12th November 2025

Modelling Methods Statement

Vementry

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1. Summary

This report proposes a methodology to simulate benthic, in-feed treatment, bath treatments and sea lice dispersal to assess the environmental impacts from Atlantic salmon finfish aquaculture. This report states the data sources, software and methodology used to determine compliance with the latest SEPA guidance.

Modelling of near-field benthic and in-feed chemical dispersion is simulated in NewDepomod based on the 2019 regulatory framework presented in SEPA (2019a). NewDepomod uses SEPA default values as a risk assessment tool to determine dispersion and depositional characteristics at the proposed site. Standardised environmental impact proxies are then used to quantify potential impact.

Far-field benthic waste dispersion and bath treatments are simulated using hydrodynamic and particle tracking models. Realistic flow features drive particle and chemical distribution and concentration, allowing impacts on nearby sensitive marine features to be determined. This study uses DHI's Mike 21 hydrodynamic model, coupled with the particle tracking module. Particle parameters and release mechanisms are adjusted to mimic realistic organic waste and chemical treatment processes.

2. Benthic Modelling

The simulation of waste feed and fish faecal matter from the proposed aquaculture site is simulated on a wider scale using a hydrodynamic model. This looks at the coastal scale distribution (10-20 km^2), using more complex flow models that are better suited for predicting particle dynamics over a larger spatial area. This allows the assessment of potential cumulative impacts from multiple farms and influences on nearby sensitive marine features.

2.1 Farfield – Mike21

DHI's Mike21 is used to simulate regional scale waste feed and fish faecal matter dispersion and deposition. This uses a calibrated hydrodynamic and particle tracking model to replicate particle emissions from all farms specified within the Screening and Risk Identification report (SEPA, 2024b). This utilises better performing spatially varying hydrodynamics to identify particle fate and accumulation near existing farms and sensitive marine features.

The modelling process first calibrates a hydrodynamic model using measured bathymetry, wind data and simulated tidal elevations to measured data at relevant locations. A second, ADCP or temporally independent dataset is used to validate the flow model that includes non-tidal generated flows (wind forcings). Once successfully calibrated and validated, a year-long model is run, the outputs of which are used to drive an offline particle tracking model.

Potential benthic impact is determined using the same method as proposed in the SEPA default nearfield assessment. This uses the deposition quantity of 250 g/m^2 as a proxy value for IQI 0.64, where any deposition over 250g/m^2 indicates impacted seabed. This will be considered for all farms and marine features in the area of interest.

The proposed Vementry and surrounding aquaculture sites and sensitive marine features listed in table 1 will be used to assess relation to far field solid impacts.

Table 1. Farm and sensitive marine features identified near the proposed Vementry site.

Name	Feature type	Location (OSGB)		Mesh resolution (m)
		East	North	
Vementry	Fish Farm	430363	1161477	31.0
BOB1	Fish Farm	434243	1157972	48.5
COLED1	Fish Farm	435782.1	1163170	35.2
COLEN1	Fish Farm	436350.9	1162387	47.7
CROSS1	Fish Farm	429526.9	1158439	66.6
EAIT1	Fish Farm	434906	1156578	45.6
LBUR1	Fish Farm	434749.1	1159483	36.3
LINB1	Fish Farm	428309.2	1158767	84.4
MUCE1	Fish Farm	434435	1165632	38.2
NEPL1	Fish Farm	434244.1	1162453	36.5
NOR1	Fish Farm	429200.2	1161211	31.6
OLN2	Fish Farm	437808.7	1164984	35.1
OLNA1	Fish Farm	437414.1	1164260	44.0
SOA1	Fish Farm	432188.9	1159966	35.0
SS0186 - Westshore	Shellfish Farm	429500	1157500	38.6
SS0312 - Bight of Kurkigarth	Shellfish Farm	439700	1163500	43.9
SS0500 - Suthra Voe	Shellfish Farm	429400	1160400	56.7
SS0588 - North Voe of Clousta	Shellfish Farm	430200	1158400	65.2
SS0600 - Bight of Cliffs	Shellfish Farm	439100	1164600	51.7
SS0601 - Park Gate	Shellfish Farm	438500	1165100	57.0
SS0617 - East of Burki Taing	Shellfish Farm	431800	1162700	42.3

SS0641 - Linga	Shellfish Farm	435900	1164000	35.3
SS0642 - Quilse	Shellfish Farm	438500	1164300	42.7
SS0650 - Seggi Bight	Shellfish Farm	429700	1159400	65.6
SS0651 - Papa Little, Aith Voe	Shellfish Farm	434100	1160100	37.0
SS0670 - Lee, Busta Voe	Shellfish Farm	434500	1164900	38.7
SS0671 - Busta Voe	Shellfish Farm	434600	1166200	63.2
SS0672 - Holm of East Burra Firth	Shellfish Farm	435300	1157800	54.1
SS0677 - Foula Wick	Shellfish Farm	437000	1164800	41.3
SS0679 - Wrawick	Shellfish Farm	432700	1167000	37.9
SS0696 -West Side of Aith Voe	Shellfish Farm	434400	1157000	42.9
SS0698 - Grunigill	Shellfish Farm	428800	1156700	70.6
SS0699 - Pynch Dyke	Shellfish Farm	436600	1164700	38.9
SS0704 - Point of Sletta Aith Voe	Shellfish Farm	434200	1158800	33.7
SS0715 - Uyeasound, Vementry	Shellfish Farm	428900	1159200	62.9
SS0723 - Treawick	Shellfish Farm	433500	1161600	34.2
SS0724 - The Ham, Papa Little	Shellfish Farm	433200	1163100	36.2

SS0725 - Boat Geo	Shellfish Farm	431900	1160600	35.8
SS0726 - Braganess	Shellfish Farm	435400	1162400	37.9
SS0727 - Cole Ness Shellfish	Shellfish Farm	434800	1158600	33.5
SS0757 - Slyde (Aith Voe)	Shellfish Farm	434400	1164200	37.9
SS0758 - North Knowe	Shellfish Farm	430500	1160800	28.5
SS0768	Shellfish Farm	433300	1159500	32.0
SS0769 - North East of Aithness	Shellfish Farm	428700	1158300	58.3
SS0778 - Longa Ness	Shellfish Farm	434100	1163600	48.8
SS0781 - Budda Scord	Shellfish Farm	435700	1165800	57.3
SS0782 - Hevden Ness	Shellfish Farm	435500	1164500	41.0
SS0783 - North Linga	Shellfish Farm	435800	1164700	40.5
SS0784 - Wetherstaness	Shellfish Farm	431200	1160700	33.1
SS0808 - Holms of Uyeasound	Shellfish Farm	428500	1157500	79.4
SS0838 - Brindister Inshore	Shellfish Farm	431200	1160000	40.6
SS0843 - Mill Bight	Shellfish Farm	434200	1160900	41.5
SS0855 - Bight of Warwick	Shellfish Farm	434700	1162300	36.9
SS0856 - Houbanster	Shellfish Farm	434700	1160600	35.6
SS0857 - Millburn	Shellfish Farm	433000	1160200	33.1
SS0864 - Moo Ness	Shellfish Farm	428500	1159800	58.7
SS0869 - Gruna	Shellfish Farm	429100	1161400	28.7
SS0870 - Northra Voe	Shellfish Farm	429500	1158500	63.2
SS0903 - Crossroads	Shellfish Farm	428400	1158700	77.8

