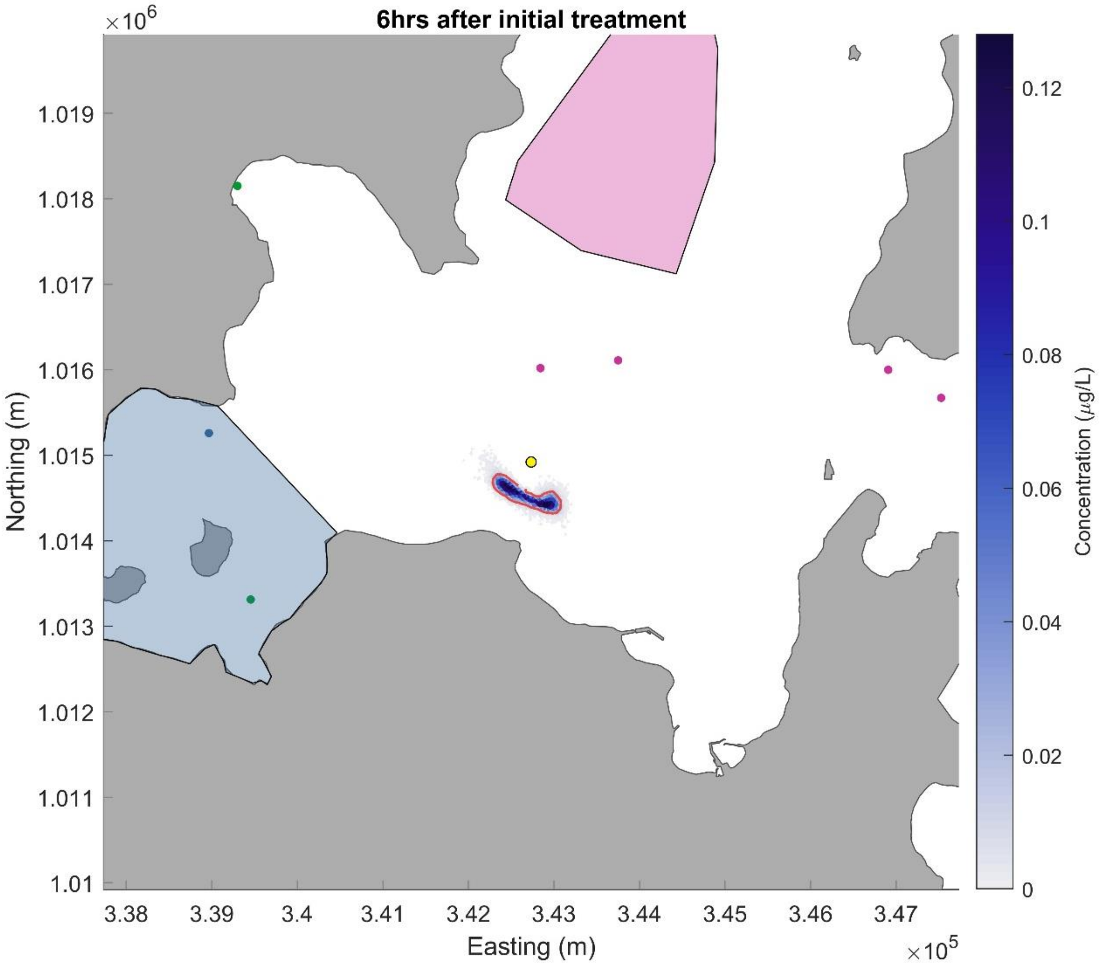

Figure 53. Spatial Cypermethrin distribution for bath treatment releases during spring tides 6hrs after treatment. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.3 Deltamethrin

4.2.3.1 Neap tides

Short-term exposure during the neap tide is assessed using a single release of 40g of Cypermethrin. Treatment concentration at sensitive features is identified in figure 54. For the majority of features no observable treatment concentrations are shown. Features MM01, MM08, MM09 and MMp01 show a minor residue of treatments with a short exposure time. Slightly larger concentrations are shown at MM02, however, this occurs in 2 plumes that quickly passes the location and only occurs in the upper water column.

