Hydrodynamic and Waste Dispersion Modelling at Isle of Rum Fish Farm Site

METHOD STATEMENT

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1 INTRODUCTION

This method statement presents the specifications and rationale for use of a hydrodynamic (HD) model coupled with the particle-tracking model, unptrack, to simulate the discharge, dispersion and fate of residues of bath medicines, along with a description and explanation for using the SEPA standard default approach of the bespoke particle tracking model NewDepomod to simulate the discharge of waste feed and faeces at a Mowi Scotland fish farm site at **Rum**. 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 Rum 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 current site layout at Rum consists of twelve circular pens of 120m circumference (Figure 1 and Figure 2) and has a consented maximum biomass of 2500 T. The pens are in a 2x(2x3) formation, held in a 75 m grid with 16 m deep nets. The current proposal (Table 1) is to decrease the number of cages to 8, each of 160 m circumference in a 100 m grid (Figure 2). An increase to the maximum standing biomass, up to 3500 T, will also be applied for.

Table 1. Details of the proposed development at Rum

SITE DETAILS	
Site Name:	Rum
Site location:	Isle of Rum
Peak biomass (T):	3,500
Proposed feed load (T/yr):	8,942.5
Proposed treatment use:	Azamethiphos
CAGE DETAILS	
Group location:	NG411029
Number of cages:	8
Cage dimensions:	160m circumference
Grid matrix (m)	100
Working Depth (m):	15
Cage group configuration:	2 x 4
Cage group distance to shore (km):	0.37

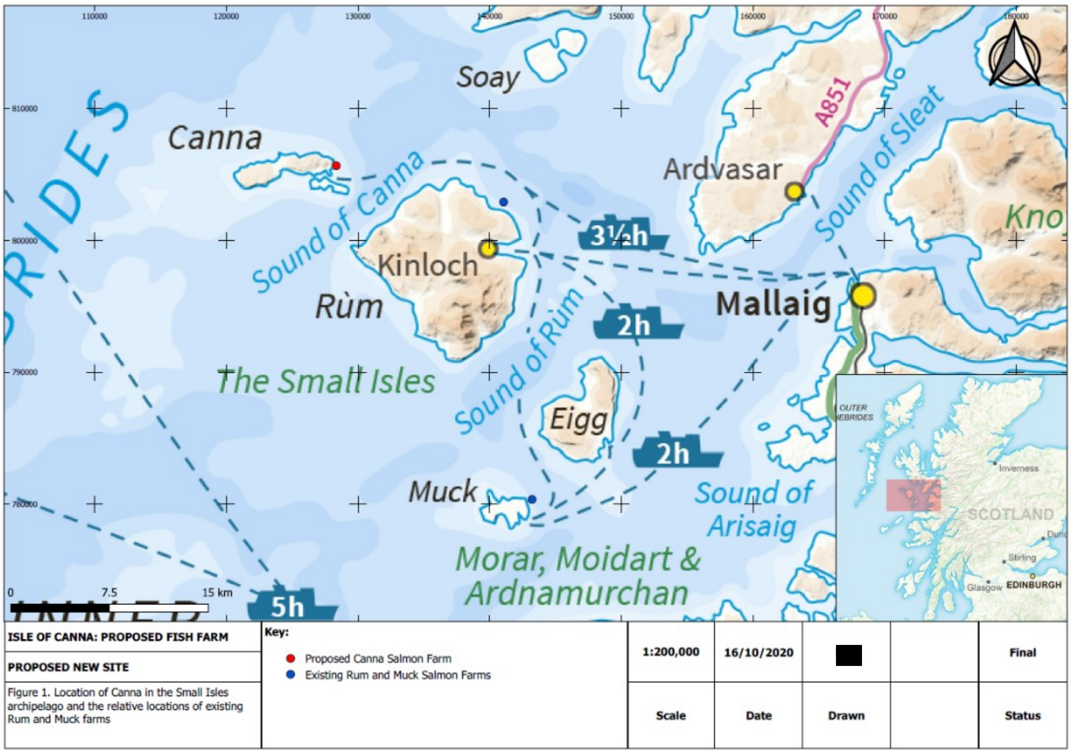

Figure 1. Site location, Isle of Rum, also including the Isle of Muck and proposed Canna salmon farms.