SS0904 - Skewart Holm (Linga)	Shellfish Farm	434500	1156800	52.4
SS0906 - Aith Voe West	Shellfish Farm	436600	1163400	42.7
SS0914 - West of Grobsness	Shellfish Farm	434400	1156000	41.2
SS0915 - Brakkatun Beach	Shellfish Farm	428900	1159200	62.9
Kelp Beds	PMF	429492	1164721	53.8
		430730	1162602	31.9
		429092	1162142	30.8
		431190	1160396	36.8
		430527	1167164	66.9
Horse Mussel	PMF	434994	1163509	39.0
		435549	1162602	36.9
Kelp and Seaweed communities	PMF	435062	1163672	28.4
		434994	1163496	38.5
		435299	1163340	34.4

2.1.1 Domain

The model domain is created using the Cartesian Ordnance Survey of Great Britain 1936 coordinate system (OSGB 1936). Coastline data is imported from Ordnance Survey (2024) 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 where the peripheries of the model domain have a coarse resolution, with an approximate cell spacing of 250m. The mesh resolution for all identified farms and sensitive marine features is specified in table 1, where the area within Swarbacks Minn has a maximum mesh resolution of 1225-2000m^2 (35-45m). Due to the close proximity of finfish, shellfish and marine features in Swarbacks Minn, an extended area of increased mesh resolution was used. The computational mesh is shown in Figure 1-3, with close ups of the identified areas of interest.

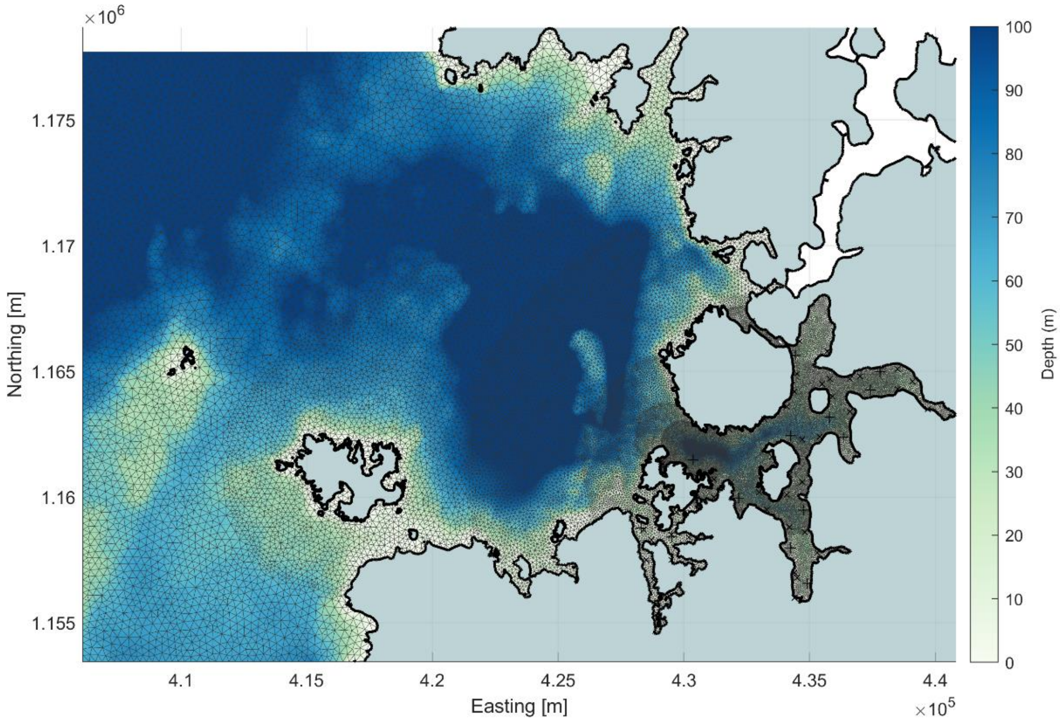

Figure 1. Hydrodynamic model domain for St Magnus Bay with depth and an unstructured triangular mesh.

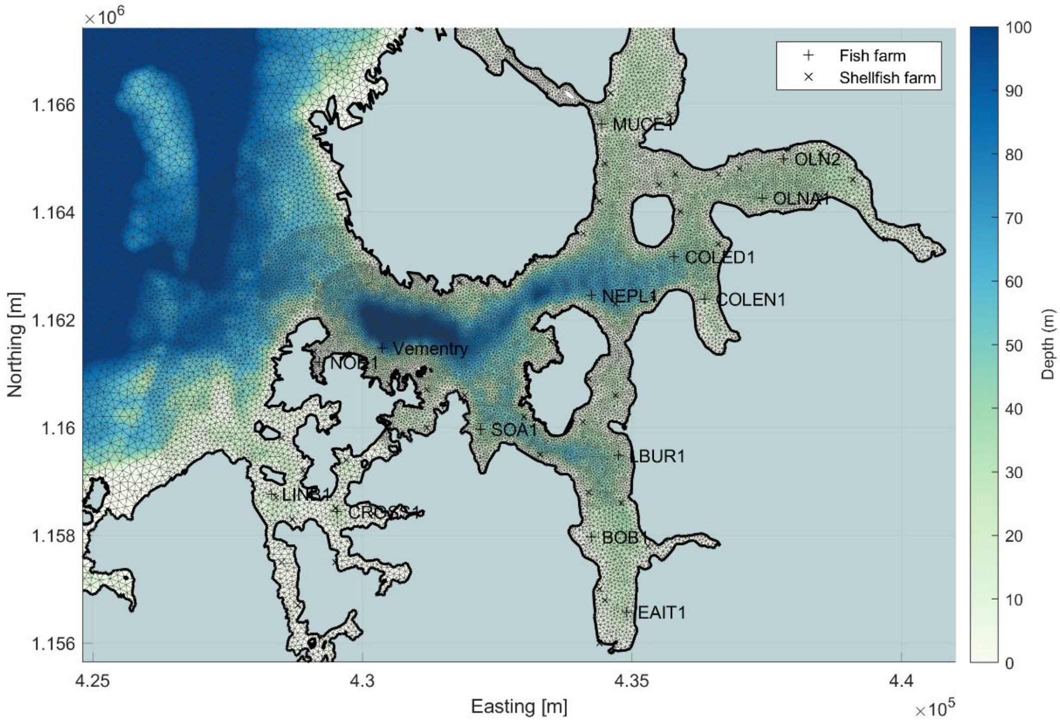

Figure 2. Swarbacks Minn with marine pen fish farm ('+') and shellfish farm ('x') locations.

