Mullach Mor, Isle of Rum (Proposed Site) Hydrodynamic and Dispersion Modelling 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 and in-feed medicines at a proposed fish farm site Mullach Mor, Isle of Rum, adjacent to the existing Rum site. 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 application. This method statement outlines the methodology that will be used at **Mullach Mor** 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 (SEPA 2023).

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

An indicative site location is provided in Figure 1 for 8 x 160 m circumference pens, held in a 100 m matrix with a net depth of 16 m. A maximum standing biomass consent of up to 2,500 T will also be applied for.

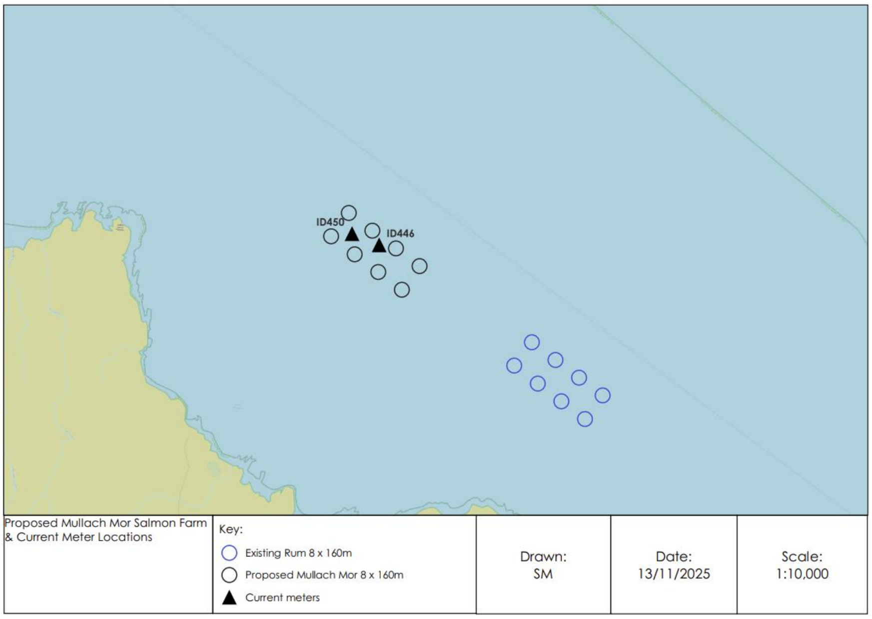

Figure 1. Location of proposed Mullach Mor salmon farm. Current meter locations are shown by the black triangles.

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 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, 2023)

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.

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 Medicine Residues

Medicinal sea lice treatments will be carried out in one of two ways at Mullach Mor:

- 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 for the 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 EQS 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.

3.1.3 Dissolved Nutrients

The methodology to assess the level of change follows the UKTAG procedure to assess coastal waters using the winter mean of Dissolved Inorganic Nitrogen (DIN) (UKTAG, 2008). Assessment levels define a level of natural variability in the water plus a ‘slight’ disturbance (defined as background level, increased by 50 %). UKTAG uses this methodology to define reference conditions for the Water Framework Directive (Water Framework Directive 2024).

The potential level of change in nutrient status due to the proposed site is evaluated in §3.2.2.

3.2 Site Specific Environmental Considerations

3.2.1 Risk Identification

Several near-by identified features of interest (Table 1) have been identified (SEPA, 2025) which are thought to be at potential risk to either medicine or solids deposition influence and hence need to be considered during the modelling for Mullach Mor. Figure 2 shows the locations of these special features. A baseline survey of the seabed at the site has been completed and reported to SEPA as part of the pre-application process, including potential features of interest.

Table 1. Table of identified features of interest (SEPA, 2025)

Feature Name	Feature Type	Location	Reason for Identification
Northern Seafan and Sponge Communities	PMF/MPA protected feature	139694 E, 804546 N	At risk from bath medicine
Northern Seafan and Sponge Communities	PMF/MPA protected feature	139661 E, 804473 N	At risk from bath medicine
Burrowed Mud	PMF/MPA protected feature	Area shown in Figure 2	At risk from solids deposition