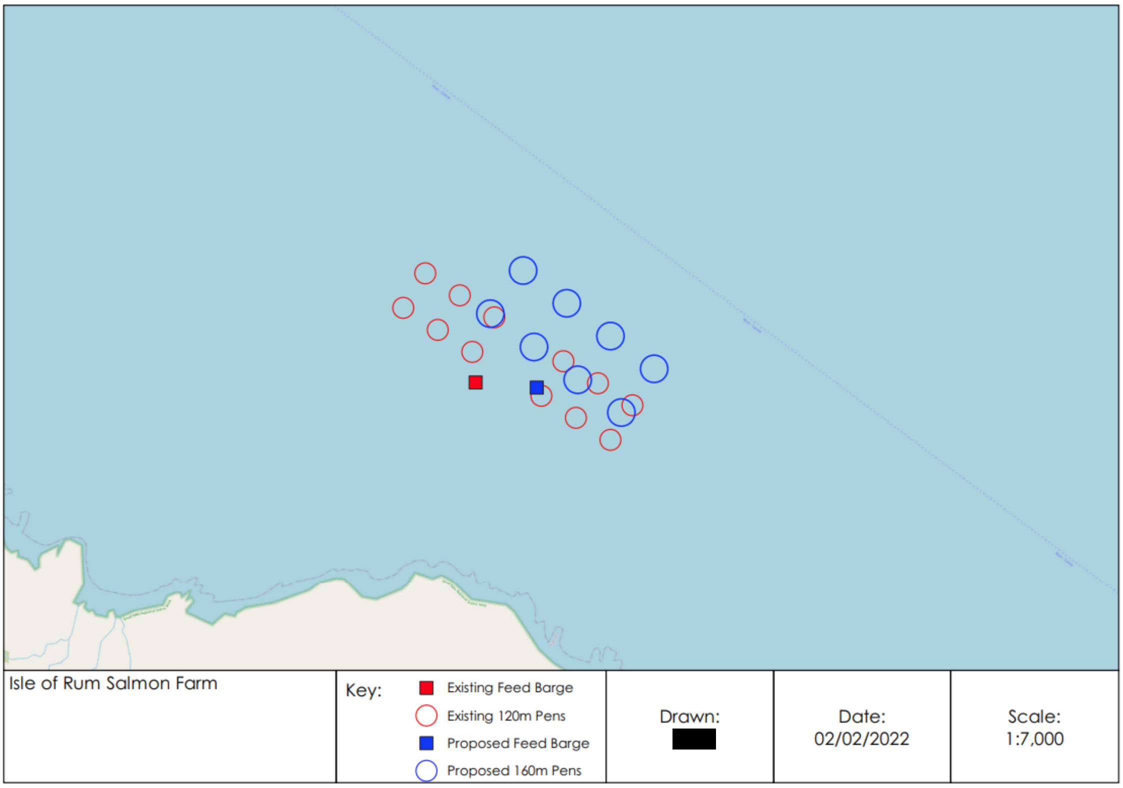

Figure 2. The proposed 8 x 160m cages (blue) over the existing 12 x 120m pen layout (red).

3 SCOPE OF MODELLING - KEY ISSUES TO BE ADDRESSED

The proposed modelling is designed to simulate the release, dispersion and fate of waste particles from the pens to the immediate area beneath and around the pens, and also to determine their 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. When the HD and unptrack models have been calibrated and undergone validation runs, they will be used in a sequential manner. 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 small isles domain.

The NewDepomod model will be run under the SEPA standard default approach (SEPA 2019).

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 are carried out in one of two ways at Rum:

- 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.

Dissolved Nutrients

The waters around Rum located in the Southern Skye water body 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 Rum. The region of Southern Skye 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).

Cumulative impacts between the Rum, Muck and Canna sites were also assessed due to the proximity of the farms (Figure 1). Rum and Muck are the only finfish farms in operation within the Small isles at the time of writing, although proposals for a biomass increase is being considered at Muck with the development of a potential new site at Canna, the ECE calculation has therefore been done using the current proposals for biomass at all three sites. The large areas of well-flushed sea between the farms decrease the likelihood of significant adverse cumulative impacts generated from the sites in combination. Based on the very low sensitivity of the water column as a receptor, the overall significance of the impacts from the cumulative impact is, again, assessed as negligible (not significant).

