Loch Duart Bath Treatment Dispersion Modelling

Dispersion modelling for Azamethiphos bath treatment consent limits for Oldany farm site, northwest Scotland

Customer	Loch Duart Ltd.
Project	A12028
Deliverable	01
Version	03
	19 May 2023

Document Control

Document Identification

Title	Loch Duart Bath Treatment Dispersion Modelling
Project No	A12028
Deliverable No	01
Version No	03
Version Date	19 May 2023
Customer	Loch Duart Ltd.
Customer Contact	[redacted]
Classification	BMT (OFFICIAL)
Author	[redacted]
Reviewed By	[redacted]
Project Manager	[redacted]

Amendment Record

The Amendment Record below records the history and issue status of this document.

Version	Version Date	Distribution	Record
00	21 March 2023	Loch Duart	First Draft
01	22 March 2023	Loch Duart	First Revision
02	28 March 2023	Loch Duart	Final Report
03	19 May 2023	Loch Duart	Final Revised Report

Contents

Tables

Figures

1 Introduction

BMT was commissioned by Loch Duart Ltd (hereafter Loch Duart) to conduct an assessment of the fate and transport of the bath treatment agent Azamethiphos at the Oldany farm in Sutherland, Scotland. The purpose of this report, prepared by BMT, is to determine whether proposed bath treatment quantities for the Oldany farm are predicted to follow compliance limits set by statutory UK Environmental Quality Standards. The bath treatment process involves immersing farmed fish in a diluted solution of Azamethiphos for a prescribed treatment period, followed by release of the treatment volume.

This report presents the results of a coupled hydrodynamic and inert tracer modelling study for subsequent dispersion of the bath treatment. The assessment of Azamethiphos dispersion and comparison against Environmental Quality Standards is based on SEPA requirements for bath treatment modelling (SEPA 2019) as set out in the previously approved method statement (BMT 2022a).

2 Hydrodynamic Modelling

2.1 Model

BMT has developed a numerical hydrodynamic and tracer model to determine the fate and transport of Azamethiphos bath treatment at the Oldany farm in Sutherland, Scotland (Figure 2.1) using a 3D hydrodynamic model TUFLOW FV.

2.2 TUFLOW FV Hydrodynamic Model

TUFLOW FV (https://www.tuflow.com) is a 3D flexible-mesh (finite volume) hydrodynamic model developed and distributed by BMT. It can be used for modelling a diverse array of inland and coastal water bodies and it is able to call the water quality model (WQM) library directly via a custom interface. The model accounts for variations in water level, the horizontal salinity distribution and vertical density stratification in response to inflows and surface thermodynamics. The finite volume numerical scheme solves the conservative integral form of the Non-Linear Shallow Water Equations in addition to the advection and transport of scalar constituents such as salinity, temperature, inert tracers and the state variables from the coupled biogeochemical model. The equations are solved in 3D with baroclinic coupling with both salinity and temperature using the UNESCO equation of state. Surface momentum exchange and heat dynamics are solved internally within the model from available meteorological boundary condition data.

2.3 Model mesh

This model has been developed as a nested TUFLOW FV model, within a larger model of the Scottish Shelf region, developed as part of the Seafood Innovation Fund (SIF) Project (BMT 2021). The two models include a low-resolution region scale model used to develop the general ocean circulation conditions; water levels, currents, temperature and salinity and a high resolution model encompassing the area of interest.

The high resolution mesh has been refined in the area of interest (Figure 2.1), with a horizontal resolution around the pens of approximately 20m to meet the requirements set out by the SEPA (2019) guidelines. The high-resolution model domain covers an overall area of 910,353 hectares, with two open boundaries of approximately 28 km extending along the southern section (The Little Minch) and 127 km extending along the northern section (North Minch) (Figure 2.1). The high-resolution mesh has 32087 2D cells with resolution varying from 2 km at the open boundary to 150 m in the near shore environment.

2.4 Model bathymetry

The bathymetry was comprised of multiple sources to ensure suitable resolution for current speeds around the area of interest (Figure 2.1). The final bathymetry comprised the following:

- Bathymetry survey data provided by Loch Duart for the farm area.
- Navionics.
- A digital elevation model (DEM) developed as part of the ongoing work in the SIF project (BMT 2021). The DEM includes regional bathymetry data from General Bathymetric Chart of the Oceans (GEBCO) and other sources provided as part of the SIF project data collection (BMT 2021).

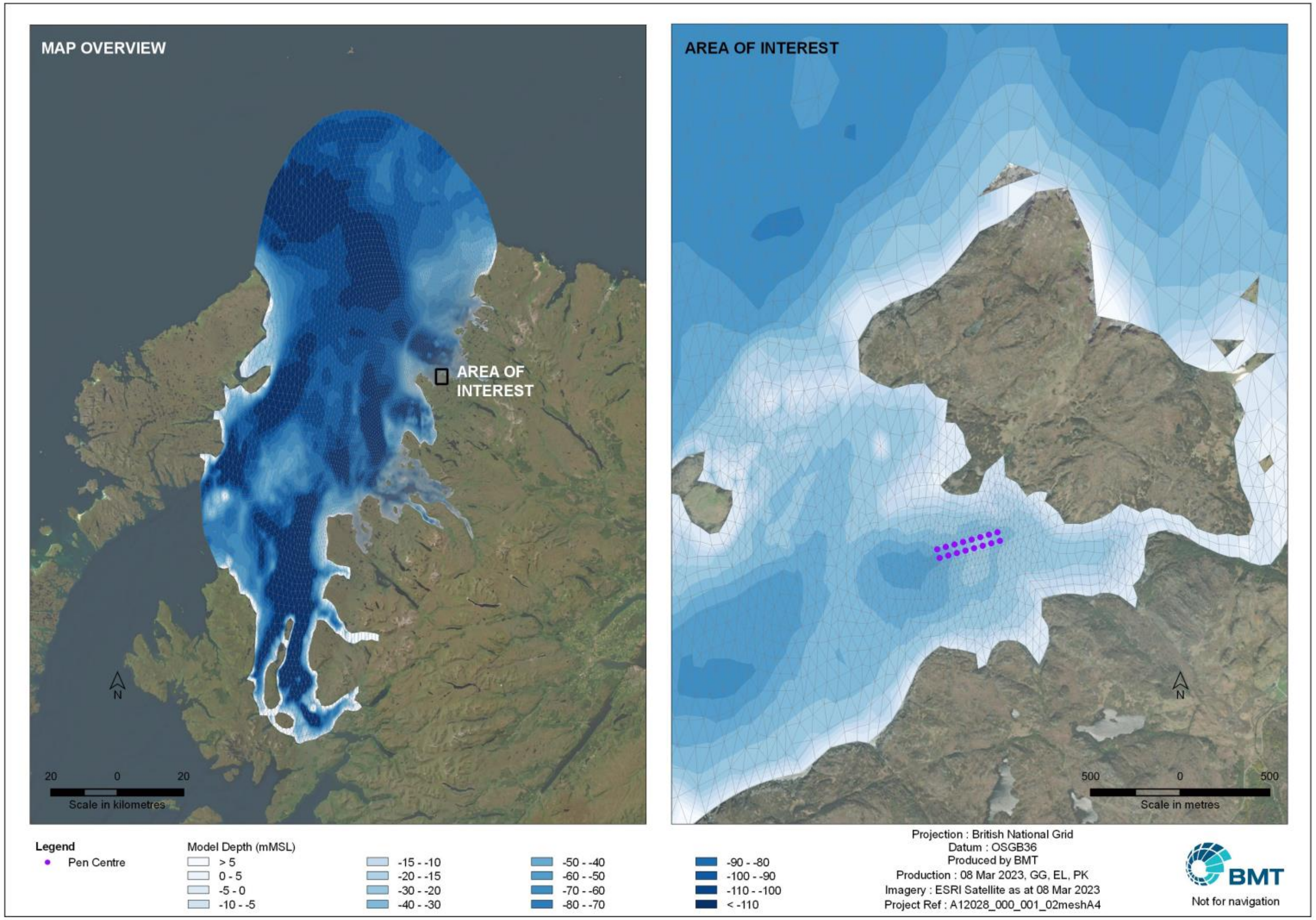


Figure 2.1 The mesh and bathymetry used for the high-resolution model.

2.5 Boundary conditions

The following meteorological and open tidal boundary conditions have been used for the larger regional model:

- Tidal boundary conditions provided by the TPXO71 global tide model.
- Regional currents, residual water levels, temperature and salinity boundary conditions were provided by the Atlantic- European North West Shelf- Ocean Physics Reanalysis developed for the Copernicus Marine Service (CMS) (https://marine.copernicus.eu/).
- Meteorological data from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 climate model.

For the high-resolution nested model, the following boundary conditions were included;

- Open boundary conditions from the larger regional model.
- Meteorological data from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 climate model.

Note that, freshwater inputs to the area of interest were considered negligible and not included in either model.

2.6 Hydrodynamic Model Calibration

The Loch Duart hydrodynamic model was calibrated against data from an Acoustic Doppler Current Profiler (ADCP) located close to the farm site (Figure 3.1). The calibration process involved the comparison of water levels, velocity direction, velocity magnitude and the x and y component of the flow to observed data, adjusting model parameters and bathymetry to achieve a desired level of model fit.

Data were extracted from the ADCP deployed as part of the project by TransTech Limited (2019). The calibration period was from 02/11/2018 to 31/01/2019.

Realistic wind conditions (from the ERA5 global reanalysis dataset, described in Section 2.5) were used to force the model so that model output was compared directly against the observed data.

The calibration has been done at 3 different depths throughout the water column:

- Mid water column - 13 m above the seabed,
- Sub-surface - 20 m above the seabed, and
- Bottom - 3 m above the seabed.

The ADCP was located approximately 28 m MSL depth (TransTech Limited 2019) with these depths meeting the regulatory guidelines of < 5 m from the water surface, and < 3 m from the bed (SEPA 2019). The depth used to simulate the release of Azamethiphos following bath treatment was 4 m, representative of treatment volume release from a tarpaulin or wellboat.

Comparisons of model against observed data are shown in Figure 2.2 to Figure 2.4, noting that water level is the same in all three plots for reference. On the plots, statistics for R, BIAS (model bias), MAE (mean absolute error), and PD (percentage difference) are included for comparison.

2.6.1 Water level

- The R value is high, signifying a strong correlation between the model predicted water level and the observed data.
- The tidal range the model predicts is comparable to the tidal range from the observed data and predicts the change in tidal range between spring and neap tides.
- The timing of the high and low water matches well between the ADCP and modelled data.
- The ADCP shows a drop in overall water level in January 2019, potentially due to a weather event not depicted by the model simulations.
- This model has a water level calibration suitable for the use of modelling the dispersion of bath treatment.

2.6.2 Velocity magnitude

- There was a negative BIAS for predicted results of 0.02 m/s for both middle and bottom depths. The BIAS at the surface, where bath treatment is released was negligible.
- Underprediction of the current speeds in the area of interest is consistent with a conservative approach leading to reduced rate of dispersion and dilution impact.
- The MAE is small for all three depths (0.01-0.03) and within the regulatory calibration guideline of 0.1m/s (SEPA 2019).
- A possible cause of some difference is due to the ADCP having a standard deviation of 0.5cm/s.
- At the surface, where the majority of the bath treatment will be, the timeseries show that the variation and peaks are effectively modelled, the majority of these peaks are due to wind events.

2.6.3 Current direction

- Due to the low speeds in the farm area, there was a lot of variation in direction, with limited trends observed in the ADCP data. This variation was very difficult to simulate most notably in the surface.
- Lower in the water column, stronger trends were observed within the ADCP data. With a stronger directional trend, the model was better able to reproduce the observed directions.
- Due to the very low current speeds in the area and limited directional trends, the model directions were deemed suitable for use in the bath treatment dispersion model.

2.6.4 Flow components

- The x and y components of the flow are representative of relatively small the flows in this area.
- Comparison of observed and predicted timeseries demonstrate that the model successfully represents changes in direction and speed.
- The BIAS and MAE were relatively low, highlighting a good comparison between the ADCP and modelled data.

Overall, the results of the calibration signified that the model was suitable for use in simulating bath treatment dispersion at the Oldany site.

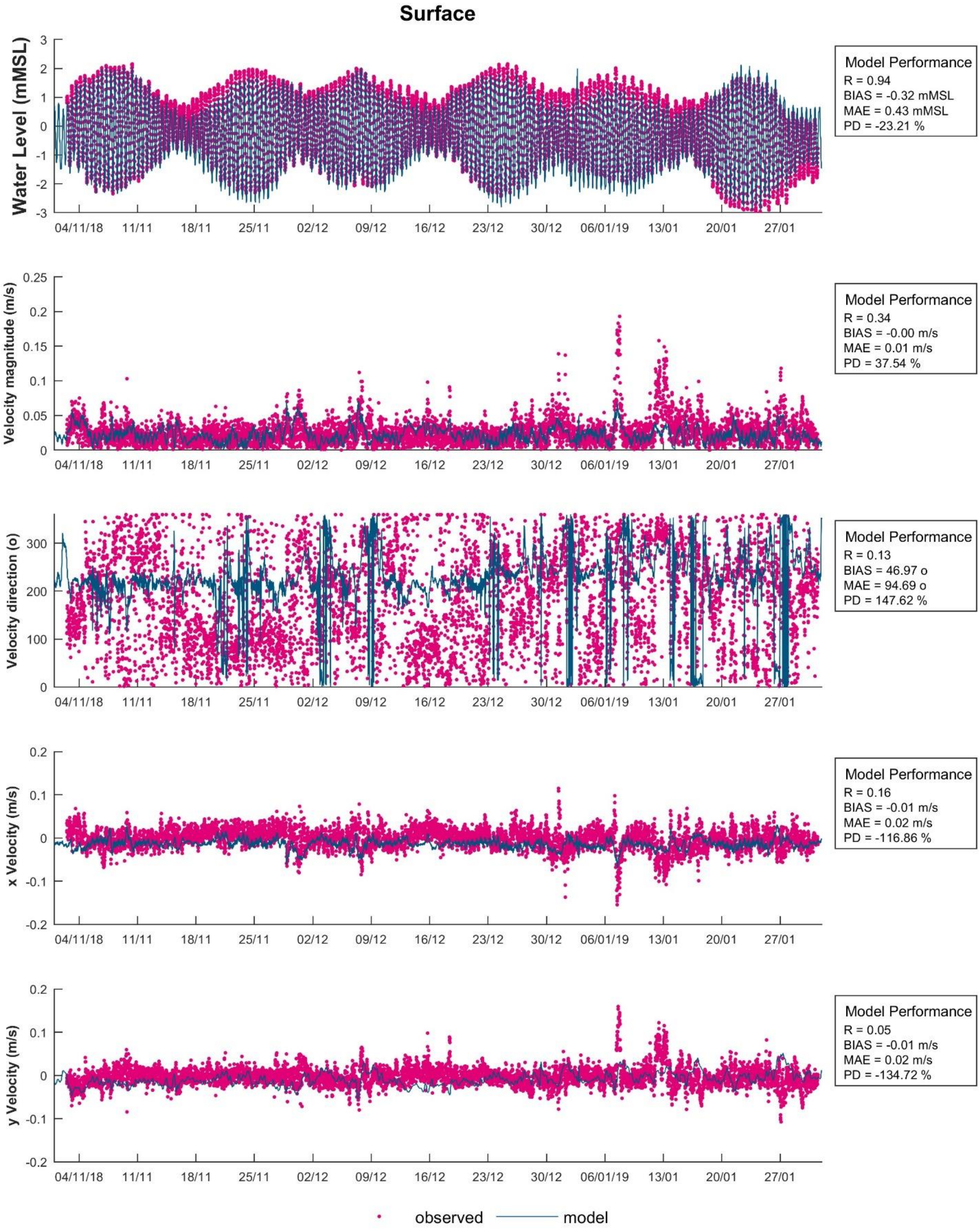


Figure 2.2 Model comparison to ADCP data at the surface (20 m above the bed).

