Bath Modelling Report
East Moclett

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1. Summary

Cooke Aquaculture Scotland Ltd. (CAS) have developed a particle tracking model, forced by a decoupled hydrodynamic model, to simulate simultaneous bath medicine release in the North Sound region. The aim of this work was two-fold: (1) to address the uncertainties regarding cumulative impacts highlighted in the East Moclett Screening modelling and risk identification report by SEPA (2019); and (2) to find appropriate bath chemical amounts for the proposed site whilst ensuring compliance with environmental standards (EQS).

A high resolution MIKE21 hydrodynamic model is used to simulate the flow dynamics across Orkney. Following calibration and validation using ADCP measurements near the proposed site, the hydrodynamic model has been shown to agree well with the measured data, therefore allowing a more accurate estimation of chemical dispersal. A particle tracking model, driven by the hydrodynamic model, was then used to predict the potential environmental influence of chemical discharges from the proposed East Moclett site, alongside 7 other licensed aquaculture sites within the vicinity. Two distinct chemical release scenarios were simulated – a point source wellboat release and an area source tarpaulin release. This allowed the derivation of two compliant masses for each chemical that are specific to the treatment mechanism used.

Maps and EQS results are presented to illustrate the predicted footprint of bath treatment medicines. The results of the bath modelling found the chemical amounts summarised in table 1 complied with all EQS standards. When the cumulative impact of the other 7 licensed farms in the North Sound region are considered, the combined chemical footprint and intensity is greater, but throughout the contribution of the proposed site is compliant with all EQS.

Table 1. Summary of site details and bath treatment results

Stocking details		
Maximum biomass (Tonnes)	3,850	
Pen Layout		
No. pens	6	
layout	2 x 3	
Circumference (m)	160	
Orientation (°)	0	
Bath Treatments		
	Wellboat release	**Tarpaulin release**
Azamethiphos		
Consent mass – 3hr (g)	335.03	295.5
Consent mass – 24hr (g)	1005.1	886.6
Cypermethrin		
Consent mass – 6hr (g)	0.131	0.135
Deltamethrin		
Consent mass – 6hr (g)	92	93

2. Introduction

This report outlines the marine model calibration and validation, as well as the results of the chemical particle tracking model used to determine bath treatment chemical compliance. This uses a hydrodynamic model to replicate coastal processes to drive a particle tracking model. These free-flowing particles simulate chemical dispersion with tidal currents. Conservative model parameters are applied to reduce environmental risk associated with chemical bath treatments. The results are then compared with Environmental Quality Standards (EQS), where modelled chemical concentration and area coverage must remain below stated values.

2.1 Site Details

East Moclett is a new proposed site situated in North Sound, Orkney (figure 1). The site has a proposed maximum consented biomass of 3,850 tons.

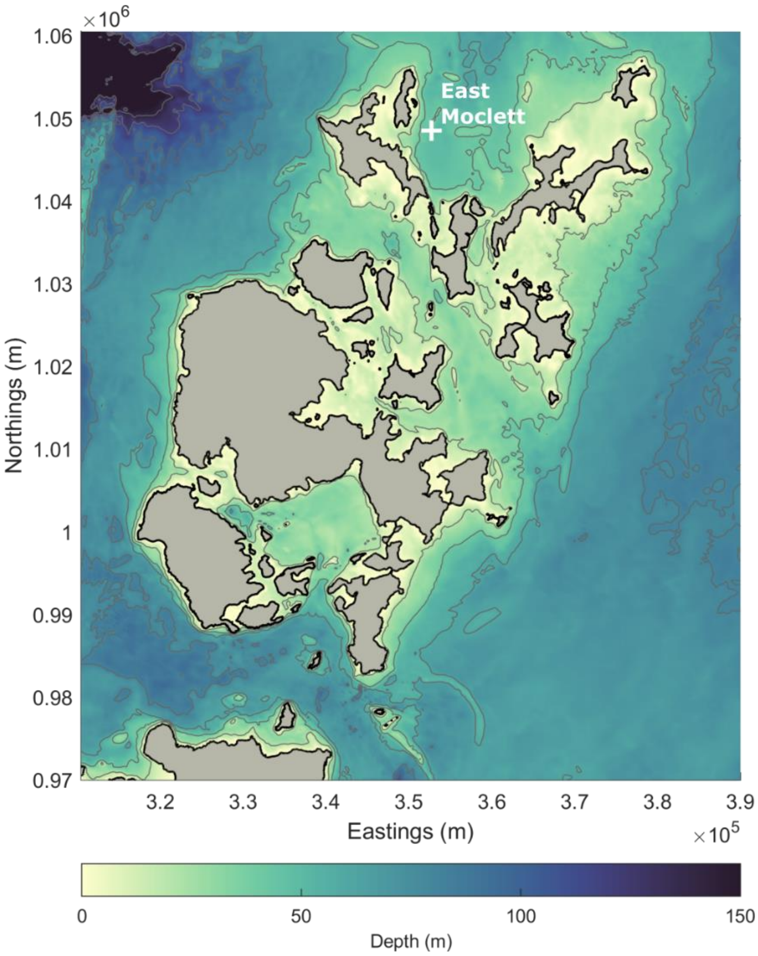

Figure 1. Site location and bathymetry with depth contours at 20m intervals.

The proposed site is located at 352756.5 E, 1048514.6 N (OSGB 1936) and consists of six 160m (circumference) pens. The pen layout is orientated north to south with a bearing of 0 degrees, comprising of two rows of three pens. Pens are moored in 110m grids, with a net depth of 21 m across all pens (table 2).

Table 2 – Site infrastructure and pen layout.

Site Name	East Moclett
Consent number	-
Company	Cooke Aquaculture Scotland
Receiving water	North Sound
Site centre (OSGB36)	352756.5 E, 1048514.6 N
Current meter location (OSGB36) (year of deployment)	352756.5 E, 1048514.6 N (2020) 352521.74 E, 1044976.98 (2021)
Average water depth (m)	54
Maximum biomass (t)	3850
Total number of pens	6
Number of pen groups	1
Formation	2 x 3
Pen group orientation (°)	0
Pen circumference (m)	160

2.2. Objectives of the Modelling Study

Given the existence of several licensed aquaculture sites within North Sound, it is pertinent to explore the cumulative effects of bath medicine discharge on the wider environment. A high resolution MIKE21 hydrodynamic model is used to simulate the flow dynamics across Orkney, the results of which are applied to force MIKE21 particle tracking models which, in turn, are used to predict the potential environmental influence of chemical discharges from the proposed East Moclett site, alongside 7 other licensed aquaculture sites within the vicinity. Maps and EQS results are presented to show the predicted dispersal of bath treatment medicines, and to infer their potential impact.

3. Model Description and Configuration

MIKE21 is used to simulate bath treatment medicine dispersion from the proposed East Moclett site. This uses a calibrated hydrodynamic and particle tracking model to replicate particle emissions from all farms identified within the Screening and Risk Identification report (SEPA, 2019). This utilises better performing spatially varying hydrodynamics to identify particle fate and accumulation near existing farms (table 3).

Table 3. Licensed farms in the North Sound region.

Name	Feature type	Location (OSGB)		Maximum mesh resolution (m^2)
		East (m)	North (m)	
East Moclett	Fish Farm	352756.5	1048514.6	1296 (36m)
Ouseness	Fish Farm	346409	1049759	1296 (36m)
Vestness	Fish Farm	347968	1049310	1296 (36m)
Scarfhall Point	Fish Farm	345252.04	1048407.92	3000 (54m)
Bay of Cleat South	Fish Farm	347064.69	1047147.74	1296 (36m)

Bay of Cleat North	Fish Farm	347297	1047575	1296 (36m)
East of Skelwick Skerry	Fish Farm	352421.73	1044977.27	1296 (36m)
Bay of Tuquoy	Fish Farm	347432	1042761	15000 (122m)

3.1 MIKE21 Hydrodynamic Model

This study uses DHI's MIKE21 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.

The model solves the two-dimensional incompressible Reynolds averaged Navier-Stokes equations, using the Boussinesq and hydrostatic pressure assumptions to simulate 2D hydrodynamics over the domain. 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. This is applied over a cartesian two-dimensional unstructured mesh.

3.1.1 Model Domain

The model boundaries, shown in figure 2a, surround Orkney and the northeast coast of mainland Scotland. 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). A flexible mesh is applied, containing 110,433 nodes and 211,908 elements. The peripheries of the model domain have a coarse resolution, with an approximate cell spacing of 2km. Mesh resolution increases in regions of specific interest or where complex flow patterns are expected (table 3). For example, the areas surrounding the proposed site (figure 2b) and the other North Sound sites where bath chemicals are licensed have a maximum mesh resolution of 1296m^2 (36m).

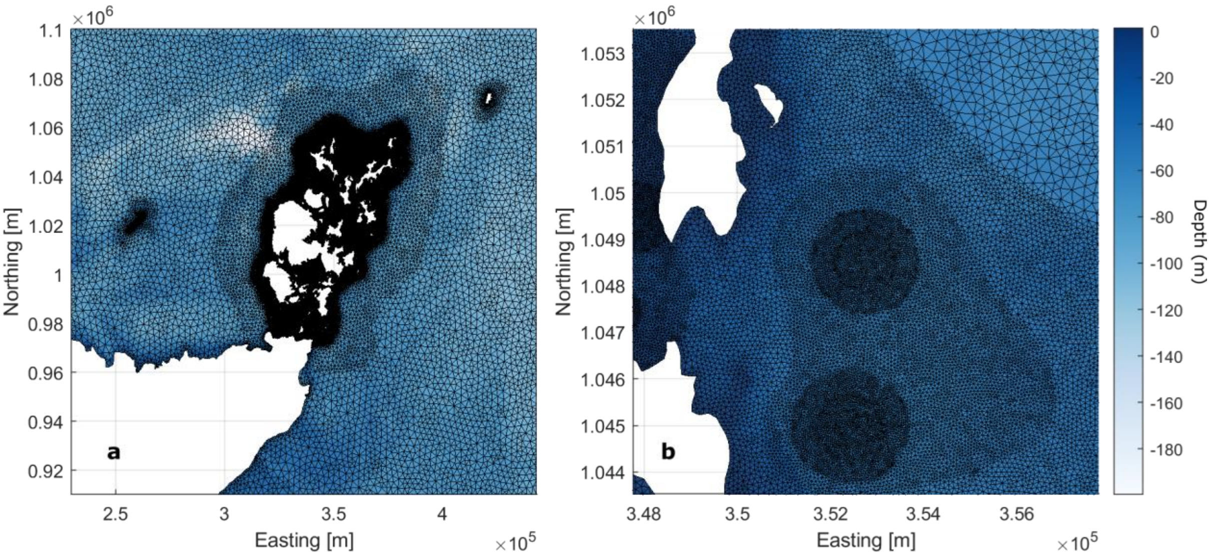

Figure 2. a) wider computational mesh. b) Computational mesh around the proposed East Moclett site.

3.1.2 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 2020). This provides wind velocity in U and V components, as well as surface pressure with a resolution of 0.25°x. 0.25° at a 3-hourly interval.

A 2- dimensional domain is proposed with a time step interval of 60 seconds, with point data outputs at 10-minute intervals and area data outputs at 30-minute intervals. The governing equations use the shallow water equations with high order time integration and spatial discretization. Minimum and maximum timesteps were relaxed to 0.01s and 60s with a critical CFL number of 0.95. 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 Manning number is used as the main calibration term. This parameter is adjusted to calibrate the model.

3.1.3 Calibration and Validation

The model was calibrated using Acoustic Doppler Current Profiler (ADCP) data from sensors deployed within 150 m of the site centre. For calibration, the measured surface elevation and depth averaged velocity was compared to the model outputs. Data statistics are presented to quantify model performance. The model was then validated against a separate measured dataset collected at neighbouring site East of Skelwick Skerry, located approximately 3.5km from the proposed site centre. The calibration and validation datasets cover different time periods ensuring model performance is satisfactory through time and space.

3.1.3.1 Calibration

The process of calibration adjusts the dissipative forcing within the model to compare with observed data. The calibration of the East Moclett hydrodynamic model took place from the 01/11/2020 to the 18/11/2020, using data from an ADCP deployed at 352756.5E, 1048514.6N. A simulation spin-up time of 48 hours was used. The bed resistance was adjusted to ensure the best fit between the observed and modelled water level and current speed. A Manning number of 32 $m^{1/3}/s$ provided optimum results. For the initial calibration and validation, the model included wind boundary forcing.

The statistical parameters and results for the calibration period are shown in table 4 and figure 3. MSL shows a good agreement with a Pearson correlation of 0.983 and mean error values indicating a small deviation of the model and the observed data. The component east and north velocities also show an acceptable level of agreement. However, larger variations exist between the modelled and observed eastward velocity component than for the northward component. Overall, the statistics still indicate a relatively accurate model, surpassing the minimum statistical thresholds outlined in the East Moclett Modelling Methods Statement (Greenwood, 2021).

Table 4. Statistical analysis of the calibrated model.

	MSL	**East**	**North**
Mean absolute error	0.162	0.019	0.039

RMS error	0.206	0.025	0.049
NRMSE (range)	0.0538	0.125	0.070
Correlation	0.983	0.820	0.962

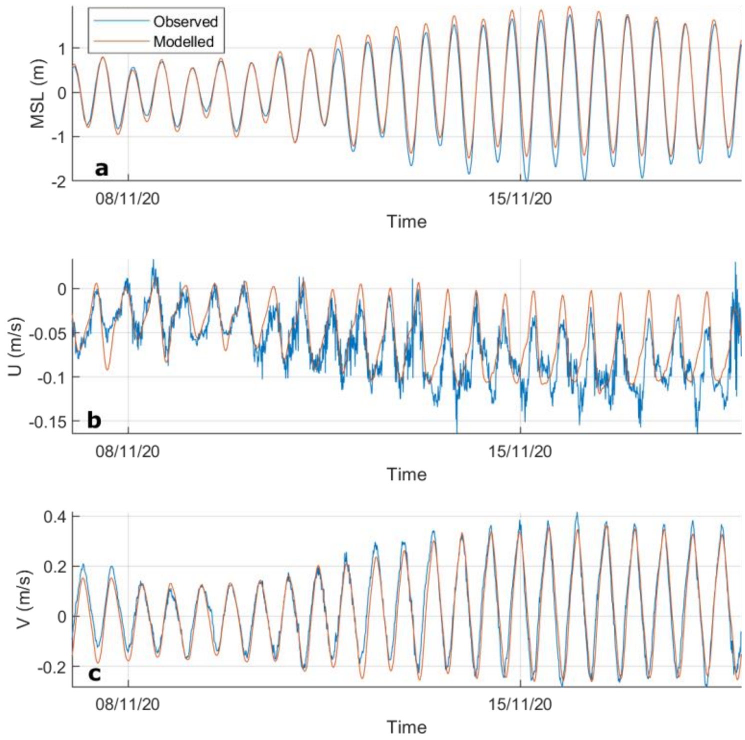

Figure 3. Modelled and observed timeseries for MSL, east and north velocity vectors for the calibration period of 01/11/2020 to the 18/11/2020.

3.1.3.2 Validation

Validation demonstrates the model accuracy by comparing simulated results with an independent observed dataset. The model was validated against a second separate ADCP deployment (352521.74 E, 1044976.98 N) from the 22/04/2021 to the 11/06/2021, covering 50 days. The assessment of the model performance uses the same MSL and east and northerly velocity components. Tidal and wind boundary forcing were updated to match the deployment period where the same bed friction value was applied.

The results of the MSL validation indicate a good agreement between the observed and modelled data. The component east and north velocities are inherently more variable in nature than MSL, meaning velocities are more difficult to predict. Larger discrepancies therefore occur between the observed and modelled velocity than observed and modelled MSL values.

The model appears to under predict the magnitude of the eastward velocity during the largest spring tides. The model better captures the variability in the northward velocity component. However, some under prediction of peak velocities still occurs during large springs. The results of the model validation period are shown in table 5 and figures 4 and 5. The statistical parameters describing model performance comfortably exceed the minimum thresholds outlined in the East Moclett Modelling Methods Statement (Greenwood, 2021).

Table 5. Statistical analysis of the validated short-term hydrodynamic model.

	MSL	**East**	**North**
Mean absolute error	0.106	0.019	0.027
RMS error	0.130	0.024	0.037
NRMSE (range)	0.033	0.059	0.085
Correlation	0.988	0.898	0.922

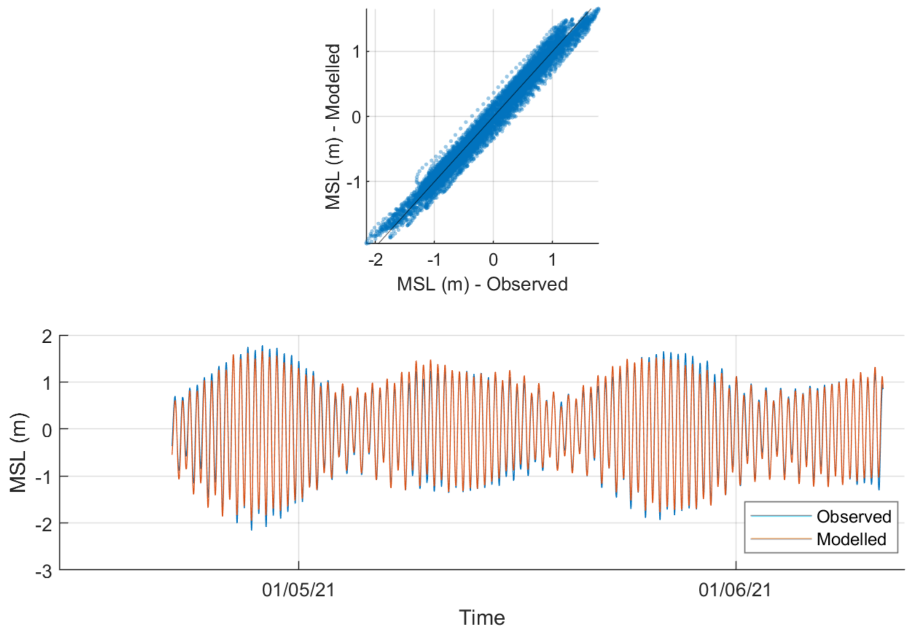

Figure 4. Mean sea level comparison for the validation period of 22/04/2021 to the 11/06/2021.

