Trilleachan Mor, Loch Seaforth (CAR/L/1013016) Hydrodynamic and Dispersion Modelling

METHOD STATEMENT

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CONTENTS

List of Figures

List of Tables

1 INTRODUCTION

This method statement presents the specifications and rationale for the use of computer modelling to predict dispersion of topical sea lice medicines at a Mowi Scotland fish farm site **Trilleachan Mor** in **Loch Seaforth** (Figure 1). The models to be used include:

(i) a hydrodynamic (HD) model, FVCOM, to simulate local and regional current speed and direction;
(ii) a particle-tracking model, UnPTRACK, to simulate the discharge, dispersion and fate of residues of bath medicines.

The purpose of the modelling is to adequately represent the coastal processes involved in particle transport in the near field and far field, and to inform and support the resulting CAR application. This method statement outlines the methodology that will be used at Loch Seaforth in order to apply for medicine consents at the cage farm site that meet regulatory requirements, are in balance with the surrounding marine environment, and which are compliant with SEPA's environmental quality standards.

The modelling report will briefly describe the following aspects of the modelling process:

- Hydrodynamic modelling; choice of model; configuration; boundary conditions; calibration and validation;
- Bath modelling using a particle-tracking approach;

2 SITE PROPOSAL

The site layout at Trilleachan Mor consists of five circular pens of 160m circumference (Figure 1 and Figure 2) with a maximum biomass of 2,130 tonnes (Table 1). The pens are in a 5 x 1 formation, held in a 100 m grid with 20 m deep nets.

Table 1. Details of the site at Trilleachan Mor, Loch Seaforth

SITE DETAILS	
Site Name:	**Trilleachan Mor**
Site location:	Loch Seaforth
Proposed treatment use:	Azamethiphos, Deltamethrin
Peak biomass (T):	2,130
Proposed feed load (T/yr):	5,442
CAGE DETAILS	
Group location:	NB 2101 0752
Number of cages:	5
Cage dimensions:	160 m circumference
Grid matrix (m)	100
Working Depth (m):	20
Cage group configuration:	5 x 1
Distance to shore (km):	0.300

Figure 1. Location (●) of the Trilleachan Mor site in Loch Seaforth, Lewis.

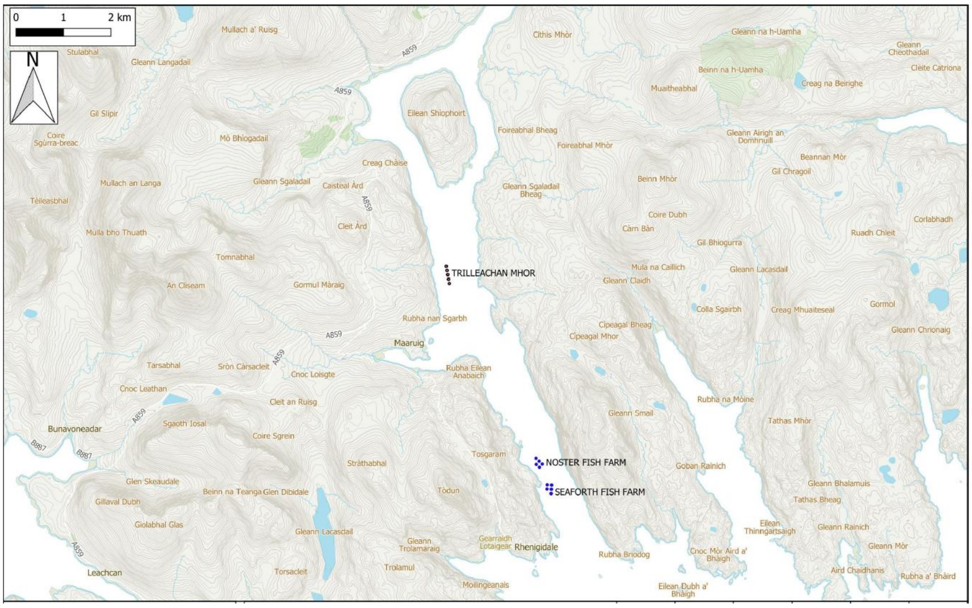

Figure 2. Locations of the five 160m cages (●) at the Trilleachan Mor site in Loch Seaforth. The neighbouring Mowi sites of Seaforth and Noster are also shown.

3 SCOPE OF MODELLING - KEY ISSUES TO BE ADDRESSED

The proposed modelling is designed to simulate the release, dispersion and fate of soluble medicines from the pens to the immediate area around the pens, and also to determine subsequent dispersion over a larger domain.

Two models will be described in this statement: the hydrodynamic (HD) model and a particle-tracking model, UnPTRACK, used to simulate the dispersion of bath medicines. The hydrodynamic model will initially be used to determine the maximum distance that particles released from the farm site will travel in all directions. This will dictate the size and shape of the study model domain for the bath medicine model. Current velocity fields will then be extracted from the hydrodynamic model and used to provide input data to the particle tracking model UnPTRACK, which will then be run to produce outputs of topical sea lice treatment concentrations.

The use of a calibrated hydrodynamic model to provide spatially-varying current data provides more realistic input data to the particle tracking model, UnPTRACK, compared to the use of a single current dataset from a fixed-location current meter, reproducing the changing flow fields in response to the topography and bathymetry of the regional domain.