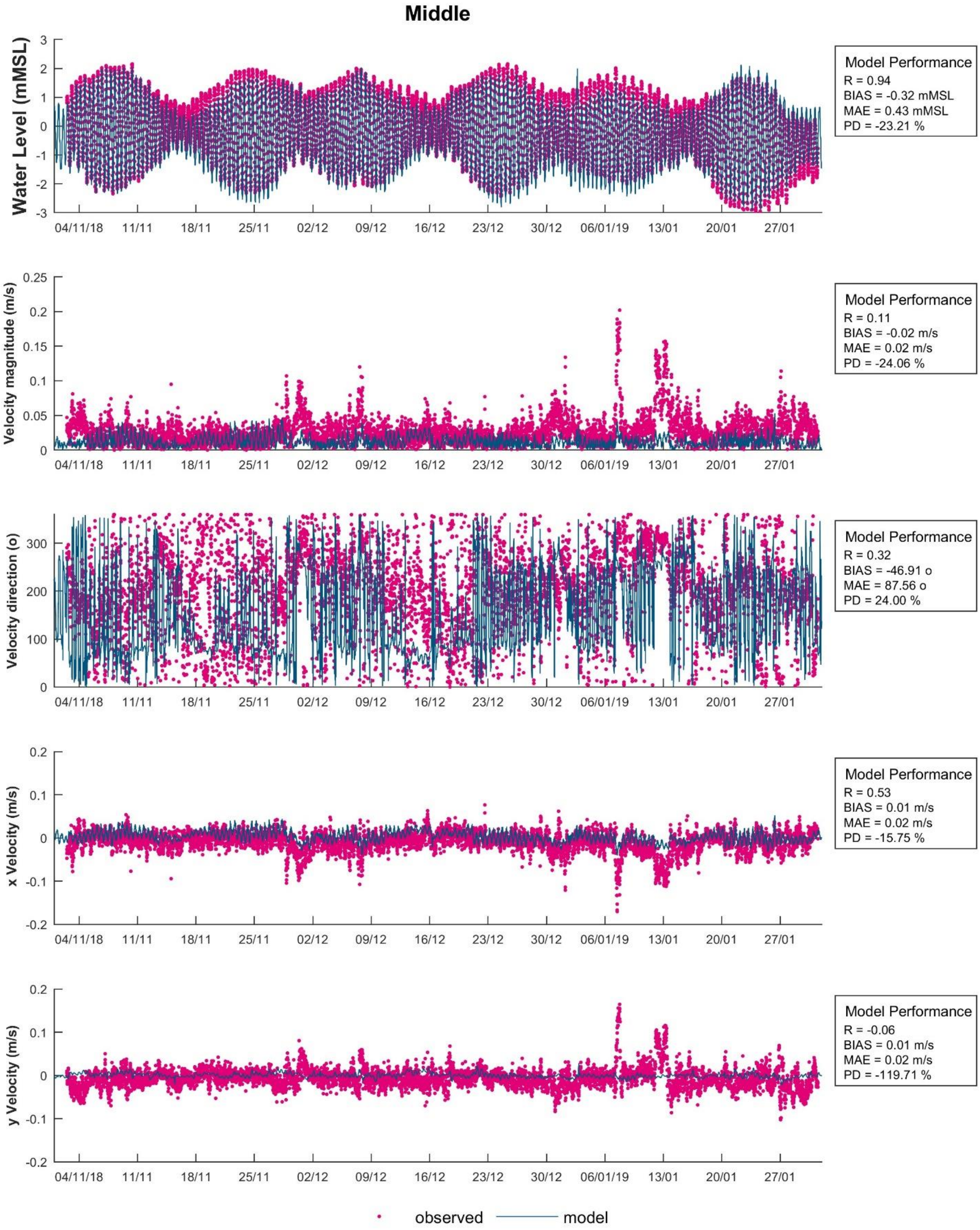


Figure 2.3 Model comparison to ADCP data at the surface (13 m above the bed).

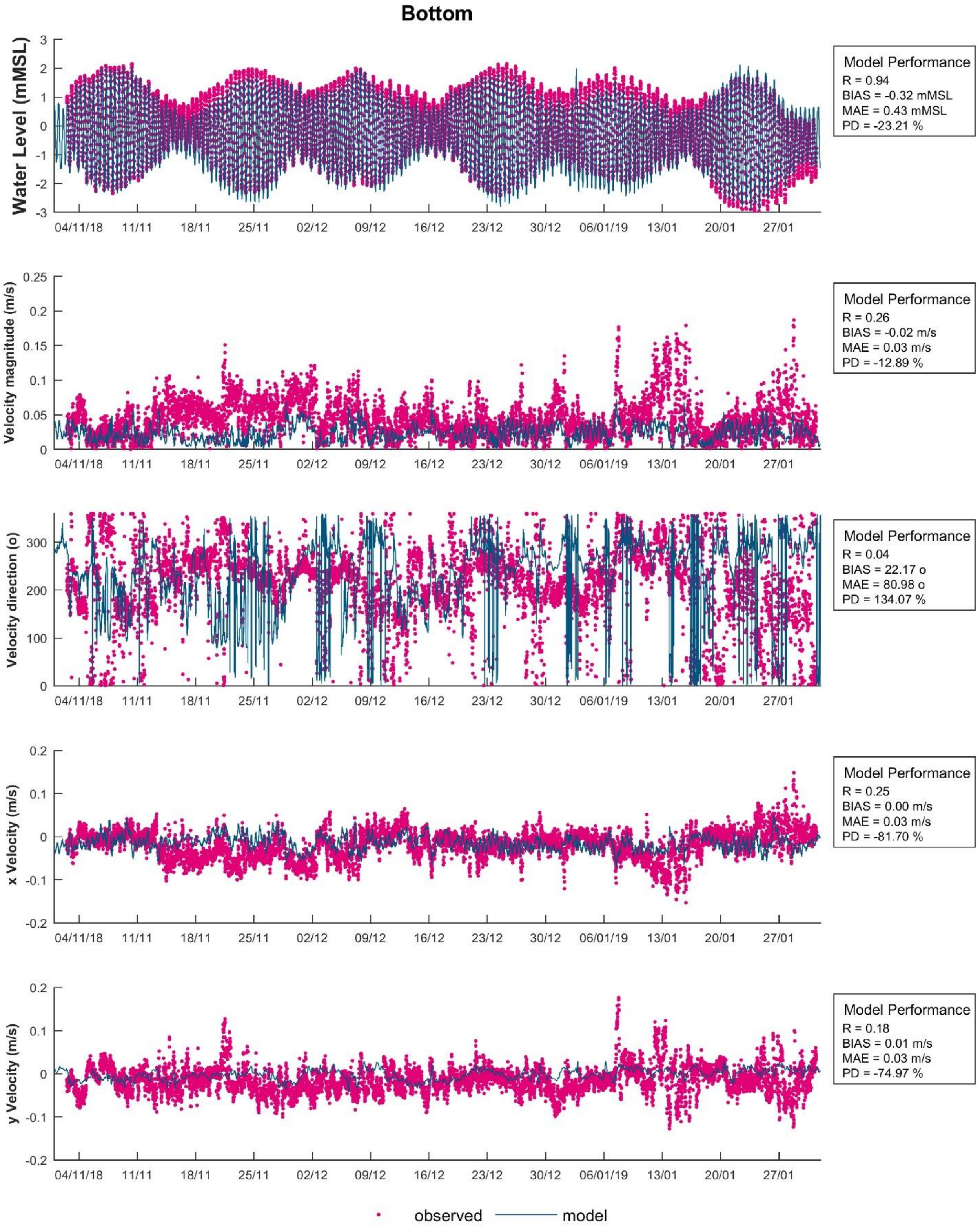


Figure 2.4 Model comparison to ADCP data at the bed (3 m above the bed).

3 Dispersion modelling

3.1 Model

The impact of bath medicine footprints was represented as plumes of dissolved constituents with increased dilution from point of treatment release. The dispersion of Azamethiphos following treatment has been simulated using a high-resolution calibrated TUFLOW FV hydrodynamic model, as described in Section 2. Water velocities in the region, were simulated using a calibrated TUFLOW FV hydrodynamic model and released bath treatment simulated using the advection and dispersion module using inert tracers. These models have been extensively used to predict the fate and transport of various discharge constituents in the marine environment to assist with Environmental Impact Assessment (EIA) process (BMT, 2022b; BMT,2021; Botelho et al, 2016; Saha,2020).

Advection/Dispersion of inert tracers

Inert tracers were used to simulate the advection and dispersion of bath treatment within the area of interest and further afield towards any sensitive receptors. The use of inert tracers is viewed as an efficient and accurate way to simulate the dispersion of Azamethiphos in a bath treatment system and assess compliance against regulatory guidelines.

3.2 SEPA Standards

When Azamethiphos is released into water, it stays in the water until it breaks down into non-toxic derivatives, for which a decay half-life of 8.9 days has been determined (SEPA, 2008). According to SEPA regulatory framework, two standards are used: one is applied three hours after any discharge, and the other is applied 72 hours after the final discharge in any treatment period. The model was used to assess if proposed treatment scenarios, based on realistic farm operations, complied with Environmental Quality Standards (EQSs) established by SEPA. To maintain safe levels of Azamethiphos in water, the mixing zone area should not exceed 250 ng/l as calculated by BathAuto after 3 hours, and after 72 hours, the area exceeding 40 ng/l should not exceed 0.5 km^2, while the maximum concentration in the domain should not exceed 100 ng/l (maximum allowable concentration - MAC) (Table 3.1).

For the purposes of this report, it should be noted that while EQS limits may be labelled as Environmental Quality Guidelines (EQG) in some of the figures, the limits remain the same.

Table 3.1 Environmental Quality Standards (EQSs) for Azamethiphos (SEPA, 2008 &2022)

Standards for Azamethiphos Timescale	Standard (ng per litre)	Type
3 hours	250	EQS
72 hours	40	EQS
72 hours	100	MAC

Predicted residual concentrations for a particular compound were compared with EQSs over an Allowable Zone of Effect (AZE). AZEs are defined as the area (or volume) of sea bed or receiving water in which SEPA will allow some exceedance of a relevant EQS (SEPA 2005). Beyond the far-field allowable zone of effect, surrounding a fish farm, bath treatment chemical concentrations must not exceed the defined environmental quality standards. For Azamethiphos it is the lower of 0.5 km^2 or 2 % of loch area within 72 hours (SEPA, 2019). As Oldany is unclassified as a sea loch under Marine

Scotland Locational Guidelines (The Scottish Government 2023a), the threshold of 0.5 km^2 has been used for this study.

3.3 Priority Marine Features

Priority Marine Features (PMF) close to the farm site are shown in Figure 3.1. These PMF sites have been extracted from Marine Scotland's National Marine Plan interactive (NMPi) maps (The Scottish Government 2023b and The Scottish Government 2023c). Timeseries concentrations at these sites were extracted and analysed for bath treatment impact.

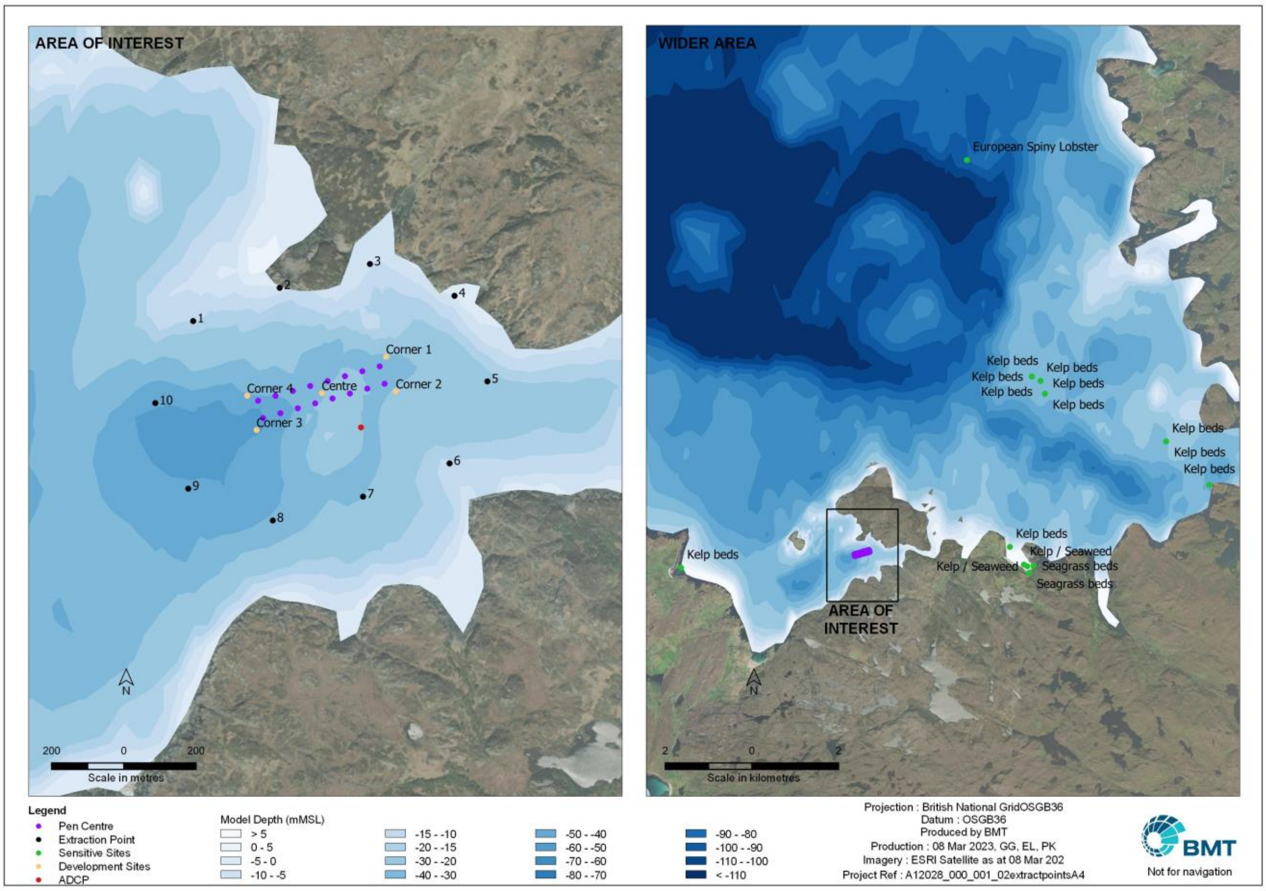


Figure 3.1 Extraction locations for timeseries of bath treatment concentrations with nearby PMFs.

