Hydrodynamic and Waste Dispersion Modelling at Stulaigh South Fish Farm Site

METHOD STATEMENT

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1 INTRODUCTION

This method statement presents the specifications and rationale for the use of computer modelling to predict potential environmental effects of a proposed Mowi Scotland fish farm site at **Stulaigh South**. The models to be used include:

(i) the particle tracking model, NewDepomod, to simulate the discharge of waste feed and faeces;
(ii) a hydrodynamic (HD) model coupled with the 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 Stulaigh South in order to apply for a cage farm site that meets regulatory requirements, is in balance with the surrounding marine environment, and which is compliant with SEPA's seabed 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;
- NewDepomod; SEPA standard default approach;
- Data collection, principally depth surveys, current data collection and benthic monitoring.

2 SITE PROPOSAL

The proposed site layout at Stulaigh South consists of six circular pens of 200m circumference (Figure 1 and Figure 2) with a maximum biomass of 3000 T. The pens are in a 2 x 3 formation, held in a 120 m grid with 16 m deep nets.

Table 1. Details of the proposed development at Stulaigh South

SITE DETAILS	
Site Name:	Stulaigh South
Site location:	Stulaigh Island South
Peak biomass (T):	3,000
Proposed feed load (T/yr):	7,665
Proposed treatment use:	Azamethiphos, Deltamethrin, Emamectin Benzoate
CAGE DETAILS	
Group location:	83345 E 822185 N
Number of cages:	6
Cage dimensions:	200m circumference
Grid matrix (m)	120
Working Depth (m):	16
Cage group configuration:	2 x 3
Cage group distance to shore (km):	0.30

Figure 1. Stulaigh South site location (●) adjacent to Stulaigh Island and South Uist.