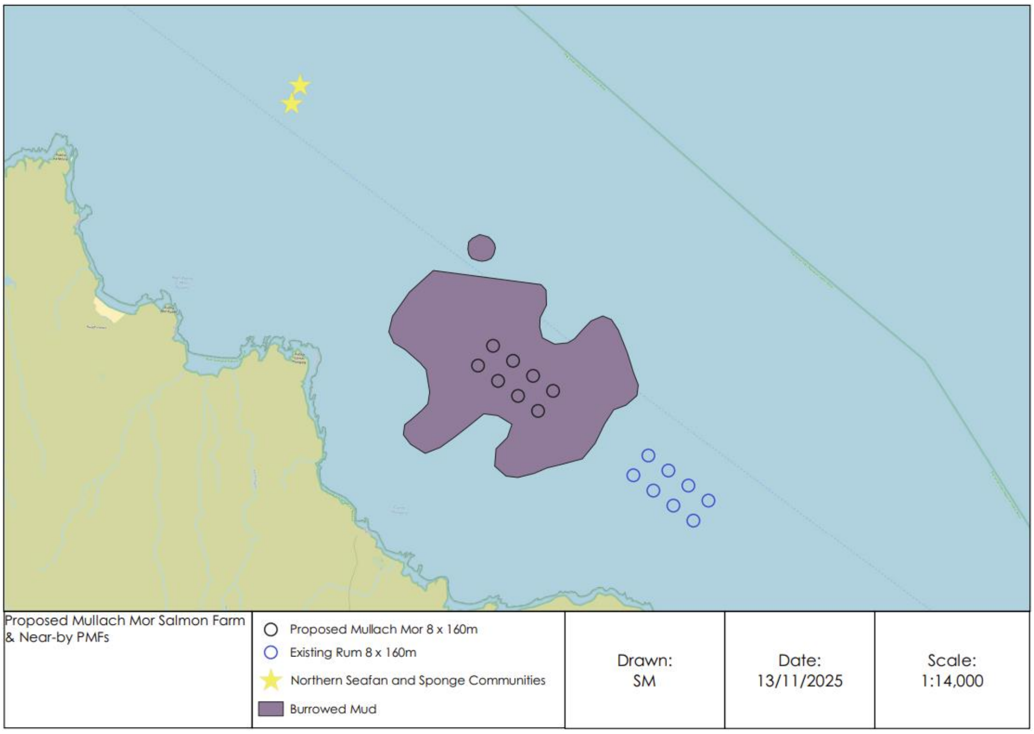

Figure 2. Identified special features near the proposed Mullach Mor salmon farm.

3.2.2 Dissolved Nutrients

The proximity to locational guidelines waterbodies has been assessed and not considered to be a risk (SEPA, 2025), however an Open Water ECE calculation will be done to ensure nutrient enhancement levels from Mullach Mor are acceptable.

The ECE models predict the relative levels of nutrient enhancement. The results of the models are scaled 0-5 to give a nutrient enhancement index (Table 2). Areas with higher ECE values are considered to be the most environmentally sensitive to further fish farming development due to high predicted levels of nutrient enhancement.

Table 2. Index of nutrient enhancement, derived from predicted levels of equilibrium concentration enhancement (ECE) for nitrogen.

Predicted ECE for nitrogenous nutrients arising from fish farming (μmol L^{-1})	Nutrient Enhancement Index
> 10.0	5
3.0 – 10.0	4
1.0 – 3.0	3
0.3 – 1.0	2
< 0.3	1
0	0

The standard 'open water' model has been adopted to calculate the ECE for the proposed site. The simple model estimates the level of enhancement of dissolved nitrogen above background levels. The model uses current data from hydrographic surveys to calculate the rate of water exchange and estimates the enhancement of dissolved nitrogen above background levels due to farming activity, following Sherwin (2000) and Gillibrand (2006). Data inputs to the open water ECE model are shown in Table 3.

Table 3. Data inputs to the Open Water ECE model for the proposed biomass at the proposed site. Velocity data from ADCP deployment ID446 were used.

Site name:	Mullach Mor
Mean "along-shore" Flow (m/s):	0.022
Mean "across-shore" flow (m/s):	0.002
Standard deviation of "along-shore" flow (m/s):	0.154
Standard deviation of "across-shore" flow (m/s):	0.051
Water depth or mixed layer depth (m):	34
Site biomass (tonnes)	2500
Nutrient source rate (kgN/day):	330.1
Nutrient decay rate (s-1):	0

The ECE value for the proposed farm based on a maximum standing biomass of up to 2,500 tonnes was calculated as 0.000004938 kgN m^{-3} or 0.353 μmol L^{-1} (Table 4) and therefore the Nutrient Enhancement Index = 2. The calculated percentage value of the background is very low and hence does not exceed the 50% trigger specified in UKTAG procedures. The nutrient contributions from the site are therefore again assessed as not having a significant impact on the water column.