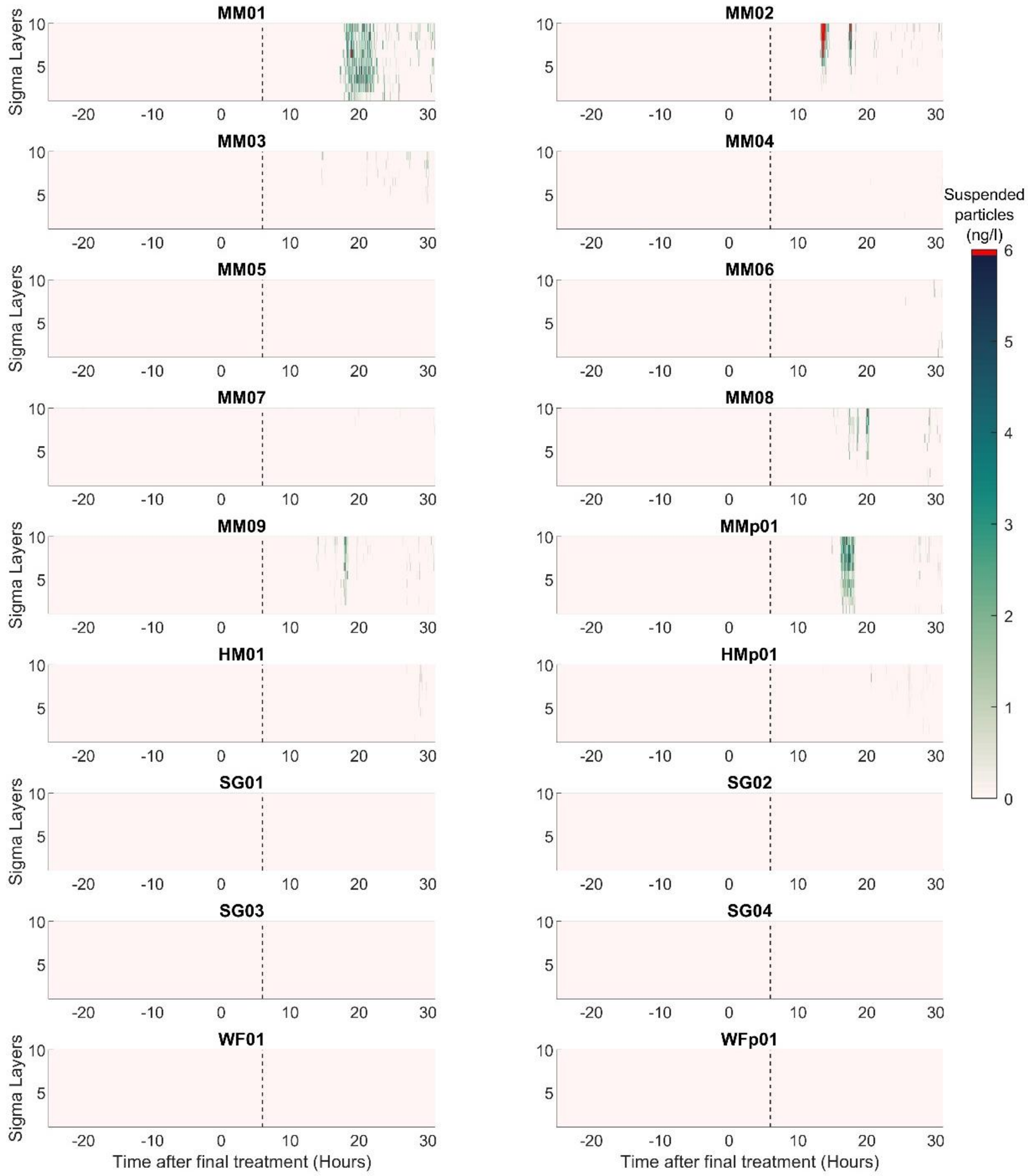

Figure 54. Neap tide Deltamethrin concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar with any values indicated in red that exceed the 6hr EQS value. Water depth is defined in model sigma layers where 1 is the bed cell and 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 55 for the 6hr EQS time. After 6hrs no treatment concentrations are shown for any of the identified sensitive marine features.