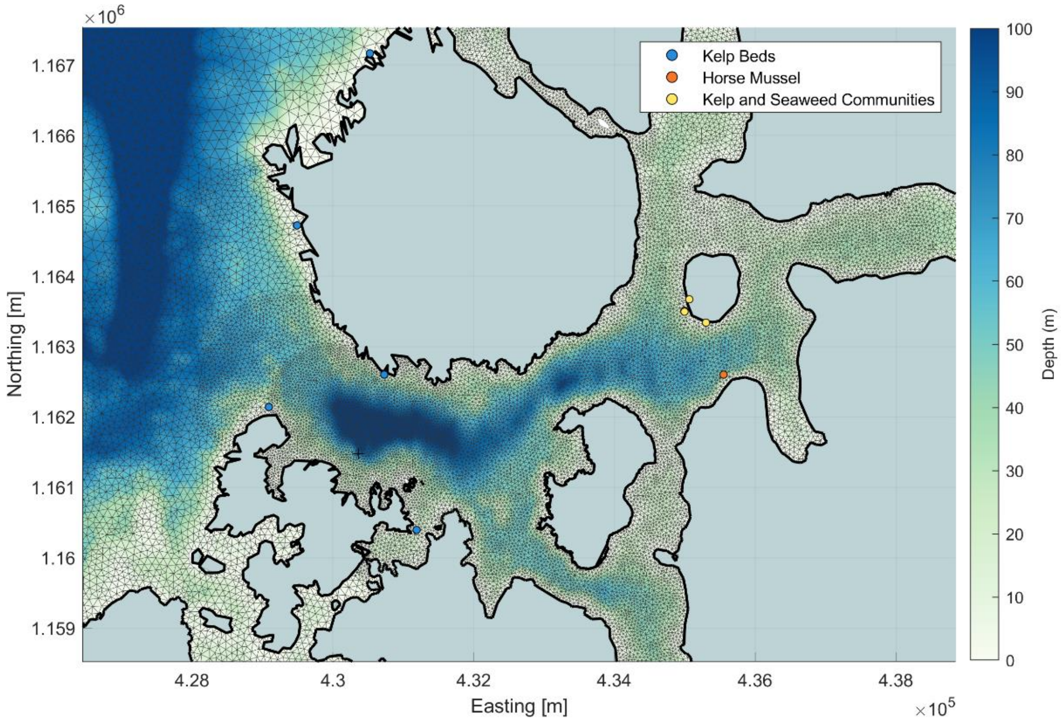

Figure 3. Swarbacks Minn identified sensitive marine features.

2.1.2 Boundary Conditions

Boundary conditions are taken from E.U Copernicus Marine Service Atlantic - European North West Shelf - Ocean Physics Analysis and Forecast (CMEMS, 2025). This is taken from a larger scale domain consisting of 50 depth layers and a horizontal resolution of 0.027° at a 15-minute time step. Surface elevation output was interpolated onto boundary nodes on the smaller-scale mesh shown in figure 1. Wind data was taken from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 model (ECMWF 2025). 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.

2.1.3 Model Configuration

A 2-dimensional domain is proposed with a time step interval of 60 s. Outputs are specified with point data frequency at 10 min (600s) intervals and area data outputs at 60 min (3600s) intervals. The model is run for 365 days, plus an additional 5 days to allow the hydrodynamic model to stabilise. 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. This has minimal effects to the output values but reduces computational time. Flooding and drying were included, with a drying depth of 0.005 and a wetting depth of 0.1. The horizontal eddy viscosity applies Smagorinsky's formulation with a constant value of 0.15.

Bed roughness is specified in the form of Manning number and is used as the main calibration term for the HD model. The best result applies a uniform value of 20 $m^{1/3}/s$ over the entire domain.

2.1.4 Flow Field Calibration and Validation

The calibration process adjusts the dissipative forcings within the model to achieve the best agreement with observed data. The initial calibration uses 2 observed datasets to tune the model, these datasets were recorded over the same time period. A description of each hydrographic data collection campaign is available in the hydrographic report. To assess model performance, statistical parameters such as mean absolute error, Root-Mean Squared (RMS) error, Normalised RMS error and Pearson correlation are calculated for water level, easterly and northerly velocity components. A guide to the minimum acceptable tolerance for these parameters is presented in table 2.

Table 2. Lower threshold of statistical parameters.

Statistical Parameter	Mean Sea Level (m)	East and North Velocity components (m/s)
Mean Absolute Error	0.2m	0.2m/s
RMS Error	0.2m	0.2m/s
NRMSE (range)	+/- 0.15	+/- 0.1-0.2
Correlation	0.90	0.60

Validation demonstrates the model accuracy by comparing calibrated, simulated results with an independent observed dataset. This uses a separate ADCP deployment or alternative time frame. An example of this may be the calibration of the model during the spring tides and validation of the model in neap tides. The statistical parameters presented in table 3 will be used to quantify the model's performance. In certain cases, this validation process may be applied at several sites in close proximity to achieve a spatially validated model.

2.1.4.1 Calibration Results

The model domain shown in Figure 1 was used to calculate the 2D flow around Vementry. The initial calibration period uses a 30-day data subset between 30/12/2023 and 29/01/2024. The first 5 days of the simulation were excluded from data processing to allow the simulation to stabilise.

A point series output, at the same location as the ADCP deployments, was generated from the model with a temporal resolution of 600s, this was resampled to match the collected hydrographic data. Figures 4 and 5 show the measured data against the modelled outputs for the calibration period for the Mean Sea Level (MSL) and the depth averaged east and north velocity components for Vementry. The calibrated model agreement statistics are shown in table 3.

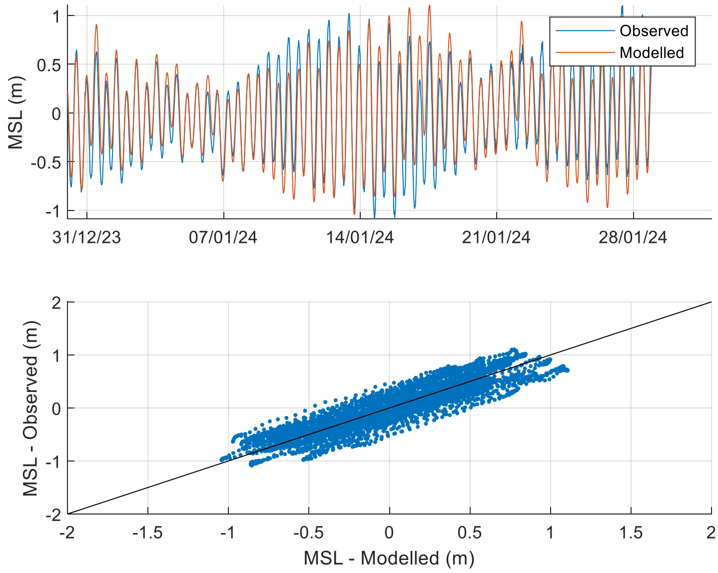

Figure 4. Mean sea level calibration results for the current meter location at Vementry.