3.4 Bath treatment

Treatment dosage

The method of bath treatment was simulated by applying 230 g of Azamethiphos to each pen with releases at different times (10:00, 13:10, and 16:15) (Pers com. Loch Duart) to represent a realistic daily treatment campaign. The Azamethiphos treatment was modelled as a tracer released over a period of 5 minutes spread over the surface 4m of the water column to represent the release of the treatment when the bath volume is released. The simulated tracer released from each pen was as follows:

- 10.00 – 10.04 230 g released (0.767 g/s over 300 s)

- 13.10 – 13.14 230 g released (0.767 g/s over 300 s)
- 16.15 – 16.19 230 g released (0.767 g/s over 300 s)

The treatment schedule was designed with consideration to the time needed for setting up each treatment, moving between pens, and the duration of the treatment.

Decay rate

A half-life of 5.6 days was applied to represent Azamethiphos decay (BMT 2022a), this equated to the time required for half of the substance to decay (equivalent to a decay rate of 0.12377 per day).

3.5 Modelled Scenarios

3.5.1 Bath treatment options

Two alternative treatment scenarios proposed in consultation with Loch Duart were simulated.

Scenario 1
Scenario 1 represents the worst-case scenario for cumulative impact, with neighbouring pens consecutively treated using 230 g of Azamethiphos per treatment at 10:00, 13:10, and 16:15 over five days, followed by treatment of the final pen with the same amount on day six. A total of 3.68 kg of Azamethiphos was discharged over the six-day period. The order of pen treatment for this scenario is shown in Figure 3.2.

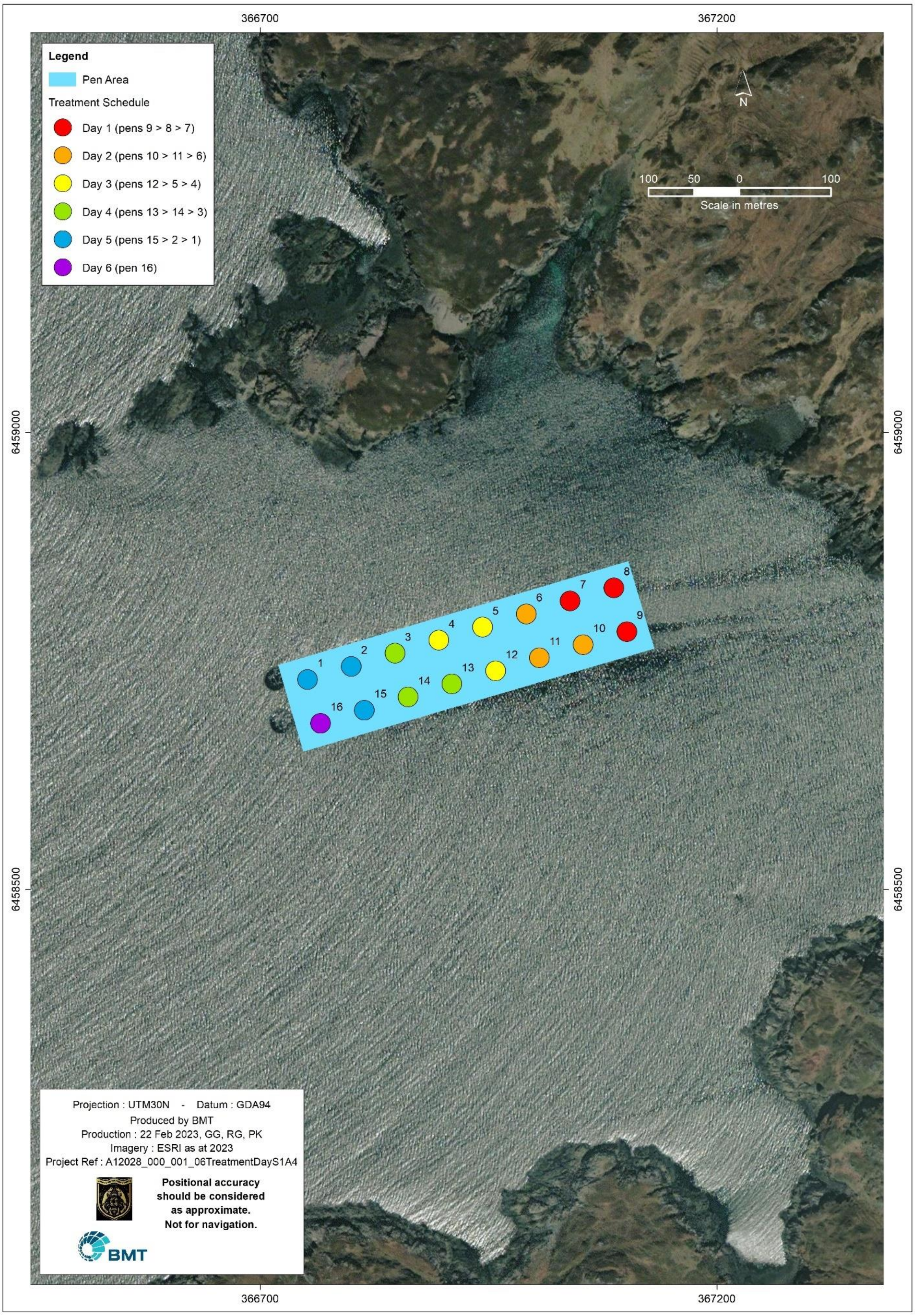


Figure 3.2 Treatment order for Scenario 1

Scenario 2

Scenario 2 represents a more realistic approach as it replicates the targeted treatment strategy that is commonly adopted to manage parasites in farmed fish. This method involves prioritising the treatment of pens with a higher parasite burden, irrespective of their position in the pen group. The influence of logistical factors during treatment such as weather and vessel operations is also captured in the alternation of number of treatments per day. As such, three pens were treated at 10:00, 13:10, and 16:15 on day 1, 2, 4, and 6, while two pens were treated on days three and five at 10:00 and 13:10. A total of 3.68 kg of Azamethiphos was discharged over the six-day period. The order of pens treated in this scenario is shown in Figure 3.3.

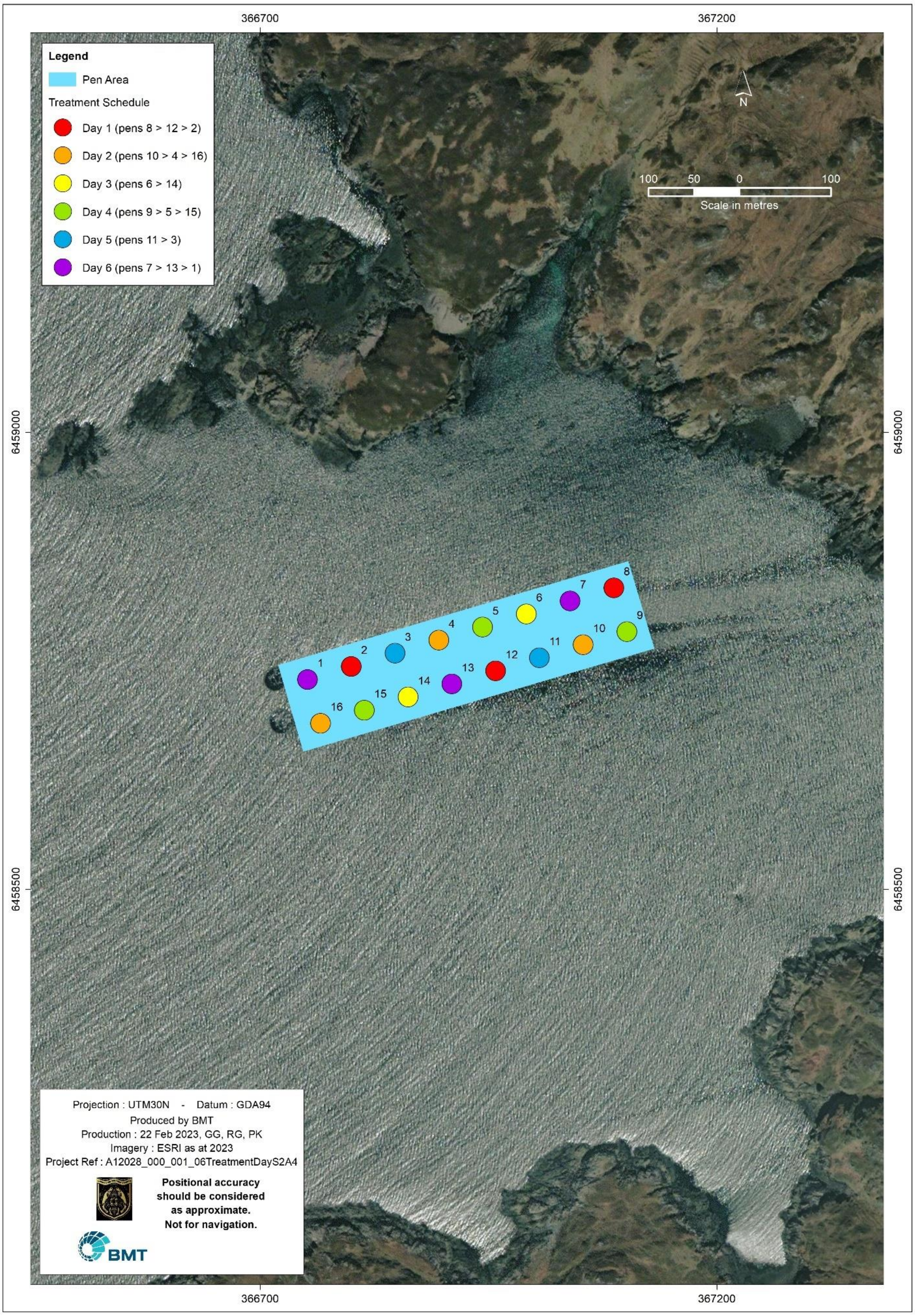


Figure 3.3 Treatment order for Scenario 2

3.5.2 Tidal conditions

To simulate the worst-case scenario, the dispersion modelling was initially conducted using TUFLOW FV flow fields over a period of two weeks centred on a small neap tidal range taken from the calibrated hydrodynamic model simulated period. This is assumed to be the least dispersive set of ambient conditions, when Azamethiphos concentrations would be greatest following bath treatment. Simulations have also been conducted during a two-week period of spring tides for comparison and to check against advection towards any PMF sites. These periods are shown in Figure 3.4.

The two-week simulation periods cover the duration of treatment, a dispersion period to the EQS assessment after 72 hours (long-term assessment as per guidelines) and an additional 240 hours to check for chance concentration peaks. It has been identified that the medicines used in bath treatments are either rapidly broken down or bind to particles in the water rendering them unavailable to marine life so that short period simulations were deemed sufficient to predict any potential impact (SSFL, 2011).

The results of the two scenarios were compared against two distinct periods representative of neap and spring tide conditions extracted from the 90-day model calibration period in 2018/2019:

- two weeks of typical neap tide conditions (14/11/2018 – 01/12/2018).
- two weeks of typical spring tide conditions (20/12/2018 – 08/01/2019).

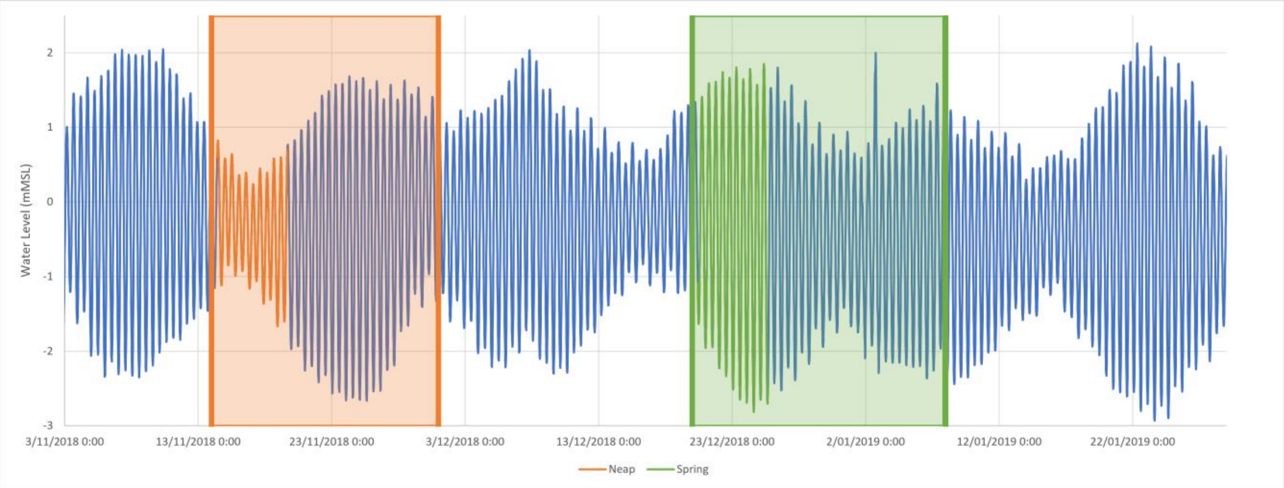


Figure 3.4 Neap (orange) and spring (green) time periods chosen for modelling. The coloured boxes indicate the periods modelled and the coloured water level lines indicate the treatment periods.

4 Results

The results of this study are presented in three different ways to show compliance with the SEPA Guidelines described in 3.2. The presentation approaches are:

- Plume dispersion maps representing snapshots of surface 4m depth averaged tracer concentration after 3 hours, 24 hours and 72 hours.
- Timeseries of tracer concentration surface 4m depth averaged at points around the site, encompassing an area of approximately 0.5 km^2.
- Timeseries of the area exceedance (area with Azamethiphos concentration greater than the thresholds of 40 ng/L and 250 ng/L), surface 4m depth averaged.
- Timeseries of tracer concentration surface 4m depth averaged at PMF sites.

Note that presentation of results under alternative depth averaging has been included in the sensitivity analysis presented in Section 4.5.4.