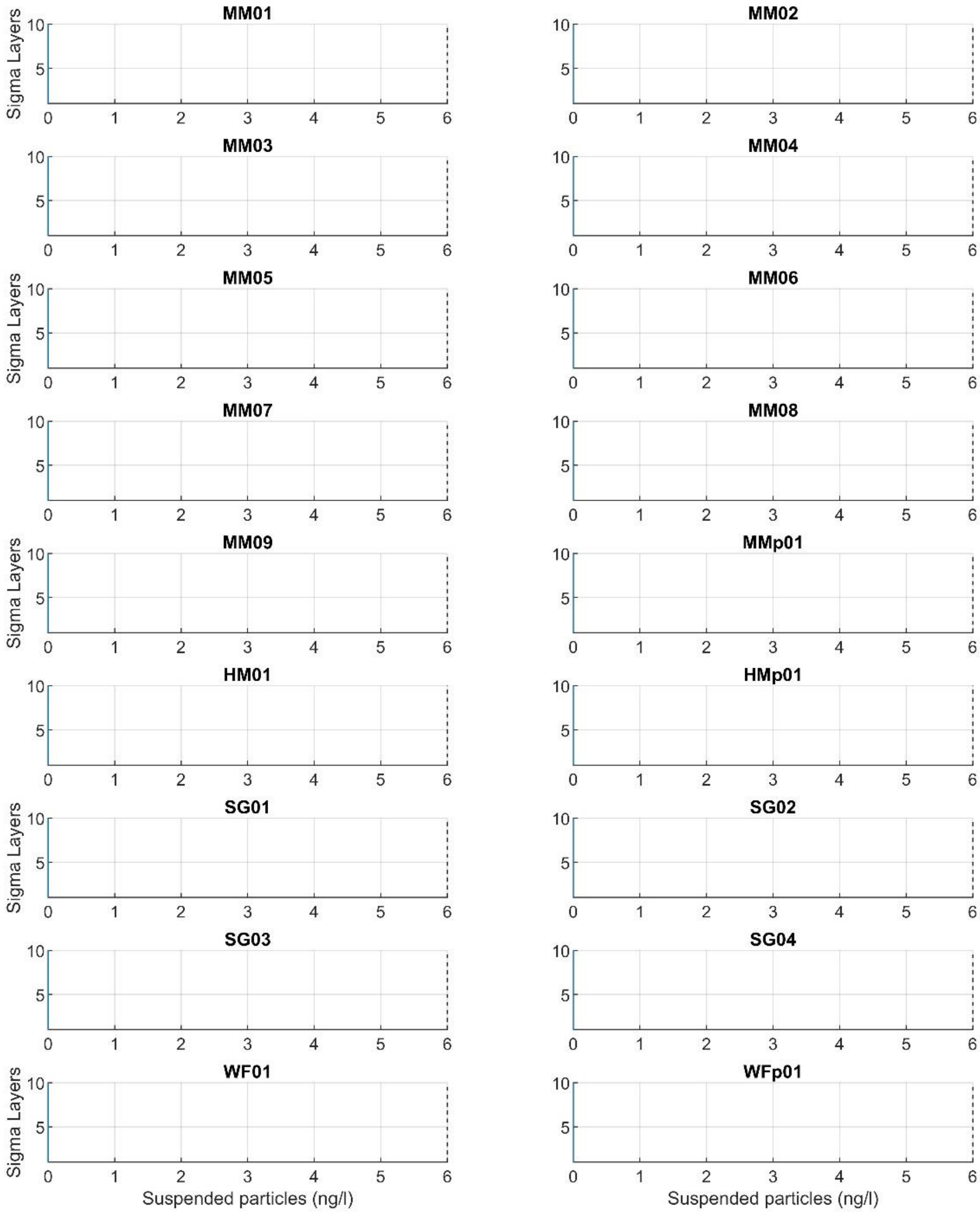

Figure 55. Neap tide vertical concentration profile of Cypermethrin after the single treatment at the 6 hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Deltamethrin is shown relative to the sensitive feature locations in figure 56. Red contour lines are shown for treatment concentrations of 6 ng/l. Treatment plume is shown to be distributed to the southeast away from sensitive feature locations.