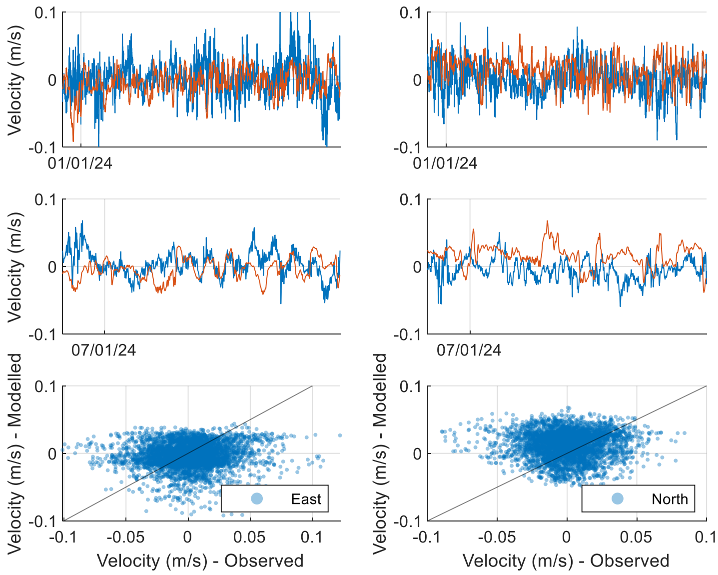

Figure 5. Vementry east (left column) and north (right column) velocity components. The top row: shows all 30 days of the calibration period. Middle row: shows smaller 7-day subset. Bottom row: scatter plot of observed and modelled velocity.

Figures 6 shows the current speed and direction distributions obtained from the model and measured ADCP data for Vementry. The speed distribution shows that both datasets are dominated by relatively low current magnitudes, with a similar distribution of current speeds. The directional distribution shows a reasonable match for northwest flow component but fails to capture the peak at 125 degrees.

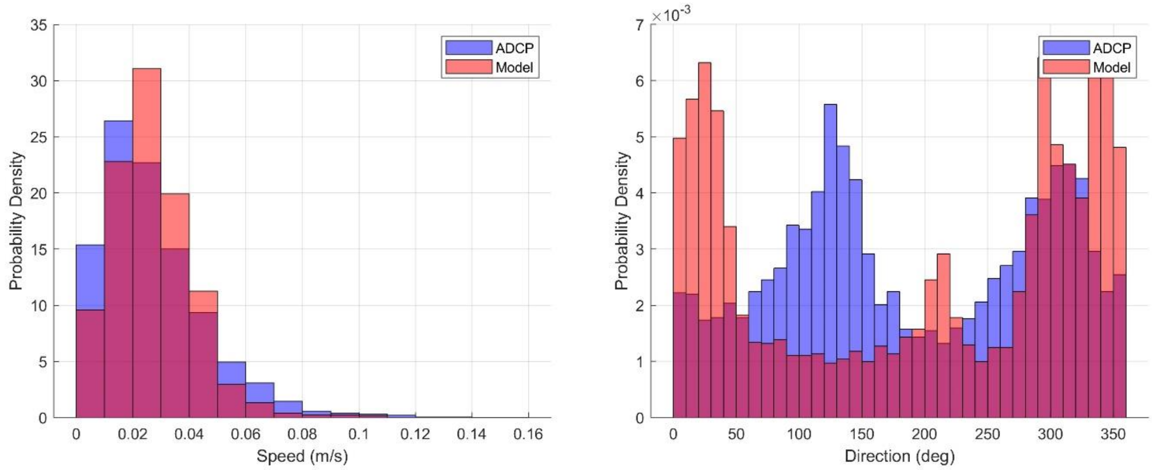

Figure 6. Vementry speed (left) and direction (right) distribution for the calibration period.

The calibration shows good agreement in the surface elevation for the 30 day period. The model data shows a similar amplitude with a very good phase agreement. East and North velocity data indicate a reduced phase correlation with a reasonable approximation of magnitude. Current distribution plots indicate similar magnitudes but show some discrepancies in the directional distribution. The statistical agreement criteria for the model performance are shown in table 3, values for the east and north velocity component correlation are below thresholds presented in table 2.

The spatial variation in currents is shown in figure 7, where flow vectors indicate average velocity direction and amplitude. Around the site location, several larger gyres occur, with conflicting flow directions within close proximity. This suggests the flow field is dominated by larger turbulent features. Such behaviour is expected in regions where tidal currents interact with complex bathymetry, generating sub-grid-scale eddies that are not explicitly resolved in a two-dimensional hydrodynamic model. Consequently, the highly spatially variable flow field means minor differences in location result in potentially very different flow statistics, making the agreement between modelled and observed velocities limited. The comparison of the modelled and measured results does show the model adequately captures the dominant energetic characteristics of the flow, supporting its suitability for subsequent dispersion modelling.

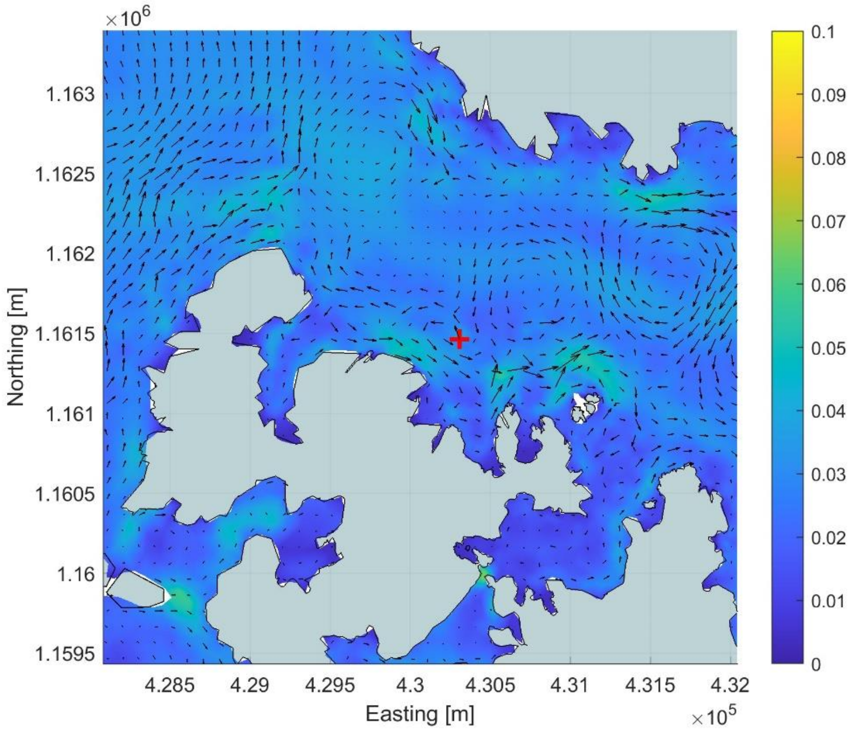

Figure 7. Average flow velocity and direction around Vementry (Red '+' marker) for the calibration period.