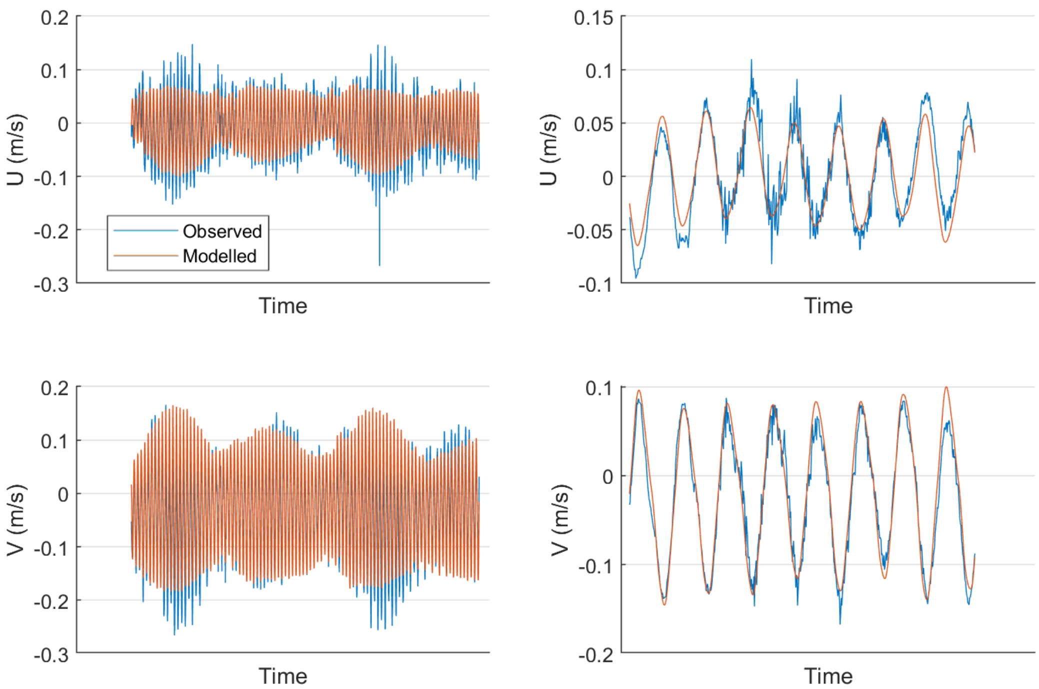

Figure 5. East and North velocity vectors for the validation period of 22/04/2021 to the 11/06/2021.

The distribution of the occurrence of speed is presented in figure 6 for the validation period. There is an increase in the percentage of lower flow speed occurrences within the modelled data (orange). The underestimation of velocity magnitude within the model can clearly be seen. There are no occurrences of velocities greater than 0.2m/s within the modelled data, whereas velocities up to 0.3m/s are observed in the ADCP dataset.

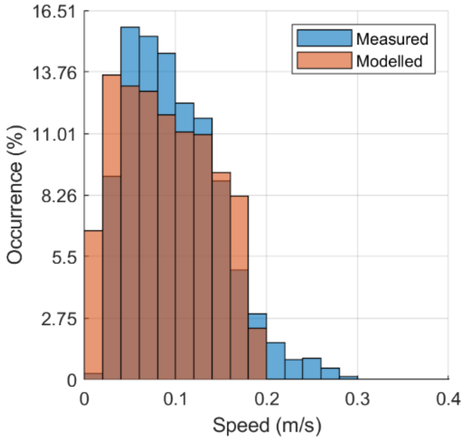

Figure 6. Observed (blue) and modelled (red) horizontal speed distribution for the validation period of 22/04/2021 to the 11/06/2021.

3.2 MIKE21 Bath Model

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

3.2.1 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. Default values of 0.1 and 0.001m^2/s were used for the horizontal and vertical dispersion coefficients, respectively.

3.2.2 Particle Source

For each bath chemical a series of two distinct model runs were carried out, those simulating a treatment regime using a wellboat and those simulating treatments using a tarpaulin.

3.2.2.1 Wellboat Release

Particles are 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 1m below the surface.

3.2.2.2 Tarpaulin Release

Particles are released instantaneously from an area source within the particle tracking model. As the treatment of individual pens in succession is not feasible within MIKE21, a central representative pen is used for all treatments. Particles are released at a depth of 1.5 m with a layer thickness of 3 m. This replicates a 3 m net depth during treatment.

3.2.3 Treatments

For every site, the maximum number of treatments is restricted to three per working day. This is the maximum number of treatments that could feasibly be conducted during a single day. For Azamethiphos, this permits 335.03g be used for each pen treatment with a wellboat at the proposed East Moclett site or 295.5g for each pen treatment with a tarpaulin. For Deltamethrin and Cypermethrin the chemical consent values provided in table 6 are permitted over a 3-hour period, allowing individual pen treatments of the consented amount.

Site specific treatment details are specified in table 6. While Scarfhall Point, Bay of Cleat South and Bay of Tuquoy were listed in SEPA (2019), no bath treatments are included in their licenses, so these sites are not considered in any of the cumulative bath treatment analyses. Similarly, Azamethiphos and Deltamethrin treatments are not included in the licenses of Ouseness, Vestness and Bay of Cleat North. Again, these sites are omitted from the modelling and analysis of these chemicals.

Table 6. Site details for bath treatment model.

Site	Easting (m)	Northing (m)	Pen Circumference (m)	Number of Pens	Azamethiphos (g/24hrs)		Deltamethrin (g/3hrs)		Cypermethrin (g/3hrs)	
					Wellboat	Tarp	Wellboat	Tarp	Wellboat	Tarp
East Moclett*	352756.5	1048514.6	160	6	1005.1	886.6	46	46.5	17.5**	18**
Ouseness	346409	1049759	80	16	0	0	0	0	47.1	47.1
Vestness	347968	1049310	80	16	0	0	0	0	49.44	49.44
Scarfhall Point	345252.04	1048407.92	50	8	0	0	0	0	0	0
Bay of Cleat South	347064.69	1047147.74	50	8	0	0	0	0	0	0
Bay of Cleat North	347297	1047575	80	20	0	0	0	0	87.92	87.92
East Skelwick Skerry	352421.73	1044977.27	130	8	363.1	363.1	26	26	69.2	69.2
Bay of Tuquoy	347432	1042761	-	-	0	0	0	0	0	0

*Proposed site information
**Mass required to be divided by 267 to achieve compliant consent mass.

To explore cumulative impacts of concurrent farm treatments, the treatment schedules across all licensed sites within the North Sound region were synchronised with respect to the first or last treatment event, depending on the chemical specific EQS time frame. For Azamethiphos, the chemical plume area exceeding the EQS threshold for 72 hours after the final treatment was used to explore cumulative contribution, therefore treatment schedules were synchronised to end at the same time. Whereas, for Cypermethrin and Deltamethrin, the chemical plume area exceeding the EQS threshold for 6-hours after the initial treatment was used to explore cumulative contribution, therefore treatments were synchronised across sites to begin at the same time. To capture both the most and least dispersive cumulative EQS scenarios, the synchronised final treatment for Azamethiphos and the synchronised initial treatment for Deltamethrin and Cypermethrin were chosen to coincide with highwater of the smallest neap tide and largest spring tide. This provides a synchronised treatment time of 19/05/2021 14:00:00 during a neap tide and 28/04/2021 09:30:00 during a spring tide. Timings of each bath model run are shown in figures 7 and 8.

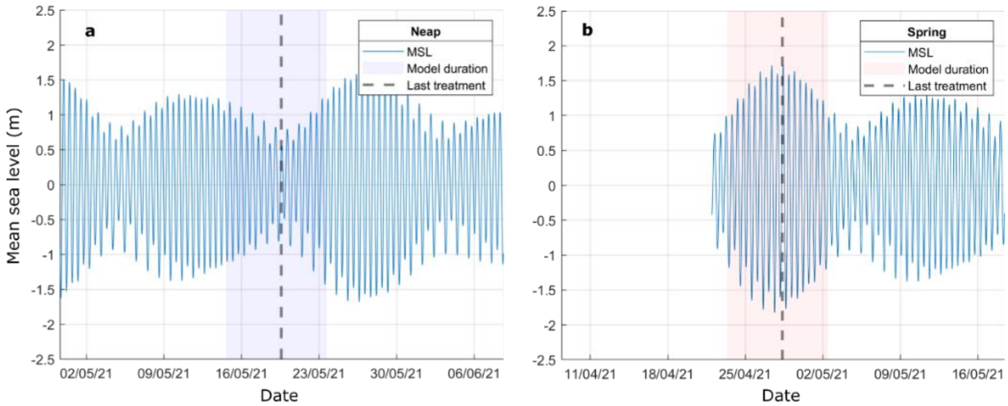

Figure 7. Mean sea level for Neap (a) and Spring (b) tides indicating model simulation duration for Azamethiphos with the final treatment from all sites indicated.

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 licensed farms of the North Sound region. The maximum chemical concentration and areal extent of the chemical plume captured 72-hour 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.

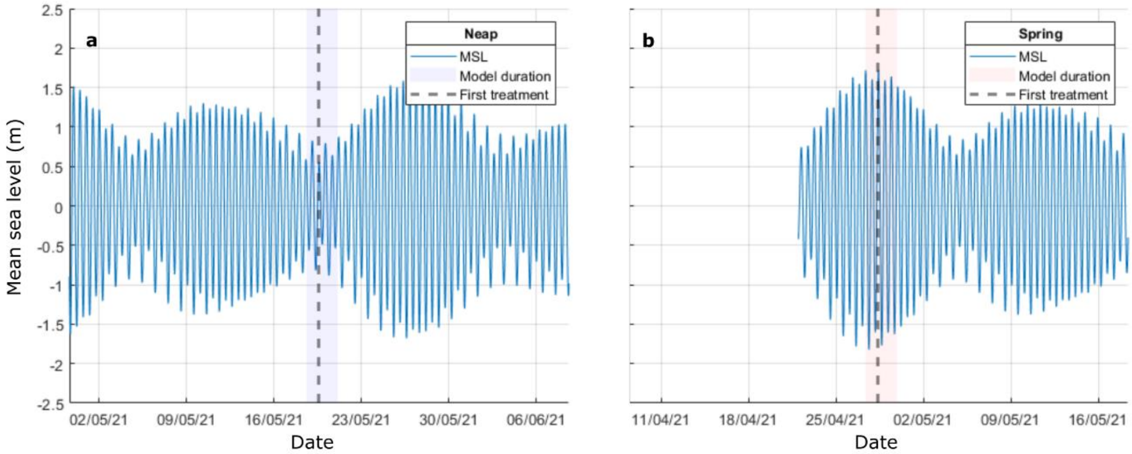

Figure 8. Mean sea level for Neap (a) and Spring (b) tides indicating model simulation duration for Cypermethrin and Deltamethrin with the final treatment from all sites indicated.

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.

The mechanism of particle release within the model differs depending on whether the bath chemicals are administered using a wellboat or tarpaulin. These are described in turn below and figures 9 and 10 provide a schematic illustrating the differences in the particle release methodology.

3.2.3.1 Wellboat Release

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.

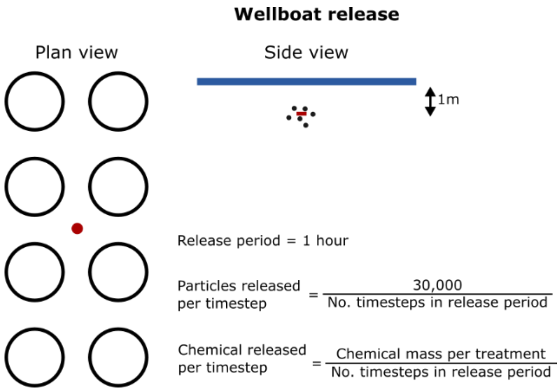

Figure 9. Wellboat release schematic. Open black circles represent pen locations, particle source location is shown in red, the blue line represents the sea surface and small black dots represent particles.

3.2.3.2 Tarpaulin Release

To ensure multiple options and flexibility for bath medicine administration, tarpaulin releases have also been simulated. To realistically simulate this treatment process, particle releases will be timed to coincide with expected treatment intervals. A treatment plan consisting of three 3-hour tarpaulin treatments per working day is applied. At the end of the 3-hour treatment interval, 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. This is consistent with the total number of particles per treatments used in the wellboat models described in the preceding section. The chemical mass assigned to the tarpaulin particle release is defined as the total amount used for the treatment of one pen.

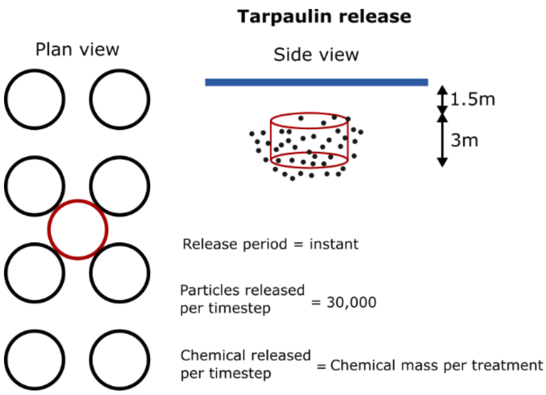

Figure 10. Tarpaulin release schematic. Open black circles represent pen locations, particle source location is shown in red, the blue line represents the sea surface and small black dots represent particles.

3.2.4 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 (2021) for Azamethiphos, Cypermethrin and Deltamethrin treatments (table 7). 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 East Moclett reveal a mean near-surface current speed of 0.169m/s over the period 10/09/2020 to 30/12/2020, which gives a 3-hour EQS area of $0.266km^2$ and a 6-hour EQS area of $0.754km^2$. 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 7. 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).				

4. Results

4.1 Modelled Flow Fields

The modelled flow dynamics across the North Sound region during peak spring-neap, flood and ebb tides are shown in figure 11. At the proposed East Moclett site, a southern flow (~0.25m/s) is observed during the spring flood tide. This reverses to a northern flow (~0.24m/s) during spring ebb tides. Neap tides follow the same direction as their spring counterparts. However, flow velocities are reduced to ~0.1m/s.

There is a general anticlockwise circulation pattern within North Sound during the flood tide. High velocity flow enters the North Sound to the northwest, as it is constrained and accelerated through Papa Sound and around the northern tip of Papa Westray. Flow speed decreases with distance southwards as the water travels towards and along the NE Westray coastline. Localised high velocity jets and intense eddies are generated as the flow is forced through a series of narrow sounds at the southern extent of the North Sound (e.g., Lashy Sound and Calf Sound). The water that does not propagate southwards through this series of channels, travels northwards approximately parallel to the Sanday coastline, and leaves North Sound to the north-east.

During the ebb tide there is a clockwise circulation pattern across the North Sound, flow enters from the north-east (0.4m/s), steered around the north of Sanday, and from the south (>2m/s) accelerated through the narrow sounds between Sanday and Westray. Lower velocity flow (<0.2m/s) propagates north-westwards along the Westray coastline and through the collection of licensed sites within south Papa Sound. Ebbing flow then leaves North Sound as two high velocity jets east and west of northern Papa Westray.

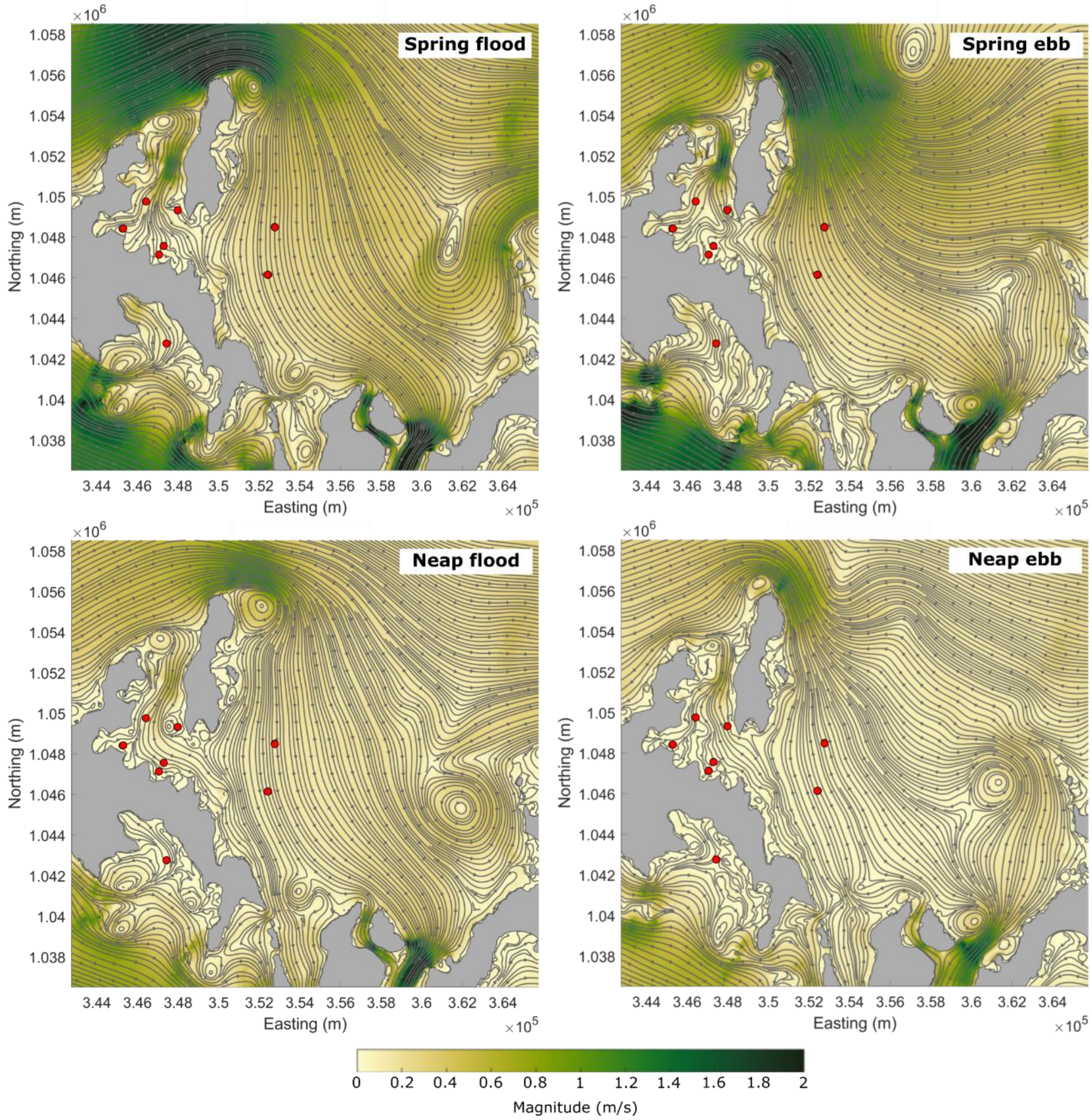

Figure 11. North Sound modelled flow field at peak flooding and ebbing tides for the spring-neap tidal cycle. Grey lines represent flow streamlines and licensed site centres are illustrated by red circles.

4.2 Bath Treatment Particle Tracking

4.2.1 Wellboat release

The simulation of wellboat bath treatments from all sites within North Sound 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 8. This indicates compliance is achieved with all proposed chemical treatments.