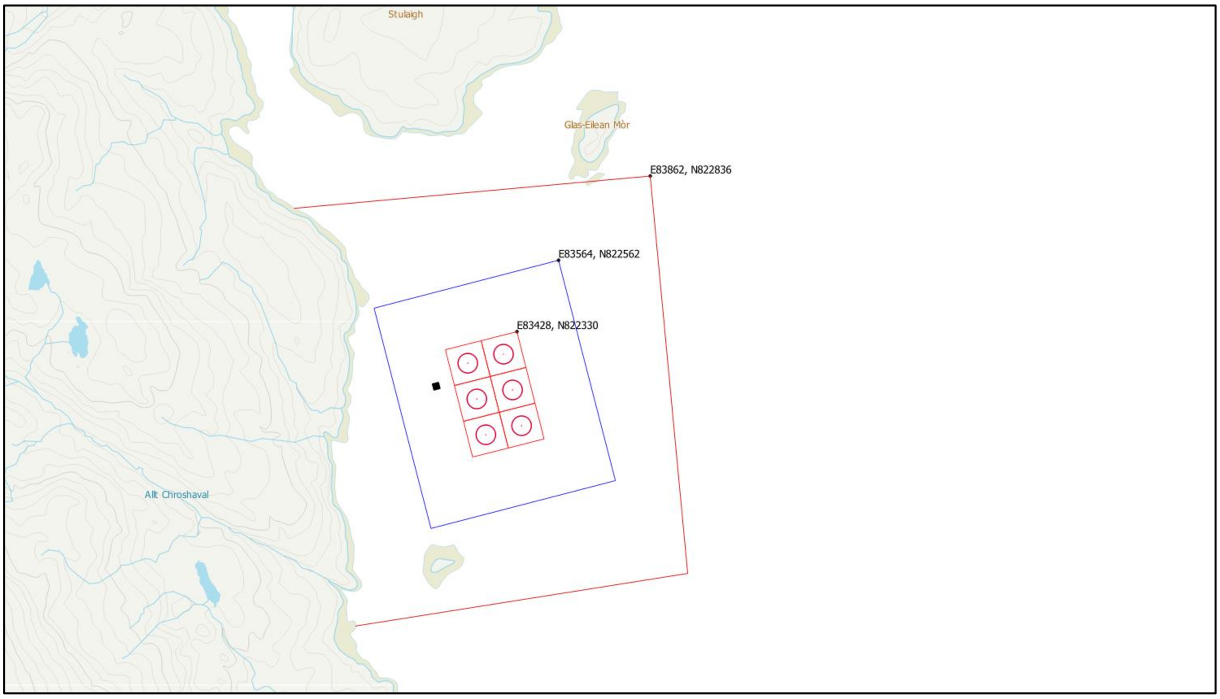


Figure 2. The proposed 6 x 200m cages (O) at Stulaigh South. The planning screening-scoping (—) and moorings (—) areas are indicated.

3 SCOPE OF MODELLING - KEY ISSUES TO BE ADDRESSED

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

Three models will be described in this statement: the hydrodynamic (HD) model, a particle-tracking model, UnPTRACK, used to simulate the dispersion of bath medicines and cumulative solids deposition, and the NewDepomod particle tracking model used to simulate the discharge of waste feed and faeces. 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.

The NewDepomod model will be run under the SEPA standard default approach (SEPA 2019, 2022a)

Outputs from both the particle tracking 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.

<u>Organic Wastes</u>

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.

Medicine Residues

Medicinal sea lice treatments may be carried out in one of two ways at Stulaigh South:

- 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 outside the mixing zone.

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

Dissolved Nutrients

The waters around Stulaigh Island located in the Sea of the Hebrides is not within a Locational Guidelines categorised water body. However, appropriate Equilibrium Concentration Enhancement (ECE) modelling (Gillibrand and Turrell, 1997; Gillibrand et al., 2002) using an adopted ‘open water’ approach has been undertaken to show the degree of nutrient enhancement likely to result from the proposed changes to the site at Stulaigh South. The region of South Uist was given a high status for dissolved inorganic nitrogen. Based on the very low sensitivity of the water column as a receptor, the overall significance of the impact is assessed as negligible (not significant).

3.2 Site Specific Environmental Considerations

The following risks were identified by the Aquaculture Modelling Screening & Risk Identification Report: Stulaigh South (STIS1) prepared by SEPA (2022b):

- Maerl Beds, PMF species, at risk from sediment influence (Figure 3).
- Northern Sea fan and Sponge Communities, PMF species, at a number of locations, at risk from sediment influence.

A key part of any application to SEPA and for the parallel planning consent to the local authority will be to demonstrate to all stakeholders via appropriate predictive modelling and operational mitigation that the discharges from the site will not pose significant adverse effects on the integrity of the adjacent environmental designations. There are no other locally known sensitive features in direct proximity of the site. Modelling will include potential interacting discharges from the site at Stulaigh (STI1, Figure 3) to the north.