Table 4. Results from the nutrient ECE modelling

Zone B volume (m^3):	109,578,434.56
Exchange rate (s^{-1}):	0.000007062
Flushing time (hours):	39.33
ECE (kg m^{-3}):	0.000004938
ECE (umol l^{-1}):	0.35

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:

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

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]:

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

where t is time; $f(x,y)$ is the Coriolis parameter; $\hat{\mathbf{z}}$ 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:

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

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

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

$$\tau_b = \rho C_D \boldsymbol{U}|\boldsymbol{U}| \qquad (4)$$

where ρ = 1,025 kg m^{-3} is the water density, **U** is the velocity in the layer closest to the seabed. The drag coefficient, C_D, can be either a constant or calculated from the bed roughness lengthscale, z_0, using:

$$C_D = \left(\frac{\kappa}{\ln\left(\frac{z_b+z_0}{z_0}\right)}\right)^2 \qquad (5)$$

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 C_D or 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:

$$\tau_x = \rho_a C_S u W \qquad (6a)$$
$$\tau_y = \rho_a C_S v W \qquad (6b)$$

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 Wu (1982) or Large and Pond (1981).

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 East Coast of Lewis and Harris (ECLH) sub-model mesh of the Scottish Shelf Model (SSM; MS, 2016). The model resolution was enhanced in the Small Isles region, particularly around the proposed Mowi site, Mullach Mor (Figure 4). The spatial resolution of the model varies from 20 m in some inshore waters and round the farm pens to 5 km along the open boundary. The model consists of 88,329 nodes and 168,561 triangular elements. The model will be run in either 2D or 3D mode, depending on the quality of the calibration. Model bathymetry (Figure 5) was taken from the EMODnet digital terrain model (EMODnet, 2025).

The model will be forced at the outer boundaries by up to 13 tidal constituents (M_2, S_2, N_2, K_2, O_1, K_1, P_1, Q_1, M_4, $2MS_6$, M_6, MS_4 and μ_2) which were derived from tidal analysis (Pawlowicz et al., 2002) of the sea surface elevations at the closest nodes from the Scottish Shelf Model climatology (Marine Scotland, 2016). Spatially- and temporally-varying wind speed and direction data will be taken from the ERA5 global reanalysis dataset (ECMWF, 2021) for the required simulation periods.