4.1 Plume dispersion maps

Snapshots in time of the tracer concentration for Scenario 1 are shown in Figure 4.1 (Spring Tide) and Figure 4.2 (Neap Tide) and for Scenario 2 are shown in Figure 4.3 (Spring Tide) and Figure 4.4 (Neap Tide). These show that the concentration is within the SEPA guidelines (Table 3.1 / Section 3.2). The concentrations shown in the figures are:

- After 3 hours the two scenarios for both spring and neap tides show concentrations less than 150 ng/L (well below EQS of 250 ng/L).
- After 24 hours during neap tide for both scenarios concentrations were less than the EQS of 150 ng/L. After 24 hours for both scenarios the spring tide had diluted further and was less than 40 ng/L.
- After 72 hours for both scenarios the predicted neap tide concentrations were less than the EQS of 40 ng/L. By 24 hours for both scenarios the spring tide had diluted further and was less than 10 ng/L.

The lower predicted concentrations for spring tide were consistent with the higher dilution expected with the larger tidal range.

Table 4.1 summarises concentration statistics at the surface 4 m depth averaged for the two scenarios under different tide conditions. According to this table, in the "Scenario 2 - neap tide" conditions, the highest concentration simulated after 72 hours from the final treatment was 26 ng/L within the model domain.

Figure 4.1 Tracer concentration surface 4 m depth averaged for Scenario 1 Spring Tide

Figure 4.2 Tracer concentration surface 4 m depth averaged for Scenario 1 Neap Tide

Figure 4.3 Tracer concentration surface 4 m depth averaged for Scenario 2 Spring Tide

Figure 4.4 Tracer concentration surface 4 m depth averaged for Scenario 2 Neap Tide

Table 4.1 Azamethiphos concentration (surface 4 m depth averaged) statistics in the area of interest.

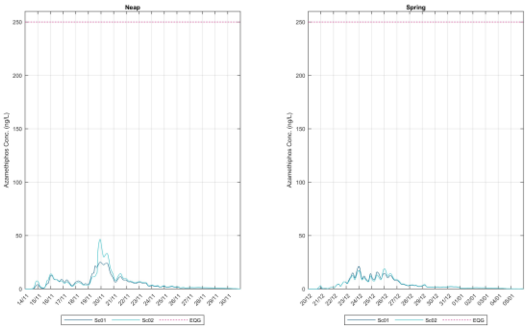
Scenario	Tide	Hours from the final treatment	Azamethiphos concentration (ng/L)		
			Maximum	Mean	Median
SC01	Neap	3 hr	85.6	1.8	<0.01
SC01	Neap	24 hr	41.6	1.4	<0.01
SC01	Neap	72 hr	22.0	0.5	<0.01
SC01	Spring	3 hr	64.0	1.5	<0.01
SC01	Spring	24 hr	26.8	0.9	<0.01
SC01	Spring	72 hr	9.8	0.4	<0.01
SC02	Neap	3 hr	114.4	2.0	<0.01
SC02	Neap	24 hr	47.8	1.5	<0.01
SC02	Neap	72 hr	25.8	0.5	<0.01
SC02	Spring	3 hr	98.4	1.4	<0.01
SC02	Spring	24 hr	26.4	0.9	<0.01
SC02	Spring	72 hr	9.6	0.3	<0.01

4.2 Timeseries of tracer concentration

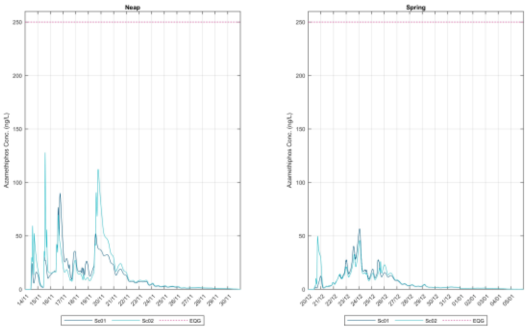
Timeseries of tracer concentration were extracted at points around the pen site, encompassing an area of approximately 0.5 km^2. These were extracted for two scenarios simulating spring and neap tidal conditions (Figure 4.5).

The concentration of bath treatment is compared to the EQS value of 250 ng/L (pink line on the graph), and these show that the only point where concentrations reach the EQS value are point 7 and this is only for a very short period of time during the treatment period well before the 3 hour extraction limit.

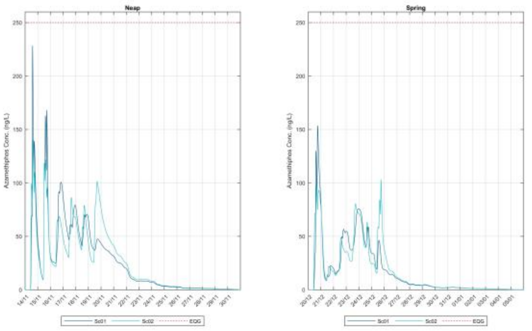
Point 1



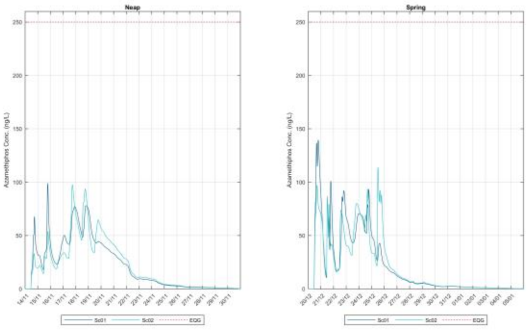
Point 2



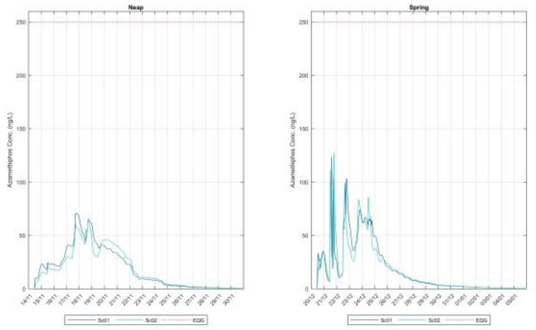
Point 3



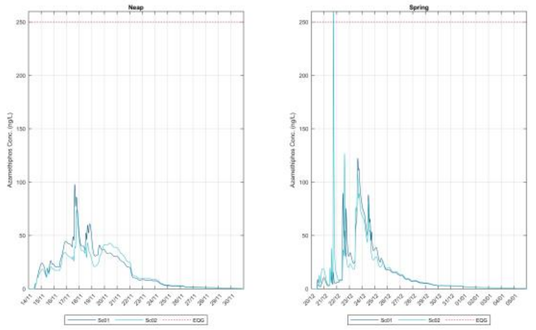
Point 4



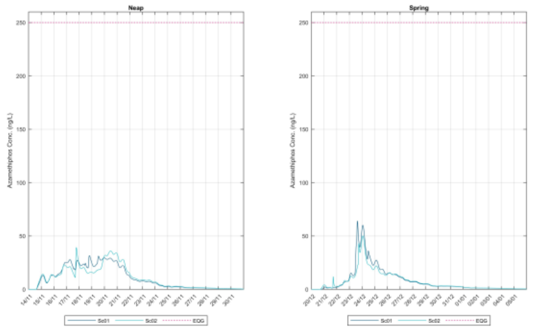
Point 6



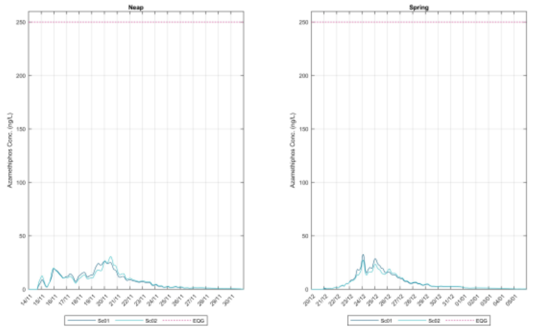
Point 7



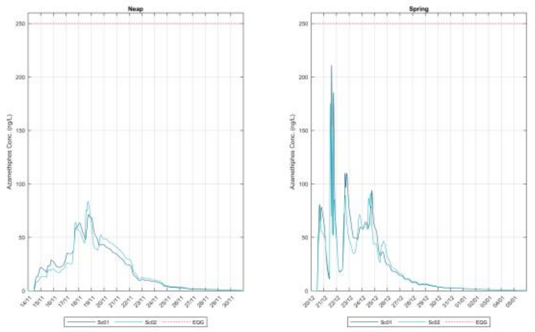
Point 8



Point 9



Point 5



Point 10

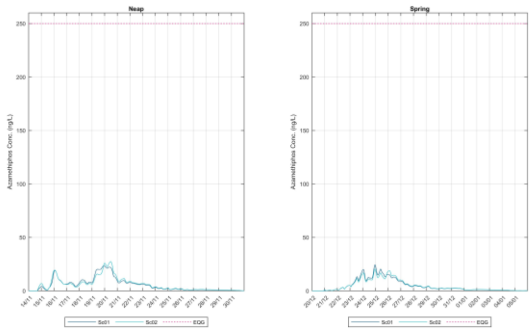


Figure 4.5 Tracer concentration surface 4 m depth averaged for Scenario 1 (dark blue) and Scenario 2 (light blue) during neap (left) and spring (right) tides against 250 ng/L EQS (pink).

4.3 Timeseries of area exceedance

Predicted residual concentrations of Azamethiphos compared to EQSs of 250 ng/L and 40 ng/L were used to calculate AZEs for two scenarios under spring and neap tidal conditions (Figure 4.6). As detailed in Section 3.2 the SEPA guidelines state that 40 ng/L AZEs after 72 hours should be less than 0.5 km^2 (SEPA, 2019). For all scenarios, predicted 40 ng/L AZEs were zero within 72 hours of the last treatment (Figure 4.6) as summarised in Table 4.2.

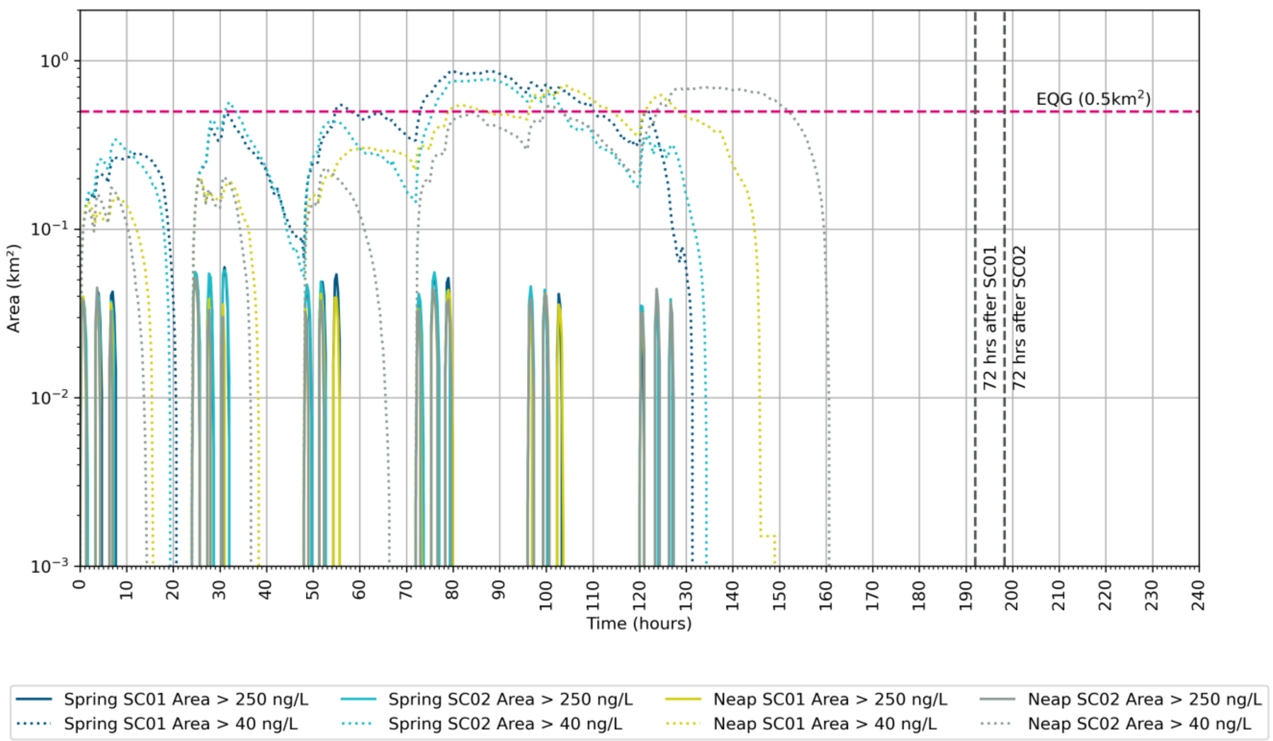


Figure 4.6 Timeseries of 250 ng/L and 40 ng/L AZEs for surface 4 m depth averaged first treatment release for Scenario 1 (SC01) & Scenario 2 (SC02) under spring and neap tides.

Table 4.2 Summary of AZEs for Azamethiphos thresholds of > 250 ng/L and > 40 ng/L

Scenario	Tide	Hours from the final treatment	Tracer dispersion area in km²	
			AZE > 250 ng/L	AZE > 40 ng/L
SC01	Neap	3 hr	0	0.592
SC01	Neap	24 hr	0	0.134
SC01	Neap	72 hr	0	0
SC01	Spring	3 hr	0	0.408
SC01	Spring	24 hr	0	0
SC01	Spring	72 hr	0	0
SC02	Neap	3 hr	0	0.682
SC02	Neap	24 hr	0	0.549
SC02	Neap	72 hr	0	0
SC02	Spring	3 hr	0	0.219
SC02	Spring	24 hr	0	0
SC02	Spring	72 hr	0	0

4.4 Timeseries concentrations at PMFs

The model predicted concentrations at all PMF sites within the model boundary including those closest to Oldany farm were well below the EQS of 40 ng/L. The highest Azamethiphos concentrations predicted for neap tide was ~0.05 ng/L and spring tide ~0.2 ng/L across all sites including kelp beds, seagrass beds and European spiny lobster sites selected as 'PMFs or sensitive habitats nearby' (as shown in Figure 3.1) for this exercise. Note that plots were not included in the report as predicted concentrations were negligible at all PMF sites.

4.5 Sensitivity Analysis

A sensitivity analysis was undertaken to ensure that the model parameter values chosen do not have an effect on the overall result of the compliance assessment. The sensitivity analysis was performed on the Scenario 1 neap tide or theoretical worst-case simulation. For comparing the results two methods of presentation have been used:

- Timeseries of tracer concentration, at points around the site, encompassing an area of approximately 0.5 km^2, extracted at the locations in Figure 3.1.
- Timeseries of AZEs for 40 ng/L and 250 ng/L EQSs.