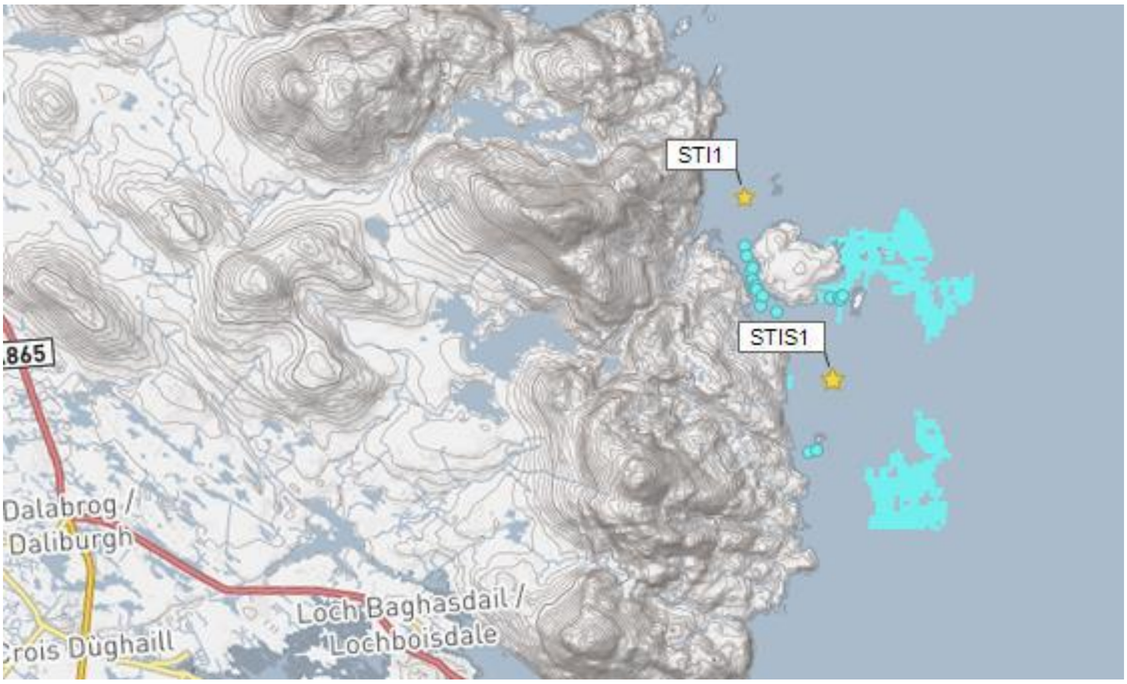


Figure 3. Identified Maerl bed features around the proposed site (SEPA, 2022b).

3.3 Site Environmental Performance

The proposed site is a new site, and hence there is no prior environmental performance to 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. 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 ρ = 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 κ=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:

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

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_S 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 4. The model resolution was enhanced in the area around the Mowi site at Stulaigh South (Figure 5). The spatial resolution of the model varied from 25m in some inshore waters and round the farm pens to 20km along the open boundary. The model consisted of 7,310 nodes and 13,699 triangular elements. The model will be run in 3D mode.

Model bathymetry was taken from the European Marine Observation and Data Network (EMODnet, https://www.emodnet-bathymetry.eu/), supplemented by a multibeam survey undertaken in June 2021 (Figure 6).

The model was 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 were 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 was, in turn, 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).