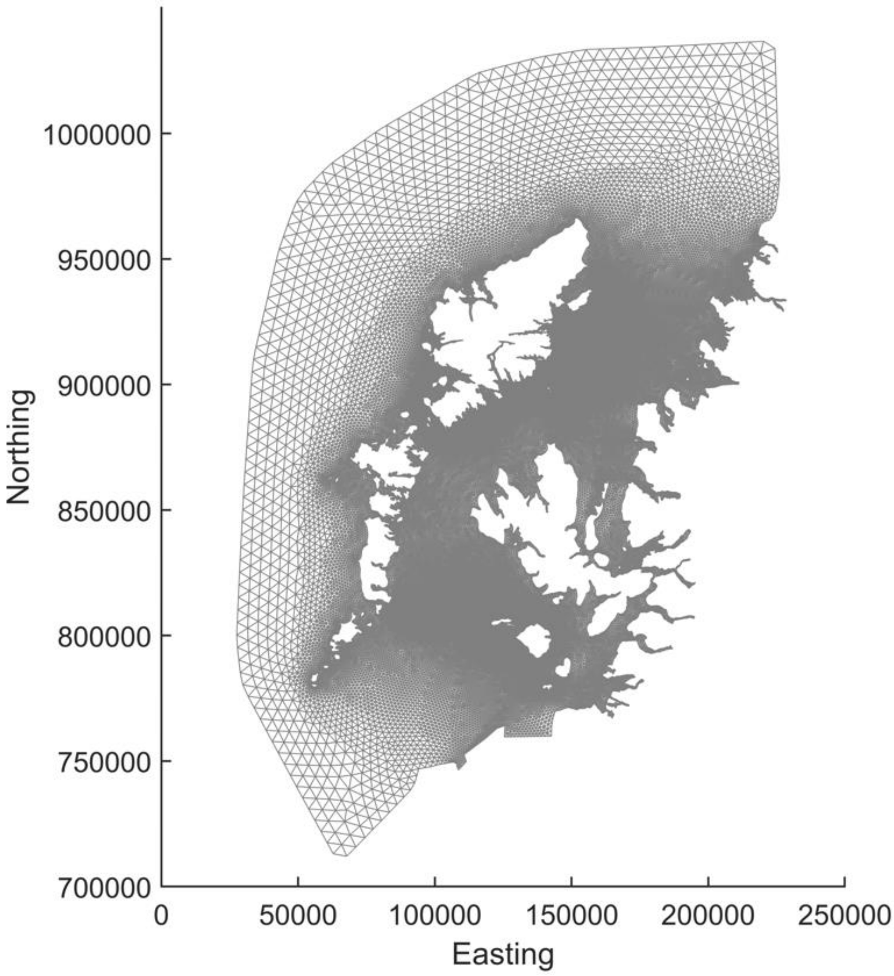

Figure 3. The ECLH mesh and domain of the modelling study.

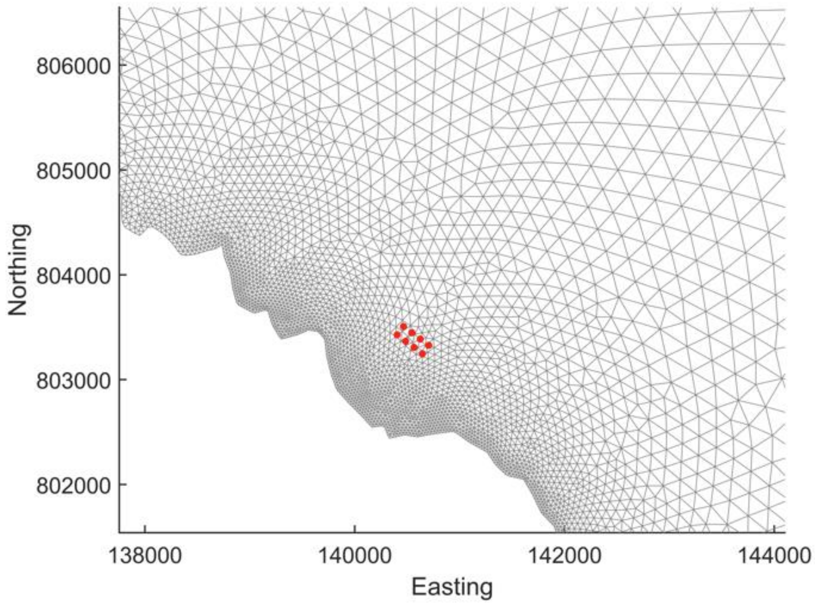

Figure 4. The unstructured mesh around the proposed Mullach Mor site in the modified model grid. The proposed pen configuration of 8 x 160 m is shown.

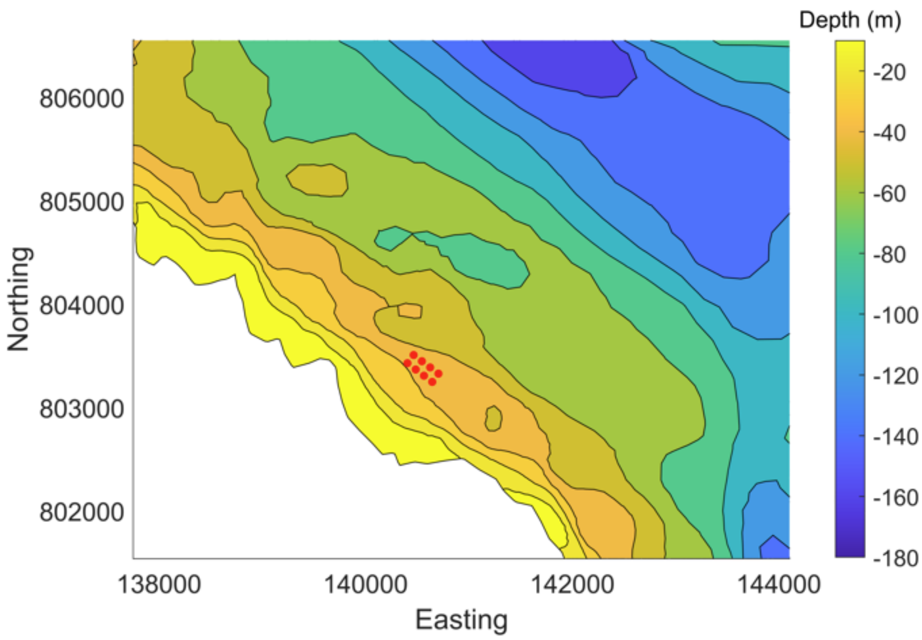

Figure 5. Model water depths (m) in the area around the proposed Mullach Mor salmon farm. The proposed pen locations are shown in red.