Table 8. Environmental standards for wellboat release MAC and area EQS for all treatments at East Moclett.

	Treatment Quantity (g)	MAC 72 hrs (µg/l)	EQS 3hrs (km^2)	EQS 6hrs (km^2)	EQS 72hrs (km^2)
Azamethiphos					
Neap	335.03	0.072 (71.8%)	0.09 (31.9%)	-	0.28 (55.7%)
Spring	335.03	0.023 (23.3%)	0.07 (25.7%)	-	0 (0%)
Cypermethrin					
Neap	35	-	-	0.35 (45.8%)	-
Spring	35	-	-	0.51 (66.9%)	-
Deltamethrin					
Neap	92	-	-	0.35 (45.8%)	-
Spring	92	-	-	0.5 (66.9%)	-

4.3.1.1 Azamethiphos

Compliance was achieved at the proposed East Moclett site using 1005.1g of Azamethiphos within a 24-hour period. This equated to 335.03g per pen assuming three wellboat treatments per day with a 3-hour interval. This corresponds to a treatable volume of 3350.3 m^3 per 3 hours.

4.3.1.1.1 Neap Tides

The dispersal of Azamethiphos is calculated for a neap tidal phase. The particle tracking model is started on the 13/05/2021 12:00:00 and finishes on 23/05/2021 16:00:00. The last treatment release period begins at all sites on the 19/05/2021 14:00:00, lasts for one hour and ends on the 19/05/2021 15:00:00. This period corresponds with the timing of the lowest high-water event within the spring/neap cycle. The run time provides over 96 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

To assess the short-term compliance for Azamethiphos, a single wellboat release of a 3-hour mass (335.03g) 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 12. The size of the chemical plume after a single treatment always remains less than the calculated mixing area of 0.27km^2.

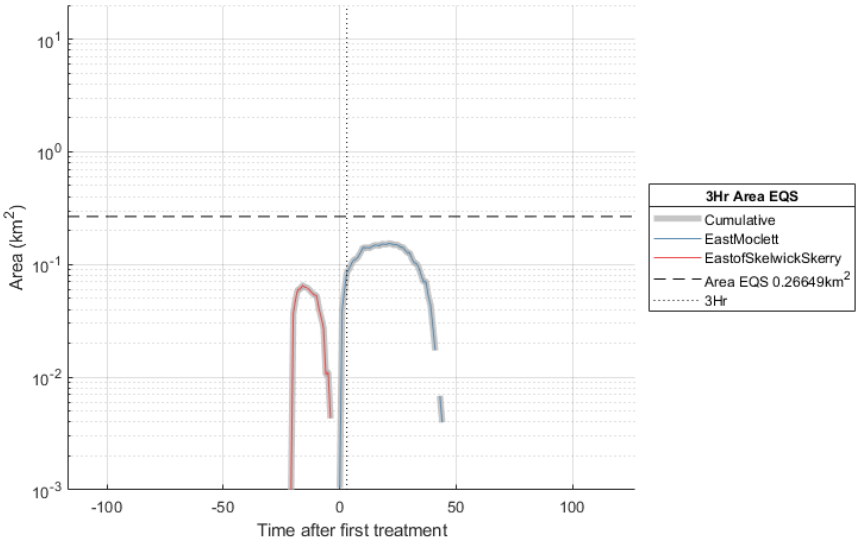

Figure 12. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after the initial 3-hour mass wellboat release of Azamethiphos during neap tides. The size of the 3-hour EQS mixing zone is shown by the horizontal dashed line. 3-hours after the initial treatment is marked by the vertical dotted line.

To assess the longer-term risks from Azamethiphos, a full treatment cycle is modelled. The MAC for the neap tidal cycle is plotted in figure 13. 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 East Moclett site is 0.0718 µg/l, this is 71.8% of the EQS value. Following this the concentration increases slightly, peaking after 77 hours at 0.089 µg/l, as the chemical is transported and concentrated within eddy systems located south and west of the proposed site. A general decline in concentration is observed over the remainder of the model run period and no cumulative chemical quantities exceed 0.1 µg/l again.

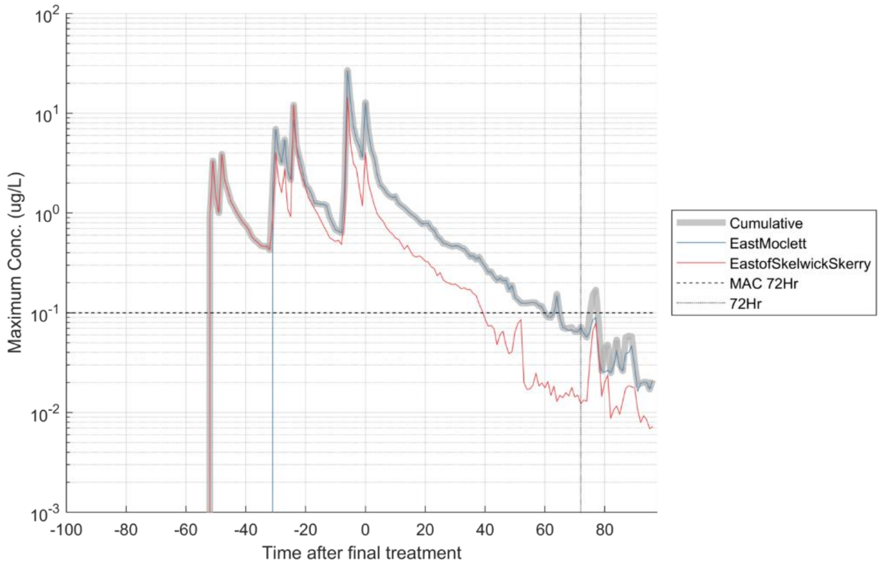

Figure 13. Maximum concentration of Azamethiphos during a neap tide wellboat treatment schedule. Cumulative impact plotted as solid grey line and MAC for the 72-hour EQS (100 ng/l) is indicated by the grey dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The area of the chemical plume exceeding 40ng/l (72-hour EQS) is plotted in figure 14. At the 72-hour EQS time, the area exceeding 40 ng/l is less than 0.5km^2 for East Moclett. The chemical plume originating from East Moclett forms the dominant contributor to the cumulative EQS areas.

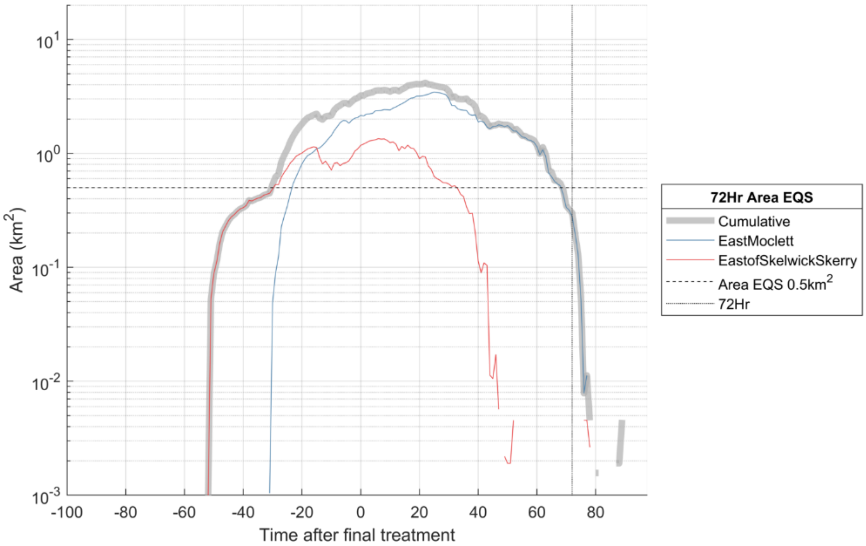

Figure 14. Chemical plume area exceeding the 72-hour (40 ng/l) EQS values after a wellboat treatment cycle using Azamethiphos during neap tides. The size of the 72-hour EQS mixing zone is shown by the horizontal dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The spatial distribution of Azamethiphos after the simultaneous release of bath treatments from all sites during neap tides is shown in figure 15. The areas where concentrations exceed the 3- and 72-hour EQS values are outlined in red. The 3hr EQS (figure 15a) indicates a single confined and concentrated plume <1km south of East Moclett following the initial wellboat release. The 72hr EQS (figure 15b) shows a larger spatial distribution of the chemical with far lower concentrations. The areas whose cumulative concentration is >40ng/l are located further from the releasing farms, within the recirculating flow to the south and west.

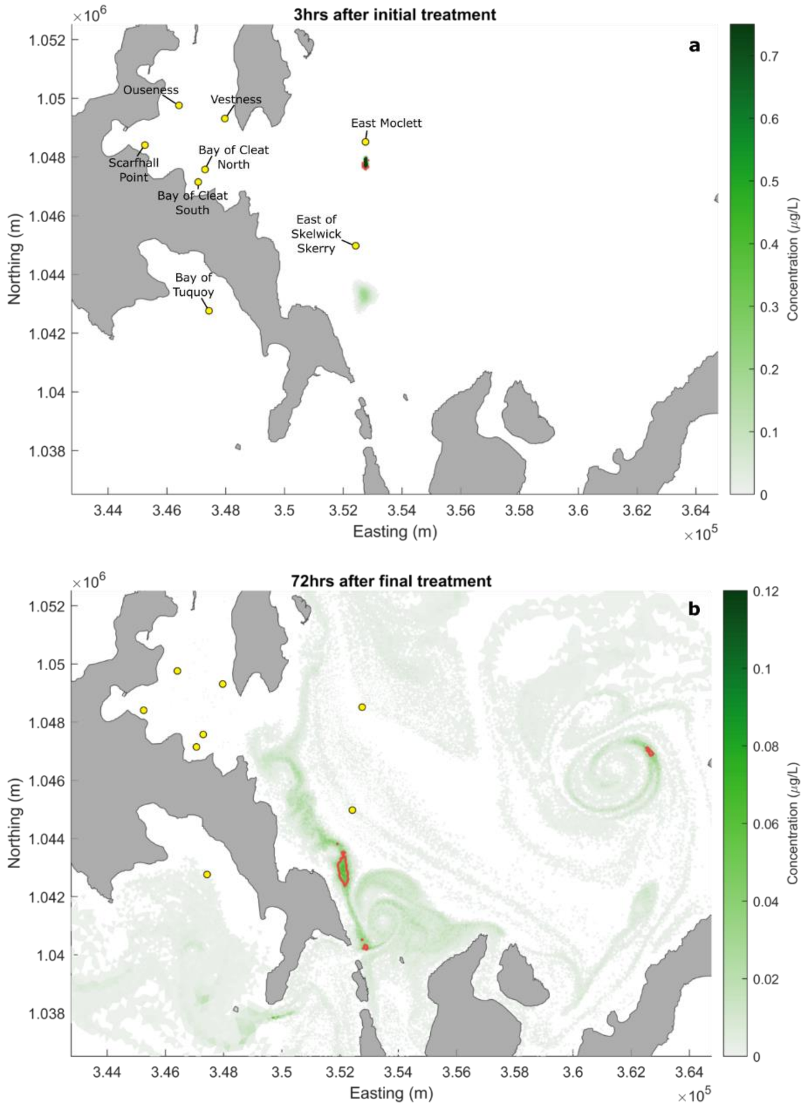

Figure 15. Spatial Azamethiphos distribution for wellboat releases during neap tides 3hr after the initial 3-hour mass release (a) and 72hr (b) after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.1.1.2 Spring Tides

The dispersal of Azamethiphos is calculated for a neap tidal phase. The particle tracking model is started on the 22/04/2021 06:00:00 and finishes on 02/05/2021 10:30:00. The last treatment release period begins at all sites on the 28/04/2021 08:00:00, lasts for one hour and ends on the 28/04/2021 09:00:00. This period corresponds with the timing of the lowest high-water event within the spring/neap cycle. The run time provides over 96 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

To assess the short-term compliance for Azamethiphos, a single release of a 3-hour mass (335.03g) 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 16. The size of the chemical plume after a single treatment always remains less than the calculated mixing area of 0.27km^2. No plumes with concentrations exceeding 250ng/l exist 23 hours after a single treatment event.

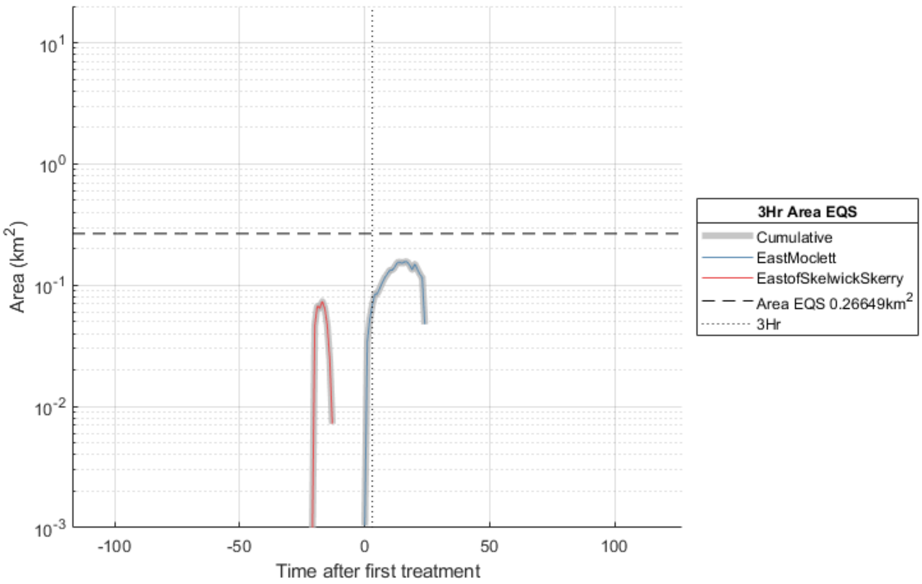

Figure 16. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after the initial 3-hour mass wellboat release of Azamethiphos during spring tides. The size of the 3-hour EQS mixing zone is shown by the horizontal dashed line. 3-hours after the initial treatment is marked by the vertical dotted 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 17. 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 East Moclett site is 0.023µg/l, this is 23.3% 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 cumulative values exceeding 0.1 µg/l.

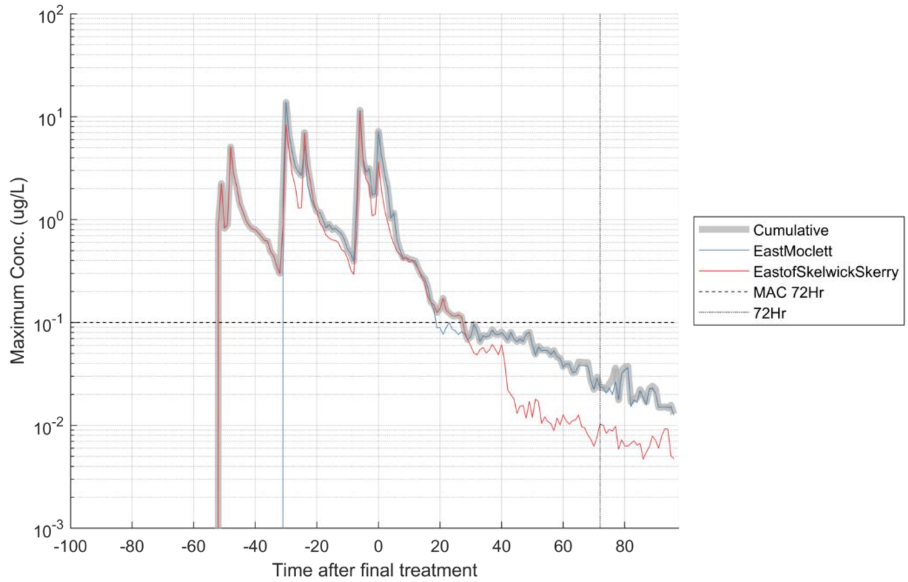

Figure 17. Maximum concentration of Azamethiphos during spring tide wellboat releases. Cumulative impact plotted as solid grey line and MAC for the 72-hour EQS (100 ng/l) is indicated by the grey dotted line. 72-hours after the final treatment is marked by the vertical dotted line.

The area exceeding the 72hr EQS value is plotted in figure 18 for the spring tide. The increased dispersion associated with the larger spring current speeds results in a faster decline in the size of the area exceeding the 72-hour EQS threshold. At 72 hours after the last treatment there are no chemical plumes with a concentration greater than 40 ng/l originating from East Moclett.

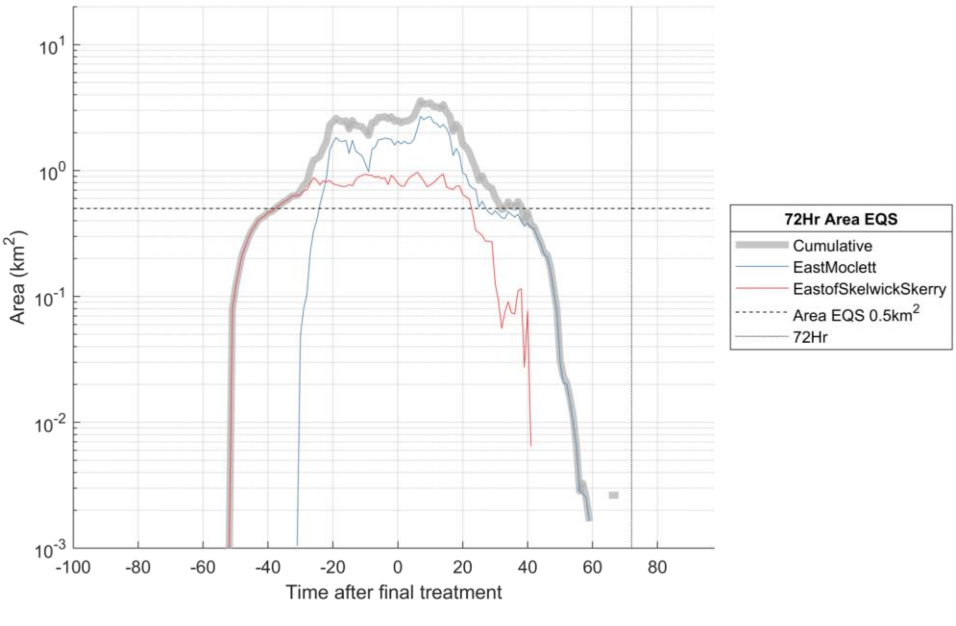

Figure 18. The chemical plume area exceeding the 72-hour (40 ng/l) EQS values after wellboat release of Azamethiphos during spring tides. The size of the 72-hour EQS mixing zone is shown by the horizontal dashed line. 72-hours after the final treatment is marked by the vertical dotted line.