3.2 Site Specific Environmental Considerations

The following risks were identified by the Aquaculture Modelling Screening & Risk Identification Report: Rum (RUM1) prepared by SEPA (2020):

- Tall Sea Pan, PMF Species, North-east of the Isle of Rum, at risk from sediment influence
- Burrowed Mud, PMF Habitat, North-east of the Isle of Rum, at risk from sediment and medicine 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 nor are there any interacting discharges in the vicinity.

3.3 Site Environmental Performance

The most recent seabed compliance survey was carried out in December 2021 and has been sent to our consultant laboratory for analysis. Once received this will be reported to SEPA for classification.

Previous compliance seabed surveys were carried out in July 2019 at 96.5% of peak biomass and April 2020 at 35% of peak biomass both of which have been fully analysed and submitted to SEPA for classification. To date SEPA have not formally responded however both of these surveys meet pen edge and mixing zone environmental standards.

4 HYDRODYNAMIC MODEL DESCRIPTION AND CONFIGURATION

The hydrodynamic model used in this study will be RiCOM (River and Coastal Ocean Model), a general-purpose hydrodynamics and transport model, which solves the standard Reynolds-averaged Navier-Stokes equation (RANS) and the incompressibility condition, applying the hydrostatic and Boussinesq approximations. It has been tested on a variety of benchmarks against both analytical and experimental data sets (e.g. Walters & Casulli 1998; Walters 2005a, b). The model has been previously used to investigate the inundation risk from tsunamis and storm surge on the New Zealand coastline (Walters 2005a; Gillibrand et al. 2011; Lane et al. 2011), to study tidal currents in high energy tidal environments (Walters et al. 2010) and, more recently, to study tidal energy resource (Plew & Stevens 2013; Walters et al. 2013; Walters 2016) and the effects of energy extraction on the ambient environment (McIlvenny et al. 2016; Gillibrand et al. 2016a).

The basic equations considered here are the three-dimensional (3D) shallow water equations, derived from the Reynolds-averaged Navier-Stokes equations by using the hydrostatic assumption and the Boussinesq approximation. The continuity equation for incompressible flows is:

$$\nabla \cdot \mathbf{u} + \frac{\partial w}{\partial z} = 0 \tag{1}$$

where $\mathbf{u}(x,y,z,t)$ is the horizontal velocity vector, $w(x,y,z,t)$ is the vertical velocity, ∇ is the horizontal gradient operator, and z is the vertical coordinate. The momentum equation in non-conservative form is given by [25]:

$$\frac{D\mathbf{u}}{Dt} + f\hat{\mathbf{z}} \times \mathbf{u} + g\nabla\eta - \frac{\partial}{\partial z}\left(A_V \frac{\partial \mathbf{u}}{\partial z}\right) - \nabla \cdot \left(A_h \nabla \mathbf{u}\right) + \mathbf{F} = 0 \tag{2}$$

where t is time; $f(x,y)$ is the Coriolis parameter; $\hat{z}$ is the upward unit vector; $\eta(x,y,t)$ is the sea surface displacement relative to mean sea level; g is the gravitational acceleration; $A_V(x,y,z,t)$ and $A_h(x,y,z,t)$ are the vertical and horizontal eddy viscosities respectively; **F** represents body forces including form drag from obstacles in the flow; and x, y are the horizontal coordinates aligned to the east and north respectively.

The free surface equation is formed by vertically integrating the continuity equation and applying the kinematic free surface and bottom boundary conditions:

$$\frac{\partial \eta}{\partial t} = \nabla \cdot \left(\int_h^\eta \mathbf{u} dz \right) = 0 \tag{3}$$

where h is the water depth relative to the mean level of the sea.

Wind speed and direction (velocity) is applied as a surface stress,

$$\tau_S = \rho_a C_W \boldsymbol{W}|\boldsymbol{W}| \tag{4}$$

where ρ_a is the density of air and W is the wind velocity. The surface drag coefficient, C_W, can be calculated using a variety of formulations (e.g. Wu, 1982; Large & Pond, 1981) and the version used will be described in the modelling report.

At the seabed, the frictional stress, $\boldsymbol{\tau}_b$, is calculated using a quadratic equation where:

$$\tau_b = \rho C_D \boldsymbol{U}|\boldsymbol{U}| \tag{5}$$

where ρ = 1025 kg m^{-3} is the water density, **U** is the velocity in the layer closest to the seabed, and C_D is the drag coefficient. The value of C_D was varied during calibration to provide the best fit to observations of sea level and velocity.