Additional quantification of the presence of turbulent features is indicated in figure 8, where the energy of the velocity variation is calculated using a Welch's Fast Fourier Transform (FFT) with a 50% Hanning window over a moving 7 day period. This shows a similar turbulent energy cascade in the measured and modelled flow, with larger, higher energy velocity variations decaying similar to the -5/3 law (Kolmogorov, 1941). Vertical dashed lines indicate frequency values of the dominant 8 tidal harmonics (M_2, S_2, N_2, K_1, O_1, P_1, Q_1 and K_2), these are clustered around the diurnal (24hr or 1.157×10^{-5} Hz) and semi-diurnal (12.5hr or 2.222×10^{-5} Hz). At these frequencies, no increase in energy occurs, suggesting no detectable presence of energy of tidal-driven flow. Below 2hrs(1.388×10^{-4} Hz), the modelled velocity variation is shown to decrease faster than the measured data, this suggests the model may underestimate higher frequency components; however, as these are close to the noise floor, the signal to noise ratio becomes insufficient.

The lack of recorded tidal forces at the site, including in the measured ADCP, shows water exchange is driven by irregular, large-scale turbulent features.

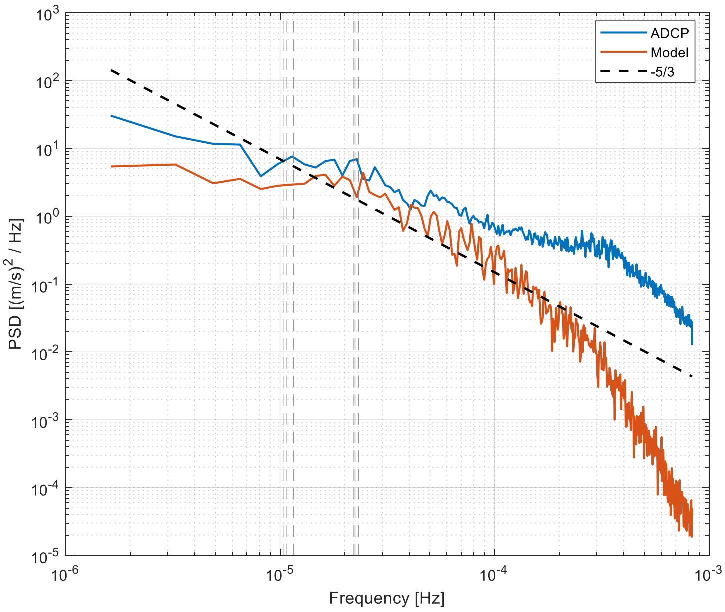

Figure 8. Tidal spectral energy with measured (blue) and modelled (red) power spectral density (PSD) with a fitted -5/3 decay curve and 8 tidal constituents' markers (vertical dashed lines).

2.1.4.2 Validation Results

Model validation was performed on a second ADCP deployment, this used identical model parameters as specified in the calibration. The validation period covers 30 days from the 12/10/2024 to the 11/11/2024. The results of the validation period are shown in Figures 8 and 9, with the model agreement statistics shown in Tables 3.

The comparison of surface elevations is shown in Figure 9. This shows similar performance to the calibration, with excellent phase agreement, and modelled magnitude showing reasonable agreement with a slight underestimation during the tailing spring and neap tides.

Easterly and northerly velocity components of the validated model behave similarly to the calibration, which shows poor phase agreement with a reasonable approximation of the velocity magnitude.

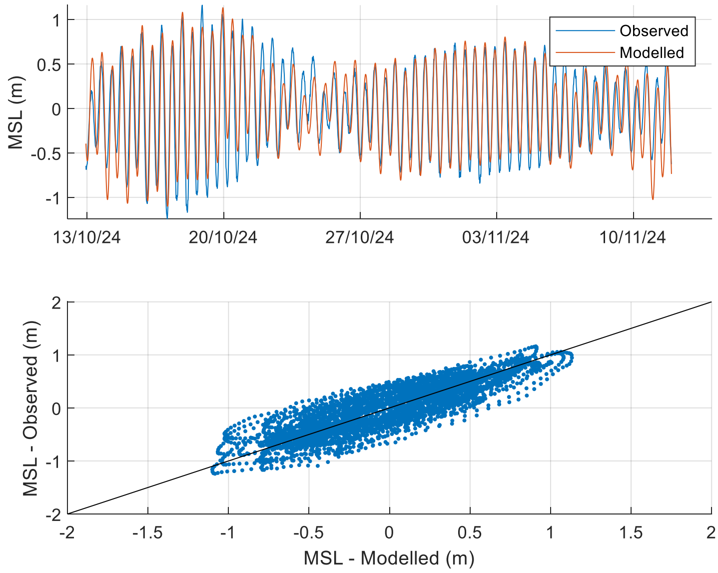

Figure 9. Mean sea level validation results for the current meter location at Vementry.

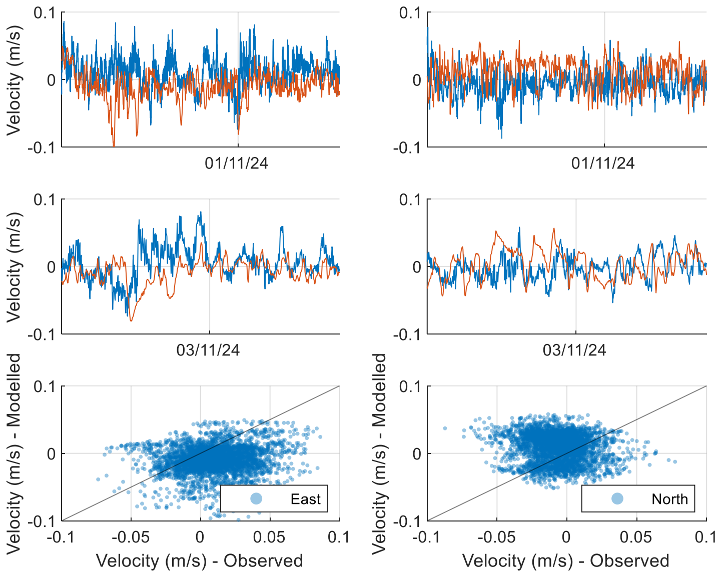

Figure 10. Vementry east (left column) and north (right column) velocity components. The top row shows all 30 days of the validation period. Middle row shows smaller 7-day subset. Bottom row shows scatter plot of observed and modelled velocity.