The spatial distribution of Azamethiphos during spring tides is shown in figure 19. Following a single treatment release, the 3hr EQS shows a confined areal coverage above the EQS threshold localized to regions close to the releasing farms. The 72-hour EQS shows chemical plumes from all sites to have been entirely dissipated, forming very low concentrations across the model domain 72 hours after the final wellboat release.

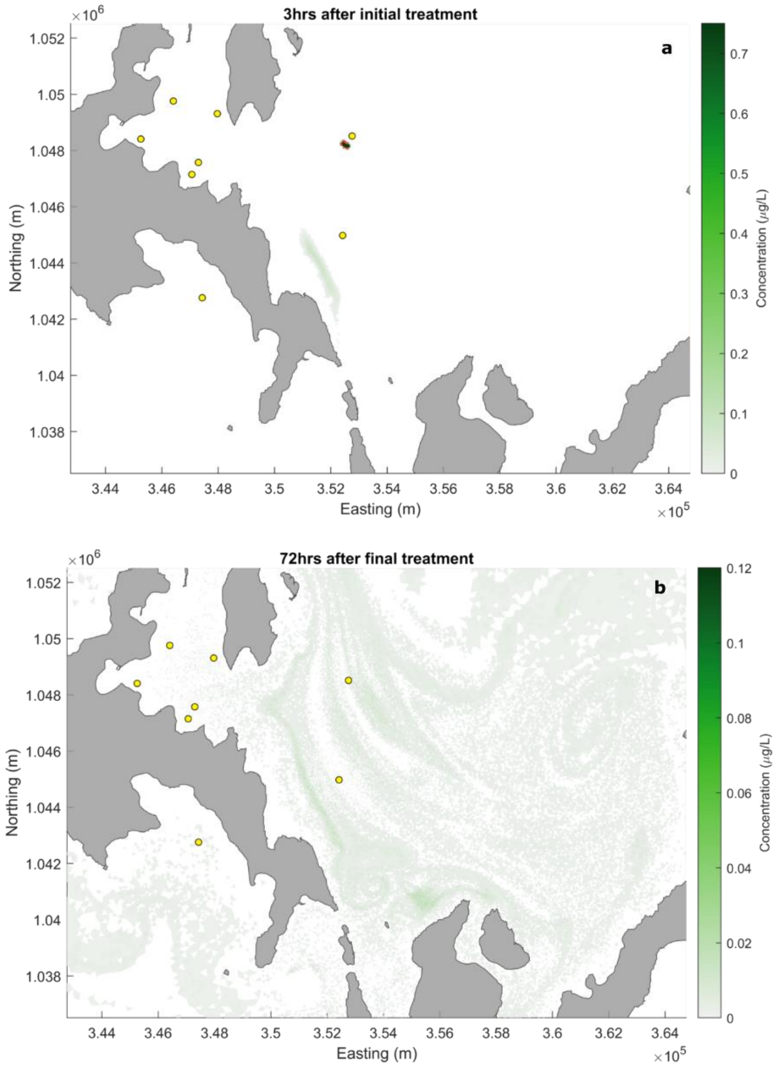

Figure 19. Spatial Azamethiphos distribution for wellboat releases during spring tides 3hr after the initial 3-hour mass release (a) and 72hr (b) after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.1.1.3 Cumulative Assessment

To determine the contribution of the proposed site on the presented cumulative impact a baseline scenario was also modelled, whereby the East Moclett site was removed from the model run. This allowed the cumulative 72-hour EQS chemical plume area with and without East Moclett to be compared. The results are shown in table 9. Due to the low number of sites simulated (only 1 existing site in North Sound has a license for Azamethiphos use), the proposed East Moclett site provides a significant contribution to the cumulative plume area. However, the actual area difference is low (0.3km^2) and remains compliant with all EQS standards applied for an individual site.

Table 9. Proposed site influence on cumulative impact.

	72-hour EQS

	Neap	Spring
All sites – including East Moclett (km^2)	0.3	0
East Moclett removed (km^2)	0	0
Area difference (km^2)	0.3	0
East Moclett percentage contribution (%)	100	0

A wellboat treatment of 335.03 g of Azamethiphos per pen with a 3-hour treatment interval, and assuming 3 treatments are achieved per working day, is shown to be compliant with all MAC and EQS. Cumulative modelling across all licensed sites within the North Sound shows that as the treatment schedule finishes, the chemicals released from East Moclett are quickly dispersed. This is especially true of treatment plans coinciding with spring tides, where there is no cumulative EQS exceedance.

The simulated treatment quantity provides a recommended consent mass of 335.03 g per treatment interval, assuming there are 3 treatments in a working day, which equates to 1005.1g per 24 hours. This treatment plan provides a treatable volume of 3350.3 m^3 with a concentration of 100000 ng/l per 3-hour period. This is equivalent to the volume of 2.23 wellboats (1500m^3 capacity) in a 3-hour period.

4.3.1.2 Cypermethrin

Environmental compliance was achieved at the proposed East Moclett site using 35g of Cypermethrin in two 3-hour interval wellboat treatments. As the consent period is 3 hours, this equated to an individual pen treatment of 17.5g. 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 0.131 g. This provides a treatment volume of 26.2 m^3 per 6 hours.

4.3.1.2.1 Neap tides

To assess compliance for Cypermethrin, a 6-hour treatment mass (35g) is modelled in isolation during neap tides. Given the most realistic treatment plan involves 3-hour treatment intervals, this 6-hour mass consists of two 3-hour wellboat treatment events (2x17.5g). The particle tracking model is started on the 18/05/2021 15:00:00 and finishes on 21/05/2021 02:00:00. The first wellboat treatment release period begins at all sites on the 19/05/2021 14:00:00, lasts for one hour and ends on the 19/05/2021 15:00:00. This period corresponds with the timing of the lowest high-water event within the spring/neap cycle. The run time provides over 30 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

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 East Moclett after a 6-hour mass treatment release remains less than the calculated mixing area of 0.75km^2 throughout the model run.

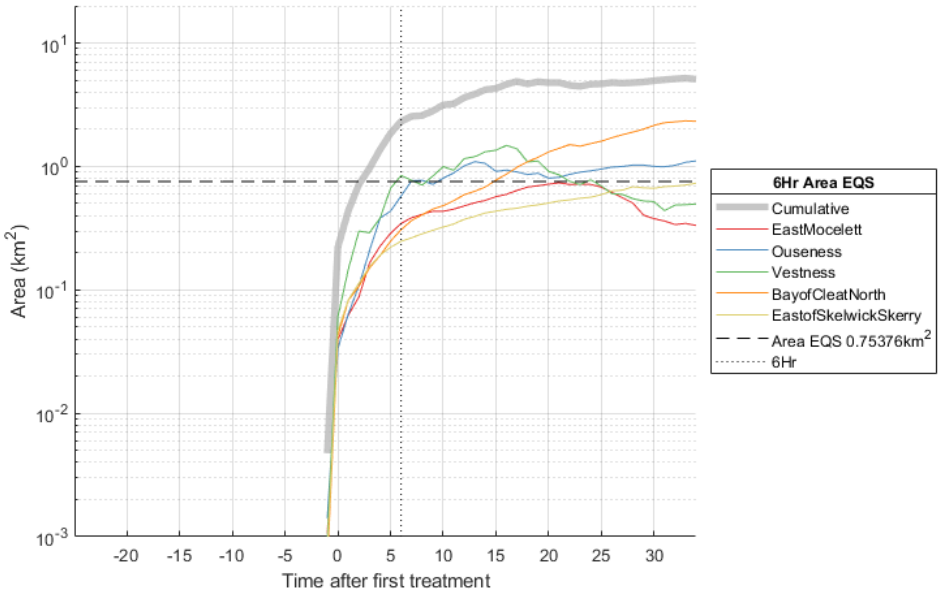

Figure 20. Chemical plume area exceeding the 6-hour (16 ng/l) EQS value after the initial 6-hour mass (35g) wellboat release of Cypermethrin during neap tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The MAC for the 6-hour treatment mass during neap tides is plotted in figure 21. East Moclett is shown to have significantly lower peak concentration values than the surrounding sites. After each treatment event chemical plumes are dispersed, and maximum concentration values fall rapidly.

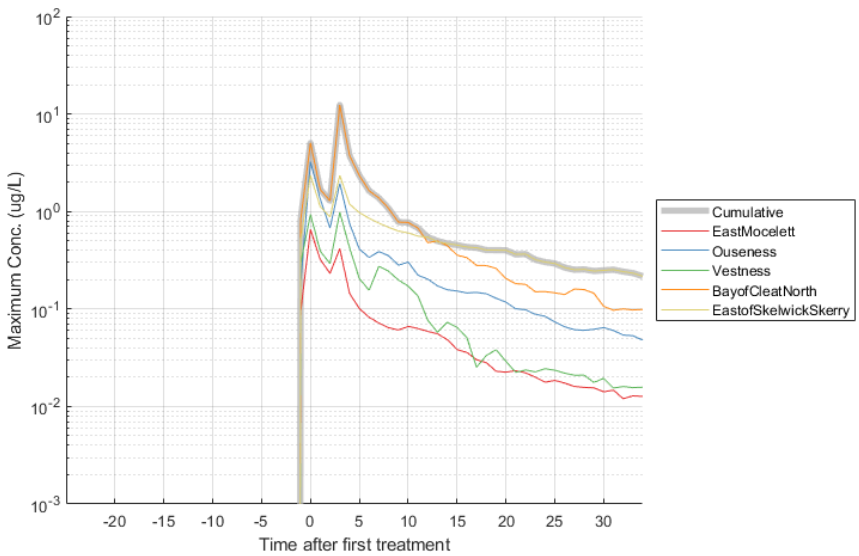

Figure 21. Maximum concentration of Cypermethrin during neap tide wellboat releases. Cumulative MAC is indicated by the grey solid line.

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 22. The areas where concentrations exceed the 6-hour EQS concentration are outlined in red. After 6-hours, the chemical plumes appear elongated in the direction of the predominant tidal flow, illustrating significant chemical transport via tidal currents. The most extensive plumes are observed within Papa Sound, originating from the cluster of licensed sites to the south. The plumes associated with East Moclett are transported northwards from the proposed site by the high velocity flow to the east of Papa Westray, the peak concentration within the East Moclett originating plumes is significantly lower than the peak concentration of the plumes arising from the other sites in the area.

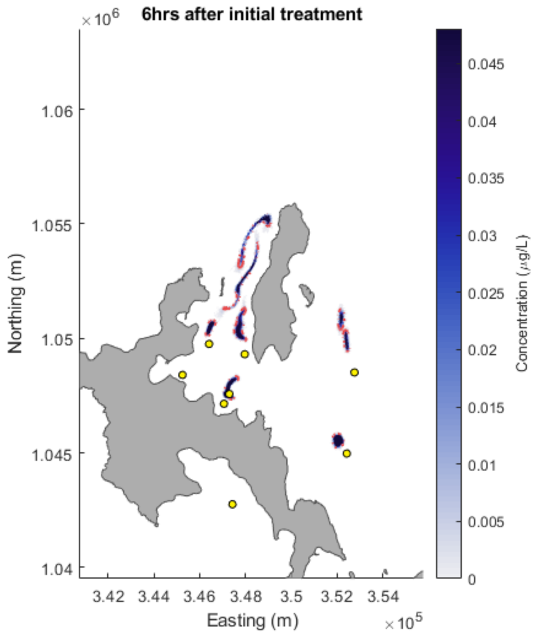

Figure 22. Spatial Cypermethrin distribution for wellboat releases during neap tides 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.1.2.2 Spring tides

To assess compliance for Cypermethrin, a 6-hour treatment mass (35g) is modelled in isolation during spring tides. Given the most realistic treatment plan involves 3-hour treatment intervals, this 6-hour mass consists of two 3-hour wellboat treatment events (2x17.5g). The particle tracking model is started on the 22/04/2021 06:00:00 and finishes on 29/04/2021 16:30:00. The first treatment release period begins at all sites on the 28/04/2021 08:00:00, lasts for one hour and ends on the 28/04/2021 09:00:00. This period corresponds with the timing of the highest high-water event within the spring/neap cycle. The run time provides over 30 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

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 23. 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 East Moclett peaks at 0.73 km^2 5 hours after the first treatment release period. Following this the chemical is efficiently dispersed by the energetic spring tidal currents, resulting in a rapid decrease in the plume size. After 9-hours to size of the chemical plume increases slightly as chemical quantities are transported to and concentrated within the eddying flow north of Papa Westray. However, this increase is relatively small and remains significantly less than the calculated EQS mixing area of 0.75km².

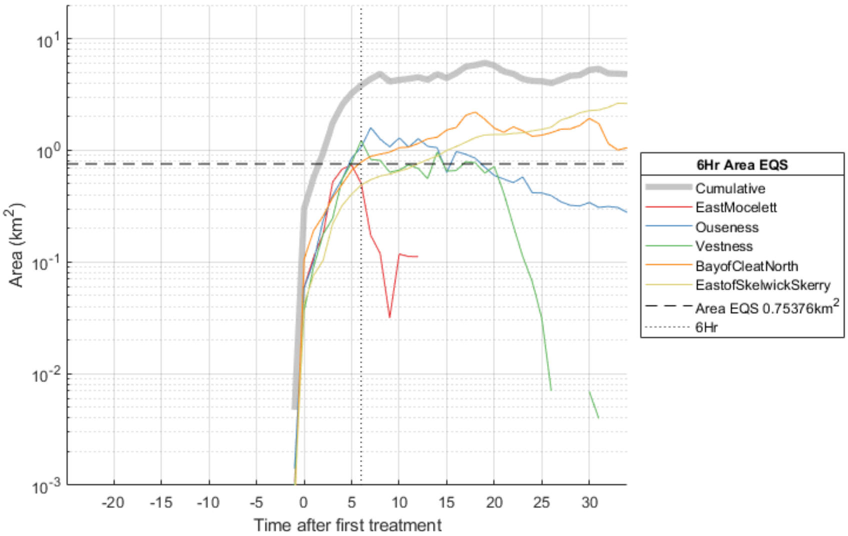

Figure 23. Chemical plume area exceeding the 6-hour (16 ng/l) EQS value after the initial 6-hour mass (35g) wellboat release of Cypermethrin during spring tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The MAC for the 6-hour treatment mass during spring tides is plotted in figure 24. East Moclett shows far lower maximum concentrations relative to the surrounding sites. These lower quantities combined with the energetic spring tidal currents result in a rapid dispersal of East Moclett's chemical plume.

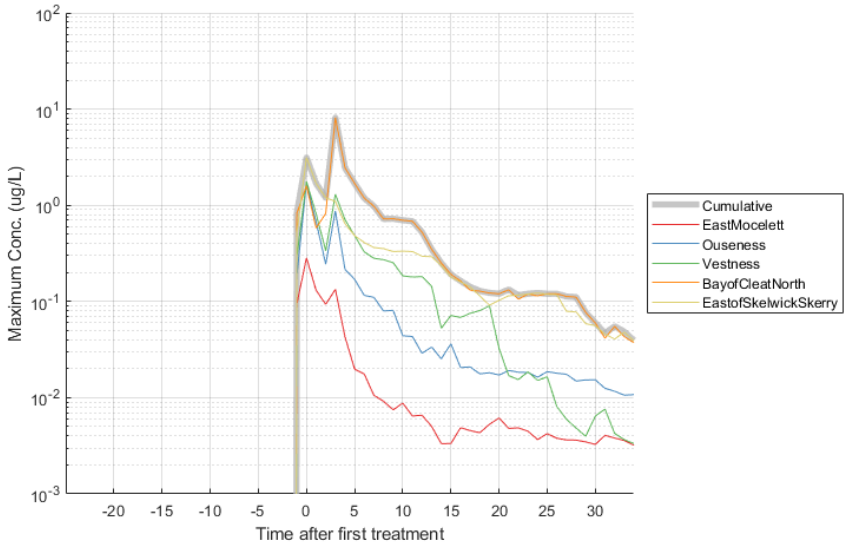

Figure 24. Maximum concentration of Cypermethrin during spring tide wellboat releases. Cumulative MAC is indicated by the grey solid line.

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 25. 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 are typically lower concentration and further elongated in the direction of the predominant tidal flow, illustrating the highly dynamic nature of Cypermethrin dispersion during spring tides. Again, the highest chemical concentrations are observed near the collection of sites in south Papa Sound.

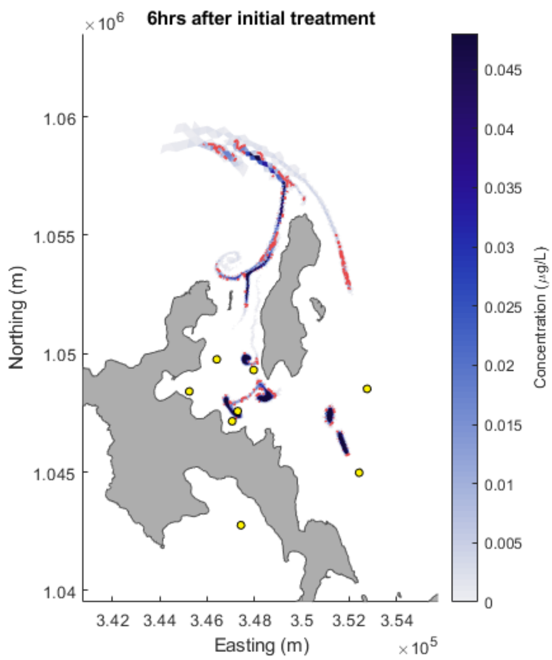

Figure 25. Spatial Cypermethrin distribution for wellboat releases during spring tides 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.1.2.3 Cumulative assessment

To determine the influence of the proposed site on the presented spatial cumulative impact, the site was temporarily omitted from the cumulative calculation of the 6-hour EQS area. This provides a baseline cumulative EQS area for all existing licensed sites in the North Sound region. The results are shown in table 10. For the neap and spring tides a respective area difference of 0.75 and 1.31 km^2 are calculated. This shows a mean contribution of 33% from the proposed East Moclett site towards the regional cumulative impact.

Table 10. Proposed site influence on cumulative impact.

	6-hour EQS	
	Neap	**Spring**
All sites – including East Moclett (km^2)	2.32	3.82
East Moclett removed (km^2)	1.57	2.51
Area difference (km^2)	0.75	1.31

East Moclett percentage contribution (%)	32.3%	34.3%

The application of 35 g of Cypermethrin for a 6-hour wellboat treatment period is shown to be compliant with all EQS thresholds. Cumulative modelling of all treatments within the area shows large chemical distributions and elevated concentrations. However, the addition of the treatment plan for the proposed East Moclett site is shown to have a reasonable contribution to the regional impact.