The equations are discretized on an unstructured grid of triangular elements which permits greater resolution of complex coastlines. The momentum and free surface equations are solved using semi-implicit techniques to optimize solution time and avoid the CFL stability constraint (Walters 2016). The material derivative in (2) is discretized using semi-Lagrangian methods to remove stability constraints on advection (Casulli, 1987; Walters et al. 2008). The Coriolis term is solved using a 3rd order Adams-Bashforth method (Walters et al. 2009). Full details of the model discretization and solution methods can be found in Walters et al. (2013) and Walters (2016). The solution methods provide a fast, accurate and robust code that runs efficiently on multi-core desktop workstations with shared memory using OpenMP.

4.1 Model Configuration

The unstructured mesh used in the modelling (Figure 3) was adapted from the mesh used by Gillibrand et al (2016a). This domain was chosen in order that the open boundary be further away from the site of interest than is the case with the Marine Scotland ECLH and WLLS domains. Model resolution was enhanced in the Small Isles region, particularly around the Mowi site at Rum (Figure 4). 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 119,925 nodes and 231,016 triangular elements. The model will be run in 2D mode.

Model bathymetry was taken from the European Marine Observation and Data Network (EMODnet, 2021).

The model was forced at the outer boundaries by eight tidal constituents (O_1, K_1, P_1, Q_1, M_2, S_2, N_2, K_2) which were taken from the Oregon State University global tide model (Egbert & Erofeeva 2002). Spatially- and temporally-varying wind speed and direction data are taken from the ERA5 global reanalysis dataset (ECMWF, 2021) for the required simulation periods.

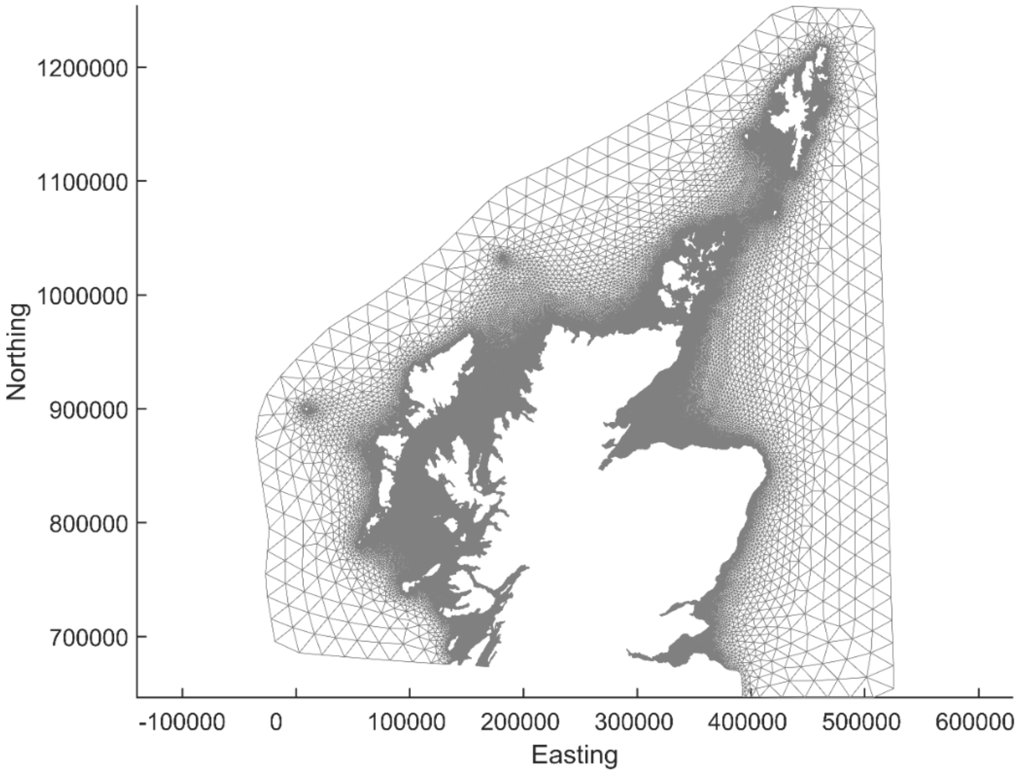

Figure 3. The mesh and domain of the modelling study, adapted from Gillibrand et al. (2016)