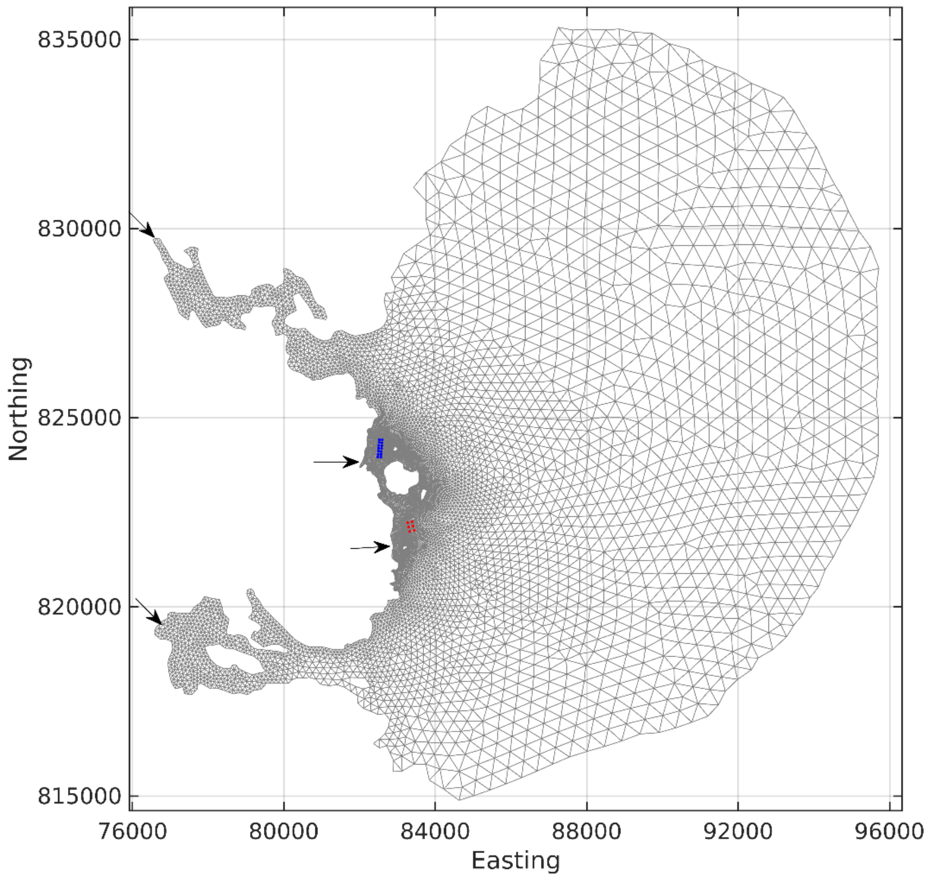


Figure 4. The model mesh and domain for the Stulaigh South modelling study. The proposed cage locations (●) and the existing pens at Stulaigh (●) are indicated, as are locations of freshwater discharge (→).

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 was run in 3D baroclinic mode. Ten layers in the vertical (eleven sigma levels) were used in the simulations, evenly distributed through the water column. River flow data from the nearest gauged river, Abhainn Roag at Mill Croft (station 106003 on the Centre for Ecology and Hydrology National River Flow Archive, https://nrfa.ceh.ac.uk/) was appropriately weighted by relative catchment area for four discharge locations into the model domain (Figure 4).