The simulated treatment quantity provides a mass of 35 g. To obtain the recommended consent mass, this must be reduced by a factor of 267 to comply with (SEPA 2018). This provides a recommended consent mass of 0.131 g, which allows a treatment volume of 26.2 m^3, assuming a treatment concentration of 5,000 ng/l. This can treat 0.016 1,500 m^3 capacity wellboats per 6 hours.

4.3.1.3 Deltamethrin

Compliance was achieved at the proposed East Moclett site using 92 g of Deltamethrin in a treatment plan involving two 3-hour wellboat treatment intervals. As the consent period is 3 hours, this equated to an individual pen treatment of 46 g. This provides a treatable volume of 23,000 m^3 per 3-hour period.

4.3.1.3.1 Neap tides

To assess compliance for Deltamethrin, a 6-hour treatment mass (92g) is modelled in isolation during neap tides. Given the most realistic treatment plan involves 3-hour treatment intervals, this 6-hour mass consists of two 3-hour wellboat treatment events (2x46g). The particle tracking model is started on the 18/05/2021 15:00:00 and finishes on 21/05/2021 02:00:00. The first wellboat treatment release period begins at all sites on the 19/05/2021 14:00:00, lasts for one hour and ends on the 19/05/2021 15:00:00. This period corresponds with the timing of the lowest high-water event within the spring/neap cycle. The run time provides over 30 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

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 26. 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 East Moclett after a 6-hour mass treatment release remains less than the calculated mixing area of 0.75km^2 throughout the model run.

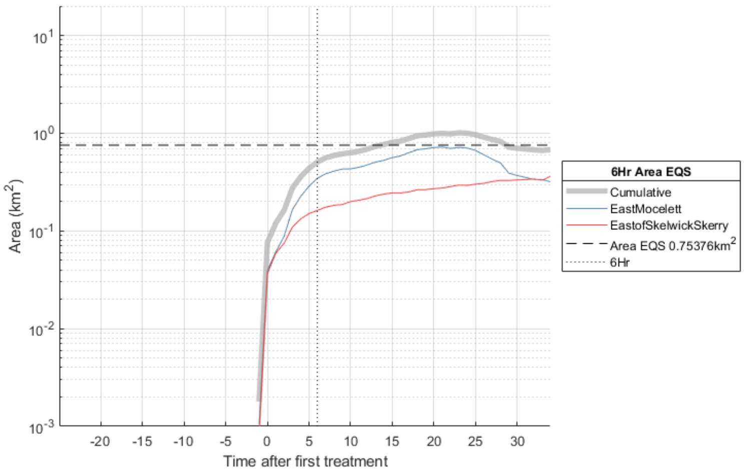

Figure 26. Chemical plume area exceeding the 6-hour (6 ng/l) EQS value after the initial 6-hour mass wellboat release of Deltamethrin during neap tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The MAC for the 6-hour treatment mass during neap tides is plotted in figure 27. The individual pen treatments are identified by the colour coded site-specific lines. After each treatment, chemical plumes are rapidly dispersed and maximum concentration values fall quickly.

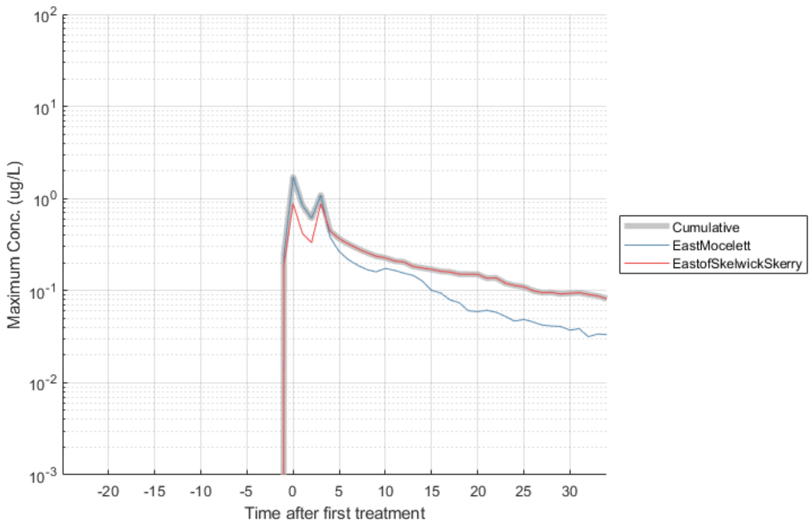

Figure 27. Maximum concentration of Deltamethrin during neap tide wellboat release. Cumulative MAC is indicated by the grey solid line.

The spatial distribution of Deltamethrin 6 hours after the first simultaneous release of bath treatments from all sites during a neap tide is shown in figure 28. The regions whose chemical concentration exceeds the EQS threshold are illustrated by the red contour. Plumes form isolated, high concentrated patches, located north of their site of origin. East Moclett plumes represent a more oval shape than those originating from East Skelwick, illustrating a higher degree of advection via tidal currents for the chemicals discharged at East Moclett.

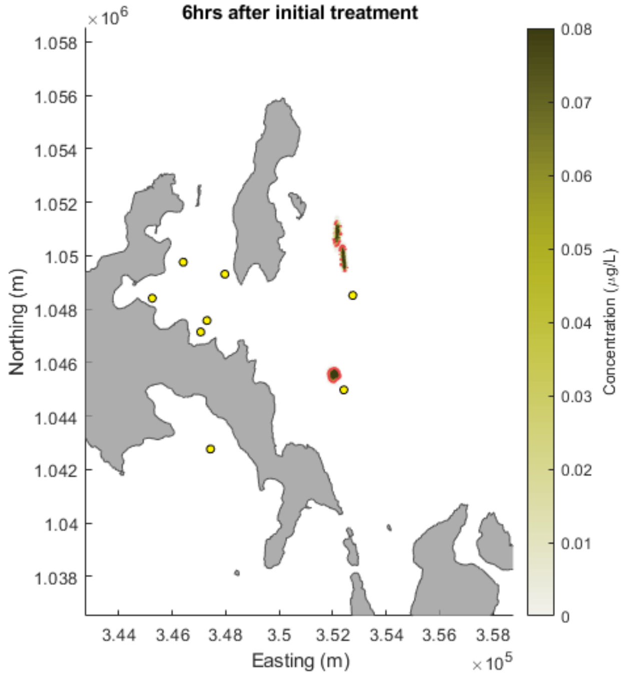

Figure 28. Spatial Deltamethrin distribution for wellboat releases during neap tides, 6 hours after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.1.3.2 Spring tides

To assess compliance for Deltamethrin, a 6-hour treatment mass (92g) is modelled in isolation during neap tides. Given the most realistic treatment plan involves 3-hour treatment intervals, this 6-hour mass consists of two 3-hour wellboat treatment events (2x46g). The particle tracking model is started on the 22/04/2021 06:00:00 and finishes on 29/04/2021 16:30:00. The first treatment release period begins at all sites on the 28/04/2021 08:00:00, lasts for one hour and ends on the 28/04/2021 09:00:00. This period corresponds with the timing of the highest high-water event within the spring/neap cycle. The run time provides over 30 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

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 29. 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 East Moclett after a 6-hour mass treatment release remains less than the calculated mixing area of 0.75km^2 throughout the model run. Spring tides create more dispersive conditions than neap tides, with a faster decrease in the size of the EQS area observed in figure 29 compared to a gradual decline seen in figure 26.

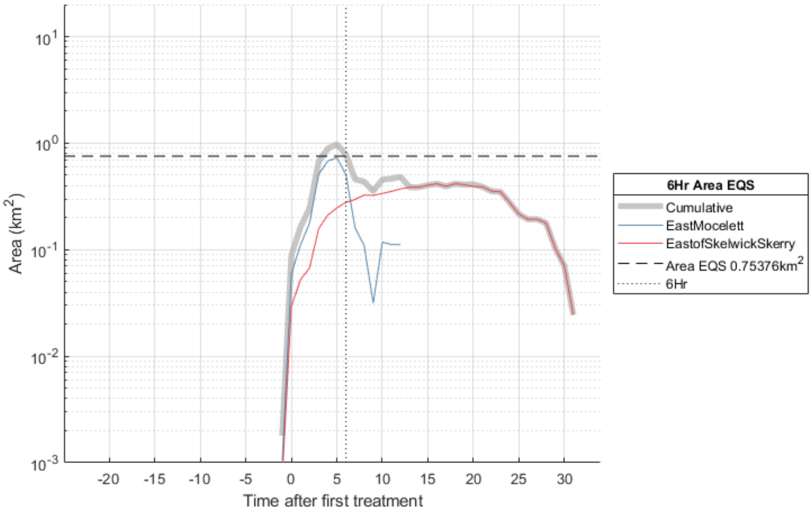

Figure 29. Chemical plume area exceeding the 6-hour (6 ng/l) EQS value after the initial 6-hour mass wellboat release of Deltamethrin during spring tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The MAC for the 6-hour treatment mass during spring tides is plotted in figure 30. East Moclett shows lower peak concentrations than the neighbouring East Skelwick site. Following the treatment events, all plumes are rapidly dispersed, and concentrations are reduced significantly.

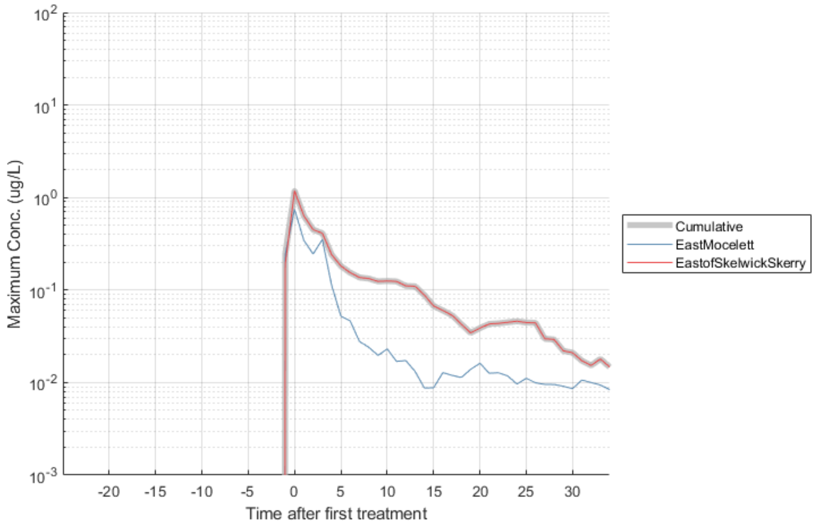

Figure 30. Maximum concentration of Deltamethrin during spring tide wellboat release. Cumulative MAC is indicated by the grey solid line.

The spatial distribution of Deltamethrin 6 hours after the first simultaneous release of the 6-hour treatment mass from all sites during a spring tide is shown in figure 31. The regions whose chemical concentration exceeds the EQS threshold are illustrated by the red contour. Due to the stronger currents, the chemical plumes exceeding the EQS threshold have lower peak concentrations and occur a greater distance from their releasing site. The increase in dispersion during spring tides is particularly evident in the dispersal of the plumes originating from East Moclett. These are transported northwards and exist as a patchwork of small, low concentration plumes along the dominant flow path.

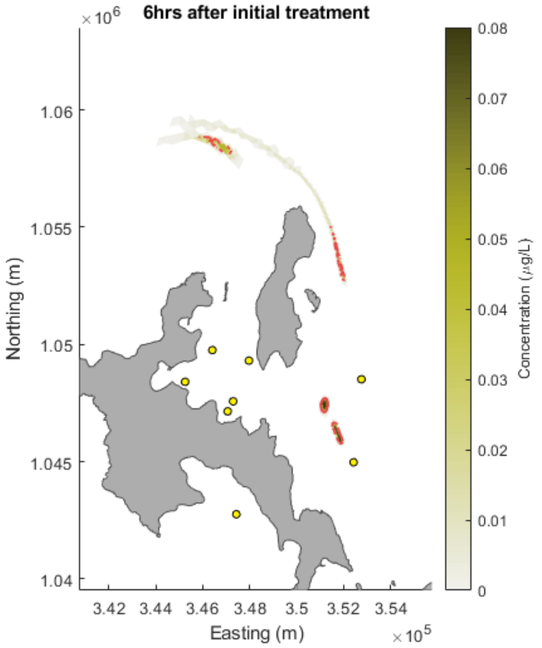

Figure 31. Spatial Deltamethrin distribution for wellboat releases during spring tides, 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.1.3.3 Cumulative assessment

To determine the influence of the proposed Deltamethrin treatment on the presented spatial cumulative impact, the site was temporarily omitted from the cumulative calculation of the 6-hour EQS area, allowing a baseline scenario to be simulated. The results are shown in table 11. Dependent on the spring-neap tidal cycle, East Moclett contributes 44-69% to the cumulative area exceeding the 6-hour EQS threshold concentration. East Moclett's contribution is less during spring tides dues to the rapid dispersal of bath chemicals from the proposed sites during more energetic spring velocities.

Table 11. Proposed site influence on cumulative impact.

	6-hour EQS	
	Neap	**Spring**
All sites – including East Moclett (km^2)	0.51	0.5
East Moclett removed (km^2)	0.16	0.28
Area difference (km^2)	0.35	0.22
East Moclett percentage contribution (%)	68.6%	44%

The application of 92 g of Deltamethrin per pen with a 6hr wellboat treatment interval, is shown to be compliant with the EQS area criteria. The simulated treatment quantity provides a treatable volume of 46,000 m^3 with a concentration of 2000 ng/l. This is equivalent to 30.6 wellboats (1,500m^3 capacity) per 6 hours.

4.3.2 Tarpaulin release

The simulation of tarpaulin bath treatments from all sites within North Sound 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 12.

Table 12. Environmental standards for tarpaulin release MAC and area EQS for all treatments at East Moclett.

	Treatment Quantity (g)	MAC 72 hrs (µg/l)	EQS 3hrs (km^2)	EQS 6hrs (km^2)	EQS 72hrs (km^2)
Azamethiphos					
Neap	295.5	0.098 (98.5%)	0.052 (19.7%)	-	0.13 (26.7%)
Spring	295.5	0.029 (29.7%)	0.05 (18.9%)	-	0 (0%)
Cypermethrin					
Neap	36	-	-	0.19 (25.7%)	-
Spring	36	-	-	0.42 (56.1%)	-
Deltamethrin					
Neap	93	-	-	0.19 (25.7%)	-
Spring	93	-	-	0.42 (55.5%)	-

4.3.2.1 Azamethiphos

Compliance was achieved at the proposed East Moclett site using 886.6g of Azamethiphos within a 24-hour period. This equated to 295.5g per pen assuming three tarpaulin treatments per day with a 3-hour interval. This corresponds to a treatable volume of 2955.3 m^3 per 3 hours.

4.3.2.1.1 Neap tides

The dispersal of Azamethiphos is calculated for a neap tidal phase. The particle tracking model is started on the 13/05/2021 12:00:00 and finishes on 23/05/2021 16:00:00. The last treatment is administered for all sites on the 19/05/2021 15:00:00, corresponding with the smallest high-water event within the spring/neap cycle.

To assess the short-term compliance for Azamethiphos, a single tarpaulin release of a 3-hour mass (295.5g) 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 32. The size of the chemical plume after a single treatment remains considerably less than the calculated mixing area of 0.27km^2, peaking at 0.13km^2 after 23 hours.

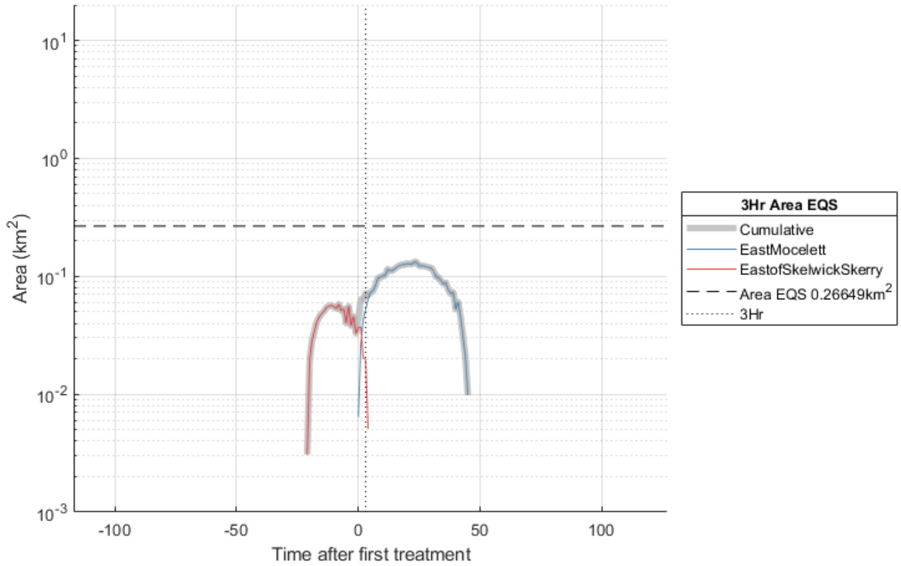

Figure 32. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after an initial 3-hour mass tarpaulin release event using Azamethiphos during neap tides.

To assess the long-term risks from Azamethiphos, the full treatment regime is modelled. The MAC for the neap tidal cycle is plotted in figure 33. The individual pen treatments are recognisable by the sharp peaks in maximum chemical concentrations. The chemical mass is introduced rapidly into the model domain creating a steep increase, following this decay and dispersion causes a rapid decrease in peak concentrations. At 72 hours after the final treatment the concentration from the proposed East Moclett site is 0.0985 µg/l, this is 98.5% of the EQS value. Following this a general decline in MAC is observed, punctuated by short-lived, small increases.

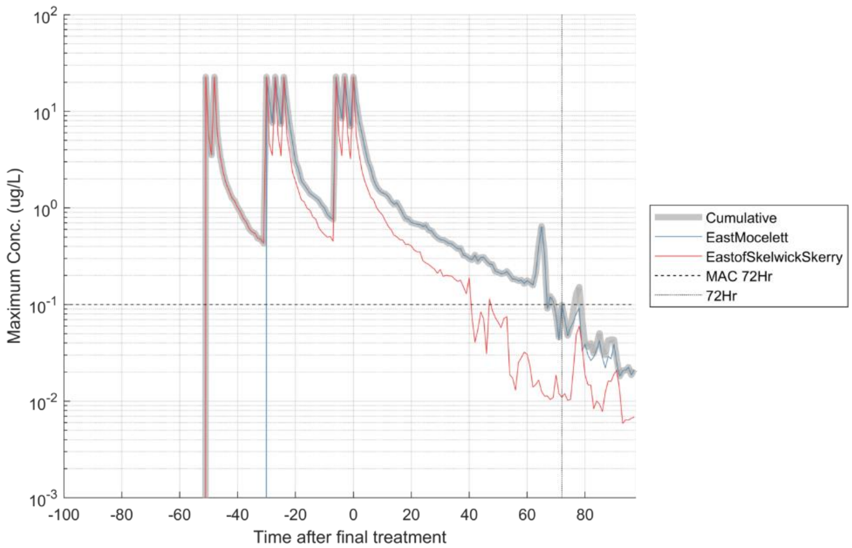

Figure 33. Maximum concentration of Azamethiphos during neap tide tarpaulin treatment cycle. Cumulative MAC is indicated by the grey solid line and MAC EQS value is illustrated by the black dashed line. 72 hours after the final treatment is shown by the dotted vertical line.