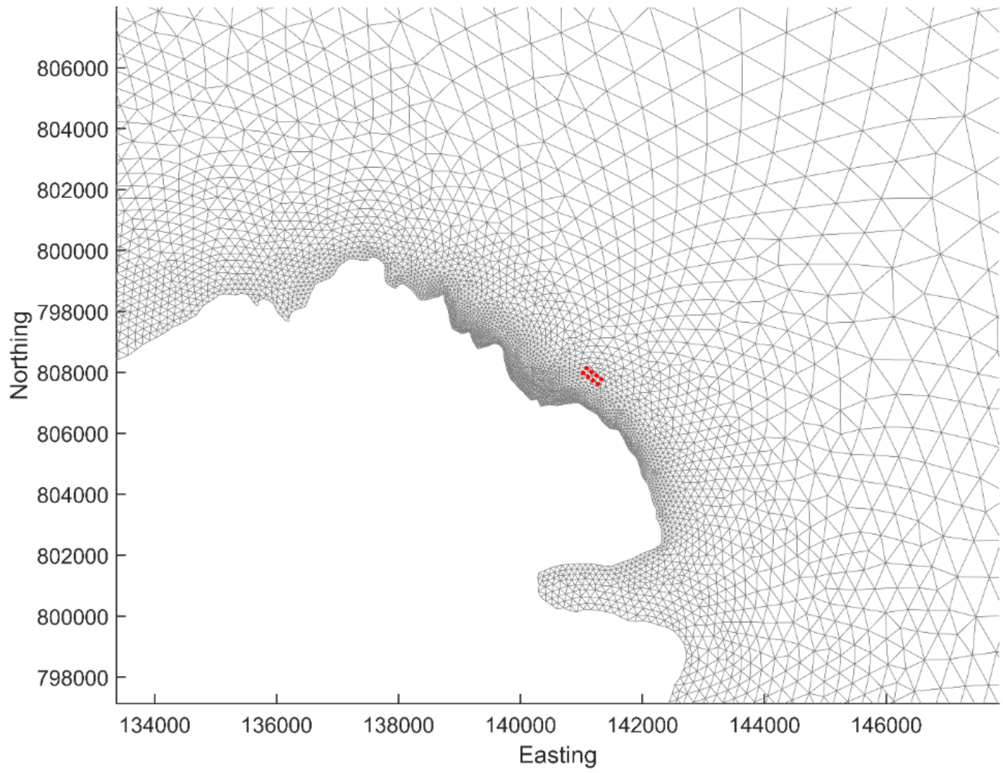

Figure 4. The unstructured mesh around the Rum site in the modified model grid, with the proposed cage locations indicated (O).