Outputs from both the particle tracking and hydrodynamic models will be used to make an application to SEPA for the site.

3.1 General Environmental Risks Associated with Aquaculture Discharges

The main components of the discharges from marine pen fish farms are associated with the discharge of particulate wastes, anti-parasitic medicine residues and dissolved nutrients. This report only addresses dispersion of medicines since no change in biomass is requested.

3.1.1 Organic Wastes

The impact of particulate material on benthic communities and the macrofaunal response to enrichment is well known. It follows the same general pattern of impact of other organic pollutant sources (Pearson and Black, 2001). The organic load discharged from pen fish farms consists of faeces and uneaten food which may settle to the nearby seabed. The extent to which these particles are dispersed by currents determines the area and intensities in which they accumulate on the seabed. In highly energetic areas this material is likely to be dispersed and assimilated by the benthic fauna with little detectable accumulation or impact. In lower energy areas however the seabed may become enriched, changing the structure of the benthic fauna. This can sometimes be associated with sediment anoxia. SEPA has adopted a variety of assessment techniques as part of its regulatory approach to match the scale of farmed-fish production to the environment’s capacity to cope. Techniques are applied over different geographic areas depending on the specific fate and behaviour of pollutants. SEPA has a defined suite of environmental standards which are used to assess the impact of discharges from marine pen fish farms to ensure that natural flora and fauna and important habitats are not put at risk.

3.1.2 Medicinal Treatments

Medicinal sea lice treatments are carried out in one of two ways:

- Bath treatments *in-situ* by enclosing the pen in question fully with a large tarpaulin. The net is lifted to gently crowd the fish together in the smallest safe volume. The tarpaulin is passed underneath the net and pulled up around the pen above the water level. When the fish are totally enclosed in the tarpaulin, treatment can begin. Oxygenation equipment is used to ensure the water is well oxygenated and prevent the fish from experiencing stressful suboptimal oxygen levels. Once the treatment is completed the tarpaulin is removed and the nets lowered to uncrowd the fish.

- Fish may be treated in tanks on board specialist wellboats. Following treatment, the dislodged lice are collected and disposed of, then the treatment water is discharged into the sea.

The regulatory approach to use of authorised medicinal substances is based on the use of predictive models to set limitations on the quantities and rate of release of these compounds to meet the relevant Environmental Quality Standards (EQS) outside a defined mixing zone (previously referred to as an allowable zone of effect or AZE), based on the hydrographic characteristics of each site. The purpose of the mixing zone is to allow an effective dose of medicine to be administered within a pen, but to ensure that the dose results in lower concentrations than those that affect the most vulnerable fauna beyond the mixing zone.

Consented volumes of medicines are regulated by site-specific numeric modelling using inputs of hydrographic, bathymetric, geographic, and farm equipment infrastructure. Release and dispersion of medicine residues is predicted and simulated environmental concentrations are compared to the appropriate Environmental Quality Standard for each medicine. The volumes of medicines consented are tailored to the hydrodynamics and bathymetry of the site and are determined such that the set EQS for each compound would not be breached.

There are presently five active ingredients available (in various product formulations) for use as sea lice medicines in Scotland, either as bath treatments (cypermethrin, azamethiphos, deltamethrin, and hydrogen peroxide) or in-feed treatment (emamectin benzoate). Of these hydrogen peroxide has lower environmental risks and its use is generally not considered as a significant concern.

3.1.3 Dissolved Nutrients

The Trilleachan Mor site sits within Loch Seaforth, a Locational Guidelines categorised water body. Local Seaforth is currently ranked as Category 2, defined as a location where “new development or expansion of existing sites would not result in the area being re-categorised as category 1”. Additional biomass is not proposed as part of this application and therefore no change to the modelled Equilibrium Concentration Enhancement (ECE, Gillibrand and Turrell, 1997; Gillibrand et al., 2002) is anticipated.

3.2 Site Specific Environmental Considerations

Screening modelling undertaken by SEPA found two nearby mussel farms and three kelp beds to be at potential risk from treatments at Trilleachan Mor. Results of the screening modelling are presented in the Aquaculture Modelling Screening & Risk Identification Report for Trilleachan Mor prepared by SEPA (2024). Impacts of treatments at Trilleachan Mor on these identified features will be assessed in the modelling report.

4 HYDRODYNAMIC MODEL DESCRIPTION AND CONFIGURATION

The hydrodynamic model used was FVCOM (Finite Volume Community Ocean Model), a prognostic, unstructured-grid, finite-volume, free-surface, 3-D primitive equation coastal ocean circulation model developed by the University of Massachusetts School of Marine Science and the Woods Hole Oceanographic Institute (Chen et al., 2003). The model consists of equations describing the evolution and conservation of momentum, temperature, salinity and turbulence parameters, the latter using a turbulence closure submodel. The horizontal grid is comprised of unstructured triangular cells and the irregular bottom is presented using generalized terrain-following coordinates. The General Ocean Turbulent Model (GOTM) developed by Burchard's research group in Germany (Burchard, 2002) has been added to FVCOM to provide optional vertical turbulent closure schemes. Horizontal viscosity and diffusivity is parameterised using a Smagorinsky scheme, with a coefficient c_s. FVCOM is solved numerically by a second-order accurate discrete flux calculation in the integral form of the governing equations over an unstructured triangular grid. This approach combines the best features of finite-element methods (grid flexibility) and finite-difference methods (numerical efficiency and code simplicity) and provides a much better numerical representation of both local and global momentum, mass, salt, heat, and tracer conservation. The ability of FVCOM to accurately solve scalar conservation equations in addition to the topological flexibility provided by unstructured meshes and the simplicity of the coding structure has make FVCOM ideally suited for many coastal and interdisciplinary scientific applications, such as typically found in Scotland. The mesh flexibility allows greater spatial resolution in near-shore areas without excessive computational demand.