The area of the chemical plume exceeding 40ng/l (72-hour EQS) is plotted in figure 34. ~60 hours after the final treatment, the size of the chemical plume decreases rapidly, meaning at the 72-hour EQS time the area exceeding 40 ng/l is significantly less than 0.5 km^2.

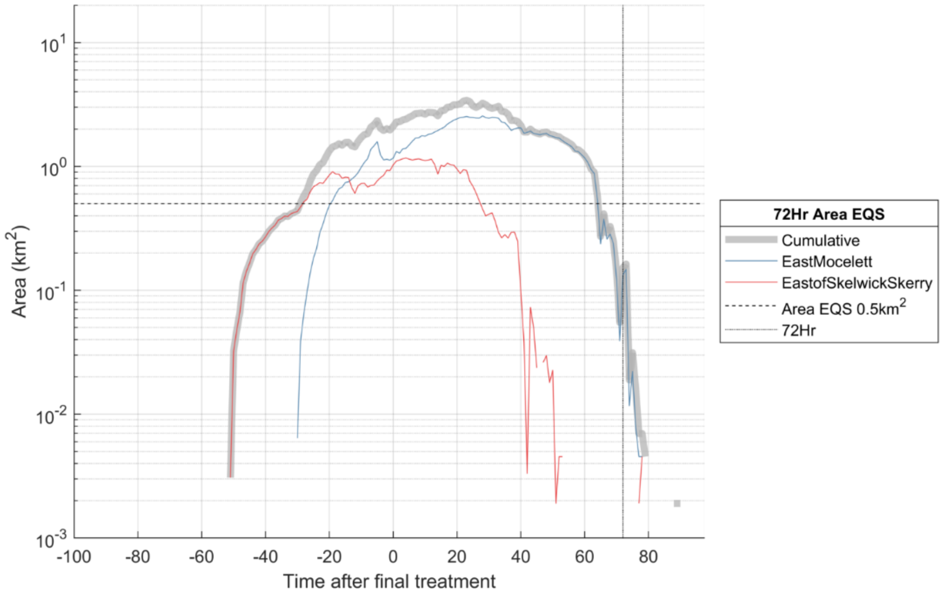

Figure 34. Chemical plume area exceeding the 72-hour (40 ng/l) EQS value after a full tarpaulin treatment cycle using Azamethiphos during neap tides. 72-hours after the final treatment is marked by the vertical dotted line.

The spatial distribution of Azamethiphos after the simultaneous release of bath treatments during neap tides is shown in figure 35. The 3-hour EQS (figure 35a) indicates two concentrated plumes near the releasing farms of East Moclett and East Skelwick. The cumulative area of these plumes does not exceed 0.27km^2. The 72hr EQS (figure 35b) shows a highly dispersed spatial distribution of the chemical, with far lower concentrations. The areas whose cumulative concentration is >40ng/l exist in isolated pockets located further from the releasing farms.

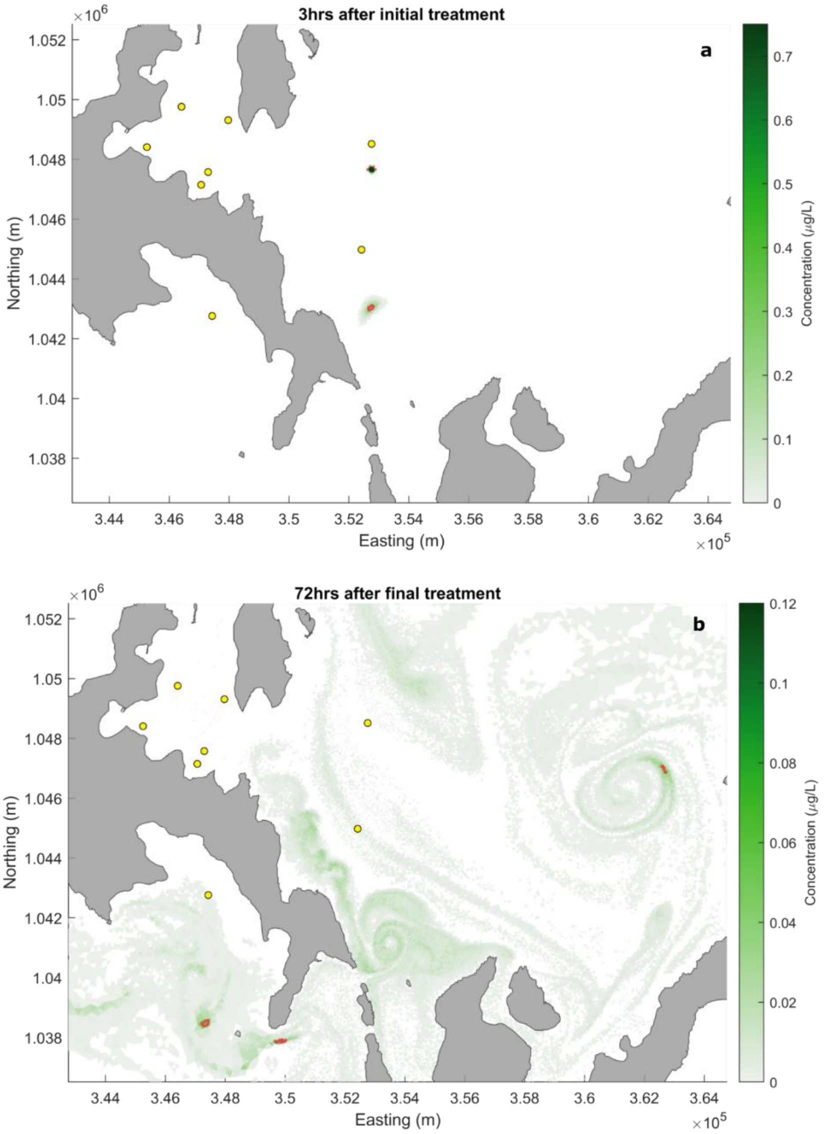

Figure 35. Spatial Azamethiphos distribution for tarpaulin release during neap tides 3hr after the initial 3-hour mass release (a) and 72hr after the last treatment event (b). Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.2.1.2 Spring tides

The dispersal of Azamethiphos is calculated for a spring tidal phase. The particle tracking model is started on the 22/04/2021 06:00:00 and finishes on 02/05/2021 10:30:00. The last treatment is administered for all sites on the 28/04/2021 09:00:00, corresponding with the largest high-water event within the spring/neap cycle.

To assess the short-term compliance for Azamethiphos, a single tarpaulin release of a 3-hour mass (295.5g) 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 36. The size of the chemical plume after a single treatment remains less than the calculated mixing area of 0.27km^2 for the entirety of the model run. There is a rapid decline in chemical plume size. No regions exceeding a concentration of 250ng/l are present 22-hours after the initial tarpaulin treatment.

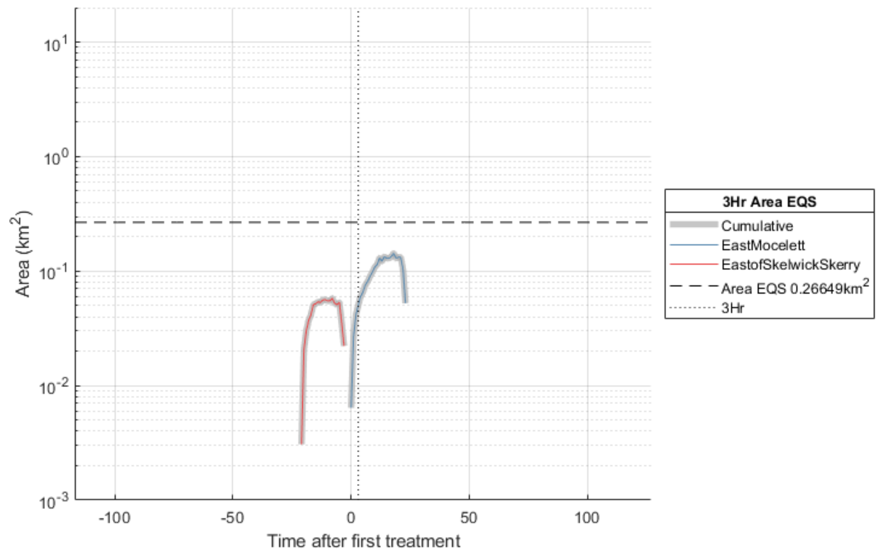

Figure 36. Chemical plume area exceeding the 3-hour (250 ng/l) EQS value after an initial 3-hour mass tarpaulin release of Azamethiphos during spring tides.

To assess the long-term risks from Azamethiphos, the full treatment regime is modelled. The MAC for the neap tidal cycle is plotted in figure 37. Again, the individual pen treatments are recognisable by the sharp peaks in maximum chemical concentrations. The decrease in maximum concentration following the final treatment occurs more quickly during spring tides than neaps. Twenty-four hours after the final treatment, maximum concentrations originating from East Moclett have decreased below the 0.1 µg/l, following this MAC continues to decrease at a slower rate.

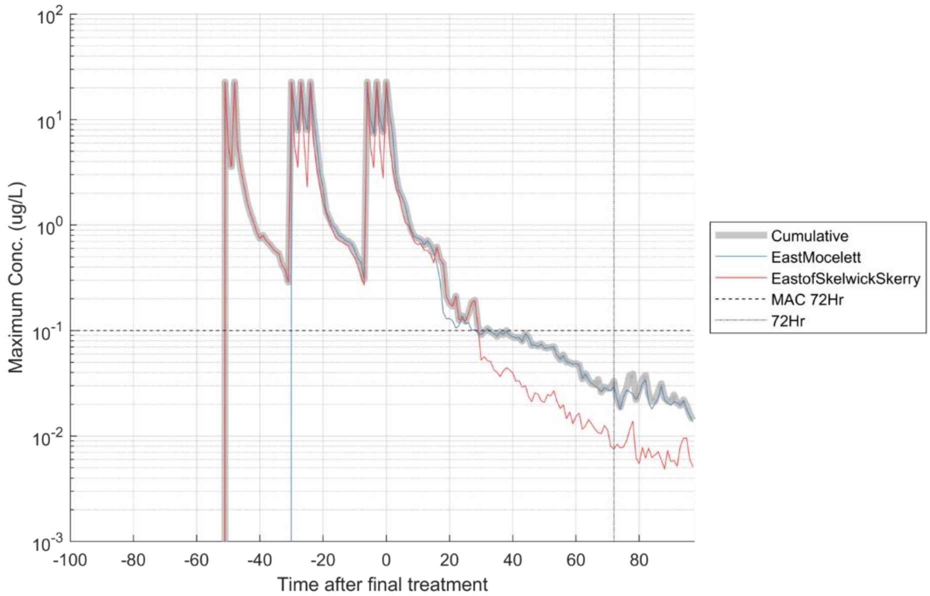

Figure 37. Maximum concentration of Azamethiphos during a spring tide tarpaulin treatment cycle. Cumulative MAC is indicated by the grey solid line and MAC EQS value is illustrated by the black dashed line. 72 hours after the final treatment is shown by the dotted vertical line.

The area exceeding the 72-hour EQS concentration (40ng/l) is plotted in figure 38. The greater mixing capability of spring tides is captured, after ~60 hours no chemical plumes with a concentration exceeding 40ng/l exist.

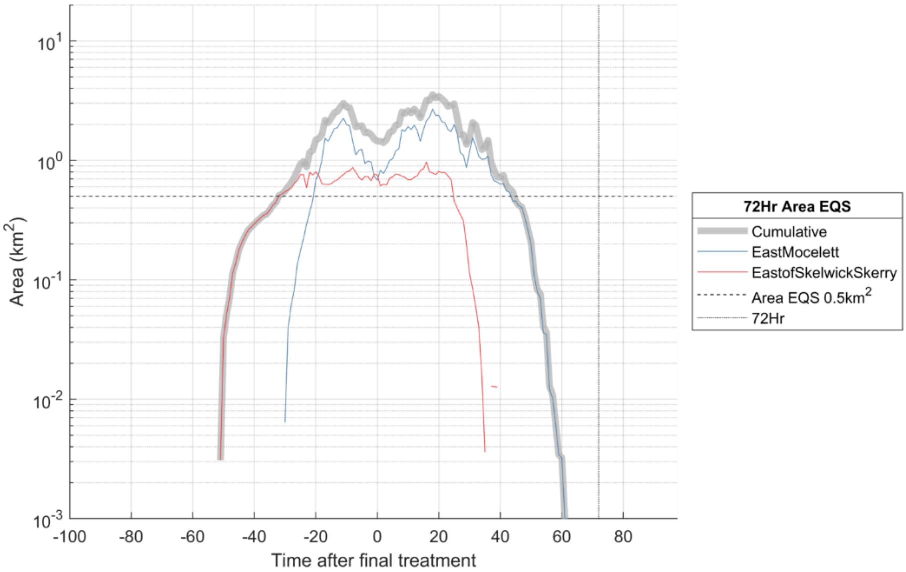

Figure 38. Chemical plume area exceeding the 72-hour (40 ng/l) EQS value after a full tarpaulin treatment cycle using Azamethiphos during spring tides. 72-hours after the final treatment is marked by the vertical dotted line.

The spatial distribution of Azamethiphos after the simultaneous release of bath treatments during spring tides is shown in figure 39 The 3-hour EQS (figure 39a) indicates a concentrated plume a small distance south of East Moclett, the size of which is ~0.05km^2. The 72-hour EQS (figure 39b) shows a highly dispersed spatial distribution of the chemical with far lower concentrations. No regions with cumulative concentrations greater than 40ng/l exist.

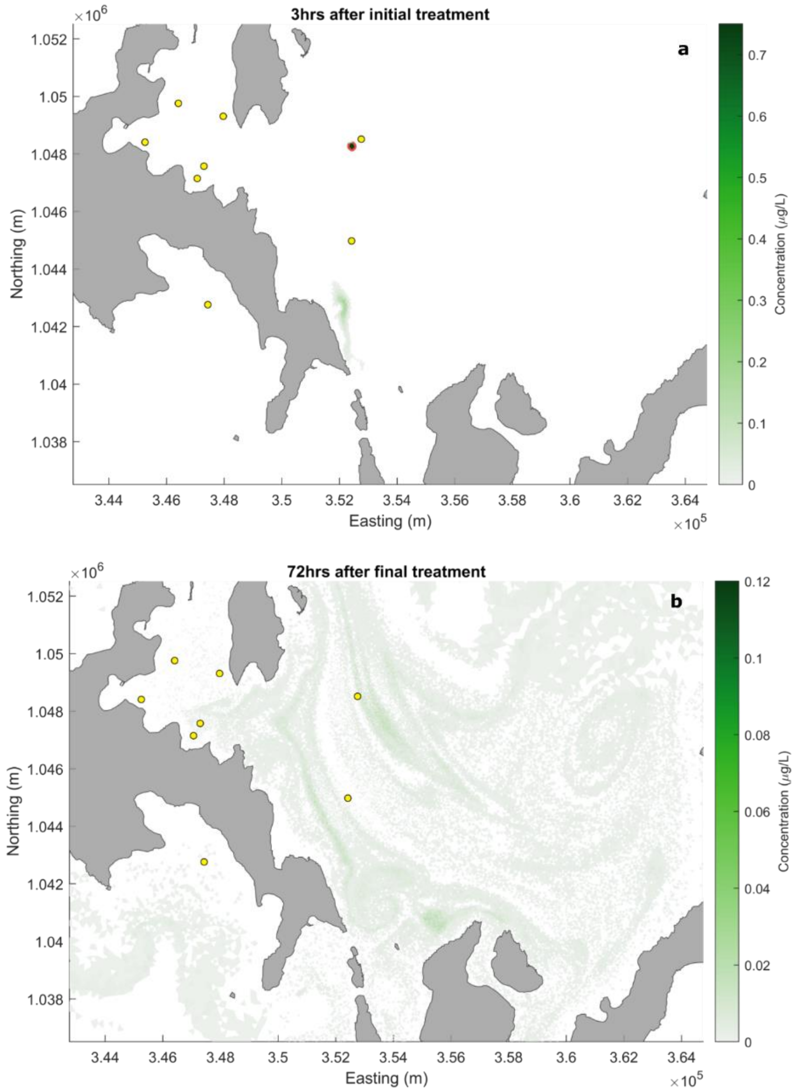

Figure 39. Spatial Azamethiphos distribution for tarpaulin release during spring tides 3hr after the initial 3-hour mass release (a) and 72hr after the last treatment event (b). Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.2.1.3 Cumulative impact

To determine the contribution of the proposed site on the presented cumulative impact, a baseline scenario was also modelled, whereby the East Moclett site was removed from the model run. The results are shown in table 13. Due to the low number of sites simulated (only 1 existing site in North Sound has a license for Azamethiphos use), the proposed East Moclett site provides a significant contribution to the cumulative impact area. The 72-hour cumulative EQS area during neap tides see the largest area contribution from East Moclett (100%), however this remains well below the 0.5km^2 EQS threshold for an individual site.

Table 13. Proposed site influence on cumulative impact.

	72-hour EQS	
	Neap	**Spring**
All sites – including East Moclett (km^2)	0.15	0

East Moclett removed (km^2)	0	0
Area difference (km^2)	0.15	0
East Moclett percentage contribution (%)	100	0

A tarpaulin treatment of 295.5 g of Azamethiphos per pen with a 3-hour treatment interval, and assuming 3 treatments are achieved per working day, is shown to be compliant with all MAC and EQS. Assuming a medicine concentration of 100000 ng/l, this treatment plan provides a treatable volume of 2955.3 m^3 in a 3-hour period. This volume is sufficient to treat 0.4 cone-shaped pens or 0.5 flat pens per 3 hours. The depth of the cone-shaped pen is calculated by applying a 25^o net angle from the circumference of the pen. In this case, the proposed 160m pens give a cone depth of 11.9m and volume of 8063.5m^3. The volume of the flat-bottom pen is calculated by assuming a uniform 3m pen depth during treatment, for a 160m circumference pen this equates to a volume of 6111.5m^3.

4.3.2.2 Cypermethrin

Environmental compliance was achieved at the proposed East Moclett site using 36g of Cypermethrin in 6-hour tarpaulin treatment plan. As the consent period is 3 hours this equated to an individual pen treatment of 18g. 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 0.135 g. This provides a treatment volume of 26.96 m^3 per 6 hours.