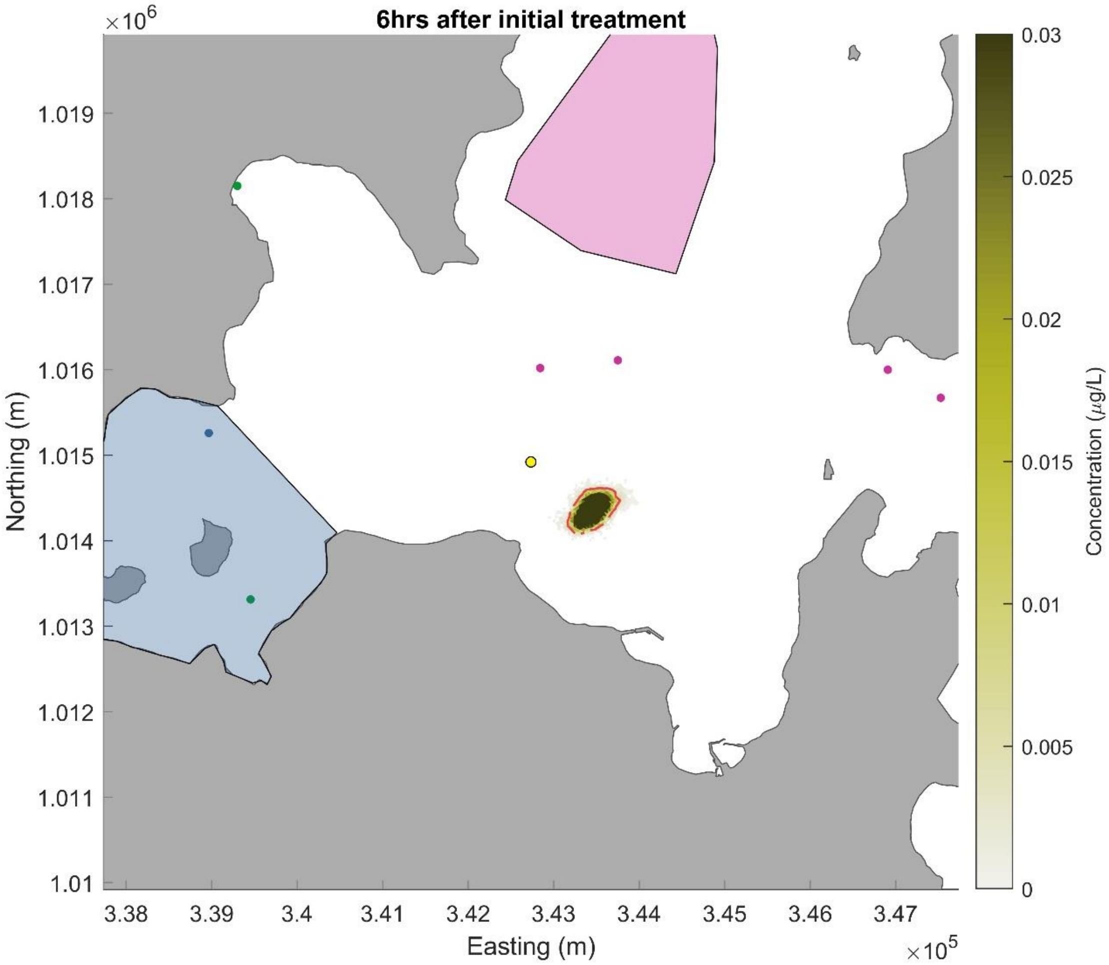

Figure 56. Spatial Deltamethrin distribution for bath treatment releases during neap tides 6hrs after treatment. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

4.2.3.2 Spring tides

Short-term exposure during the spring tide is assessed using a single release of 40g of Deltamethrin. Treatment concentration at sensitive features is identified in figure 57. MM02, MM03, MM08, MM09 and MMp01 show low concentrations of passing treatments. These occur much latter in the simulation around 30hrs after treatment.