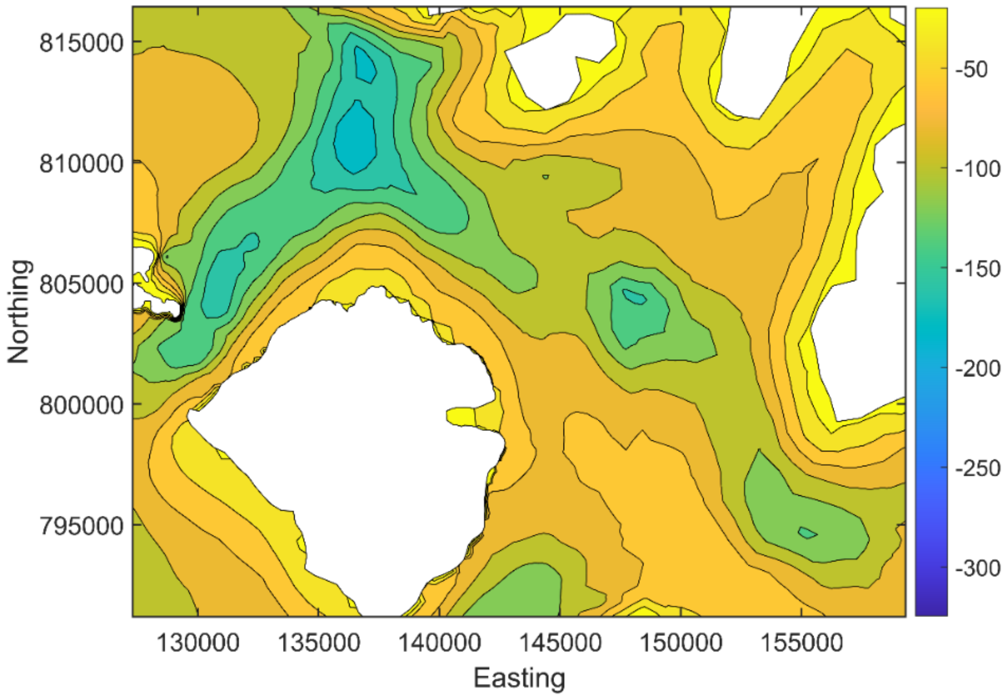

Figure 5. Model water depths (m) in the area around Rum salmon farm.

4.2 Model Calibration

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

(i) Calibration: August – December 2018 (ID242)
(ii) Validation: August – October 2016 (ID113)

In total, the data extend over 138 days. Calibration will be performed in a standard fashion, with bed friction adjusted using the drag coefficient, C_D, 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.

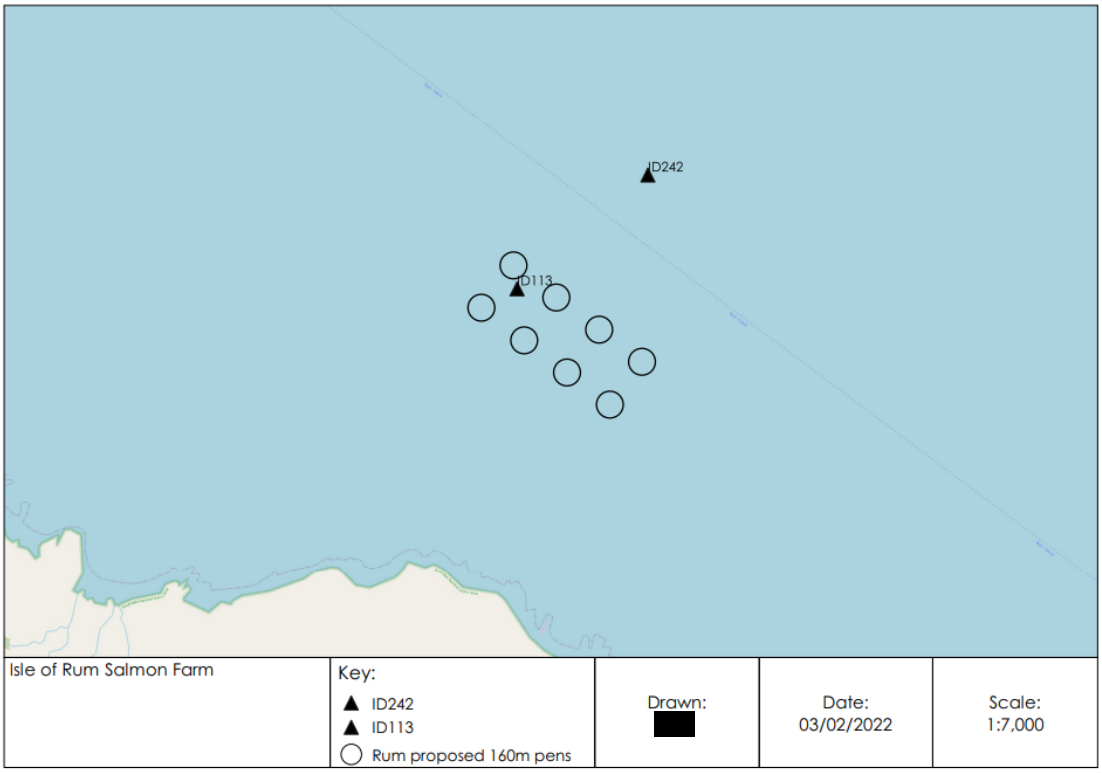

Figure 6. Positions of the current meters in relation to the proposed 160m pens at Rum.

5. DESCRIPTION OF THE PARTICLE TRACKING MODEL

Bath 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., 2016b), 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:

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

where $\vec{U}_{\boldsymbol{P}}$(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):

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

where R is a real random number uniformly distributed over the range -1 ≤ R ≤ 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 Muck by Anderson Marine Services Ltd. on 27th March 2017. The dye study gave a mean horizontal diffusivity of 0.03 m^2s^{-1}, so this value, along with other sensitivity testing values will be used in the bath modelling.