4.3.2.2.1 Neap tides

To assess compliance for Cypermethrin, a 6-hour treatment mass (36g) is modelled in isolation during neap tides. Given the most realistic treatment plan involves 3-hour treatment intervals, this 6-hour mass consists of two 3-hour tarpaulin treatment events (2x18g). The particle tracking model is started on the 18/05/2021 15:00:00 and finishes on 21/05/2021 02:00:00. The first tarpaulin treatment release is administered for all sites on the 19/05/2021 15:00:00, corresponding with the smallest high-water event within the spring/neap cycle. The run time provides over 30 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

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 40. 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 East Moclett after a 6-hour mass treatment release increases rapidly as bath medicines are first introduced into the domain. After 5 hours the growth in the chemical plume is more gradual, peaking at 0.75km^2, 30 hours after the first tarpaulin release. Throughout the model run the chemical plume area remains less than the calculated mixing area of 0.75376km^2.

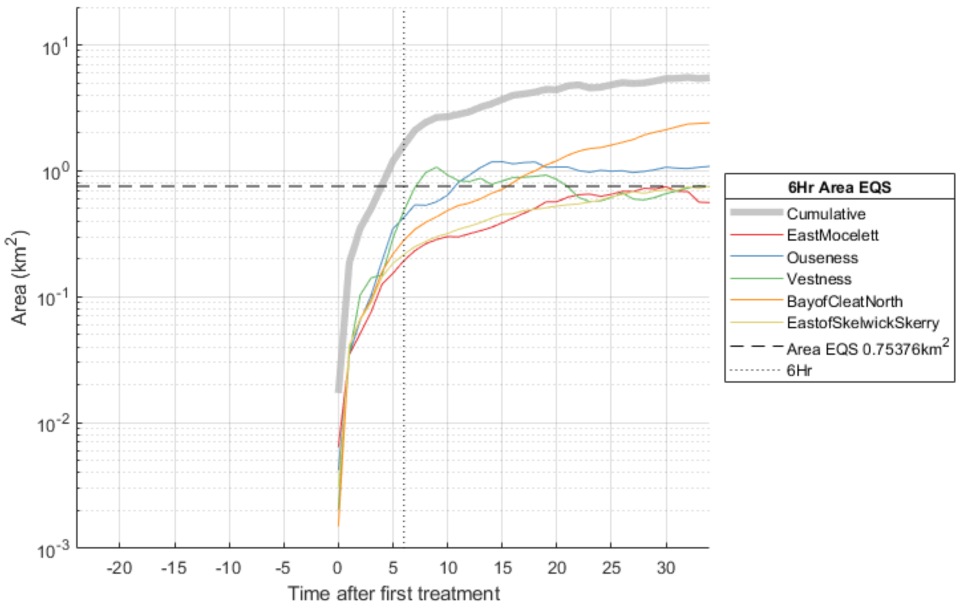

Figure 40. Chemical plume area exceeding the 6-hour (16 ng/l) EQS value after an initial 6-hour mass tarpaulin release of Cypermethrin during neap tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The MAC for the 6-hour treatment mass during neap tides is plotted in figure 41. The individual pen treatments are recognisable by the sharp peaks in maximum chemical concentrations. East Moclett has a maximum chemical concentration that is significantly lower than the other sites modelled, illustrating a minimum contribution to the cumulative MAC from the proposed site.

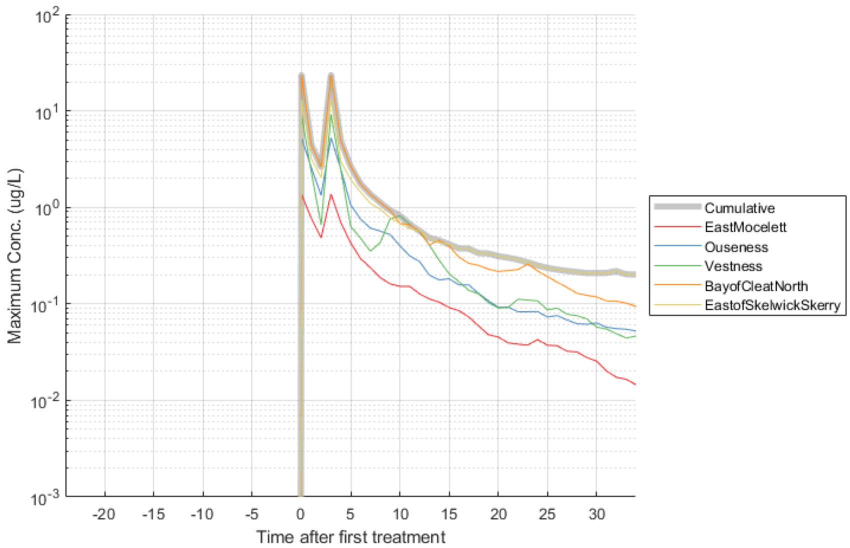

Figure 41. Maximum concentration of Cypermethrin during neap tide tarpaulin releases. Cumulative MAC is indicated by the grey solid line.

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 42. Large plumes exceeding the EQS threshold exist within Papa Sound, originating from the collection of sites to the south. The chemical plume originating from East Moclett, after 6 hours is located 1.3km northwards of the proposed site. At this point the chemical plume is relatively small (<0.2km^2), with a lower peak concertation than the plumes originating from other sites.

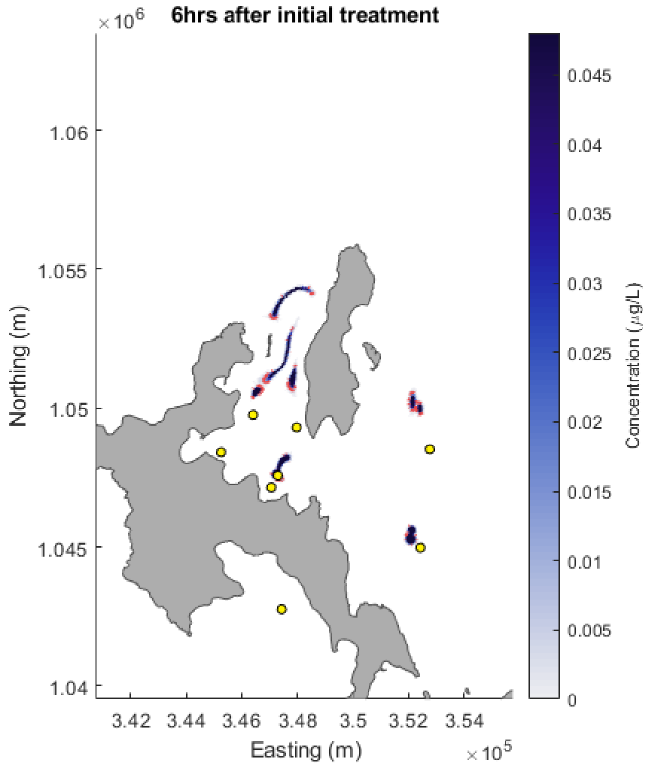

Figure 42. Spatial Cypermethrin distribution following tarpaulin releases during neap tides 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.2.2.2 Spring tides

To assess compliance for Cypermethrin, a 6-hour treatment mass (36g) is modelled in isolation during neap tides. Given the most realistic treatment plan involves 3-hour treatment intervals, this 6-hour mass consists of two 3-hour tarpaulin treatment events (2x18g). The particle tracking model is started on the 22/04/2021 06:00:00 and finishes on 29/04/2021 16:30:00. The last treatment is administered for all sites on the 28/04/2021 09:00:00, corresponding to the highest high-water event within the spring/neap cycle. The run time provides over 30 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

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 43. 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 East Moclett after a 6-hour mass treatment release increases rapidly as bath medicines are first introduced into the domain. At 6 hours after the first treatment, the plume area is 0.42km^2. After this, the size of the plume fluctuates whilst remaining below the EQS threshold of 0.75km^2. Changing tidal flow velocities and direction through time disperses and accumulates the bath chemicals causing the chemical plume to grow and shrink throughout the run period.

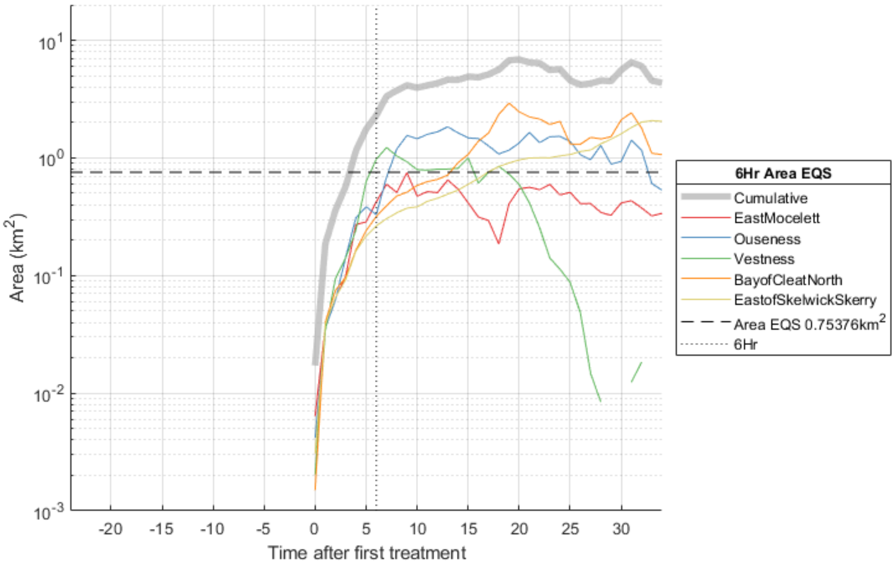

Figure 43. Chemical plume area exceeding the 6-hour (16 ng/l) EQS value after an initial 6-hour mass tarpaulin release of Cypermethrin during spring tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The MAC for the 6-hour treatment mass during spring tides is plotted in figure 44. Again, East Moclett makes a minimal contribution to the cumulative MAC, with far lower maximum concentrations than existing sites within the region. When compared to figure 41 (neap tides), the reduction in maximum chemical concentration occurs more quickly during spring tides at all sites.

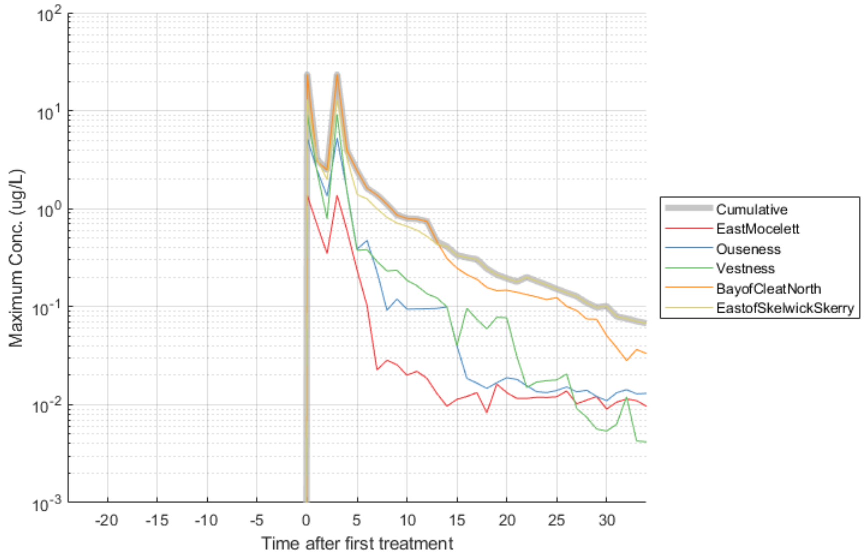

Figure 44. Maximum concentration of Cypermethrin during spring tide tarpaulin releases. Cumulative MAC is indicated by the grey solid line.

The spatial distribution of Cypermethrin 6 hours after the first simultaneous release of bath treatments from all sites during a spring tide is shown in figure 45. The chemical plumes exceeding the EQS concentration are typically elongated along the streamlines of the dominant tidal flow through Papa sound. The chemical plume originating from East Moclett is observed ~8.5km to the north, at the northern tip of Papa Westray, illustrating the highly dispersive nature of the proposed site during spring tides.

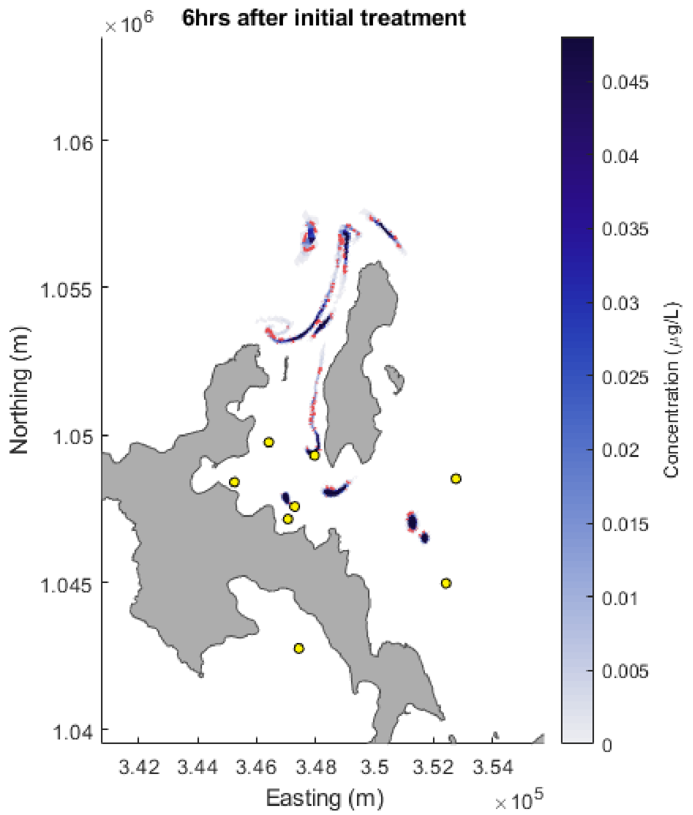

Figure 45. Spatial Cypermethrin distribution following tarpaulin releases during spring tides 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.2.2.3 Cumulative impact

To determine the influence of the proposed Cypermethrin treatment on the presented spatial cumulative impact, the site was temporarily omitted from the calculation of the cumulative EQS area, allowing a baseline scenario to be simulated. The results are shown in table 14. Cumulative modelling of all treatments within the area shows large chemical plumes with elevated concentrations. The addition of the treatment plan for the proposed East Moclett site has a moderate contribution to the regional impact. For both spring and neap tides, East Moclett contributes less than 20% to the to the cumulative area exceeding the 6-hour EQS threshold concentration.

Table 14. Proposed site influence on cumulative impact.

	6-hour EQS	
	Neap	**Spring**

All sites – including East Moclett (km^2)	1.6	2.3
East Moclett removed (km^2)	1.41	1.88
Area difference (km^2)	0.19	0.42
East Moclett percentage contribution (%)	11.9	18.3

The application of 36 g of Cypermethrin in a 6-hour tarpaulin treatment plan is shown to be compliant with all EQS thresholds. To obtain the recommended consent mass, this must be reduced by a factor of 267 to comply with (SEPA 2018). This provides a recommended consent mass of 0.135 g, which allows a treatment volume of 26.96 m^3, assuming a treatment concentration of 5,000 ng/l. This volume is sufficient to treat 0.0034 cone-shaped pens or 0.0044 flat pens per 6 hours. The depth of the cone-shaped pen is calculated by applying a 25^o net angle from the circumference of the pen. In this case, the proposed 160m pens give a cone depth of 11.9m and volume of 8063.5m^3. The volume of the flat-bottom pen is calculated by assuming a uniform 3m pen depth during treatment, for a 160m circumference pen this equates to a volume of 6111.5m^3.

4.3.2.3 Deltamethrin

Tarpaulin treatment compliance was achieved at the proposed East Moclett site using 93 g of Deltamethrin within a 6-hour period. As the consent period is 3 hours, this equated to an individual pen treatment of 46.5 g. A treatment plan involving two 3-hour tarpaulin treatments is simulated. This provides a treatable volume of 46,500 m^3 per 6-hour period.

4.3.2.3.1 Neap tides

To assess compliance for Deltamethrin, a 6-hour treatment mass (93g) is modelled in isolation during neap tides. Given the most realistic treatment plan involves 3-hour treatment intervals, this 6-hour mass consists of two 3-hour tarpaulin treatment events (2x46.5g). The particle tracking model is started on the 18/05/2021 15:00:00 and finishes on 21/05/2021 02:00:00. The first tarpaulin treatment release is administered for all sites on the 19/05/2021 15:00:00, corresponding with the smallest high-water event within the spring/neap cycle. The run time provides over 30 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

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 46. 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 East Moclett remains below the 0.75km^2 EQS threshold throughout the model run.

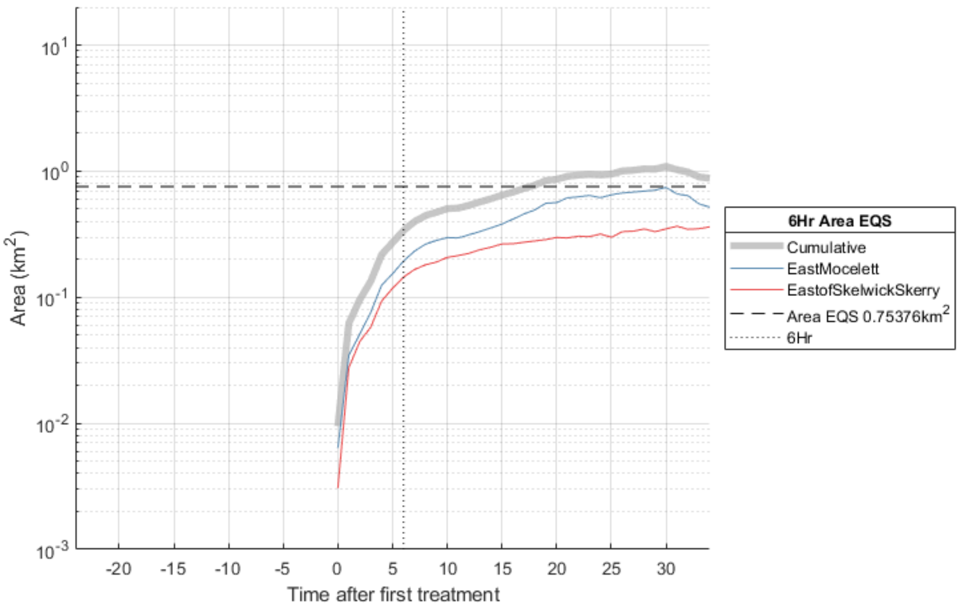

Figure 46. Chemical plume area exceeding the 6-hour (6 ng/l) EQS value after an initial 6-hour mass tarpaulin release of Deltamethrin during neap tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The MAC for the 6-hour treatment mass during neap tides is plotted in figure 47. East Moclett has lower peak concentrations than East Skelwick. After each treatment, chemical plumes are rapidly dispersed and maximum concentration values fall quickly. No MAC environmental standards are applied for Deltamethrin.