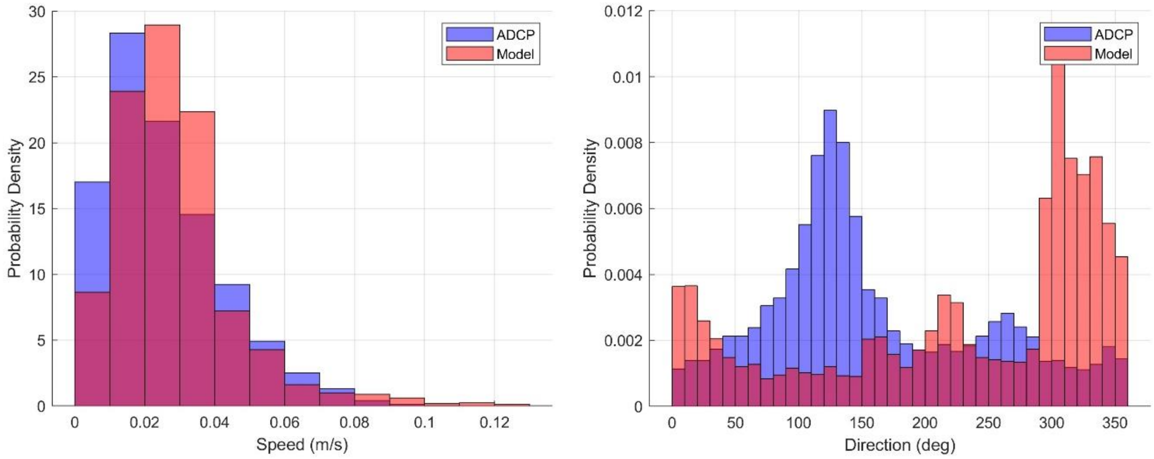

Figure 11. Vementry speed (left) and direction (right) distribution for the validation period.

The large-scale turbulence assessment for the validation period is shown in figure 12, which shows very similar energy densities for the lower frequency components for the ADCP and modelled data. A very small peak is indicated in both the ADCP and model around the semi-diurnal tidal component (12.5hr or 2.222 x 10^{-5} Hz). This peak is not prominent enough to ensure repeatable and more obvious tidal characteristics associated with tidally dominant locations. Modelled higher frequency features are shown to be potentially underestimated; however, these values occur near the noise floor and therefore, turbulent features will be indistinguishable from background noise.

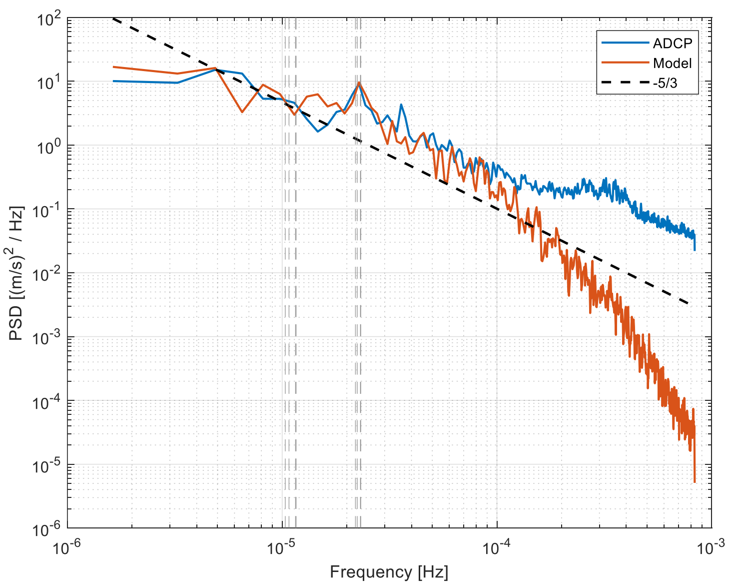

Figure 12. Tidal spectral energy with measured (blue) and modelled (red) power spectral density (PSD) with a fitted -5/3 decay curve and 8 tidal constituents' markers (vertical dashed lines).

The statistical parameters for the model are shown in table 3, with performance values around the lower acceptable limit. This is with the exception of the velocity correlation, where additional analysis has identified the site centre location as being primarily driven by irregular large-scale features. This provides a model that shows poor short-term phase resolving flow features. However, over longer durations and larger spatial distances, these immediate phase-resolving characteristics become less significant, specifically when determining particle fate using large numbers of particles. This permits the application of this model for wider use when considering far-field effects.

Table 3. East and North velocity component calibration and validation performance statistics.

	Model Component	Mean Absolute Error (m/s)	RMS Error (m/s)	NRMSE (range)	Correlation
Calibration	MSL	0.225	0.271	0.124	0.901
	East	0.023	0.030	0.134	0.070
	North	0.024	0.030	0.171	0.002
Validation	MSL	0.228	0.287	0.119	0.871
	East	0.026	0.034	0.213	0.100
	North	0.025	0.031	0.188	-0.130

2.1.5 Particle Tracking Model

The release of aquaculture waste feed and faeces are 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 will be located out with the hydrodynamic warm-up period, allowing flow fields to fully establish.

2.1.5.1 Particle Source

Each farm specified in Table 1 is modelled at peak biomass for the entire model duration. To simulate waste feed and faeces, two particle classes are specified for each farm. This allows separate particle parameters to be applied to each particle type. The quantities of waste and excreted solids use the same formulation specified in the SEPA default model (SEPA, 2019a). Default particle properties are specified in Table 4. Where calibration data is available, these parameters may be adjusted.

Table 4. Default (uncalibrated) particle parameters.

Particle class	Waste feed	Excreted solids
Decay (s)	0	0
Settling velocity (m/s)	0.095	0.032
Horizontal dispersion (m^2/s)	0.1	0.1
Vertical dispersion (m^2/s)	0.001	0.001

Erosion threshold ($N/m^2/s$)	0.02	0.02

Particles are released using an area source within the particle tracking model. As it is not feasible to define each individual pen manually, the rectangular area of the cage group is used with random particle placement. An example of this is shown in Figure 13, where the individual pens and the representative pen group in the particle tracking model are shown. This offers the most representative particle dispersion where concentration and area coverage are most similar to the individual pen simulation. Particles are released at a depth of half the pen depth with a layer thickness of the pen depth.

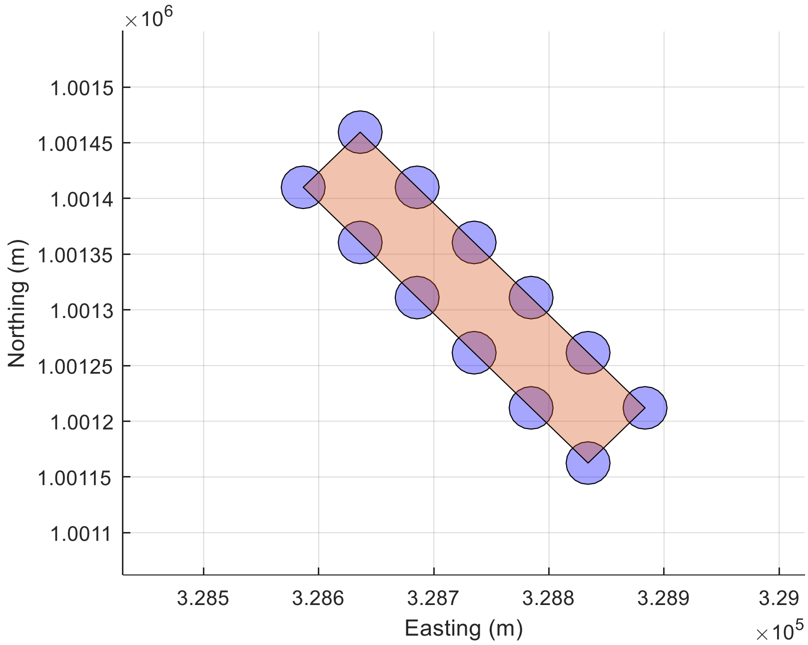

Figure 13. Example farm layout with 12 pens (blue), and the hydrodynamic model particle release area (red).