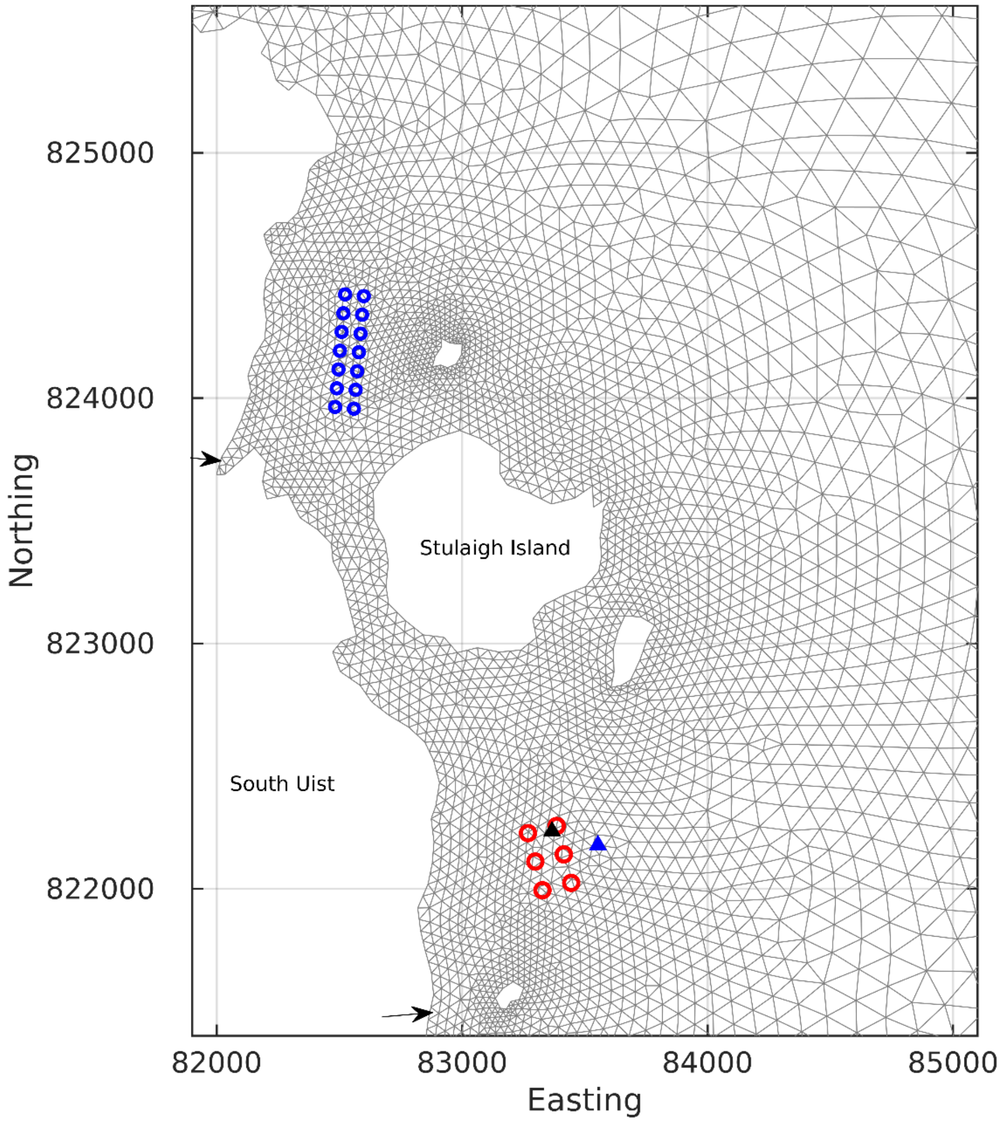
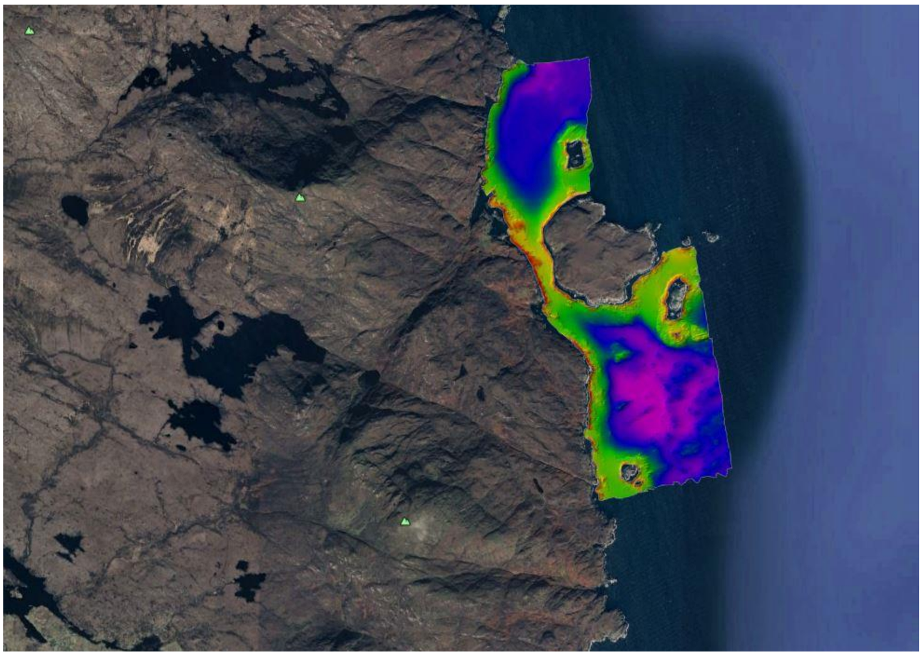


Figure 5. The unstructured mesh around the Stulaigh South site in the modified model grid, with the proposed cage locations indicated (○). The existing pens at Stulaigh (○) and the ADCP deployment locations ID208 (▲) and ID224 (▲) are indicated, as are locations of freshwater discharge (→).