The choice of vertical diffusion coefficient is less certain but a value of K_V = 0.001 m^2s^{-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:

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

where γ = 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.

5.1 Model Tests

The dispersion model has been subjected to various tests, including the standard Brickman test (Brickman et al., 2009) to ensure advection is treated accurately in spatially-varying flow fields (Figure 7). The model was tested using a range of time steps from 36s to 3600s and successfully reproduced the final particle location distribution for all time steps (Figure 8). In the simulations described below, a time step of 600s was used.

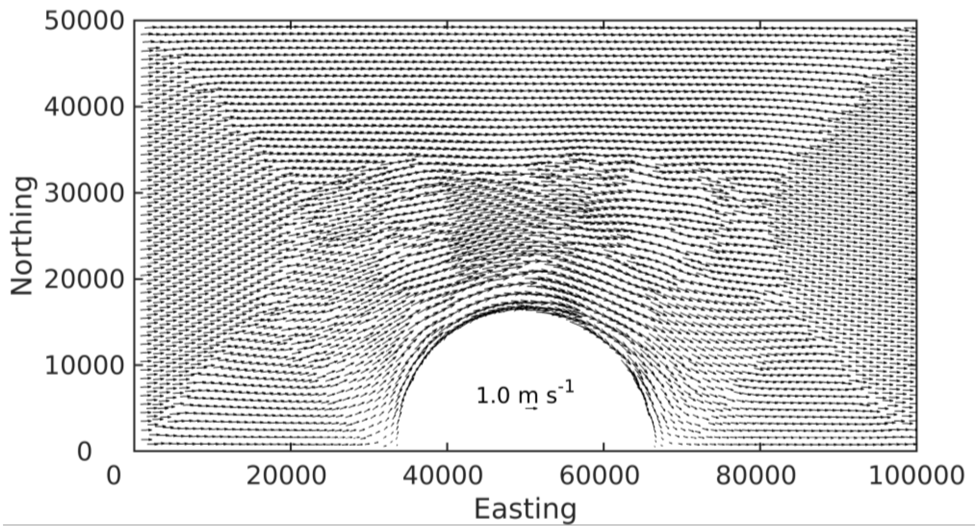

Figure 7. Flow vectors for the Brickman test. Flow at the left-hand boundary is 1 m s^{-1}.

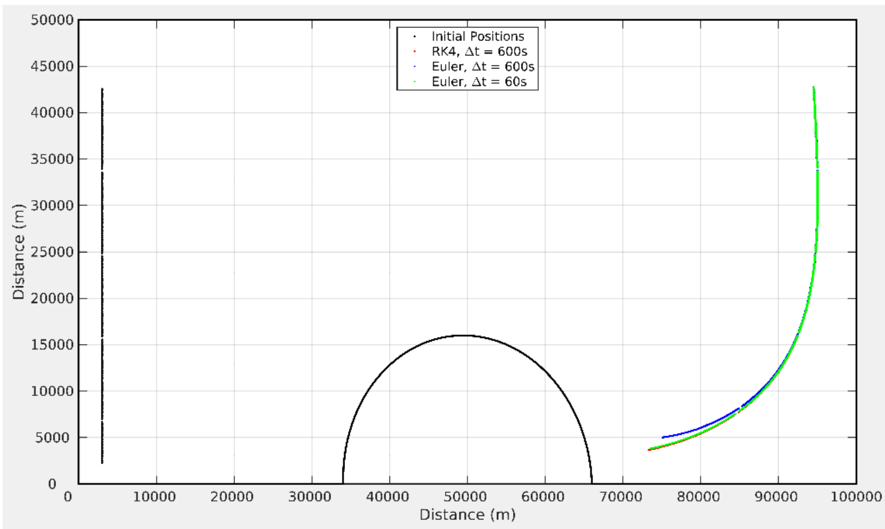

Figure 8. Results from the advection test. Particle locations 24 hours after release from the source locations at x = 3000m. The results for the RK4 scheme (Δt = 600s) and the Euler with a shorter time step (Δt = 60s) are effectively identical, and in the correct distribution (Brickman et al., 2009). The results from the Euler scheme with the longer time step (Δt = 600s) deviate slightly.