4.2 Model Calibration

The local area model will be calibrated against current data and seabed pressure data, measured in the Small Isles area using Acoustic Doppler Current Profilers (ADCP), see Figure 1 for ADCP locations. Data are available from:

(i) Calibration: February 2025 – April 2025 (ID446)
(ii) Validation: June 2025 – August 2025 (ID450)

In total, the data will extend over 111 days. Calibration will be performed in a standard fashion, with bed friction adjusted using the drag coefficient, C_D, in 2D or the bed roughness lengthscale, z_0, in 3D 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., 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 $\vec{U}_P$(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 ≤ R ≤ 1, and K_H and K_Z are the horizontal and vertical eddy diffusivities respectively. For the baseline simulations, we use a small constant eddy diffusivity of K_H = 0.1 m^2 s^{-1}, however sensitivity testing to this will be explored .

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 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.

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

Depositional modelling at Mullach Mor will be performed utilising the NewDepomod model (SAMS, 2021), configured in the default parameter values specified by SEPA and using the measured flow data to force the model. These model runs will focus on the localised deposition beneath the current and proposed pens, to check for any significant change in environmental impact.

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 v1.5.0-final-(SEPA edition) or a more recent version.

6.1 Waste Feed & Faeces

The model will be configured exactly as specified by SEPA in the modelling guidance published in July 2019 (SEPA, 2019) and March 2022 (SEPA, 2022). The site will be initially modelled for a maximum biomass of up to 2,500 T, with a feed load of 7 kg/tonne/day at both current and proposed layouts. 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. If required, the modelled biomass will be reduced until the benthic EQS are achieved.

A regular model grid will be prepared. The grid will cover a 2 km x 2 km area, with a 25 m grid spacing in both directions. The grid size will be 80 x 80 cells. Flat bathymetry will be used with a water depth of 31.1 m. The flowmetry file will be made up of data from a stitch of ID446 and ID450, then truncated to be 90 days exactly.

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 Mullach Mor is sited in a high wave exposure location (wave exposure index = 3.6) the deposition limit at pen edge should be set at 4,000 g m^{-2} yr^{-1}.

6.2 In-Feed Medicine

The use of the in-feed medicine Emamectin Benzoate (EMBZ) will also be applied for. This will utilise the in-feed medicine model of NewDepomod with the proposed layout of the site. The model will be run for 118 days, with hourly results over the final two days (Days 116 – 118) saved to file. This approach follows that of the standard default modelling approach outlined in the SEPA Regulatory Modelling Guidance (SEPA, 2023a, b). The mean concentrations of EMBZ will be calculated from this output for comparison with the EQS value of 136 ng/kg (wet weight, equivalent to 272 ng/kg dry weight), which is the current position standard.

6.3 Special Feature - Burrowed Mud

Due to the potential risk from solids deposition influence on the Burrowed Mud identified special feature, the solids footprints (both waste feed & faeces and EMBZ) will be plotted together with the feature area to check for any interaction. It is expected that there will be some overlap due to the presence of Burrowed Mud directly beneath the proposed site, however potential effects are likely to be localised due to the dispersive nature of the surrounding environment. Burrowed Mud is known to be widespread in the marine environment around the Small Isles, thus localised effects are likely to be a minor proportion of the habitats distribution and should not affect the integrity of the feature in this area.

7. BATH TREATMENT DISPERSION MODELLING

7.1 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 up to 11 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.

An appropriate treatment depth will be chosen for application of the medicine for the proposed pens. The initial mass released per pen is calculated from the reduced pen volume and a treatment concentration of up to 120 µg/L. The higher concentration than the recommended treatment dose (100 µg/L) allows for discretionary over-treatment by fish health specialists. The number of cage treatments that can be performed in a single day will be 1. Particles are released at random positions within a cage radius of the cage centre and within the treatment 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.