The model is forced by a tidal condition along the open boundary, and by frictional stresses at the surface and seabed. At the seabed, the frictional stress, $\boldsymbol{\tau}_b$, is calculated using a quadratic equation where:

$$\tau_b = \rho C_D \boldsymbol{U}|\boldsymbol{U}| \tag{1}$$

where $\rho = 1025$ kg m^{-3} is the water density, **U** is the velocity in the layer closest to the seabed. The drag coefficient, C_D, is calculated from the bed roughness lengthscale, z_0, using:

$$C_D = \left(\frac{\kappa}{\ln\left(\frac{z_b+z_0}{z_0}\right)}\right)^2 \tag{2}$$

where $\kappa=0.4$ is von Karman's constant, and z_b is the height above the bed of the lowest velocity point. The value of z_0 was varied during calibration to provide the best fit to observations of sea level and velocity.

Wind forcing is applied as a surface stress calculated from hourly wind speed and direction. Wind stress is calculated from the wind velocity by a standard quadratic relation:

$$\tau_x = \rho_a C_W u W \tag{3a}$$
$$\tau_y = \rho_a C_W v W \tag{3b}$$

where (u,v) are the East and North components of wind velocity respectively, W is the wind speed ($W = [u^2+v^2]^{½}$), ρ_a is the density of air, and the surface drag coefficient C_W is calculated following Large and Pond (1981).

4.1 Model Configuration

The unstructured mesh to be used in the marine modelling is shown in Figure 3. The model resolution was enhanced in the area around the Mowi sites in Loch Seaforth (Figure 4). The spatial resolution of the model varied from 28 m in some inshore waters and round the farm pens to ~500 m along the open boundary. The model mesh consists of 30,147 nodes and 57,668 triangular elements. The model will be run in 3D mode.

Bathymetry was taken from the Marine Scotland East Coast of Lewis and Harris (ECLH) model, which has reasonably high spatial resolution around Loch Seaforth, and supplemented by a local depth survey around the Seaforth and Noster sites (Figure 5). The combined data were interpolated onto the Seaforth model mesh. The combined data capture the deep channel to the northeast of the Seaforth and Noster pen groups

The model will be forced along its open boundary by time series of sea surface height (SSH) at each boundary node for the relevant simulation periods; FVCOM appears to perform better when boundary forcing is applied as a time series rather than when tidal constituents are used. The SSH time series will be generated using the RiCOM hydrodynamic model (Walters and Casulli, 1998; Gillibrand et al., 2016b) on the Scottish Shelf Model ECLH grid (Marine Scotland, 2016), which will, in turn, be forced by eight tidal constituents (O_1, K_1, Q_1, P_1, M_2, S_2, N_2, K_2) taken from the full Scottish Shelf model (SSM).

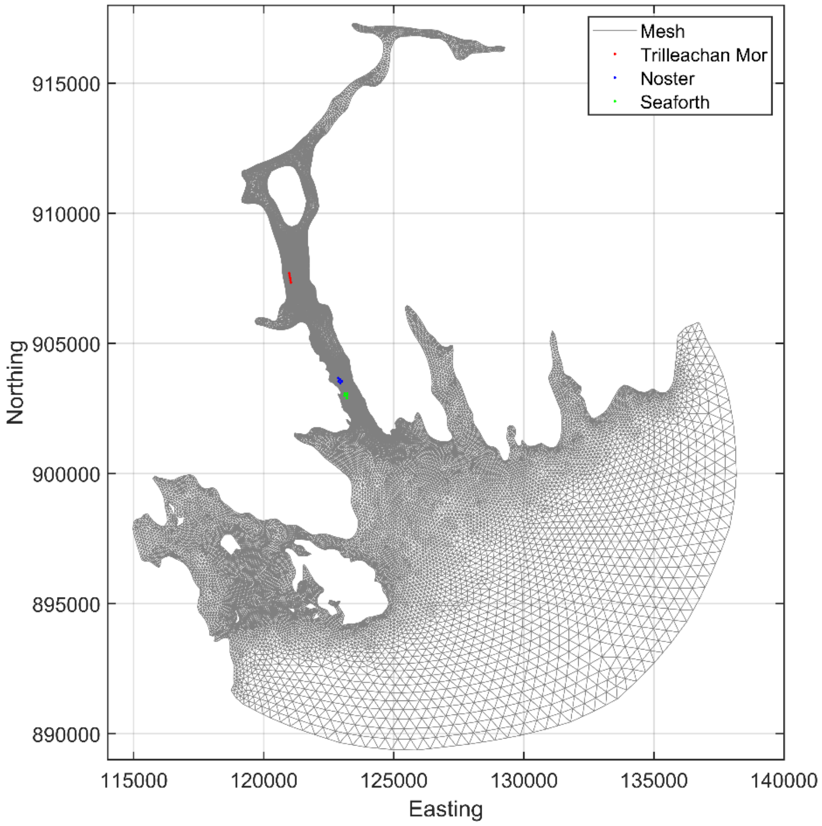

Figure 3. The model mesh and domain for the Loch Seaforth modelling study. The cage locations at Trilleachan Mor (●), Noster (●), and Seaforth(●) are indicated.