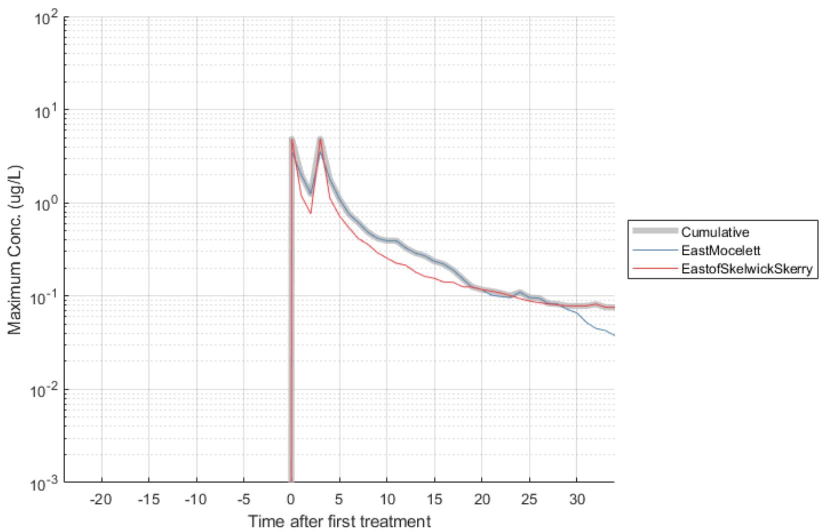

Figure 47. Maximum concentration of Deltamethrin during neap tide tarpaulin releases. Cumulative MAC is indicated by the grey solid line.

The spatial distribution of Deltamethrin 6 hours after the simultaneous release of bath treatments from all sites during a neap tide is shown in figure 48. Multiple small plumes exceeding the EQS threshold are observed north of their site of origin. The plumes originating from East Skelwick remain relatively close to the releasing site within the 6-hour period, whereas the plumes originating from East Moclett are advected a greater distance.

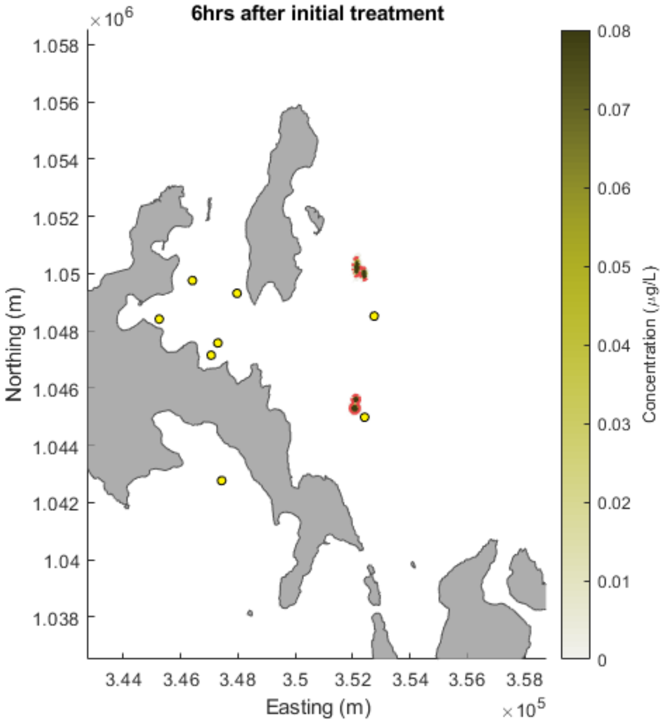

Figure 48. Spatial Deltamethrin distribution following tarpaulin releases during neap tides 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.2.3.2 Spring tides

To assess compliance for Deltamethrin, a 6-hour treatment mass (93g) is modelled in isolation during neap tides. Given the most realistic treatment plan involves 3-hour treatment intervals, this 6-hour mass consists of two 3-hour tarpaulin treatment events (2x46.5g). The particle tracking model is started on the 22/04/2021 06:00:00 and finishes on 29/04/2021 16:30:00. The last treatment is administered for all sites on the 28/04/2021 09:00:00, corresponding to the highest high-water event within the spring/neap cycle. The run time provides over 30 hours after the final treatment release for the chemical plume to be observed before the simulation is ended.

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 49. 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 East Moclett after a 6-hour mass treatment release increases rapidly as bath medicines are first introduced into the domain. At 6 hours after the first treatment, the rate of increase levels out. After this, the size of the plume fluctuates whilst remaining below the EQS threshold of 0.75km^2. Changing tidal flow velocities and direction through time disperses and accumulates the bath chemicals causing the chemical plume to grow and shrink throughout the run period.

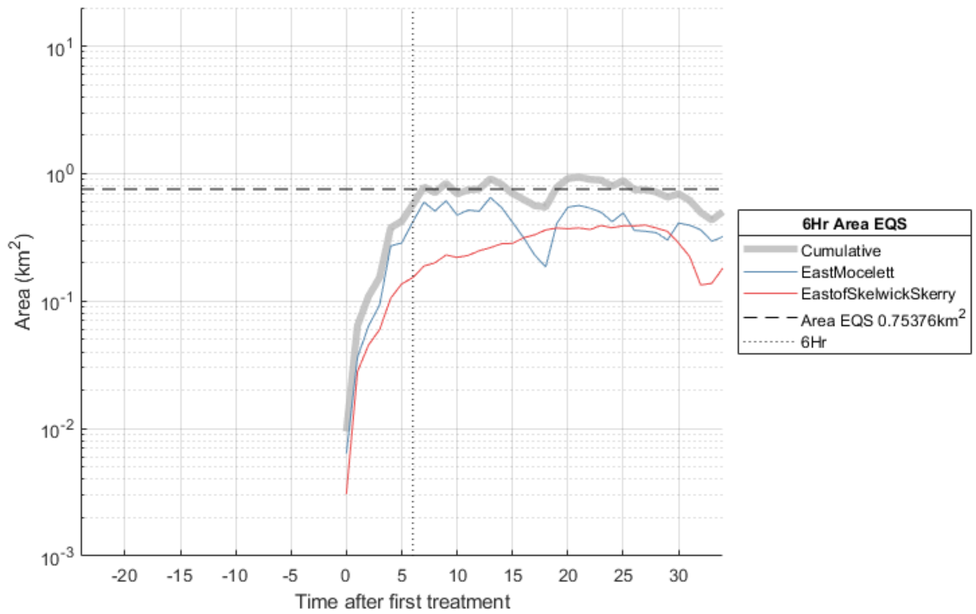

Figure 49. Chemical plume area exceeding the 6-hour (6 ng/l) EQS value after an initial 6-hour mass tarpaulin release of Deltamethrin during spring tides. The size of the 6-hour EQS mixing zone is shown by the horizontal dashed line. 6-hours after the initial treatment is marked by the vertical dotted line.

The MAC for the 6-hour treatment mass during spring tides is plotted in figure 50. Following the final treatment maximum concentrations fall rapidly as the chemical is advected and dispersed by the energetic spring tidal streams.

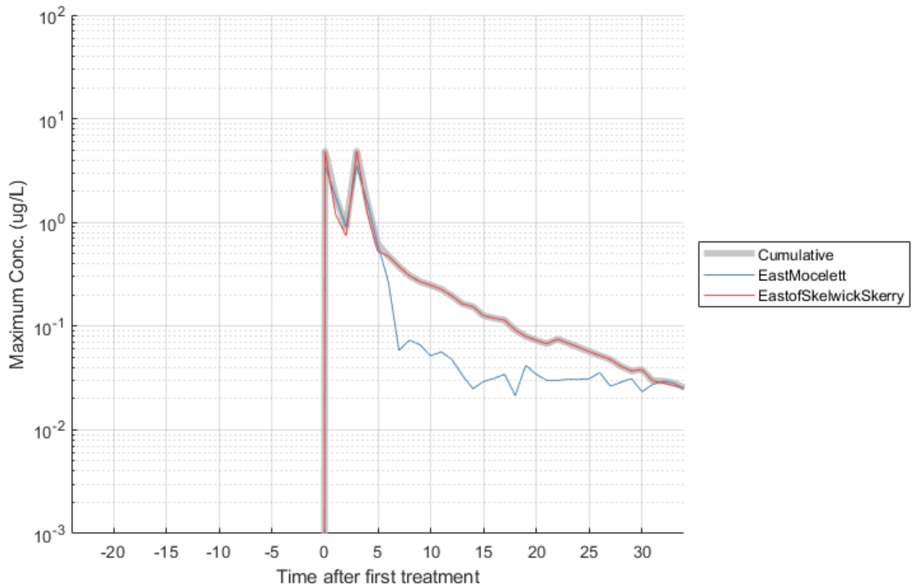

Figure 50. Maximum concentration of Deltamethrin during spring tide tarpaulin releases. Cumulative MAC is indicated by the grey solid line.

The spatial distribution of Deltamethrin 6 hours after the simultaneous release of bath treatments from all sites during a neap tide is shown in figure 51. Again, the chemical footprint occurs as several individual plumes. However, compared to the neap tide, these spring tide plumes are formed of lower concentrations and occur a greater distance from the releasing site. This is particularly true for East Moclett with figure 51 illustrating the highly dispersive nature of the proposed site. After 6 hours the chemical plumes have been transported northwards of Papa Westray, where they are likely to be dispersed rapidly and thoroughly in more exposed open waters.

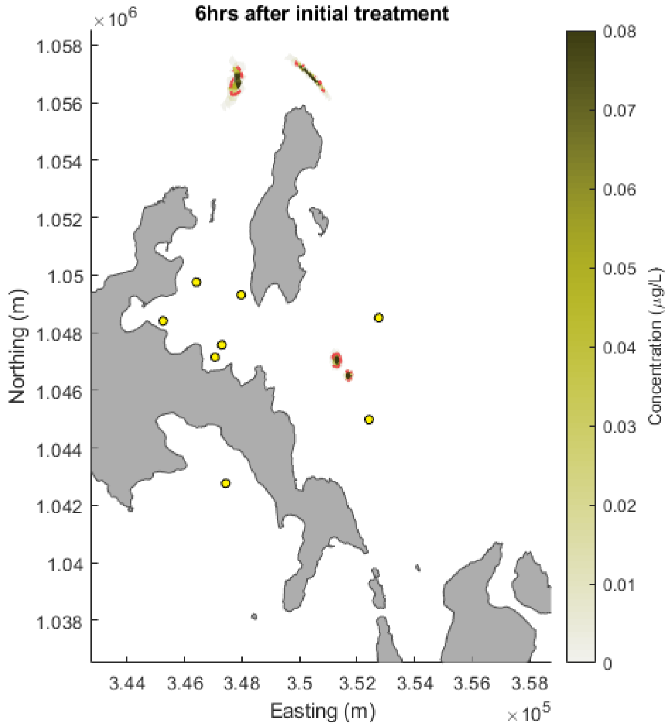

Figure 51. Spatial Deltamethrin distribution following tarpaulin releases during neap tides 6hr after the last treatment event. Areas above EQS values are indicated within the red contour and site locations are identified using a yellow marker.

4.3.2.3.3 Cumulative impact

To determine the influence of the proposed Deltamethrin treatment on the presented spatial cumulative impact, the site was temporarily omitted from the calculation of the cumulative EQS area, allowing a baseline scenario to be simulated. The results are shown in table 15. Due to the low number of sites simulated (only 1 existing site in North Sound has a license for Deltamethrin use), the proposed East Moclett site provides a significant contribution to the cumulative impact area. However, this remains well below the 0.5km^2 EQS threshold for an individual site.

Table 15. Proposed site influence on cumulative impact.

	6-hour EQS	
	Neap	**Spring**
All sites – including East Moclett (km^2)	0.34	0.57
East Moclett removed (km^2)	0.15	0.15
Area difference (km^2)	0.19	0.42

East Moclett percentage contribution (%)	55.9	73.7

The application of 93 g of Deltamethrin across 6 hours, is shown to be compliant with the EQS area criteria. The simulated two 3-hour tarpaulin treatments provides a treatable volume of 46,500 m^3 with a concentration of 2000 ng/l. This volume is sufficient to treat 4.18 cone-shaped pens or 7.6 flat pens per 6 hours. The depth of the cone-shaped pen is calculated by applying a 25^o net angle from the circumference of the pen. In this case, the proposed 160m pens give a cone depth of 11.9m and volume of 8063.5m^3. The volume of the flat-bottom pen is calculated by assuming a uniform 3m pen depth during treatment, for a 160m circumference pen this equates to a volume of 6111.5m^3.

5. Discussion

The results of the bath treatment simulation provide maximum chemical quantities suitable for maintaining environmental compliance for effective sea lice treatments. This study employs two different treatment scenarios – simulating a wellboat release of bath treatment medicines and a tarpaulin release of treatment medicines. It is important to have flexibility in terms of sea lice treatments and increasing the number of treatment options. To ensure environmental compliance is maintained, numerical modelling of these different treatment techniques and treatment dependent chemical quantities is completed.

For Azamethiphos, the maximum compliant chemical quantity was found to be greater for wellboat treatments, compared to tarpaulin releases. This represented a 13% increase in the compliant mass per 24 hours for Azamethiphos. This is due to the constant release of particles over a longer period in the wellboat simulation, creating less intense long-term chemical footprints, than when particles are released instantaneously in the tarpaulin models. When comparing compliance between the two treatment methods on a shorter timescale, as is the case for the 6-hour EQS for Deltamethrin and Cypermethrin, the difference in the compliant mass for wellboat and tarpaulin treatments is less pronounced, with less than a 3% difference. Again, wellboat release is observed to create less intense chemical plumes. However, over such a short EQS period the intensity of these still exceed the EQS threshold. Over longer durations, these less intense wellboat plumes will likely disperse more rapidly than tarpaulin plumes.

Both spring and neap tides are simulated to assess chemical dispersion in a range of conditions and ensure EQS compliance was consistent across different flow regimes. When considered in isolation the proposed chemical quantities for East Moclett pass all EQS thresholds. When the cumulative impact of the other 7 licensed farms in the North Sound region are considered, the combined chemical footprint and intensity is greater, but throughout the contribution of the proposed site is reasonable. It is key to note that the scenarios modelled here are purposefully designed to replicate a worst-case chain of events, which lead to larger, more concentrated chemical plumes than are considered plausible.

Applying a synchronised treatment plan, whereby all licensed farms finish/start their treatment schedules at the same time, leads to an accumulation of chemical plumes, which in turn, results in an exacerbation of concentrations and spatial coverage. In reality, synchronised treatments across multiple farms by the same operator is highly improbable due to constraints on the number of staff and wellboats available.

In the particle tracking model, the horizontal and vertical dispersion coefficients were set to the default values of 0.1m^2/s and 0.001m^2/s, respectively. This limits the random, turbulent processes that drive non-advective mixing of the chemical plume within the model. Therefore, resulting in a more cohesive chemical plume with higher concentrations. In reality, both dispersion coefficients vary through time and space, driven by a host of factors such as weather conditions, wave action, stratification and tidal state. Given bath treatments are conducted over a range of these conditions, chemical particles will frequently be released from a site in more dispersive conditions than modelled.

The bath treatment particle tracking model is forced by depth-averaged flows derived from a 2D hydrodynamic model. The effect of vertical flow features on the dispersion and advection of the chemical plumes is not captured in the model. To accurately resolve three-dimensional flow variability, a 3D hydrodynamic model is required, greatly increasing the computational resource needed. Additionally, when compared to hydrographic data collected close to the proposed site (section 3.1.3), the modelled horizontal velocities represent a slight underestimation of observed velocities, particularly during spring tides. Therefore, the chemicals released in the particle tracking model encounter less efficient mixing regimes than would be expected in reality.

6. Conclusions

This report outlines the methodology and results for the simulation of bath treatment chemicals at the proposed East Moclett site. The work presented in this report aims to address the uncertainties surrounding the cumulative farm effects highlighted in the East Moclett screening modelling and risk identification report by SEPA (2019), as well as deriving appropriate bath chemical quantities for East Moclett that are compliant with EQS standards.

A 2D marine model was used to provide current fields to drive an offline particle tracking model, used to simulate bath chemical release and dispersal. Hydrographic data from two separate deployments located close to the proposed site were used to calibrate and validate the hydrodynamic model. The model was found to successfully resolve surface water level, east and north velocity components, with strong agreement between modelled and in situ data (MSL R^2 = 0.988 and MSL RMSE = 0.13m). The resultant modelled flow field shows the North Sound region to be highly variable and complex, with localised tidal jets, lower velocity recirculatory areas and intense eddies.

To explore the cumulative impacts and determine environmental compliance under a realistic bath treatment plan, bath medicine chemicals were released in particle tracking models driven by the calibrated and validated hydrodynamic model. Three-hour interval wellboat treatments, an hour of which consists of a constant discharge of chemical treatment solution into the model domain, was considered a realistic treatment regime, given the large pen size proposed for East Moclett. For Azamethiphos, modelling of the entire treatment cycle revealed a recommended consent mass of 1005.1g per 24-hour period or 335.03g per 3-hour window was shown to be compliant with EQS. This equates to a treatment volume of 2.2 wellboat treatments (1,500m^3 capacity) per 3 hours. For Cypermethrin, modelling of the 6-hour treatment mass revealed a recommended consent mass of 0.131 g per 6-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 consent mass of 92 g per 6 hours, while maintaining EQS compliance. This provides a treatable volume equal to 30.6 wellboat treatments (1,500m^3 capacity) per 6 hours.

To ensure multiple options for bath medicine administration, three-hour tarpaulin treatments, at the end of which the chemical treatment solution was released instantaneously into the model domain, were also modelled. For Azamethiphos, modelling of the entire treatment cycle revealed a recommended consent mass of 886.6 g per 24-hour period or 295.5 g per 3-hour window was shown to be compliant with EQS. This equates to a treatment volume of 0.4 cone-shaped pens - assuming a 25° net angle, giving a 160m circumference pen a volume of 8063.5m^3 - or 0.5 flat-bottom pens – assuming a uniform 3m net depth, giving a 160m circumference pen a volume of 6111.5m^3 - per 3 hours. For Cypermethrin, modelling of the 6-hour treatment mass achieved a recommended consent mass of 0.135 g per 6-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 consent mass of 93 g per 6 hours, while maintaining EQS compliance. This provides a treatable volume equal to 5.8 cone-shaped pens, or 7.6 flat-bottom pens per 6 hours.

The numerical simulation of bath treatments has revealed multiple feasible treatment options for East Moclett using Azamethiphos and/or Deltamethrin administered via wellboats and/or tarpaulin containment. 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.

7. References

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