4.5.1 Horizontal diffusion coefficient

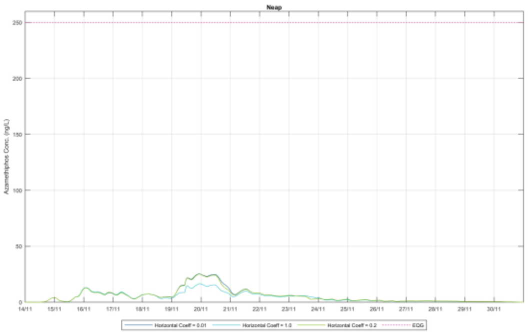
In TUFLOW-FV, the global horizontal scalar diffusivity refers to the scalar diffusion coefficient that is used to calculate the rate at which a scalar quantity, such as temperature or concentration, is mixed and transported in the horizontal direction due to turbulent eddies and mixing processes (TUFLOW 2017, 2018).

This coefficient was applied uniformly throughout the computational domain and was set at 0.2 m^2/s for the base simulations. The global horizontal scalar diffusivity is typically calibrated using field data or laboratory experiments to ensure that it accurately represents the actual horizontal diffusion properties of the fluid being modelled. For this exercise, selection of global horizontal scalar diffusivity has been guided by dye releases conducted near the Oldany site by Anderson Marine Surveys Ltd in September 2022 (AMS 2022). Site-specific standard nominal value of the horizontal dispersion component, 0.1 m^2/s has been quantified during the dye experiment. Typical reported values for horizontal dispersion component measured using dye patch studies in coastal waters varied widely (e.g. from 0.02 – 2.17 m^2/s; Anderson Marine Surveys 2022, Elliott et al 1997; Morales et al 1997). Two values of 0.01 and 1.0 m^2/s were used to represent a range of realistic diffusion coefficients.

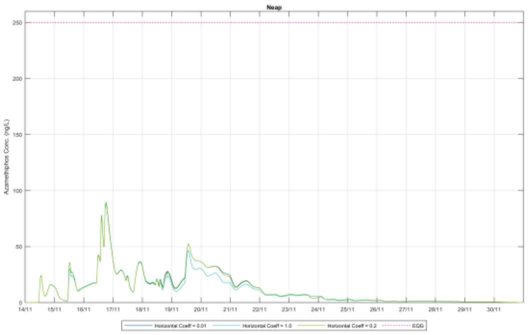
Timeseries of tracer concentration

The timeseries of tracer concentration (Figure 4.7) show that the horizontal diffusion coefficient we used (0.2 m^2/s) and the lower value (0.01 m^2/s) had very similar results. For most of the simulation period, the results of the higher horizontal diffusion coefficient (1.0 m^2/s) were similar, with short periods of lower concentration. This indicates that the value we used (0.2 m^2/s) is conservative and suitable for modelling bath treatment at this site.

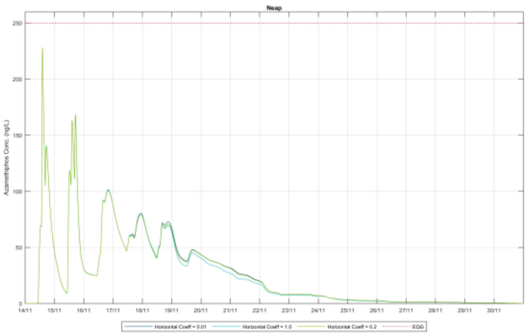
Point 1



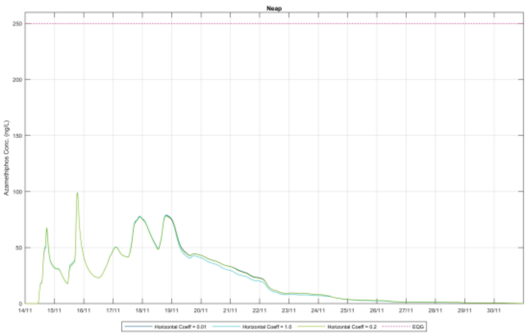
Point 2



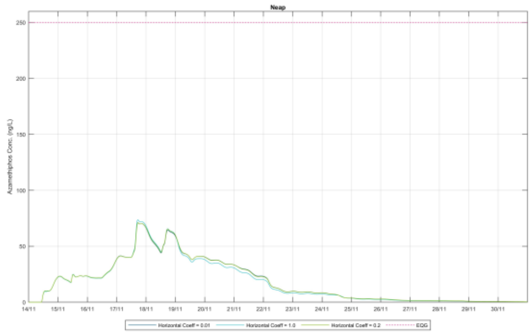
Point 3



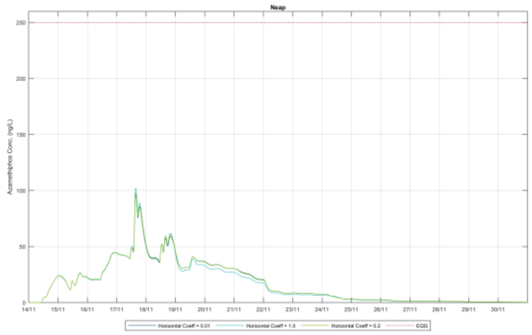
Point 4



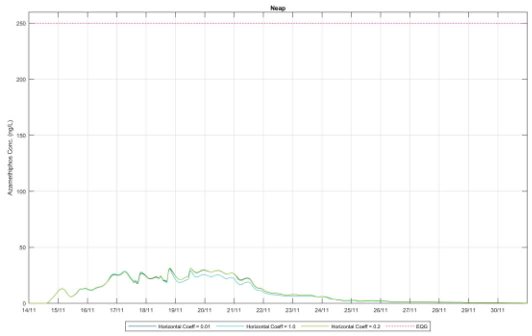
Point 6



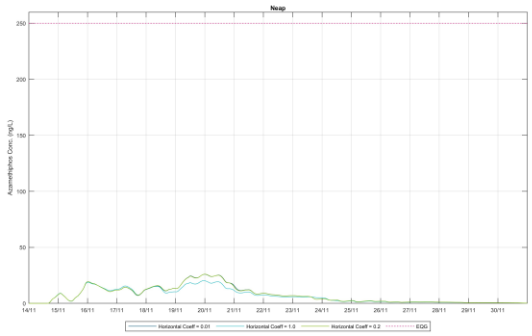
Point 7



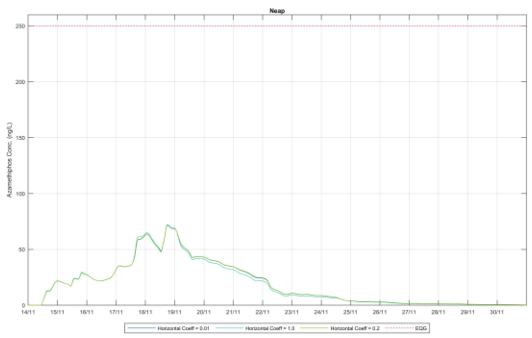
Point 8



Point 9



Point 5



Point 10

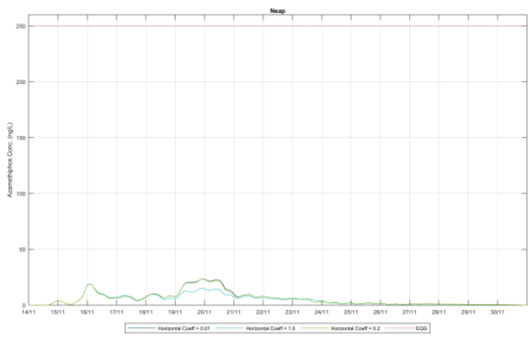


Figure 4.7 Tracer concentration surface 4m depth averaged for Scenario 1 neap tide. Sensitivity results for horizontal coefficients of 0.01 m^2/s (dark blue), 1.0 m^2/s (light blue) and 0.2 m^2/s (green) against the EQS value of 250 ng/L (pink).

AZE timeseries

The timeseries of 40 ng/L AZE (Figure 4.8) show that the horizontal diffusion coefficient we used (0.2 m^2/s) and the lower value (0.01 m^2/s) had very similar results. When run with the higher horizontal diffusion coefficient (1.0 m^2/s) the model predicted a faster decrease in impacted area following the final treatment. This indicates that the values we used (0.2 m^2/s) is conservative and suitable for modelling bath treatment at this site.

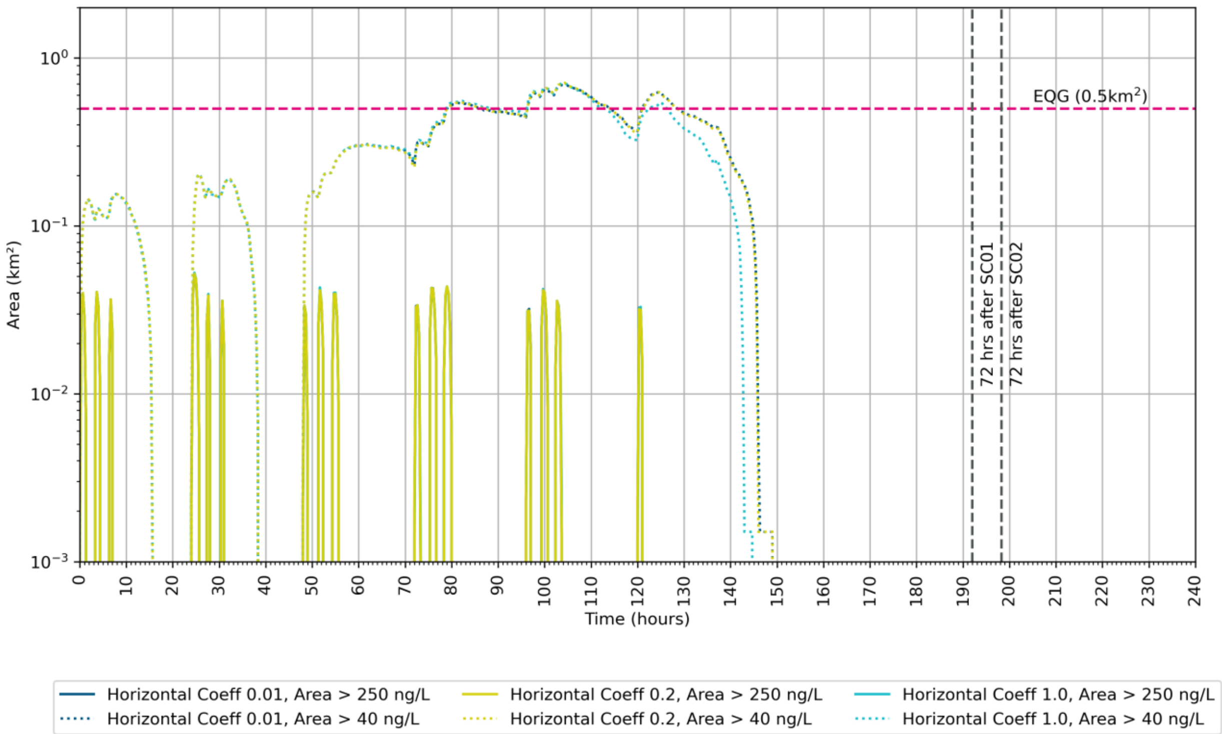


Figure 4.8 Timeseries of 250 ng/L and 40 ng/L AZE surface 4 m depth averaged from first treatment release comparing a range of horizontal diffusion coefficients.

4.5.2 Vertical diffusion coefficient

The vertical scalar diffusivity is calculated within TUFLOW, based on limits specified in the model configuration file. Base runs (in Section 4) use a standard limit of 0 – 1. The global vertical scalar diffusivity limits for TUFLOW FV represent a range of possible values for the vertical scalar diffusivity, rather than a specific value. The lower limit of ‘0’ means that the vertical scalar diffusivity must be greater than zero, while the upper limit of ‘1’ represents the maximum value of the vertical scalar diffusivity that can be used in the model.

In the absence of a specific value for the vertical scalar diffusivity, it is common practice to use a range of values that are considered reasonable for the specific aquatic system being modelled, based on available data and knowledge of the system. So, in the absence of a specific value for the vertical scalar diffusivity, the TUFLOW-FV model calculates the actual values of the vertical scalar diffusivity during the simulation based on the local flow and turbulence conditions, subject to the constraint of the global vertical scalar diffusivity limits that we specify. The model does not use the maximum value of the global vertical scalar diffusivity limit as the default value, but instead uses the calculated values that fall within the specified range.

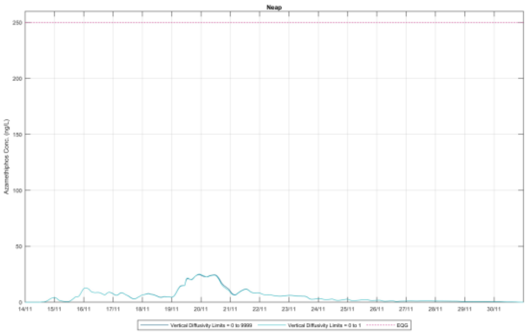
The selection range of appropriate values for the vertical scalar diffusivity can affect the accuracy of the model results, and it was necessary to perform sensitivity analyses to evaluate the sensitivity of the model results to different values of the vertical scalar diffusivity within the specified range. Thus, for this assessment, we compared the model results with a larger limit of 0 – maximum vertical coefficient (i.e. 9999) based on local flow conditions, allowing for an increased vertical diffusion.

The Smagorinsky model calculates the eddy viscosity and diffusivity coefficients based on the local flow conditions and the rate of strain of the flow (TUFLOW 2017, 2018). These coefficients are then used to calculate the vertical scalar diffusivity at each computational cell and time step.

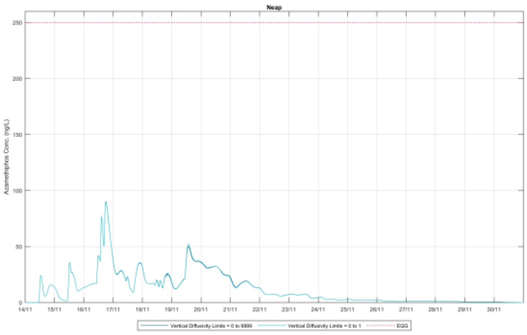
Timeseries of tracer concentration

The timeseries of tracer concentration (Figure 4.9) show very little difference between the two results, indicating that the assessment is independent of vertical scalar diffusivity limit chosen.