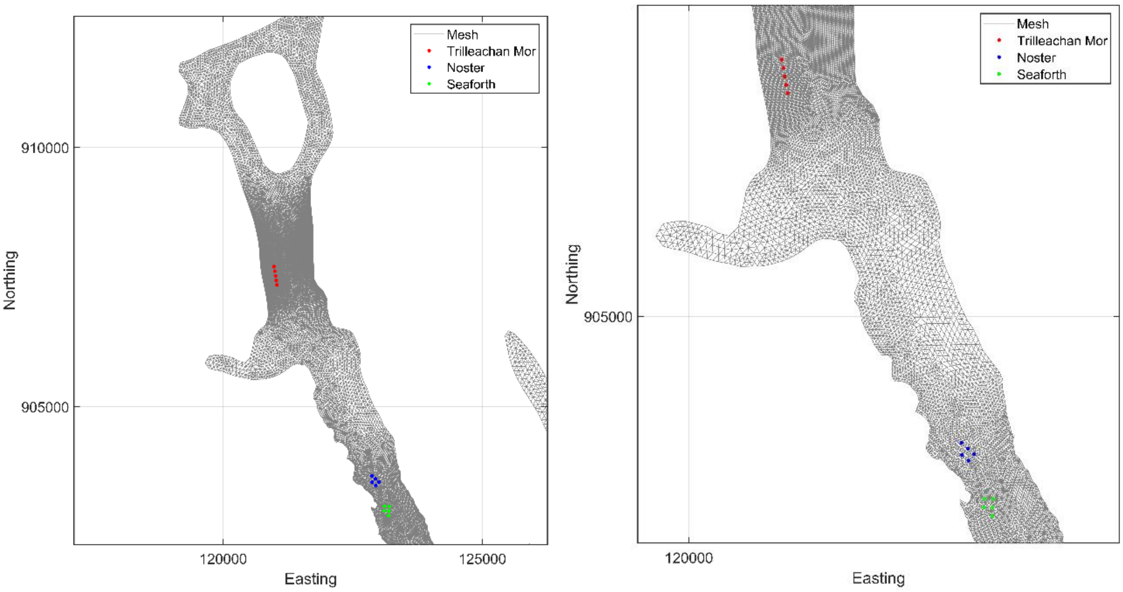

Figure 4. The unstructured mesh around the Loch Seaforth sites, with the cage locations at Trilleachan Mor (●), Noster (●) and Seaforth (●) indicated.

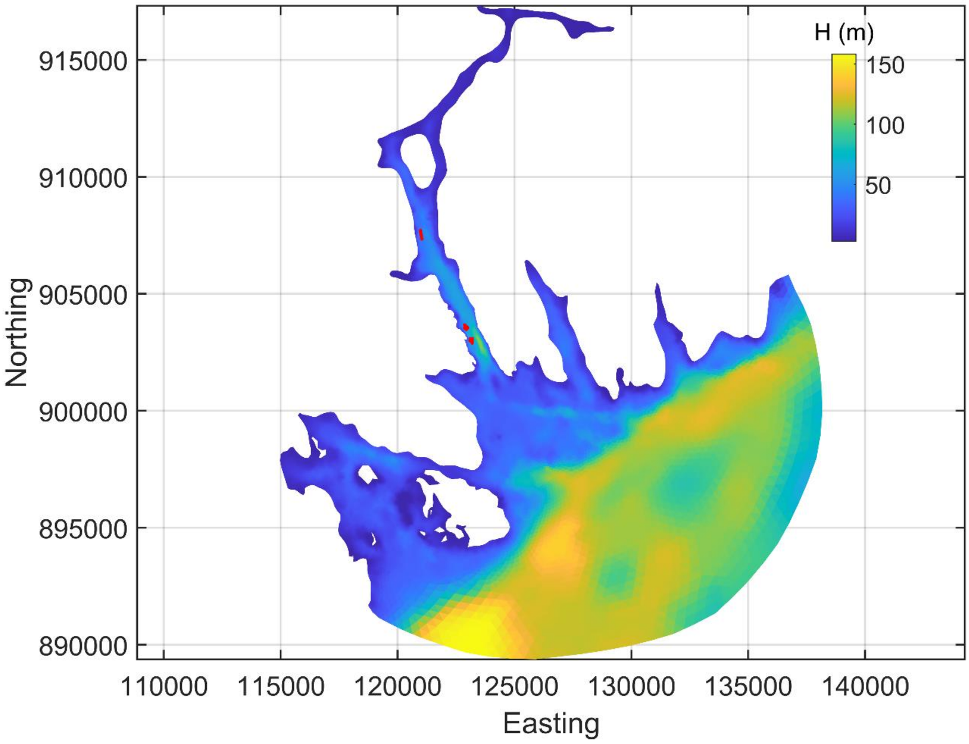

Figure 5. Model water depths (H, m) in the model domain (right), incorporating the local depth survey data. The proposed cage locations are indicated (●).

Spatially- and temporally-varying wind speed and direction data are taken from the ERA5 global reanalysis dataset (ECMWF, 2021) for the required simulation periods and interpolated spatially onto the model mesh element centre locations.