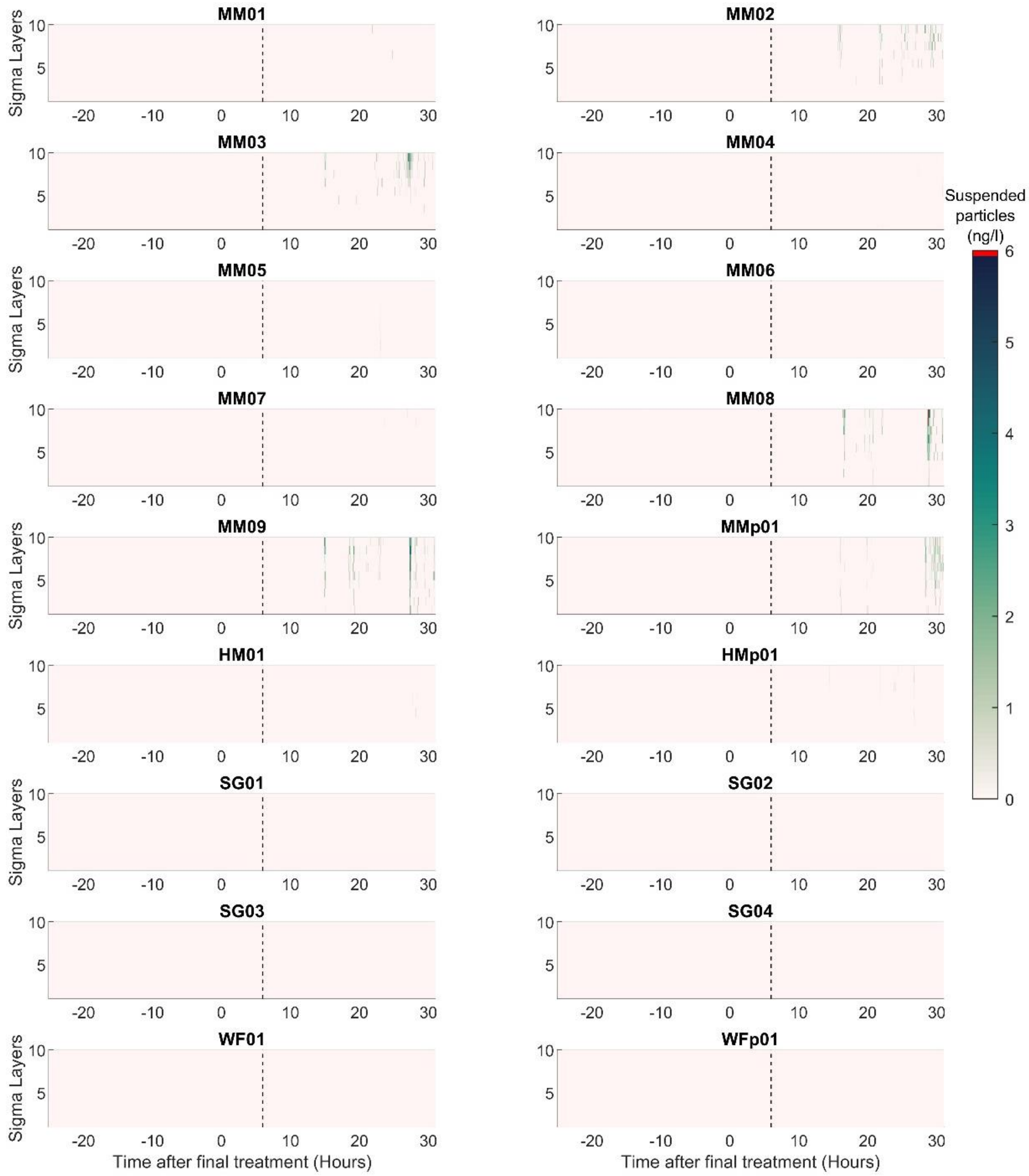

Figure 57. Neap tide Deltamethrin concentration in the water column at identified sensitive marine feature locations. Concentration in ng/l is shown in the colour bar with any values indicated in red that exceed the 6hr EQS value. Water depth is defined in model sigma layers where 1 is the bed cell and 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 58 for the 6hr EQS time. No treatment concentrations are shown for any of the identified sensitive marine features.