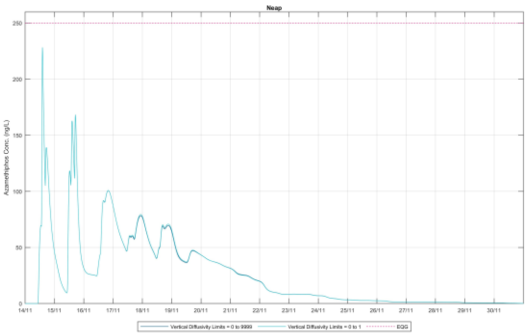
Point 1



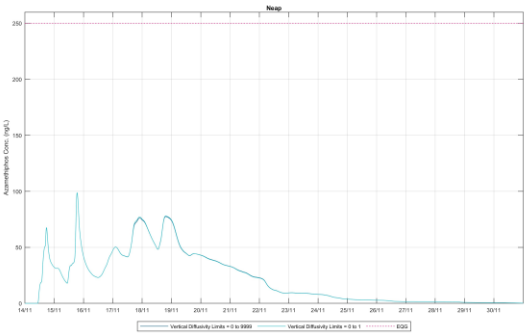
Point 2



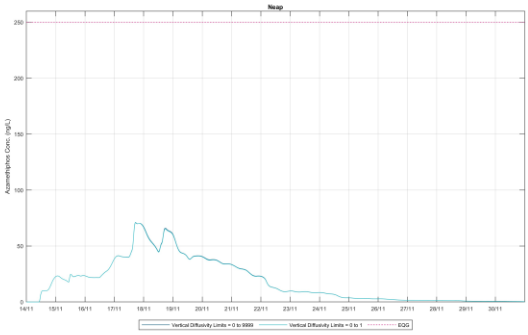
Point 3



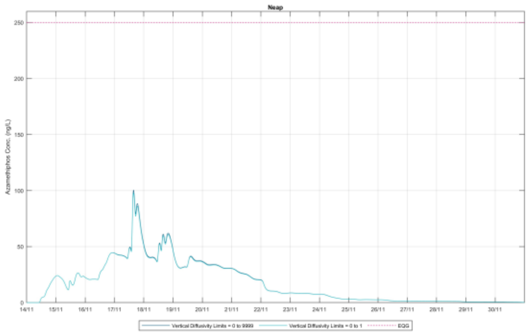
Point 4



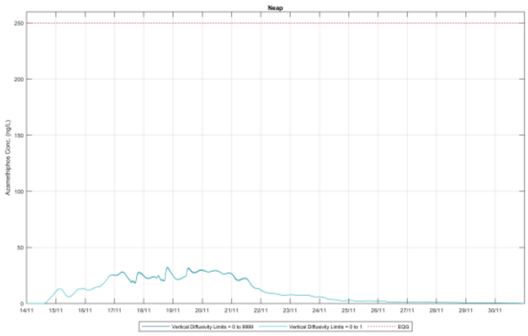
Point 6



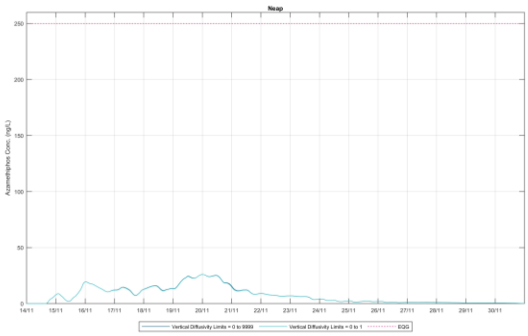
Point 7



Point 8



Point 9



Point 5 Point 10

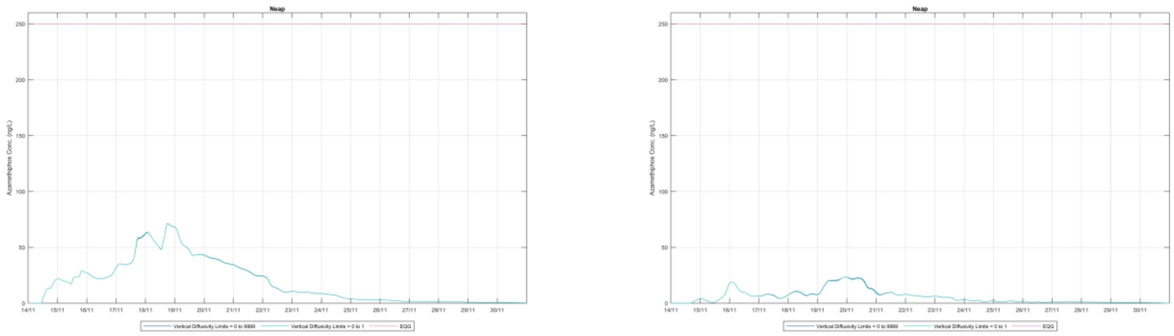


Figure 4.9 Tracer concentration surface 4 m depth averaged for Scenario 1 neap tide. results using vertical diffusivity limits of 0 to 9999 (dark blue) and 0 to 1 (light blue), against EQS value of 250 ng/L (pink).

AZE timeseries

The AZE timeseries (Figure 4.10) similarly show very little difference between the two results..

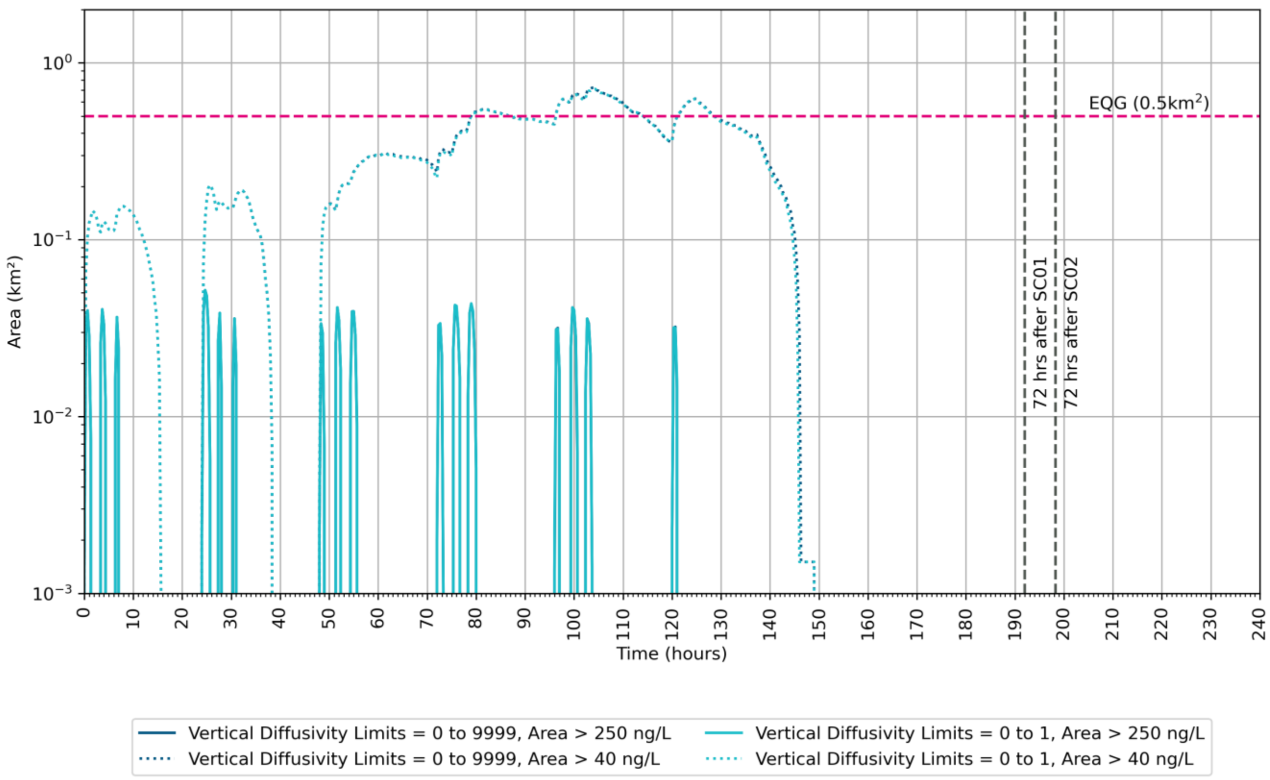


Figure 4.10 Timeseries of 250 ng/L and 40 ng/L AZEs for surface 4 m depth averaged first treatment release, comparing the vertical diffusivity limits.

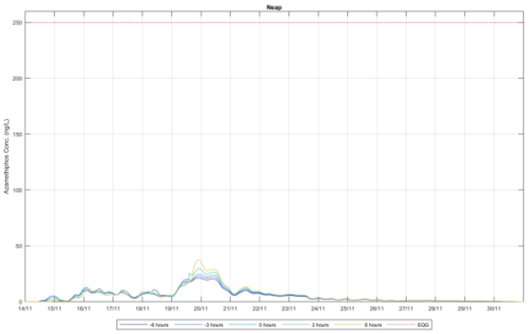
4.5.3 Time of release

Varying the time of release by +/- 6 and 3 hours was included to ensure a range of bath treatment release times related to tidal cycles were tested for sensitivity in results.

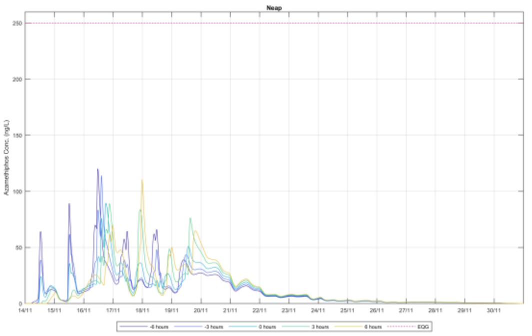
Timeseries of tracer concentration

The timeseries of tracer concentration (Figure 4.11) depict the results from the different release times. Note the y axis of these plots are date time and so the peaks that occur due to the treatment release occur at different times. Although differences can be seen between the results, the overall result does not change. The only extraction point where the EQS is reached is point 3, where it is reached for a very short period of time during the treatment period.

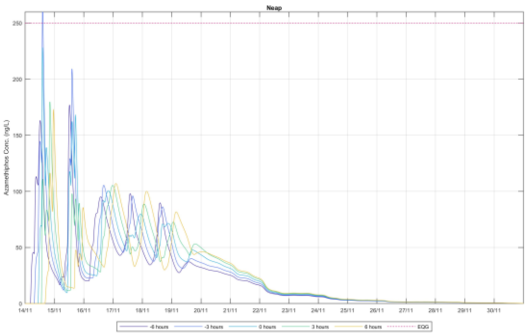
Point 1



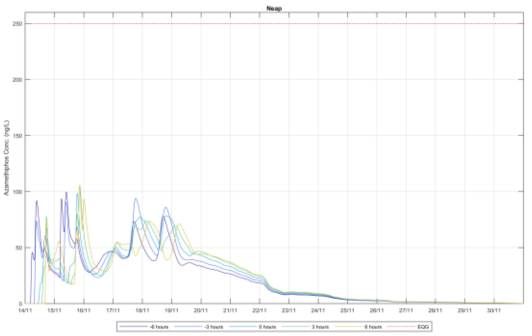
Point 2



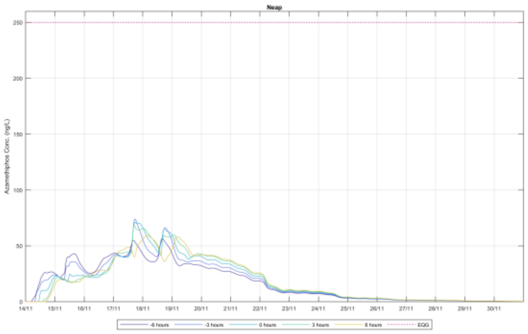
Point 3



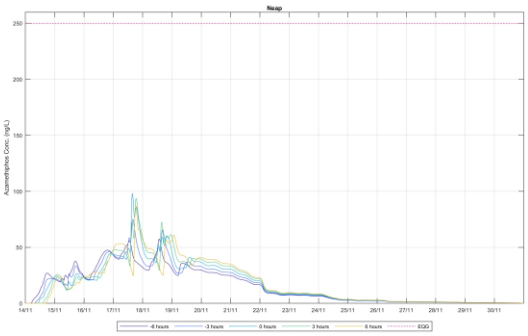
Point 4



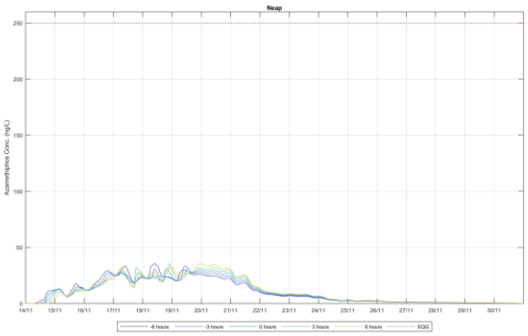
Point 6



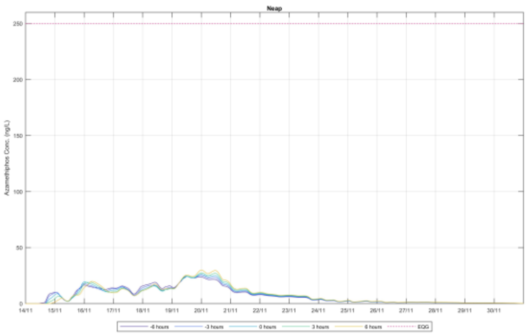
Point 7



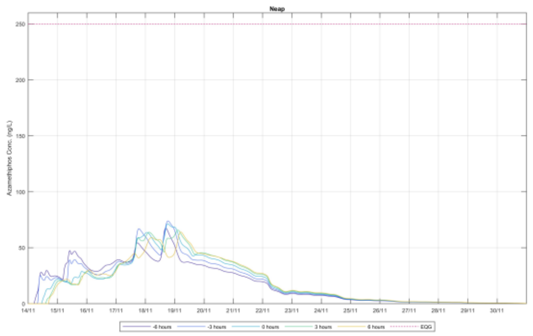
Point 8



Point 9



Point 5



Point 10

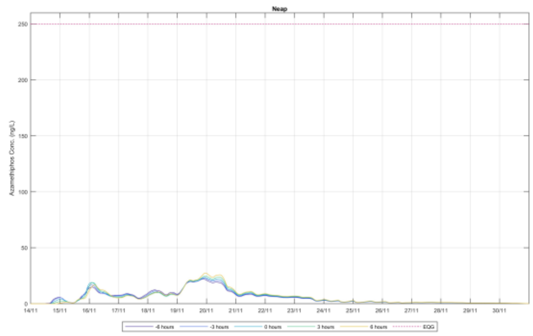


Figure 4.11 Tracer concentration surface 4 m depth averaged for Scenario 1 neap tide. Results for varying start times of -6, -3, 0, +3 and +6 hours compared to the original, against the EQS value of 250 ng/L (pink).

AZE timeseries

The predicted AZE timeseries (Figure 4.12) show the results from the different release times. Note the y axis of this plot is in hours from the start of release so the peaks that occur due to the treatment release are at the same point. Although small differences can be seen between the results, the overall exceedance assessment is the same, with all sensitivity test results predicting concentrations below the EQS within 72 hours of the last treatment.