Stratification is expected to be moderate in this location and the model will be run in 3D baroclinic mode. At least ten layers in the vertical (eleven sigma levels) will be used in the simulations, with layers concentrated near the surface and seabed. Initially, sigma levels will be defined at:

σ = [0.00 -0.02 -0.08 -0.16 -0.32 -0.50 -0.68 -0.84 -0.92 -0.98 -1.00]

Further levels will be added if required to achieve a satisfactory calibration.

Climatological river flow data will be used, taken from the Marine Scotland Scottish Shelf Model climatology (Marine Scotland, 2016).

4.2 Model Calibration

The hydrodynamic model will be calibrated against current data and seabed pressure data, measured at Trilleachan Mor using Acoustic Doppler Current Profilers (ADCP). Data are available from:

(i) Calibration: 17 June 2005 – 11 July 2005 (ID435)
(ii) Validation: 18 June 2024 – 17 August 2024* (ID440)

* estimated recovery date

The data should extend over 83 days. ADCP data from the neighbouring Seaforth and Noster sites may also be used for model evaluation.

The model will be run in 3D, and calibration will be performed primarily by adjusting the bed roughness length scale, z_0, and the horizontal viscosity coefficient, c_s, to obtain the best fit against the sea surface height and current data. Once the best comparison with the calibration data has been achieved, the parameter set will be tested without further adjustment against the validation datasets.

4.2.1 Near-Surface Current Measurements

The second deployment listed above (ID440) utilised a Nortek Signature 1000 ADCP instrument (Nortek, 2023). The objective of these measurements was to more accurately measure the currents in the near-surface region of the water column, where bath medicines are applied and disperse following traditional tarp treatments. The Nortek Signature 1000 is a high frequency (1 MHz) ADCP, allowing smaller cell sizes (0.2 – 2.0 m) and higher frequency sampling. The instrument was deployed at mid-depth, *ca.* 15 m below mean sea level (MSL), meaning that less of the sub-surface water column will be lost to side-lobe reflections; measurements will be made to within about 2 m of the water surface.

These data will be processed in two ways:

1. The near-surface cell will be selected in the usual way, namely as the shallowest cell which contains valid data throughout the deployment. As for standard deployments, this cell will be at a depth of a few metres below the lowest measured sea surface height. Given that spring tides in the area have a range of about 4.5 – 5.0 m, the near-surface cell selected in this manner will be about 4.5 m below MSL. This is only just

within the 0 – 5 m depth water column in which bath medicine dispersion occurs; when the SSH is positive (above MSL) the measured currents will likely lie below the actual near-surface layer in which dispersion is taking place.

2. To improve the estimation of currents in the near-surface layer (0 – 5 m depth), velocity data will be extracted from a fixed depth (e.g. 2.5 m) relative to the moving water surface (by "surface tracking"). This will provide a more accurate estimate of current speed and direction affecting dispersing patches of bath medicine in the top 5 m of the water column, accounting for tidal oscillations in the sea surface height throughout the deployment. The current speed and direction obtained in this approach will be compared to the standard approach. Provided a realistic value is obtained, the mean current speed acquired with this approach will be used to estimate the 3-hour mixing zone. The hydrodynamic model output will be compared to the data from both approaches.

The new near-surface observations (ID440) will measure currents closer to the surface, but traditional processing methods still only provide data at depths below about 4 m below MSL, due to data losses at low tide. Using a surface-tracking approach, whereby the first valid cell below -2.5 m depth relative to the sea surface is selected for each record, will provide a better representation of the current speeds in the near surface layer, where bath medicine application and dispersion takes place. **Therefore we propose to use this method to calculate the 3-hour mixing zone.**

5. DESCRIPTION OF THE PARTICLE TRACKING MODEL

Bath medicine dispersion modelling will be undertaken using a particle tracking model coupled with the hydrodynamic model flow fields described above to simulate the dispersion of bath medicine from the pens following treatment. The dispersion model has been developed from an earlier particle-tracking model code that has been used to simulate the transport and dispersal of pelagic organisms, including sea lice larvae (Gillibrand and Willis, 2007) and harmful algal blooms (Gillibrand et al., 2016), and solute veterinary medicines (Willis et al., 2005) in Scottish coastal waters. The new model, UnPTRACK (Gillibrand, 2022), has been developed to use flow data from unstructured mesh hydrodynamic models. The model approach for a veterinary medicine is the same as for live organisms except that the medicine has no biological behaviour but instead undergoes chemical decay; the numerical particles in the model represent "droplets" of medicine of known mass, which reduces over time at a rate determined by a specified half-life. Particles are released at pen locations at specified times, according to a treatment schedule. The number of particles combined with their initial mass represents the mass of medicine required to treat a pen. The particles are then subject to advection, from the modelled flow fields, and horizontal and vertical diffusion. Particle locations are tracked throughout the simulation and output to file every hour, together with particle properties such as particle age and the mass of medicine represented (subject to decay). From the particle locations, concentrations of medicine are calculated and compliance with Environmental Quality Standards (EQS) assessed.