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

7.2 3-Hour EQS

The UnPTRACK model will also be used to assess the 3-hour EQS. The 3-hour mixing zone will be taken from the BathAuto excel spreadsheet using a mean surface speed of 9.26 cm s^{-1} from ID446, which is thought to be a conservative representation of the surface layer at Mullach Mor. The model will output every 20 minutes (rather than hourly) and concentrations from these simulations will be calculated on a smaller (10 m x 10 m) grid to that used in the 72-hour model runs, this will be to more accurately calculate the smaller areas of medicine over the initial 3-hour period. Time series over spring and neap tides of the area where the 3-hour EQS of 250 ng L^{-1} is exceeded and the peak concentration for each individual pen treatment will be shown.

7.3 Special Feature – Northern Seafan & Sponge Communities

Due to the potential risk from bath medicine influence at the Northern Seafan and Sponge Communities features, predicted concentrations of Azamethiphos will be extracted from these locations and the maximum concentrations derived. Since they are benthic habitats, the calculations will be undertaken for a 5 meter thick layer immediately above the seabed. Concentration depth profiles at the identified special features will also be given.

7.4 Cumulative Modelling

Cumulative bath modelling is required to be undertaken due to the close proximity of the proposed Mullach Mor and existing Rum site. The simulations will follow a treatment scenario of 1 pen treatment a day, starting with the Rum pens and following with the proposed Mullach Mor pens (Table 5). This will be run over both neap and spring tides. Each pen treatment will release 1.23 kg of Azamethiphos, the current 3-hour consent at Rum and the sought for consent for Mullach Mor. The length of the treatment simulation will follow suit of the standard runs, 16 days to cover the treatment of each pen, a dispersion period to the EQS assessment of 72 hours after the final treatment and an extra 25 hours to check for chance concentration peaks. In standard runs, a 72-hour EQS area is set at 0.5 km^2, but this will be doubled to 1 km^2 to accommodate the fact that there are two sites being modelled. Peak concentrations against the 72-hour MAC and the altered area (1 km^2) where the 72-hour EQS is exceeded will be checked as normal.

Table 5. Cumulative modelling initial treatment scenario, time (h) with respect to the beginning of the simulation

Site	Pen Number	Treatment time (h)	Treatment Amount (kg)
Rum	1	0	1.23
Rum	2	24	1.23
Rum	3	48	1.23
Rum	4	72	1.23
Rum	5	96	1.23
Rum	6	120	1.23
Rum	7	144	1.23
Rum	8	168	1.23
Mullach Mor	1	192	1.23
Mullach Mor	2	216	1.23
Mullach Mor	3	240	1.23
Mullach Mor	4	264	1.23
Mullach Mor	5	288	1.23
Mullach Mor	6	312	1.23
Mullach Mor	7	336	1.23
Mullach Mor	8	360	1.23

A second cumulative modelling treatment scenario will be undertaken, this will be to check that the 72-hour EQS and MAC are comfortably met if the adjacent sites are to be treated simultaneously. The simulations will mirror the set-up of the first except a pen from each site will be treated each day, over both spring and neap tides (Table 6). This in turn will decrease the model running time to 8 days to cover the treatment time, a dispersion period to the EQS assessment of 72 hours after the final treatments and an extra 25 hours. Again, the 72-hour EQS area of 0.5 km^2 will be doubled to reflect that two sites are being modelled.

Table 6. Cumulative modelling second treatment scenario, time (h) with respect to the beginning of the simulation

Site	Pen Number	Treatment time (h)	Treatment Amount (kg)
Rum	1	0	1.23
Rum	2	24	1.23
Rum	3	48	1.23
Rum	4	72	1.23
Rum	5	96	1.23
Rum	6	120	1.23
Rum	7	144	1.23
Rum	8	168	1.23
Mullach Mor	1	0	1.23
Mullach Mor	2	24	1.23
Mullach Mor	3	48	1.23
Mullach Mor	4	72	1.23
Mullach Mor	5	96	1.23
Mullach Mor	6	120	1.23
Mullach Mor	7	144	1.23
Mullach Mor	8	168	1.23

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 most deployments. These instruments are deployed in mooring frames with 20^{o} 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. ID446 and ID450 will be used together in the bath modelling. Current data will be stitched and truncated to exactly 90 days long 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.

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 no footprint exists at present.