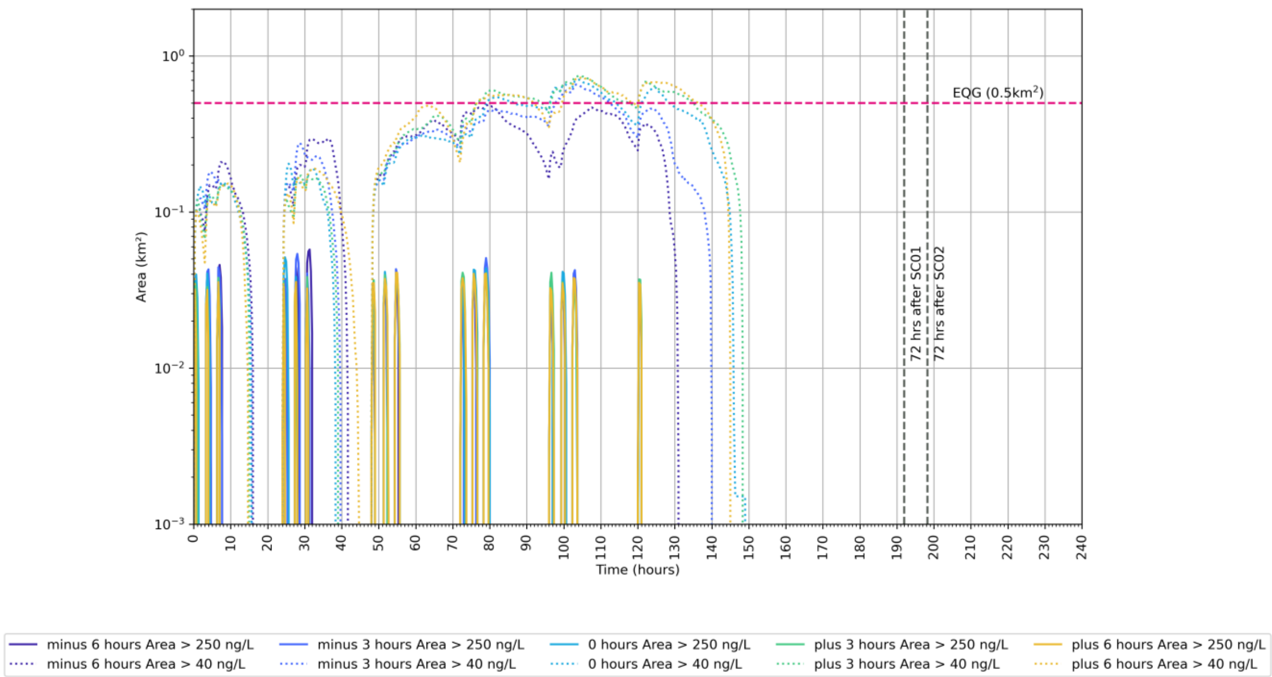


Figure 4.12 Timeseries of 250 ng/L and 40 ng/L AZE surface 4 m depth averaged from first treatment release comparing the start times.

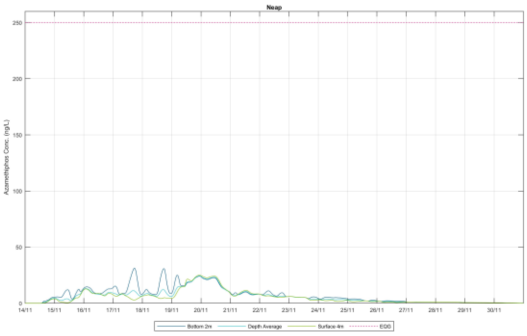
4.5.4 Depth Averaging

The results presented in Section 4 for determining consenting limits were depth averaged over the surface 4 m as representative of the depth of treatment release and greatest predicted surface concentrations for bath treatment. As part of this sensitivity analysis the same results were extracted using the following:

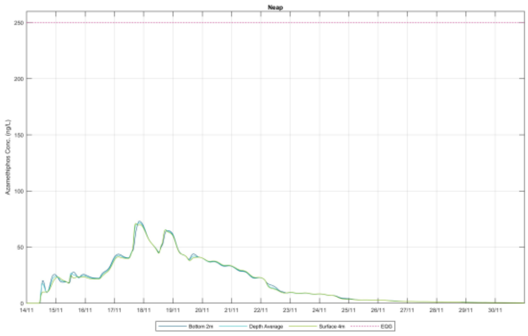
- Depth averaged across the whole water column (average assessment).
- Depth average over the bottom 2 m (location of sensitive benthic habitats).

The timeseries comparison of tracer concentration show that while there were differences in predicted concentrations averaged over surface, bottom and full water column all methods of depth averaging fell within SEPA compliance criteria (Figure 4.13). Sensitivity to depth average method predicted compliance was also consistent over all 10 points of extraction.

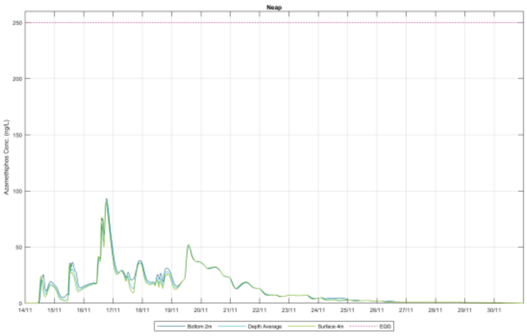
Point 1



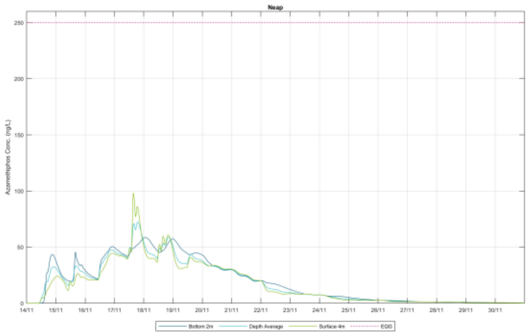
Point 6



Point 2

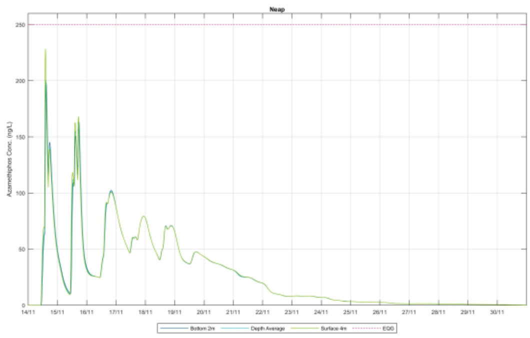


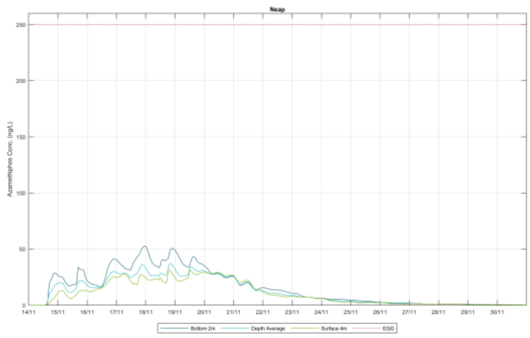
Point 7



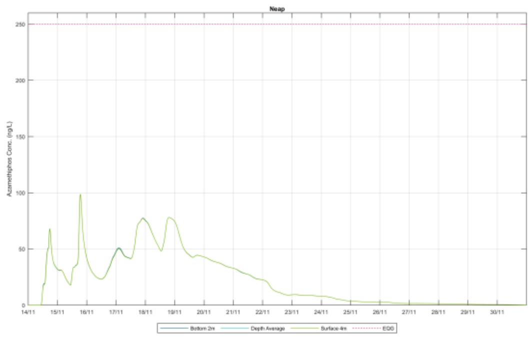
Point 3

Point 8

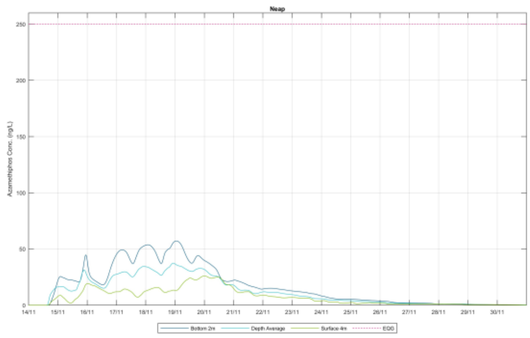




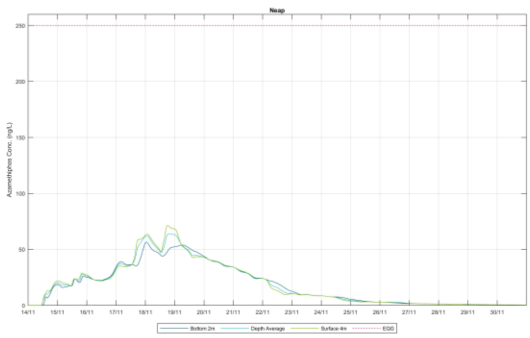
Point 4



Point 9



Point 5



Point 10

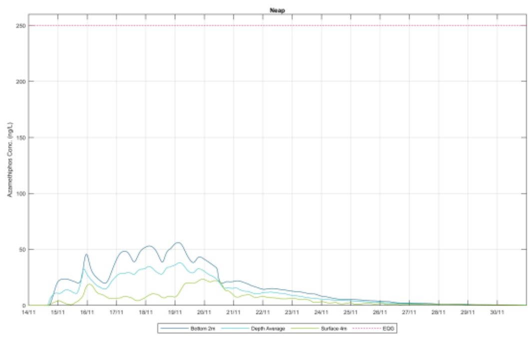


Figure 4.13 Tracer concentration for Scenario 1 neap tide, showing the result averaged over the bottom 2 m (dark blue), depth averaged across the whole water column (light blue) and averaged over the surface 4 m (green), along with the EQS value of 250 ng/L (pink).

AZE timeseries

The AZE timeseries (Figure 4.14) predict differences between the AZEs for 40 ng/L EQS in each section of the water column with all AZEs decrease below the EQS at the same time, likely as the tracer in the shallow areas is dominating. This indicates the overall result does not change with selection of depth averaging and so again, analysing the surface 4 m is suitable for assessing if the guidelines have been met at this site.

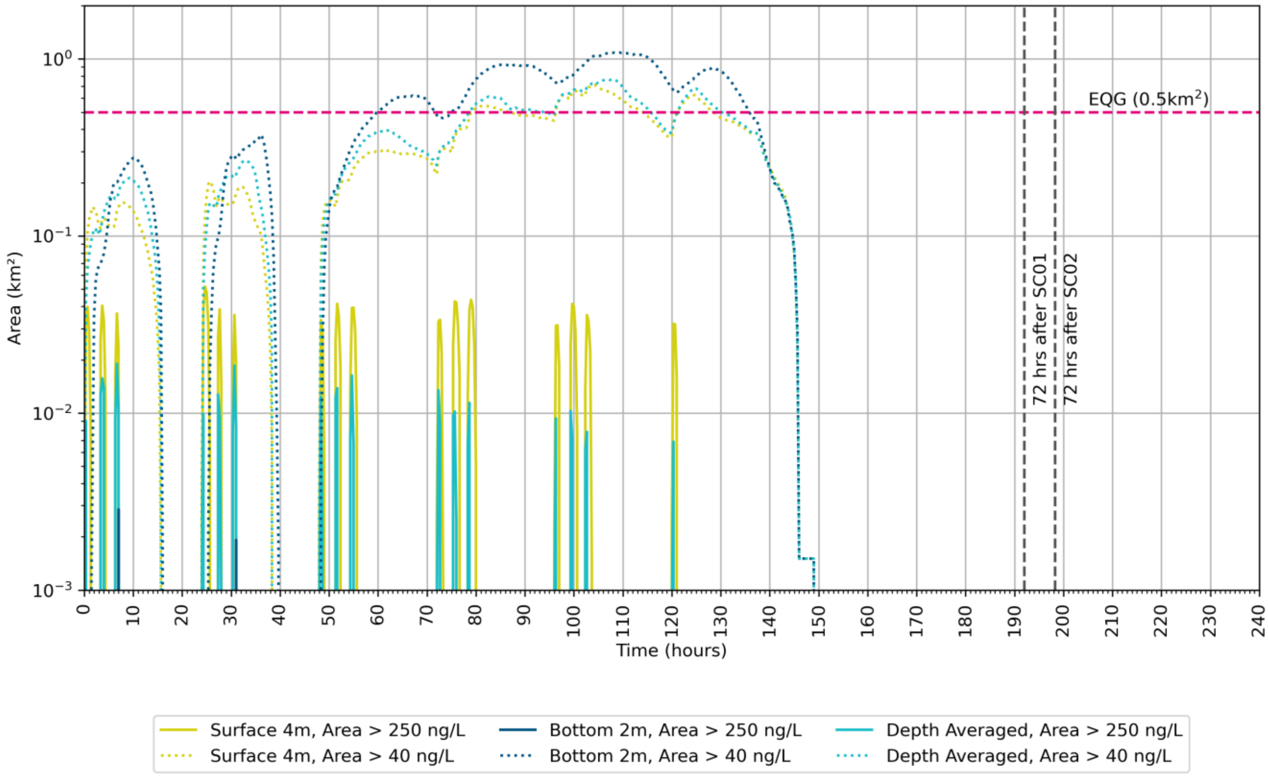


Figure 4.14 Timeseries of AZE for 250 ng/L and 40 ng/L comparing the depth averaging method.

4.6 Mass balance

To assess mass balance and effects of numerical dispersion, three releases of 230g tracer mass at three separate 5 minute intervals (10:00 to 10:005am, 1:10 to 1:15pm, and 4:15 to 4:20 pm) were introduced into the model domain on day one. A total of 690 g was released with zero decay (i.e. inert tracer simulation). The model was simulated for 4 months (01/10/2018 to 01/02/2019), and the timeseries of volume, tracer mass, and concentration within the domain over time were extracted for analysis (Figure 4.15).

At the initial stages of the simulation before the tracer reached the model boundary, mass was constant, and concentration fluctuated with tidal changes in model volume (Figure 4.15). Tracer mass gradually reduces as a function of time as mass is lost at the open boundary until a steady sate equilibrium is reached towards the last month of simulation (Figure 4.15).

To quantify tracer mass exiting the domain, a tracer mass balance was conducted. Cumulative fluxes across the open boundaries were compared against residual tracer mass in the model domain (Figure 4.16). Additionally, the net mass was calculated by adding the fluxes of tracer across the open boundaries to the residual tracer mass with a negligible (<2%) difference over the four month simulation (Figure 4.16). These findings further reinforce confidence in the accuracy of the simulation and confirm that mass conservation is maintained within the domain throughout the advection-dispersion calculations.