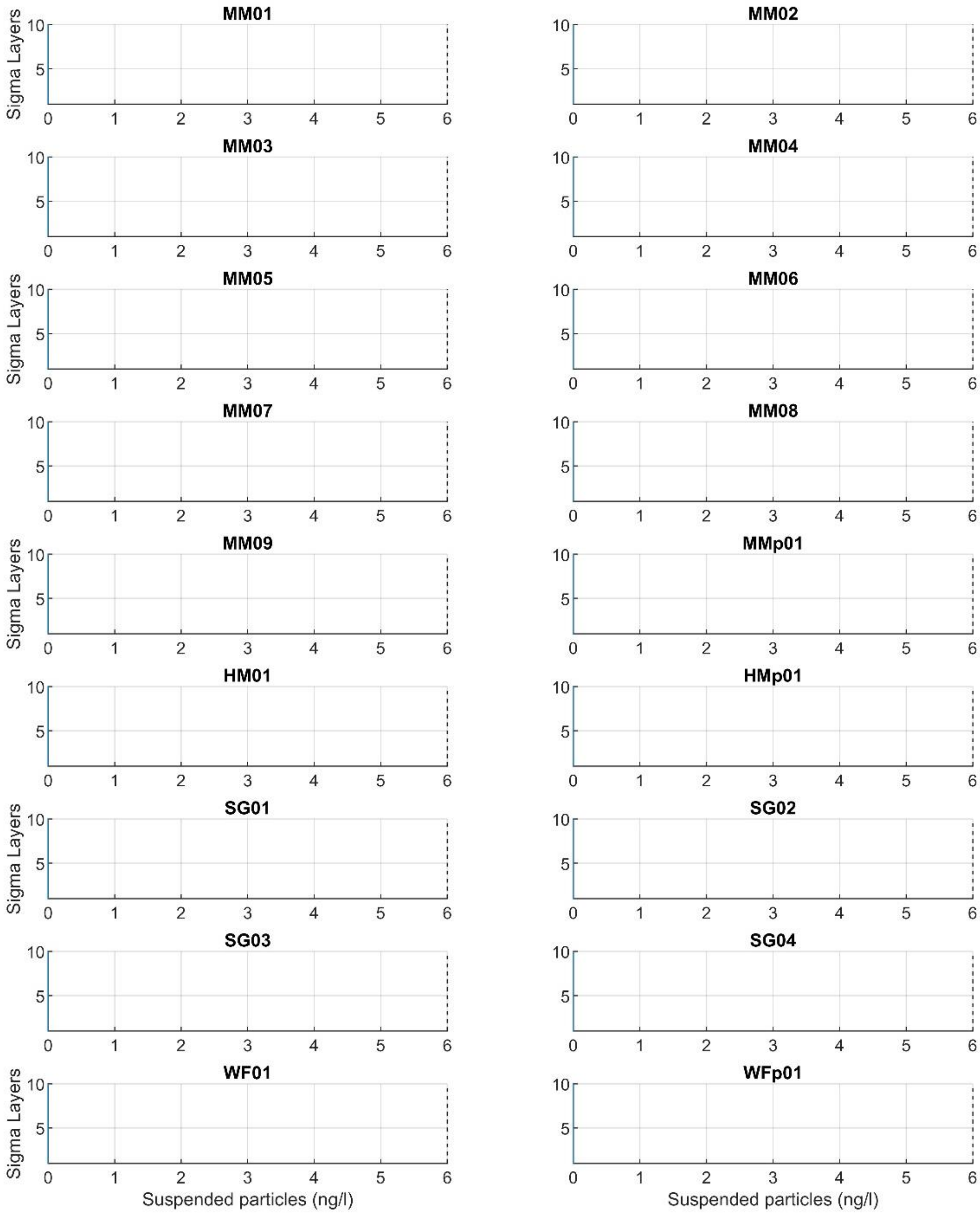

Figure 58. Spring tide vertical concentration profile of Cypermethrin after the single treatment at the 6 hr EQS time. Profiles for all identified sensitive marine feature locations are shown.

The spatial distribution of Deltamethrin is shown relative to the sensitive feature locations in figure 59. Red contour lines are shown for treatment concentrations of 6 ng/l. Treatment plume is shown to be distributed to the south away from sensitive feature locations.