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

Mowi Scotland Ltd. maintains a Quality Manual which defines the Quality and Environmental Policy of Mowi Scotland Farming Limited and includes an overview of its processes and acts as a signpost to key elements of its Quality Management System according to the requirements of BS EN ISO 9001, BS EN ISO 14001, GLOBALG.A.P. and British Retail Consortium Global Standard Food. Note the BRC standard is relevant to Blar Mhor processing plant only.

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.

10. REFERENCES

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

Casulli, V., 1987. Eulerian-lagrangian methods for hyperbolic and convection dominated parabolic problems. In: Taylor, C., Owen, D., Hinton, E. (Eds.), Computational Methods for Non-linear Problems, Pineridge Press, Swansea,U.K., pp. 239–268.

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

EMODnet, 2025. Bathymetry | European Marine Observation and Data Network (EMODnet)

Gillibrand, P.A., 2006. Improving Assimilative Capacity Modelling for Scottish Coastal Waters: II. A Model of Physical Exchange for Open Water Sites. Scottish Association for Marine Science, Dunstaffnage Marine Laboratory, Oban, Marine Physics Report No. 168, June 2006, 16 pp.

Gillibrand, P.A., 2021. UnPTRACK User Guide. Mowi Scotland Ltd., November 2021, 33pp. https://github.com/gillibrandpa/UnPTRACK

Gillibrand, P.A.; Lane, E.M.; Walters, R.A.; Gorman, R.M., 2011. Forecasting extreme sea surface height and coastal inundation from tides, surge and wave setup. Austr. J. Civil Eng., 9, 99-112.

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., 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

Lane, E.M.; Gillibrand, P.A.; Arnold, J.R.; Walters, R.A., 2011. Tsunami inundation modelling with RiCOM. Austr. J. Civil Eng., 9, 83-98.

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 wider domain Scottish Shelf Model. Available at: The wider domain Scottish Shelf Model | Marine Scotland Information

McIlvenny, J. , Tamsett, D., Gillibrand, P.A. and Goddijn-Murphy, L., 2016. Sediment Dynamics in a Tidally Energetic Channel: The Inner Sound, Northern Scotland. Journal of Marine Science and Engineering, 4, 31; doi:10.3390/jmse4020031

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. and Black, K., 2001, The environmental impact of marine fish cage culture. in Environmental Impacts of Aquaculture-Kenneth D Black. Sheffield Academic Press, pp. 1-31.

Plew, D. R.; Stevens, C. L., 2013. Numerical modelling of the effect of turbines on currents in a tidal channel–Tory Channel, New Zealand. Renew. Energy, 57, 269-282.

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, 2025. Aquaculture Modelling Screening & Risk Identification Report: Rum 2 (RUM2). Scottish Environment Protection Agency, June 2025.

UK Technical Advisory Group (UKTAG), 2008. UK Environmental Standards and Conditions (Phase 2), March 2008.

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., 2005a. Coastal ocean models: two useful finite element methods. Cont. Shelf Res., 25(7), 775-793.

Walters, R. A., 2005b. A semi-implicit finite element model for non-hydrostatic (dispersive) surface waves. Int. J. Num. Meth. Fluids, 49(7), 721-737.

Walters R.A., 2016. A coastal ocean model with subgrid approximation. *Ocean Mod*., 102, 45-54.

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

Walters, R.A.; Gillibrand, P.A.; Bell, R.; Lane, E.M., 2010. A Study of Tides and Currents in Cook Strait, New Zealand. Ocean Dyn., 60, 1559-1580.

Walters, R.A., Lane, E.M., Hanert, E., 2009. Useful time-stepping methods for the Coriolis term in a shallow water model. Ocean Model., 28, 66–74. doi: 10.1016/j. ocemod.20 08.10.0 04.

Walters, R.A. ; Lane, E.M.; Henry, R.F., 2008. Semi-lagrangian methods for a finite element coastal ocean model. Ocean Model., 19, 112–124.

Walters, R. A.; Tarbotton, M. R.; Hiles, C. E., 2013. Estimation of tidal power potential. Renew. Energy, 51, 255-262.

Water Framework Directive 2024. Water Framework Directive - European Commission (europa.eu)

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.

Wu, J. Wind-stress coefficients over sea surface from breeze to hurricane, J. Geophys. Res., 1982, 87(C12), 9704–9706, doi:10.1029/JC087iC12p09704.