2.1.5.2 Particle Tracking Calibration

The particle parameters specified within the model can be adjusted to improve model performance. To provide more realistic particle dispersion characteristics, drogue release studies can be used. Several drogue releases will be performed throughout the flood and ebb tide at the proposed farm location. The data collected during this study can be used to calculate the average horizontal dispersion. This value is then applied within the model for the horizontal dispersion coefficient.

3. In-feed Chemical Modelling

In-feed treatments can be used to control sea lice numbers on salmon farms. Slice™, (active ingredient Emamectin Benzoate (EmBZ)), is applied as a coating to daily feed rations. To quantify the potential environmental effects of using such chemotherapeutants, depositional modelling using NewDepomod is required to determine chemical accumulation.

Methods to quantify environmental impacts of in-feed treatments are defined in SEPA (2019a), this outlines the EQS standards which determine maximum treatment and total allowable quantities. This study uses the most recent guidelines recommended by UK Technical Advisory Group (2022). This has informed SEPA's guidelines on the interim position of the use of Emamectin Benzoate (SEPA 2023a) where, the 100m mixing zone methodology is applied with a chemical contour value of 272 ng/kg of dry sediment. This is equivalent to 0.136 µg/kg of wet sediment.

3.1 Model Parameters

The SEPA regulatory default model for in-feed chemical treatment uses similar model parameters. However, input particle parameters listed in Table 5 are defined for the respective solids and in-feed EmBZ files. Simulation length is reduced to 223 days, where the EQS is recorded at 118 days.

Table 5 Infeed parameter specific to chemical modelling.

Parameter	Benthic (solids input)	In-feed (EmBZ input)
Consolidation time of faeces	0	345600
Consolidation time of feed	0	345600
Degrade T50 chemical (s)	Infinity	21600000

3.2 Post-processing

Post-processing of the 3 hourly output files averages the chemical mass for each cell over a 48 hr period, ending on the 118th day. This average value is then used to determine compliance with EQS.

4. Bath Treatments

Bath treatments are used to reduce harmful sea lice infections and are an alternative to in-feed treatments. Bath treatments are administered using either tarpaulins or wellboat treatments. Tarpaulin treatments create a reduced volume impervious enclosure, where chemical treatments can be provided. After the treatment is complete, the tarpaulin is removed, and the chemical solution is dispersed in open water. Wellboat treatments pump fish into a holding tank on a vessel, where the lice treatment is administered, once completed, the fish and solution are pumped back into the open nets.

To determine the quantity of chemical used, a Mike21 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 (2024a) for Azamethiphos, Cypermethrin and Deltamethrin treatments (table 6). 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:

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

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, this is applied 72 hours after the final treatment of a full site treatment cycle.

Table 6. 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).				

4.1 Bath Model

To determine environmental compliance from chemical bath treatments, the calibrated Mike21 hydrodynamic model is used to simulate flow fields around the site. Chemical treatments are simulated through the release of particles within a particle tracking model. Particle release is timed to match realistic treatment patterns to replicate likely plume formations. This assumes treatments only occur during working hours (9am-5pm) with a minimum 3hr spacing and a maximum of 3 treatable pens per day. For example, a farm consisting of 12 pens could treat 3 pens a day with a 3-hour interval, taking 4 days to treat the entire farm. Chemical concentration and area coverage are then tracked for the maximum EQS time + 24hrs after the last treatment. In the case of Azamethiphos, this is a total of 96 hrs. The additional 24hrs allows for concentrations to be monitored to ensure no secondary breaches of EQS occur. Plume dispersion is then compared to the environmental standards to ensure compliance.

4.1.1 Hydrodynamic Model

DHI's Mike21 FM model is used to simulate free-surface flow in a coastal environment. The model uses a flexible mesh to replicate regional hydrodynamics. The hydrodynamic model used for bath treatments uses the same hydrodynamic model parameters specified in section 2.1.

4.1.1.1 Domain

The model domain uses the same flexible mesh described in section 2.1.1. This has a mesh resolution of approximately 250m near the offshore boundaries and a resolution of 36m for the near site locations. Bathymetry data are taken from the UK Hydrographic Office (UKHO 2021) with coastlines extracted from the Ordnance Survey (2024).

4.1.1.2 Boundary Conditions

Boundary conditions for water level and wind forcing are specified in section 2.1.2. Water level at the model boundaries is taken from the E.U Copernicus Marine Service Atlantic - European North West Shelf - Ocean Physics Analysis and Forecast. Wind forcing within the domain is interpolated from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 model (ECMWF 2025).

4.1.1.3 Model Configuration

The 3-dimensional formulation is applied with a time step interval of 60 s. The governing equations use the same shallow water equations as specified in section 2.1.3. The bed roughness is defined using the Manning roughness, where the value assigned in the model validation is applied.

4.1.1.4 Calibration and Validation

As the model uses the same mesh, boundary conditions and model parameters as the hydrodynamic model in section 2.1, the model calibration and validation results in section 2.1.4 holds for the bath hydrodynamic model.

4.1.2 Particle Tracking 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 from those used within the hydrodynamic model. However, simulation start time will be located out with the hydrodynamic warm-up period and will coincide with bath treatments finishing on the spring and neap tides.

4.1.2.1 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.

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

At this stage, the particle mass is set to 0kg.

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 $1.43\text{x}10^{-6}$ /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.

4.1.2.2 Particle Source

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 12 and 13 provide a schematic illustrating the differences in the particle release methodology.

4.1.2.2.1 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.

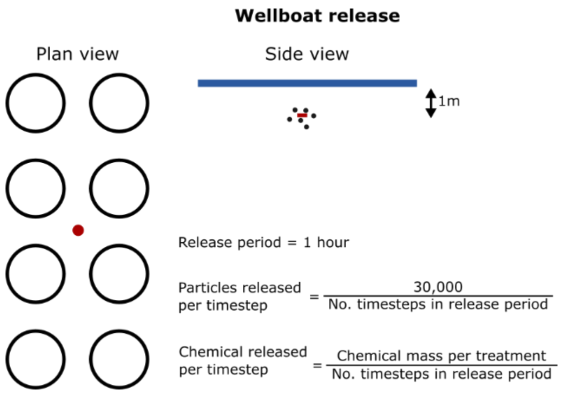

Figure 14. Wellboat release schematic. Open black circles represent pen locations, particle source location is shown in red, the blue line represents the sea surface and small black dots represent particles.