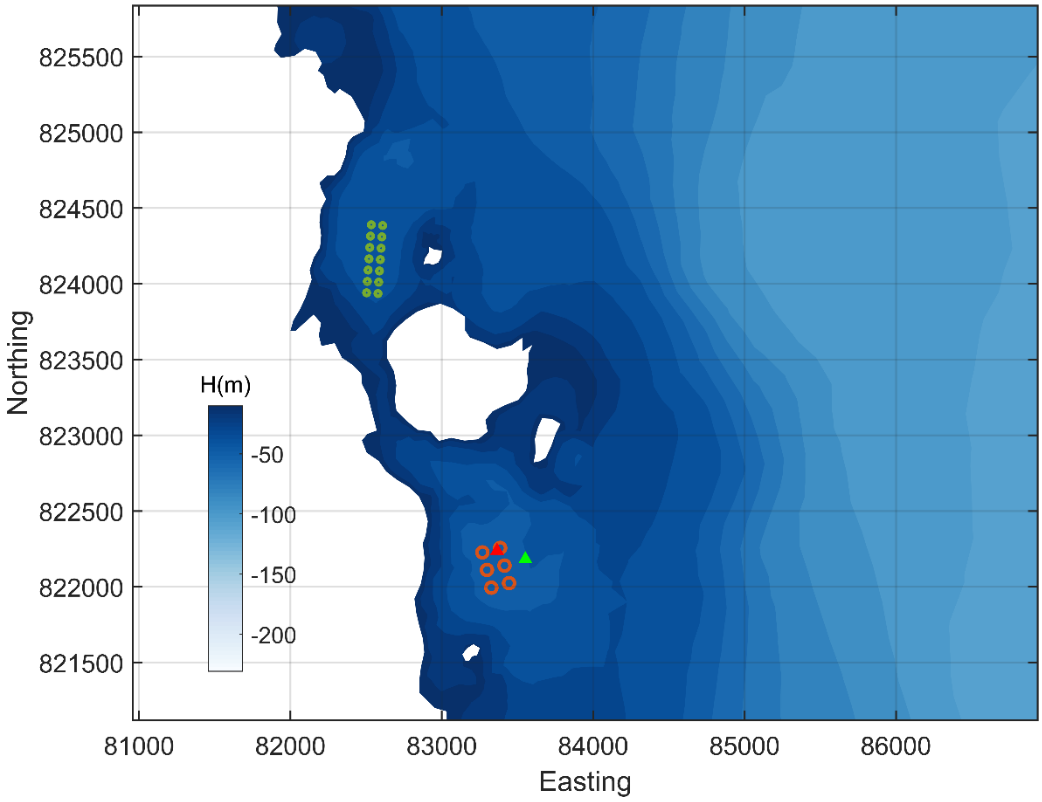


Figure 6. Multibeam survey of bathymetry around Stulaigh Island (top) from June 2021. Model water depths (m) in the area around the proposed salmon farm (bottom), incorporating the multibeam data. The proposed cage locations indicated (○). The existing pens at Stulaigh (○) and the ADCP deployment locations ID208 (▲) and ID224 (▲) are indicated.

4.2 Model Calibration

The hydrodynamic model will be calibrated against current data and seabed pressure data, measured in the Stulaigh South area using Acoustic Doppler Current Profilers (ADCP, Figure 6). Data are available from:

(i) Calibration: 08 March – 17 April 2018 (ID208)
(ii) Validation: 22 May – 14 August 2018 (ID224)

In total, the data extend over 123 days. The model will be run in 3D, and calibration will be performed by adjusting the bed roughness length scale, z_0, 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 dataset.