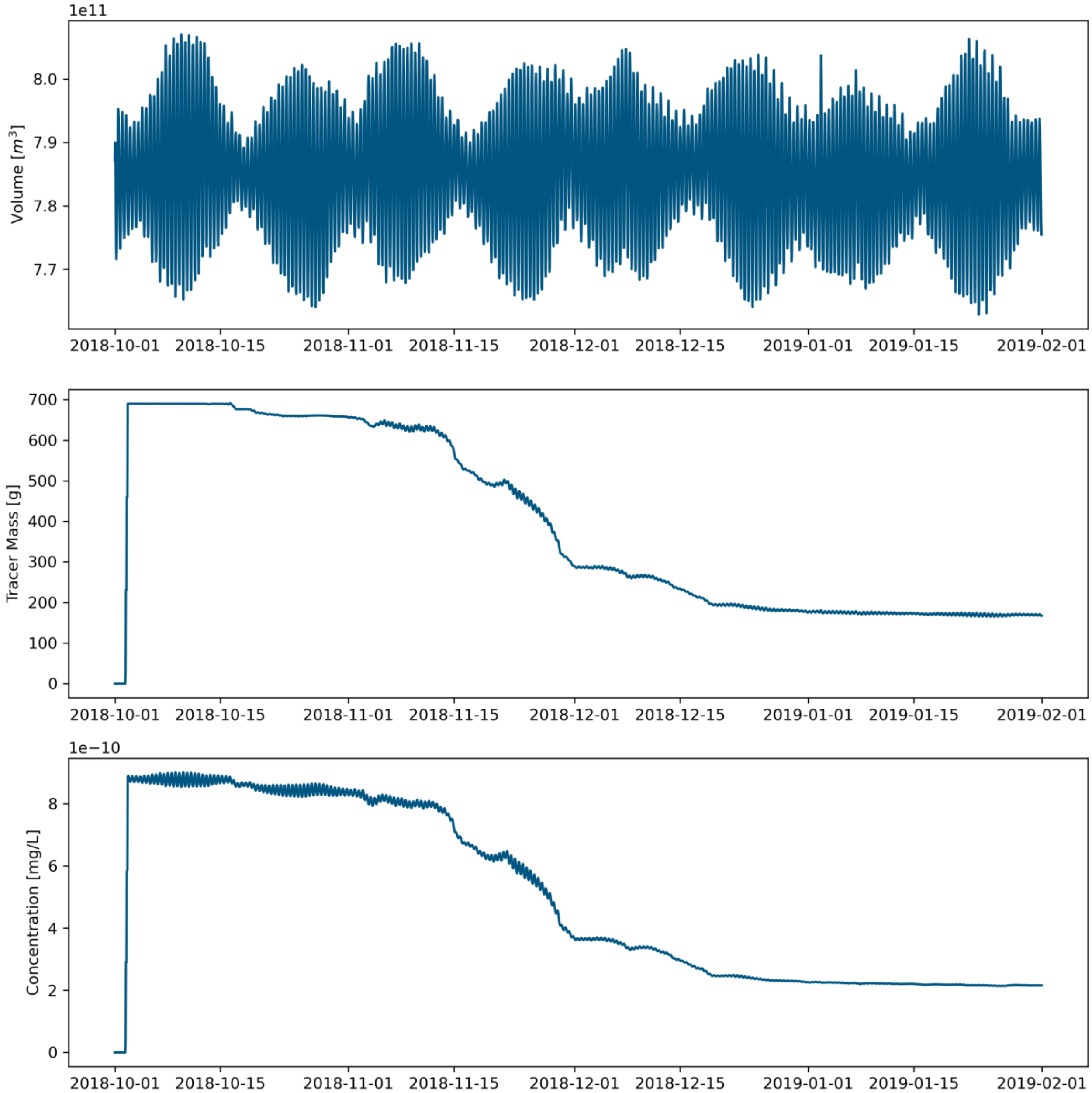


Figure 4.15 Mass balance plots for volume, tracer mass and tracer concentration in the model domain

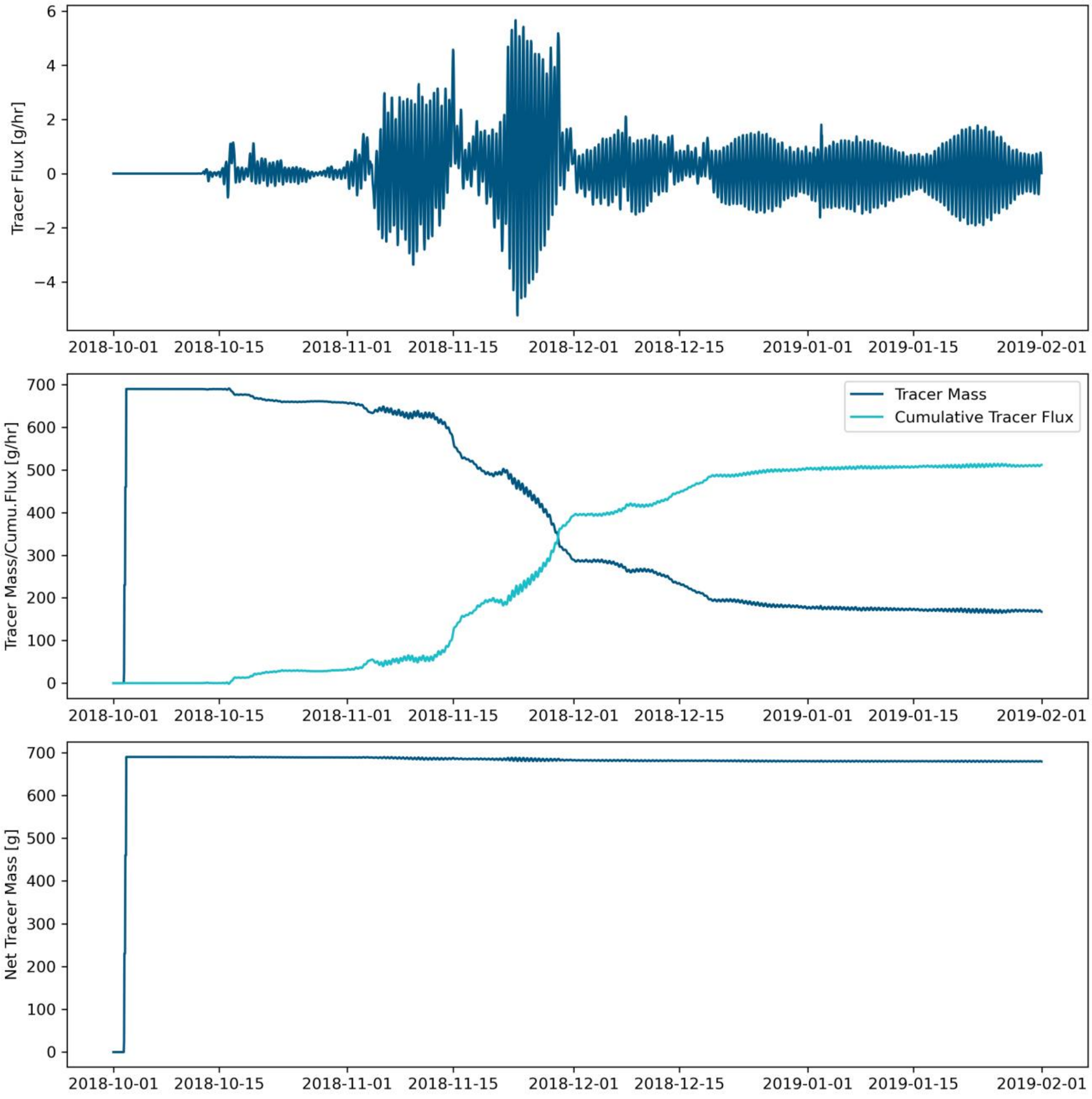


Figure 4.16 Total tracer fluxes (top), cumulative tracer fluxes with tracer mass (middle) and net tracer mass (bottom) plots from the mass balance analysis

5 Conclusions

Two alternative treatment scenarios were simulated to evaluate the impact of different treatment schedules for Azamethiphos, under worst-case conditions (Scenario 1) and a more realistic regime (Scenario 2). Scenario 1 represents the worst-case scenario, where neighbouring pens are consecutively treated with 230 g of Azamethiphos per treatment at 10:00, 13:10, and 16:15 over five consecutive days with the final pen treated on day six. Scenario 2, which reflects a more realistic treatment regime treatment of the pens were distributed evenly across the site with three pens treated at 10:00, 13:10, and 16:15 on day 1, 2, 4, and 6 and for days three and five, two pens are treated, at 10:00 and 13:10. The total amount of Azamethiphos discharged over the six-day period was the same for both scenarios at 3.68 kg.

The simulations were run for release during neap and spring tides in the model, and a variation of diffusion coefficients, time of release and depth averaging used to assess the sensitivity of the outcomes to key model parameters.

Based on the model results, it was concluded that the proposed treatment scenarios of 230 g per pen, treating up to three pens per day (daily total 690g), were predicted to consistently meeting all EQS as prescribed by SEPA. The maximum concentration observed during the baseline simulations, 72 hours after the final treatment, was found to be less than 26 ng/L, which is well below the allowable limit. Additionally predicted AZEs for EQS of 40 ng/L were substantially less than the allowable 0.5 km^2 within 72 hours of final treatment. Sensitivity testing predicted concentrations consistently meeting the EQS criteria for MAC, despite the conservative modelling approach. During spring tides, the greater dispersion resulted in concentrations comfortably meeting the EQS for MAC.

As part of the analysis of dispersion model simulations, the impact of bath treatments on Priority Marine Features (PMFs) in the wider area around the farm were investigated. The concentration levels of Azamethiphos were assessed during and after treatments, and it was found that they never exceeded the permissible limit. Additionally, the concentration values remained below 1 ng/L at all PMFs located near the farm.

These results indicate that the proposed treatment scenarios, which involved a daily release of up to 690 g of Azamethiphos, were predicted to comply with UK Environmental Quality Standards and potential risks associated with such treatments were deemed minimal.

References

Anderson Marine Surveys (2022) Oldany – Dye dispersion study. Report prepared for Loch Duart Ltd. AMSL Report No 22/09.4 – rev0 September 2022

BMT (2021) Technical Report Sea Lice Management Decision Support, A report prepared for Stakeholders: CEFAS, Scottish Sea Farms, Marine Scotland Science, SEPA, Aquatera. Report No IF00KFS065 v1.2.

BMT (2022a) Method Statement - Azamethiphos dispersion Modelling, TUFLOW FV Hydrodynamic-Tracer Modelling. Report prepared for Loch Duart Ltd.

BMT (2022b) Ardyaloon WWTP Water Quality Assessment, Baseline monitoring and dispersion modelling study. Report No R-1752_00-2.

Botelho, DA, et al. (2016) "Linking Nearfield CFD Models of Buoyant Discharges to Farfield Dispersion Models." Proceedings of International Symposium on Outfall Systems. Ottawa, Canada University of Ottawa. Vol. 18.

Elliott, AJ, Barr, AG & Kennan D (1997). Diffusion in Irish Coastal Waters. Estuarine, Coastal and Shelf Science 44, 15-23

Morales RA, Elliot AJ & Lunel T (1997). The influence of tidal currents and wind on mixing in the surface layers of the sea. Marine Pollution Bulletin 34, 15-25

Saha, Monika. (2020) Microbial Water Quality Modelling of the Detroit River. Diss. University of Windsor (Canada)

Scottish Environment Protection Agency (SEPA) (2005) Regulation and Monitoring of Marine Cage Fish Farming in Scotland Annex H, Methods for Modelling In-feed Anti- parasitics and Benthic Effects (issue No. 2.3).

Scottish Environment Protection Agency (SEPA) (2008) Regulation and Monitoring of Marine Cage Fish Farming in Scotland Annex G, Models for assessing the use of chemicals in bath treatments (issue No. 2.2).

Scottish Environment Protection Agency (SEPA) (2019) AQUACULTURE MODELLING, Regulatory Modelling Guidance for the Aquaculture Sector, July 2019 – Version 1.1

Scottish Environment Protection Agency (SEPA) (2022) Environmental standards, Protecting the quality of sea water, https://www.sepa.org.uk/regulations/water/aquaculture/environmental-standards/ [Accessed 06 September, 2022]

The Scottish Government (2023a) Locational Guidelines for the Authorisation of Marine Fish Farms in Scottish Waters. Produced for Marine Scotland Science by Marine Scotland Communications. Available at www.scotland.gov.uk.

The Scottish Government (2023b) Marine Scotland Maps NMPi. Available at https://marinescotland.atkinsgeospatial.com/nmpi/?region=NC (Accessed: 08 January 2023)

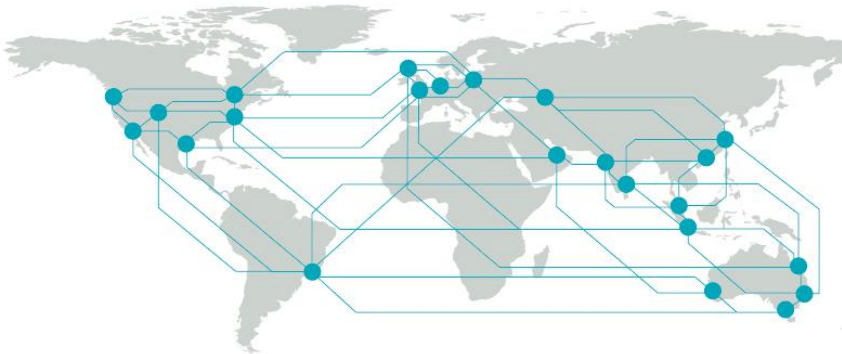
The Scottish Government (2023c) Policy Marine Environment – Priority Marine Features. Available at https://www.gov.scot/policies/marine-environment/priority-marine-features/ (Accessed: 08 January 2023)

Scottish Sea Farms Ltd (SSFL) (2011) Bath and Infeed Treatment Method Statement. A Report prepared for Scottish Environment Protection Agency

TUFLOW (2017) TUFLOW FV User Manual. BMT Commercial Australia Pty Ltd, Australia.Retrieved from https://www.tuflow.com/Support/Documents.aspx

TUFLOW (2018). TUFLOW FV Science Manual. BMT Commercial Australia Pty Ltd, Australia. Retrieved from https://www.tuflow.com/Downloads/TUFLOWFV%20Science%20Manual.pdf

TransTech Limited (2019) HYDROGRAPHIC AND SITE SURVEY REPORT, Oldany Finfish Pen Site, Sutherland. Report prepared for Loch Duart Ltd.



BMT is a leading design, engineering, science and management consultancy with a reputation for engineering excellence. We are driven by a belief that things can always be better, safer, faster and more efficient. BMT is an independent organisation held in trust for its employees.

11 Bon Accord Crescent
Aberdeen
AB11 6DE
Great Britain
+44 (0)1224 414200

Registered in the United Kingdom
Registered no. 02326885
Registered office
Level 5, Zig Zag Building,
70 Victoria Street, London,
SW1E 6SQ
+44 20 8943 5544

For your local BMT office visit www.bmt.org

Contact us

enquiries@bmtglobal.com

www.bmt.org

Follow us

www.bmt.org/linkedin

www.bmt.org/youtube

www.bmt.org/twitter

www.bmt.org/facebook