4.1.2.2.2 Tarpaulin Release

To ensure multiple options and flexibility for bath medicine administration, tarpaulin releases will also be 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.

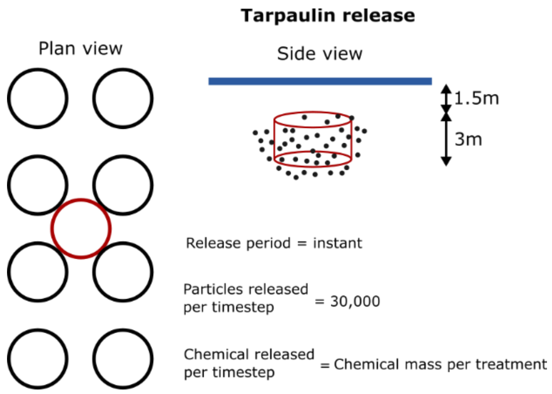

Figure 15. Tarpaulin release schematic. Open black circles represent pen locations, particle source location is shown in red, the blue line represents the sea surface and small black dots represent particles.

4.1.2.3 Model Runs

To determine a compliant treatment mass and schedule, several variables must be considered. This requires numerous model runs, testing different scenarios and model sensitivities. A significant variable is the tidal phase at the final treatment release time. To account for this, multiple tidal phases will be tested where the least dispersive of all combinations of these scenarios will be used to determine chemical mass.

5. Sea Lice Model

The risk assessment for sea lice (*Lepeophtheirus salmonis*) originating from farmed fish and affecting wild sea trout has been screened out in the *Screening and Risk Identification Report: Vementry* (SEPA, 2024b). However, Cooke Scotland remains committed to enhancing its understanding of lice dispersal patterns across the broader model domain, particularly given the lack of historical wild fish monitoring in the area. SEPA continues to be the competent authority responsible for evaluating the validity of this discretionary modelling approach.

The methodology for developing a sea lice model will follow the Salmon Scotland: Bespoke Screening Model Methods Statement (Salmon Scotland, 2024). This methodology was set out to help standardise an approach when applying a more refined sea lice model under SEPA's Sea Lice Risk Framework. This uses a hydrodynamic, particle tracking, and a biological model to simulate the distribution of infectious sea lice larvae.

4.1.1 Hydrodynamic Model

DHI's Mike21 FM model is used to simulate free-surface flow in a coastal environment. The model uses a flexible mesh to replicate regional hydrodynamics. The hydrodynamic model used in the previous sections is applied.

4.1.1.1 Domain

The model domain uses the same flexible mesh described in section 2.1.1. This has a mesh resolution of approximately 250m near the offshore boundaries and a resolution of 36m for the near site location. Bathymetry data are taken from the UK Hydrographic Office (UKHO 2021) with coastlines extracted from the Ordnance Survey (2024).

4.1.1.2 Boundary Conditions

Boundary conditions for water level and wind forcing are specified in section 2.1.2. Water level at the model boundaries are taken from the E.U Copernicus Marine Service Atlantic - European North West Shelf model with a 15 min interval. Wind forcing within the domain is interpolated from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 model (ECMWF 2025).

4.1.1.3 Model Configuration

The 2-dimensional formulation is applied with a time step interval of 60 s. The governing equations use the same shallow water equations as specified in section 2.1.3. The bed roughness is defined using the Manning number, where the value assigned in the model validation is applied.

4.1.1.4 Calibration and Validation

As the model uses the same mesh, boundary conditions and model parameters as the hydrodynamic model in section 2.1, the model calibration and validation results in section 2.1.4 holds for the bath hydrodynamic model.

4.1.2 Particle Tracking 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 from those used within the hydrodynamic model. However, the simulation start time will be 15th of March, running until 31st May. The first 2 weeks of the modelled period will be used for the population development of sea lice larvae, this will be excluded from the model results. Data analysed will only consider results between the 1st of April to the 31st of May.

4.1.2.1 Particle Configuration

Particle mass was set at a constant value of 1kg. Particle decay was set to $0s^{-1}$ with age-specific mortality rates later applied in the post-processing. Settling and erosion of particles was turned off. Horizontal dispersion of particles via turbulent processes will use a horizontal dispersion coefficient of $0.1m^2/s$.

At every timestep, the life cycle phase of each lice particle was defined in the model based on the particle age since release and the temperature dependent maturation rate of sea lice changing from non-infectious Nauplii to infectious Copepodid. In this case, water temperature is assumed to be 10^oC, giving a minimum age of maturity of 3.64 days (Stein et al., 2005).

Vertical swimming behaviour was applied as a negative settling speed. This applies a constant upward swim speed of 0.14cm/s.

Output of the particle tracking model consisted of the location, age, and life stage (nauplii or copepodid) of each particle saved at hourly intervals.

4.1.2.2 Particle Source

Particles were released at a fixed rate of 1 particle per 5 minutes for each site from the start of the simulation to the end. Particles are introduced into the model domain from rectangular area sources, representative of individual sites and defined using the central location of the corner pens within each cage group. Particles are randomly released across the rectangular source area in a vertical layer spanning from the sea surface to the depth of the cage bottom.

4.1.2.3 Biological model

Population dynamics of *L. salmonis* were incorporated into the particle tracking results through a biological model applied at the post-processing stage. Within the particle tracking model, modelled lice particles are effectively super-particles, whereby a single particle represents a packet of larvae. Therefore, the first post-processing step is to derive a particle value (P) representing the number of *L. salmonis* organisms a model particle consists of upon release. This is derived by:

$$P = \frac{N_{fish} \times N_{egg} \times IR}{N_P}$$

Where N_{fish} is the number of fish at a site. To simulate a worst-case scenario all sites are assumed to be operating at maximum biomass throughout the model duration. The number of fish hosts (N_{fish}) is then calculated using the maximum consented biomass multiplied by 240. N_{egg} is the number of eggs released per gravid female per day. This was calculated based on the methodology by Stein (2005), whereby each female louse is assumed to have 2 egg strings containing 150 eggs per string, all of which successfully mature to Nauplii and are released into the model domain. IR is the infection rate, i.e., number of gravid female *L. salmonis* per fish. An infection rate of 0.5 lice per fish is applied to the particle tracking results for the work detailed in this report, this represents the CoGP treatment trigger level. As infection rates are applied in post-processing, this methodology means the impact of different infection rates can be tested without rerunning all particle tracking models.

A life-cycle specific mortality rate is also applied within the biological model, therefore reducing the particle value (P) throughout time. For pre-infectious larvae (Nauplii) a mortality rate of 17% per day was applied. For infectious Copepodid a mortality rate of 22% per day was applied. All modelled particles were given a maximum age of 14 days, providing a 14-day life span for each louse within the model.

5. References

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