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, 2021), 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:

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

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):

$$\delta_H = R[6.K_H.\Delta t]^{1/2}$$
$$\delta_Z = R[6.K_Z.\Delta t]^{1/2} \quad (2)$$

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 at the nearby site Stulaigh by Anderson Marine Services Ltd. In April 2017. The dye study gave a mean horizontal diffusivity of 0.179 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:

$$M_P = M_0 e^{\gamma t_p} \quad (3)$$

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.

For deposition modelling, UnPTRACK contains a bed model in which up to 10 sediment layers can be defined and which allow consolidation and erosion of deposited waste material.

The model has tested for accuracy in simulating advection, diffusion and chemical decay (Gillibrand, 2021). 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 (2021).

6. DEPOSITION SIMULATIONS

Two sets of simulations will be performed with regards to depositional modelling at Stulaigh South. The first set focussing on localised deposition beneath the proposed pens utilising the NewDepomod model, configured in the default parameter values specified by SEPA and using the measured flow data to force the model. The second set investigating the cumulative deposition arising from the site at Stulaigh South together with that from neighbouring Stulaigh farm. For this set, flow fields from the hydrodynamic model, FVCOM, will be used to force the particle tracking model UnPTRACK.

6.1 Local Deposition: NewDepomod

NewDepomod is a bespoke modelling software designed to simulate the dispersion of particulate wastes from salmon farms. The model (SAMS, 2021) has been developed by the Scottish Association for Marine Science (SAMS) and is supplied under licence. The version used for the modelling described here will be v1.4.0-final-(SEPA edition) or a more recent version.

The model will be configured exactly as specified by SEPA in the modelling guidance published in July 2019 (SEPA, 2019) and updated in January 2022 (SEPA, 2022a). The site will be modelled for a maximum biomass of 3000 tonnes using a feed load of 7 kg/tonne/day. This configuration of the model produces a conservative estimate of the benthic footprint, with a deposition rate of 250 g m^{-2} equating to approximately an Infaunal Quality Index (IQI) of 0.64 (the boundary between moderate and good status). Work by SEPA has shown that footprints predicted by this "standard default" configuration broadly match the footprint area derived from seabed samples, although there is a great deal of variability from site to site.

A regular model grid will be prepared. The grid will cover a 3km x 3km area, with a 25m grid spacing in both directions. The grid size will be 120 x 120 cells. Flat bathymetry will be used with a water depth of 42.1 m. The flowmetry file combined the data from both of the deployments; after merging the length of the combined record will be at least 90 days in total.

Following the standard default approach, NewDepomod will be used to simulate one year of deposition at the maximum farm biomass. Results will be analysed over the final 90 days of the simulation, with the mean deposition rate across the model domain being calculated and the footprint area being delimited by the 250 g m^{-2} contour (SEPA, 2019). As Stulaigh South is sited in a high wave exposure location (wave exposure index = 3.5), the deposition limit at pen edge will be set at 4,000 g m^{-2} yr^{-1}.

6.2 Cumulative Deposition: Particle Tracking Model, UnPTRACK

The cumulative deposition modelling approach utilises a coupled hydrodynamic and particle tracking method, whereby water currents in the region, modelled using the calibrated hydrodynamic model described in Section 4, advect particles representing waste solids around the model domain. Deposition from the existing Stulaigh site will be modelled as well as deposition from the proposed site at Stulaigh South (Table 2). Parameter settings for deposition modelling using UnPTRACK will be similar to those in the SEPA standard default approach for NewDepomod. Deposition will then modelled for 365 days, and the mean deposition over the final 90 days calculated. Deposition footprints will be discussed relative to the PMF features highlighted in §3.2.