Velocity data to drive the model can be obtained from current meter (ADCP) observations or from hydrodynamic model simulations. In the case of the latter, the particle-tracking model will use the same numerical grid as the hydrodynamic model, with the modelled velocity fields used to advect the numerical particles. In the case of the former, a numerical grid is constructed to cover the area of the simulated dispersion, and the observed current data applied at each of the grid nodes; in this case, the velocity field experienced by the numerical particles is spatially non-varying in the horizontal, although vertical shear can be present if multiple current meters, or multiple bins from an ADCP deployment, are used. In both cases, realistic bathymetry can be used, although this is not expected to be a critical factor in the dispersion of bath treatments.

Within the particle tracking model, particles are advected by the velocity field and mixed by horizontal and vertical eddy diffusion, simulating the physical transport and dispersion of the cells. The mathematical framework of the model follows standard methodology for advection and diffusion of particles (e.g. Allen, 1982; Hunter et al., 1993; Ross and Sharples, 2004; Visser, 1997), whereby the location $X^{t+\Delta t}_P = X^{t+\Delta t}_P(x,y,z)$ of particle P at time t+Δt, can be expressed as:

$$X_P^{t+\Delta t} = X_P^t + \Delta t\left[\vec{U}_P + w_P\right] + \delta_H + \delta_Z \tag{1}$$

where $\vec{U}_P(x,y,z)$ is the 3D model velocity vector at the particle location, w_p is an additional vertical motion term due to, for example, particle settling or vertical migration and Δt is the model time step. Particle advection is treated using a fourth-order Runge-Kutta algorithm. Horizontal and vertical eddy diffusion are represented in the model by the “random walk” displacements δ_H and δ_Z respectively, given by (Proctor et al., 1994):

$$\begin{aligned}\delta_H &= R[6.K_H.\Delta t]^{1/2}\\ \delta_Z &= R[6.K_Z.\Delta t]^{1/2}\end{aligned} \tag{2}$$

where R is a real random number uniformly distributed over the range $-1 \leq R \leq 1$, and K_H and K_Z are the horizontal and vertical eddy diffusivities respectively. For the present simulations, we use a small constant eddy diffusivity of $K_H = 0.1$ m^2 s^{-1}. A dye release study was conducted in Loch Seaforth by Anderson Marine Services Ltd. in February 2018. The dye study gave a mean horizontal diffusivity of 0.05 m^{2}s^{-1}, so this value will be used in the sensitivity analysis of the dispersion modelling.

The choice of vertical diffusion coefficient is less certain but a value of $K_V = 0.001$ m^{2}s^{-1} is thought to be reasonably conservative for near-surface waters.

In Equation (1) for solute substances, w_p represents additional vertical motion of the particle due to, for example, buoyancy. For the present simulations, $w_p = 0$ since the bath treatments simulated here are administered in the cages with the medicine mixed into ambient seawater. Chemical decay is simulated by varying the particle properties. At the time of release, each numerical particle represents a mass, M_0, of azamethiphos (active ingredient of Salmosan). The age since release, t_p, of every particle is stored, and the chemical mass, M_P, represented by each particle changes according to:

$$M_P = M_0 e^{\gamma t_p} \tag{3}$$

where $\gamma = \ln(0.5)/T_D$ and T_D is the half-life of the chemical decay. The mass M_P of every particle is stored in each output file.

The model has tested for accuracy in simulating advection, diffusion and chemical decay (Gillibrand, 2022). The random walk algorithm correctly simulated the increase in particle variance with specified horizonal dispersion coefficients of 0.1 m^{2}s^{-1} and 1.0 m^{2}s^{-1}. Chemical decay was similarly tested and the modelled concentration decayed with the specified half-life. These tests are not reported further here but are described by Gillibrand (2022).

6. BATH TREATMENT DISPERSION MODELLING

6.1 24-hour EQS

Modelling of bath treatments will be undertaken using a particle tracking model, UnPTRACK (Gillibrand, 2022), forced by the flow fields from the hydrodynamic model described above, to simulate the discharges and subsequent compliance with the EQS.

To simulate the worst-case scenario, the dispersion modelling will initially be conducted using flow fields over a period of 9 days centred on a small neap tidal range taken from the hydrodynamic model simulations. This is assumed to be the least dispersive set of ambient conditions, when medicine dispersion is least likely to meet the required EQS.

A treatment depth of 5 m will be chosen initially as a realistic depth during application of the medicine for 160 m circumference pens. The initial mass released per pen is calculated from the reduced pen volume and a treatment concentration of 100 µg/L, with a treatment mass of 1.02 kg per pen and a total mass of 5.10 kg of azamethiphos released during treatment of the whole farm (5 pens). The number of cage treatments that can be performed in a single day will be determined by the modelling but is expected to be just one pen per day. If modelling indicates more than one pen per day can be treated, treatments will be separated by a minimum of 3-hour intervals. Particles are released at random positions within a cage radius of the cage centre and within the 0 – 5 m depth range.

The length of the model simulations will depend on the treatment schedule, but will include the treatment period, a dispersion period to the EQS assessment at 72 hours after the final treatment, and an extra 25 hours to check for chance concentration peaks. Every hour of the simulation, particle locations and properties (including the decaying mass) will be stored and subsequently concentrations calculated. Concentrations will be calculated over the standard depth range, 0 – 5 m.

From the calculated concentration fields, time series of two metric will be constructed for the whole simulation:

(i) The maximum concentration (µg/L) anywhere in the model domain;
(ii) The area (km^2) where the EQS is exceeded.

These results will be used to assess whether the EQS or maximum allowable concentration (MAC) is likely to be breached after the allotted period (72 hours after the final treatment).