The model was also tested for diffusion and chemical decay. The random walk algorithm correctly simulated the increase in particle variance with specified horizonal dispersion coefficients of 0.1 m^2s^{-1} and 1.0 m^2s^{-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 Rum. 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 Rum together with that from neighbouring Small isles sites at Muck and the proposed new site at Canna. For this set, flow fields from the hydrodynamic model, RiCOM, 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 1.2.6-final.

The model will be configured exactly as specified by SEPA in the modelling guidance published in July 2019 (SEPA, 2019). The site will be modelled for a maximum biomass of both existing 2500 tonnes and the proposed 3500 tonnes with 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 2km x 2km area, with a 25m grid spacing in both directions. The grid size will be 81 x 81 cells. Flat bathymetry will be used with a water depth of 41.5 m, the weighted average of the depths at the two current meter deployments (ID113 and ID242). The flowmetry file combined the data from both of the deployments; after merging the length of the combined record will be 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 Rum is sited in a high wave exposure location the deposition limit at pen edge will be set at 4,000g/m2/yr.

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 a calibrated hydrodynamic model, namely RiCOM, described in Section 4, advected particles representing waste solids around the model domain. Deposition from the existing Muck site and the proposed Canna site was modelled as well as deposition from the site at Rum (Table 2). Parameter settings for deposition modelling using unptrack will be similar to those in the SEPA standard default approach for NewDepomod. Deposition was then modelled for 365 days, and the mean deposition over the final 90 days calculated.

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

Site Name	Location	Operator	Biomass (T)	Status
RUM1	Rum	Mowi	3500*	Active
AMM1	Muck	Mowi	4069**	Active
CNNA1	Canna	Mowi	2500	Not licensed

*proposed max. value
**to be applied for

7. BATH TREATMENT DISPERSION MODELLING

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 as a realistic depth during application of the medicine for 160m 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 9.84 kg of azamethiphos released during treatment of the whole farm (8 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 1 or 2 at 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.

7.1 Cumulative Bath Treatment Dispersion Modelling

The unptrack model will be used to assess the cumulative impacts of the site at Rum together with a neighbouring salmon farm. Following the SEPA screening report, the cumulative assessment will include only Muck in addition to Rum due to the intention not to seek an azamethiphos consent for the proposed organic site at Canna (Table 3).

The cumulative bath treatment dispersion modelling will simulate simultaneous bath medicine treatments at both sites to assess compliance with environmental quality standards.

Table 3. Sites to be included in the cumulative bath treatment modelling assessment including the 24hr limit and total mass of medicine used at each site.

Site Name	Location	Biomass (T)	24hr Consent (kg)	Total Medicine Mass Released (kg)	Status
RUM1	Rum	3500	1.23 / 2.46**	9.84*	Active
AMM1	Muck	4069	1.02	8.16	Active
CNNA1	Canna	2500	0	0	Not licensed

*mass of azamethiphos to be applied for

** dependent on bath modelling results

8. DATA REQUIREMENTS FOR SIMULATIONS

8.1 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 20° 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. ID113 and ID242 will be used together in the bath and cumulative solids modelling. ID113, ID123 and ID127 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.

8.2 Bathymetry Data

Only bathymetry from the EMODnet dataset will be used in the modelling. This contains many publicly collected multibeam data and since a flat seabed is to be used in the SEPA Standard Default approach in NewDepomod, detailed bathymetry around the site was deemed unnecessary.

9. MODEL OUTPUTS

9.1 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. Calibration of the NewDepomod model will not take place since the “standard default” approach will be used.

9.2 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.

9.3 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. 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.

10. CRITICAL ELEMENTS FOR CAR APPLICATION

10.1 Modelling

The extent of the benthic footprint must be clearly delineated, and proposed transect locations identified. The IQI = 0.64 contour level will be identified.

10.2 Benthic Survey

In order to assess whether environmental capacity exists to accommodate a proposed expansion to a fish farm, SEPA requires a baseline survey to be carried out. At least two previous compliant environmental surveys are required. The generic survey design consists of 4 transects, each with 7 stations. The length of transects and spacing of the sampling stations can be estimated from the model footprints.

Each transect must start at the cage edge and the furthest station must reach IQI > 0.64 and/or reflect the background value. Each transect requires 7 stations, and depending on existing seabed monitoring requirements, historic data and model outputs, other stations may be required.

Although a formal classification has not been given for the last 3 benthic monitoring surveys yet, the ones from July 2019 and April 2020 met pen edge and mixing zone environmental standards.

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