Table 2. Sites to be included in the cumulative depositional modelling

Site Name	Location	Operator	Biomass (T)	Status
STIS1	Stulaigh South	Mowi	3000*	Proposed
STI1	Stulaigh	Mowi	2850	Active

*maximum proposed value

7. IN-FEED MEDICINE DISPERSION MODELLING

Simulations for emamectin benzoate will follow the SEPA standard default methodology (SEPA, 2019, 2022a) to ascertain a mass of emamectin that can be discharged and meet the current sedimentary EQS (131 ng kg^{-1} dry weight). NewDepomod will be used to simulate the dispersion of emamectin over 118 days. Results will be analysed over the final 2 days of the simulation (Days 116 – 118), with the mean deposited concentration across the model domain being calculated and the footprint area being delimited by the EQS contour converted to a wet weight equivalent (65.5 ng kg^{-1}).

8. BATH TREATMENT DISPERSION MODELLING

8.1 24-hour EQS

Modelling of bath treatments will be undertaken using a particle tracking model, UnPTRACK (Gillibrand, 2021), 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 7 – 8 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 5m will be chosen initially as a realistic depth during application of the medicine for 200 m circumference pens. The initial mass released per pen is calculated from the reduced pen volume and a treatment concentration of 120 µg/L, with a total mass of 9.55 kg of azamethiphos released during treatment of the whole farm (6 pens). The higher concentration than the recommended treatment dose allows for discretionary over-treatment by fish health specialists. 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. 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 same depth range as the treatment is applied (i.e. 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 decay rate (half-life) of azamethiphos;
(ii) The horizontal diffusion coefficient;
(iii) The vertical diffusion coefficient;
(iv) 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.

8.2 Short-term EQS

The UnPTRACK model will also be used to assess the 3-hour EQS for azamthiphos and the 6-hour EQS for deltamethrin. The 3-hour and 6-hour mixing zones will be taken from the BathAuto excel spreadsheet using a mean surface speed of 9.50 cm s^{-1} from ID208, which is thought to be representative of the 0-5m surface layer at Stulaigh South. The model will output every 20 minutes (rather than hourly) and concentrations from these simulations will be calculated on a smaller (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.

9. DATA REQUIREMENTS FOR SIMULATIONS

9.1 Bathymetry Data

Bathymetry from the EMODnet dataset (https://emodnet.ec.europa.eu/en/bathymetry) will be used in the modelling, combined with water depths obtained from a multibeam bathymetric survey of the area adjacent to the proposed site. The EMODnet digital terrain dataset consists of (EMODnet, 2022): (i) bathymetric surveys, such as single and multibeam surveys, echosoundings and even historic leadline soundings. These data sets are most preferred as data sources because of their high resolution; (ii) composite data sets, which includes a set of surveys merged and gridded altogether; (iii) the worldwide GEBCO Digital Bathymetric grid used to fill gaps between the above two datasets.

The local multibeam survey was conducted in June 2021.

9.2 Hydrographic Data

Current data collected at the farm site 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. All 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 all 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) as far as possible whilst also ensuring that data quality was not compromised. ID208 and ID224 will be carefully stitched together, taking into account the tide and state of the spring-neap cycle to form a 90+ day long record, to be used within NewDepomod for the local solids depositional modelling. 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.

Details on the stitching together of multiple current meter records to provide a flowmetry file for NewDepomod will be provided. Detailed information on the stitching process will be provided prior to the application.

10. MODEL OUTPUTS

10.1 Model Calibration

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. A comparative performance of ≤ 10% variation for 90% of the combinations evaluated is desired but represents a high bar in these environments. Calibration of the NewDepomod model will not take place since the “standard default” approach will be used.

10.2 Validation of Model

On completion of the necessary calibration the HD model will be run with an independent dataset without further change to the internal parameters.

10.3 Model Results

Model results will be provided to SEPA in the form of selected (due to large file sizes) raw output files (calibration, validation, NewDepomod 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.

10.4 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. There is an unknown element of quality assurance within the NewDepomod package. The software is under continued development by the Scottish Association for Marine Science (SAMS) in collaboration with industry and SEPA end users. All outputs from the NewDepomod runs will be sense checked by experienced Depomod operators and any unexpected outputs and discrepancies will be raised with SAMS.

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