Sensitivity analyses will investigate the effects of:

(i) The horizontal diffusion coefficient;
(ii) The vertical diffusion coefficient;
(iii) The tidal state at time of release. Simulations will be performed with the release times varied by ±2, ±4 and ±6 hours.

All simulations, including the sensitivity analysis, will be repeated for a spring tide period.

6.2 Short-term EQS

The UnPTRACK model will also be used to assess the 3-hour EQS for azamethiphos and the 6-hour EQS for deltamethrin. The 3-hour and 6-hour mixing zones will be taken from the BathAuto excel spreadsheet using the mean surface speed calculated from ID440, which is thought to be representative of the 0 – 5 m surface layer at Trilleachan Mor. The model will output results every 20 minutes (rather than hourly) and concentrations from these simulations will be calculated on a finer (10m x 10m) grid to that used in the 72-hour model runs; this is done to more accurately calculate the smaller areas of medicine over the initial 3 – 6 hour period. Time series over spring and neap tides of the area where the 3-hour EQS of 250 ng L^{-1} for azamethiphos and the 6-hour EQS of 6 ng L^{-1} for deltamethrin are exceeded and the peak concentration for each individual pen treatment will be shown.

7. DATA REQUIREMENTS FOR SIMULATIONS

7.1 Bathymetry Data

Bathymetry was taken from the Marine Scotland East Coast of Lewis and Harris (ECLH) model, which has reasonably high spatial resolution around Loch Seaforth, and supplemented by a local depth survey around the Seaforth and Noster sites (Figure 5). The combined data were interpolated onto the Seaforth model mesh. The combined data capture the deep channel to the northeast of the Seaforth and Noster pen groups

7.2 Hydrographic Data

Current data collected at the farm sites are used to characterise the local flow field. This information is essential for assessing the impact from fish farm discharges. In particular, current data are used in the modelling of dispersion of dissolved and solid substances. One of the current meter deployments that will be used in the modelling for this site used a Teledyne RDI Sentinel V100 Acoustic Doppler Current Profiler, which Mowi Scotland now use as standard in most deployments. These instruments are deployed in mooring frames with 20º free gimbal movement that automatically levels the instrument when deployed on the seabed.

Meters were set up to meet the requirements outlined in the SEPA guidance (SEPA, 2019, 2023) as far as possible whilst also ensuring that data quality was not compromised. Data will be processed in the usual fashion to the level of the SEPA HG-analysis spreadsheet. The individual HG-analysis files will be reported to SEPA with the CAR application.

For Trilleachan Mor, additional near-surface current measurements were made using a Nortek Signature 1000 ADCP (Nortek, 2023). This high-frequency (1 MHz) instrument can be deployed at mid-water depths, allowing measurement of current speed and direction much closer to the water surface than is possible with traditional ADCP measurements. In this way, current speeds appropriate to bath medicine dispersion in the top 5 m of the water column were measured. The instrument was deployed at about 15 m depth below mean sea level. Data quality control and post-processing was carried out using usual routines for ADCP data. However, the traditional post-processing routines still lead to a loss of near-surface data, since the topmost cell that can be used is determined by sidelobe reflections at low tide; the topmost valid cells are still ~4 m below mean sea level. Therefore, additional processing will be performed to extract current data from a fixed depth relative to the moving sea surface (surface tracking). Previous instrument diagnostic data demonstrated that cells -2.5 m below the moving sea surface were valid, and these will be selected and compiled into a near-surface time series. Details of the quality control and processing will be described in the hydrographic report for the deployment (ID440).

7.3 Dye and Drogue Data

A dye release study was conducted in Loch Seaforth, near the Seaforth and Noster sites, on 25th and 28th February 2018 by Anderson Marine Surveys Ltd. Seven separate releases of dye were made, and horizontal dispersion coefficients estimated for each release using standard methods. A mean horizontal diffusivity for the location of $K_H = 0.05$ m^2 s^{-1} was derived. This value will be used as part of the sensitivity testing of the model predictions.

Drogue releases were carried out simultaneously with the dye releases, using standard-pattern drogues with reduced sail depth (≈1m, due to relatively shallow water depths), fitted with GlobalSat GPS dataloggers recording at 2min intervals.

The data from both dye and drogue releases have been provided to SEPA previously but can be supplied again if required.

8. MODEL OUTPUTS

8.1 Model Calibration and Validation

Model calibration will be carried out for the hydrodynamic model. Field current meter data will be compared to model values. The model will be run in a hindcasting mode, over the same time period as the meter data was collected. Once a parameter set is selected via the calibration process, independent validation simulations, using exactly the same parameter set, will be performed against a separate current meter dataset and quantitative assessment of model performance undertaken. The calibration and validation procedure, and performance of the model, will be submitted to SEPA in a report with the application.

8.2 Model Results

Model results will be provided to SEPA in the form of selected (due to large file sizes) raw output files (calibration, validation and bath medicine baseline runs only). Plots of results for all simulations will be provided and time series data files of key model results (e.g. predictions of bath medicine peak concentration and area exceeding the EQS) will be provided for all runs. The results from all model runs will be written up in the submitted application report.

8.3 Quality Assurance

Quality assurance information is not available for the hydrodynamic modelling package; however, the model is in regular use in the academic modelling community, is regularly published and cited in the peer-reviewed scientific literature, and is being actively used and developed. The particle tracking model has also been thoroughly tested against standard model tests, and published in the peer-reviewed literature.