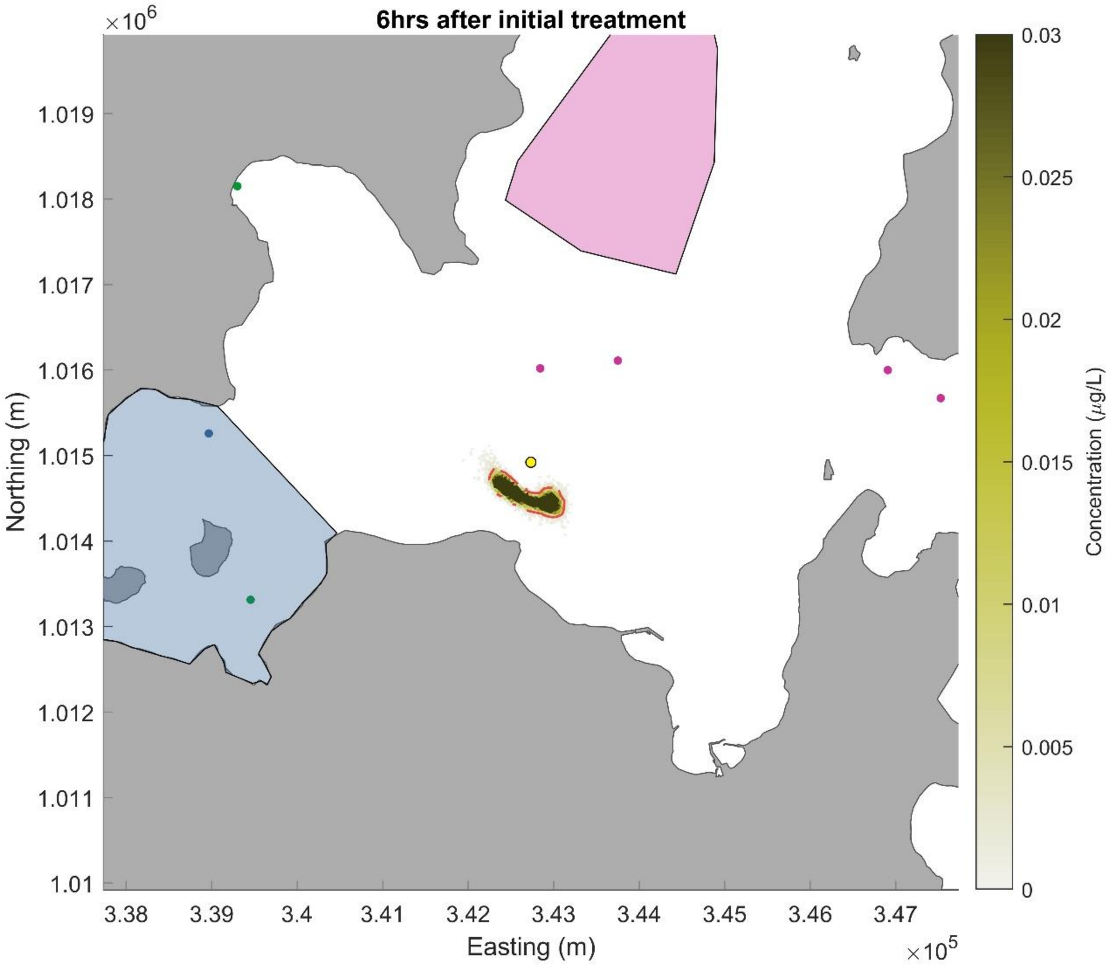

Figure 59. Spatial Deltamethrin distribution for bath treatment releases during spring tides 6hrs after treatment. Areas above EQS values are indicated within the red contour, site location is identified using a yellow marker and PMF location are shown as points or polygons.

5. Conclusions

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

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 3 treatments per day with a treatment interval of 3hrs. For Azamethiphos, modelling of the entire treatment cycle revealed a recommended consent mass of 575g per 24-hour period, or 191.67g per 3-hour window, was shown to be compliant with EQS. This equates to a treatment volume of 1.43 wellboat treatments (1,500m^3 capacity) per 3 hours. For Cypermethrin, modelling of the 6-hour treatment mass revealed an adjusted treatment mass of 0.05618g per 3-hour period. 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 treatment mass of 20g per 3-hours, while maintaining EQS compliance. This provides a treatable volume of 10,000 m^3, equal to 6.66 wellboat treatments (1,500m^3 capacity) per 3-hours.

Azamethiphos, Cypermethrin and Deltamethrin have been assessed at 18 sensitive feature locations and 2 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 MM02, MM03, MM08 and MMp01 are shown to have infrequent and highly diluted interaction with bath treatment plumes. These often occur in the upper water column and pose very little risks to benthic sensitive features. 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 Quanterness using Azamethiphos 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: Quanterness (QUAN1) 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