9. REFERENCES

Aleynik, D., Dale, A. C., Porter, M., and Davidson, K., 2016. A high resolution hydrodynamic model system suitable for novel harmful algal bloom modelling in areas of complex coastline and topography. Harmful Algae 53, 102–117. doi:10.1016/j.hal.2015.11.012

Allen, C.M., 1982. Numerical simulation of contaminant dispersion in estuary flows. Proc. Royal. Soc. London (A), 381, 179–194.

AMSL, 2020. MOWI Dispersion Measurements – Lewis and Harris July 2020. August 2020, 9 pp.

Burchard, H., 2002. Applied turbulence modeling in marine waters. Springer:Berlin-Heidelberg-New York-Barcelona-Hong Kong-London-Milan Paris-Tokyo, 215pp.

Chen, C., H. Liu, and R.C. Beardsley, 2003. An unstructured, finite-volume, three-dimensional, primitive equation ocean model: Application to coastal ocean and estuaries. J. Atmos. Ocean. Tech., 20, 159 – 186.

ECMWF, 2021. ERA5 dataset, European Centre for Medium-Range Weather Forecasts. Available at: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5

Gillibrand, P.A., 2022. UnPTRACK: A multi-purpose particle tracking model for unstructured grids, User Guide. Mowi Scotland Ltd., June 2022, 33pp. https://github.com/gillibrandpa/UnPTRACK

Gillibrand, P.A., Gubbins, M.J., Greathead, C. and Davies, I.M., 2002. Scottish Executive locational guidelines for fish farming: predicted levels of nutrient enhancement and benthic impact. Scottish Fisheries Research Report Number 63/2002, Fisheries Research Services, Marine Laboratory, Aberdeen. 52 pp.

Gillibrand, P.A., B. Siemering, P.I. Miller and K. Davidson, 2016b. Individual-Based Modelling of the Development and Transport of a *Karenia mikimotoi* Bloom on the North-West European Continental Shelf. Harmful Algae, DOI: 10.1016/j.hal.2015.11.011

Gillibrand, P.A. and Turrell, W.R., 1997. The use of simple models in the regulation of the impact of fish farms on water quality in Scottish sea lochs. Aquaculture, 159, 33 – 46.

Gillibrand, P.A., Walters, R.A., and McIlvenny, J., 2016a. Numerical simulations of the effects of a tidal turbine array on near-bed velocity and local bed shear stress. *Energies*, vol 9, no. 10, pp. 852. DOI: 10.3390/en9100852

Gillibrand, P.A. and K.J. Willis, 2007. Dispersal of Sea Lice Larvae from Salmon Farms: A Model Study of the Influence of Environmental Conditions and Larval Behaviour. Aquatic Biology, 1, 73-75.

Hunter J.R., Craig, P.D., Phillips, H.E., 1993. On the use of random walk models with spatially variable diffusivity. J Comput. Phys., 106:366–376

Large. W.G. and Pond, S., 1981. Open ocean momentum flux measurements in moderate to strong winds. J. Phys. Oceanogr., 11, 324—336.

Marine Scotland 2016. The Scottish Shelf Model. Marine Scotland. http://marine.gov.scot/themes/scottish-shelf-model

Nortek, 2023. Signature-1000 https://www.nortekgroup.com/products/signature-1000

Pawlowicz, R.; Beardsley, B.; Lentz, S., 2002. Classical tidal harmonic analysis including error estimates in MATLAB using T_TIDE. Computers & Geosciences, 28, 929-937.

Pearson, T., & Black, K., 2001. The environmental impact of marine fish cage culture. In: Environmental Impacts of Aquaculture (ed. Black, K.D.). Sheffield Academic Press, pp. 1 – 31.

Proctor, R., R.A. Flather and A.J. Elliott, 1994. Modelling tides and surface drift in the Arabian Gulf---application to the Gulf oil spill. Continental Shelf Research, 14, 531-545.

Ross, O.N., Sharples, J., 2004. Recipe for 1-D Lagrangian particle tracking models in space-varying diffusivity. Limnology and Oceanography: Methods, 2, 289-302.

Scottish Association of Marine Science (SAMS), 2021, NewDepomod https://www.sams.ac.uk/science/projects/depomod/

SEPA, 2019. Aquaculture Modelling. Regulatory modelling guidance for the aquaculture sector. Scottish Environment Protection Agency, Air & Marine Modelling Unit, July 2019, 68pp.

SEPA 2023. Interim Marine Modelling Guidance for Aquaculture Applications. Scottish Environment Protection Agency, December 2023, 11 pp.

SEPA, 2024. Aquaculture Modelling Screening & Risk Identification Report: Trilleachan Mor (TRM1). Scottish Environment Protection Agency, April 2024, 31 pp.

Visser, A.W., 1997. Using random walk models to simulate the vertical distribution of particles in a turbulent water column. Mar. Ecol. Prog. Ser., 158, 275-281.

Walters, R.A.; Casulli, V., 1998. A robust, finite element model for hydrostatic surface water flows. Comm. Num. Methods Eng., 14, 931–940.

Willis, K.J, Gillibrand, P.A., Cromey, C.J. and Black, K.D., 2005. Sea lice treatments on salmon farms have no adverse effect on zooplankton communities: A case study. *Marine Pollution Bulletin*, 50, 806 – 816.