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The Finest Salmon from
SCOTLAND

Marine Modelling
Bath Treatments and Solids Dispersal

West Gigha, Isle of Gigha

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Approved By	[redacted]

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List of Abbreviations

2D	Two-dimensional simulations along horizontal plane
3D	Three-dimensional simulations along horizontal and vertical plane
ABS	Agent Based Simulations
ADCP	Acoustic Doppler Current Profiler
AMX	Alphamax bath treatment
BFS	Bakkafrost Scotland Limited.
BODC	British Oceanographic Data Centre
CAR	Controlled Activities Regulations
CD	Chart Datum (local)
CMEMS	Copernicus Marine Emergency Management system
CFS/CFSv2	Climate forecasting system / version 2
COGP	Code of Good Practice
CTD	Conductivity, Temperature, Depth
D*	Dimensionless grain size
D_{50}	Median grain size
DHI	Environmental consultancy and developers of MIKE 3/ECO Lab
DTM	Digital Terrain Model
DTU-10	Oceanographic model computing surge
EmBz	Emamectin Benzoate (SLICE active ingredient)
EQS	Environmental Quality Standard
HD	Hydrodynamics
Hs	Significant wave height
HYCOM	Oceanographic model simulating tidal harmonics
MAE	Mean Absolute error
MLWS	Mean Low Water Springs
MS	Marine Scotland
NB	*Nota Bene:* Note Well
NCEP	National Centres for Environmental Protection
NMPI	National Marine Plan Interactive
MS / MSS	Marine Scotland/ Marine Scotland Science
OS	Ordnance Survey
p_c	Probability of connectivity
PSU	Practical Salinity Unit
Q	Cumec: unit of discharge
r^2	Proportion of the variance for a dependent variable explained by the model
RMSE	Route Mean Squared Error
SDM	Standard Default Method
SEPA	Scottish Environment Protection Agency
SLICE	In-feed treatment containing the active ingredient, EmBz
SSH	Sea Surface Height
T	Tonnes (biomass)
Tp	Peak wave period
U10/V10	u/v vectors at 10m height
u*	Shear velocity
u_z	Roughness Length
UKHO	UK Hydrographic Office

UTM-29	Universal Trans Mercator – 29: Cartesian projected coordinate system
WGS84	Lat/Long Coordinate system
WLLS	Wider Loch Linnhe system (Marine Scotland Model)
μ	Mu; Statistical mean
θ	Theta: Shields parameter
τ_E	Tau-E; Critical resuspension thresholds
σ	Standard deviation

1. Executive summary

This report summaries detailed hydrodynamic and particle tracking simulations undertaken to support Bakkafrost Scotland Limited's (BFS's) application for a 3,104T finfish aquaculture farm to the west of the Isle of Gigha. The methodology presented herein has been developed in collaboration with SEPA and follows a Modelling Method Statement pre-approved by SEPA and supports a risk assessment undertaken in NewDepomod and presented in a separate report.

This advanced modelling exercise reviews the dispersion of feed and faeces particles from the proposed farm in isolation and in combination with BFS's two existing farms in the area (East Tarbert Bay and Druimyeon Bay). This exercise concludes that the waste feed and faeces from the proposed farm is dispersed over a wide area at low concentrations and is anticipated to have minimal impact (if any) on the wider marine environment.

Bath treatments are proposed at the site and were reviewed using the modelling methodology presented herein. Releases of Azamethiphos and Deltamethrin were reviewed using a conservative tarpaulin treatment method over a Spring and Neap tidal phases. The simulations outline that treatment medicines are dispersed over a wide area within the Sound of Jura, at low concentrations and satisfy SEPA's EQS and MAC standards. The modelling outlines that single dose of Azamethiphos (589.69 g per pen, 4717.5 g total) and Deltamethrin (24g per pen, 192g total) are within guidelines.

This corresponds to a single dose of *Alpahamax*® or *Salmosan*® (0.2ppm), administered in a Tarpaulin of volume 5,897 m^3 to three pens a day, in three-hour intervals.

The modelling applied is considered conservative in terms of the treatment methodology used, the decay rate of Azamethiphos and Deltamethrin applied, and the dispersion coefficient applied. Additionally, three sensitivity tests were undertaken to review modeller assumptions, finding the compliance of bath treatments was insensitive to modeller assumptions and waste feed and faeces dispersion was sensitive to variation from SEPA's prescribed values.

2. Introduction

This report summarises work undertaken by Bakkafrost Scotland (BFS) to review the dispersion of aquaculture related discharges including bath medicines, waste feed and faeces. The impact of these releases will be assessed against the Scottish Environment Protection Agency's (SEPA's) CAR (Controlled Activity Regulation) requirements and on a set of sensitive receptors, defined through collaboration with SEPA. This report will assess three modelled conditions, outlined below.

- Feed and Faeces: This will be assessed against a 100 m Mixing Zone (around the 250 $g/m^2/yr$) and the average depositional intensity.
- Azamethiphos : This will be assessed against 3-hour, 24-hour and 72-hour concentrations, and the area encompassed by the 250 ng/l and 40 ng/l (respectively) limit. The peak concentration at 72-hour will also be assessed against 100 ng/l.
- Deltamethrin: This will be assessed against 6-hour concentrations and the area encompassed by the 6 ng/l concentration contour.

2.1 Proposed Site

The proposed finfish site, West Gigha, is located to the west of the Isle of Gigha, in the Sound of Jura (see Figure 2.1) and is influenced by a semi-diurnal, microtidal tidal regime with a mean spring range of 0.8 m (Sound of Gigha[1]). The site is considered exposed to significant sea swell to the southwest, where a substantial fetch exists (82 km) towards the Malin Peninsula in the north of Ireland. The farm is 450 to 700 m west of the Gigha shoreline in depths of between - 36 and - 54 mCD. In the absence of significant freshwater influence (with no significant discharges in the vicinity or the proposed site) the site is considered well mixed and flushed by tidal and frictional wave related currents.

[1]2019. *Admiralty Total Tide*. Euronav Navigation Systems

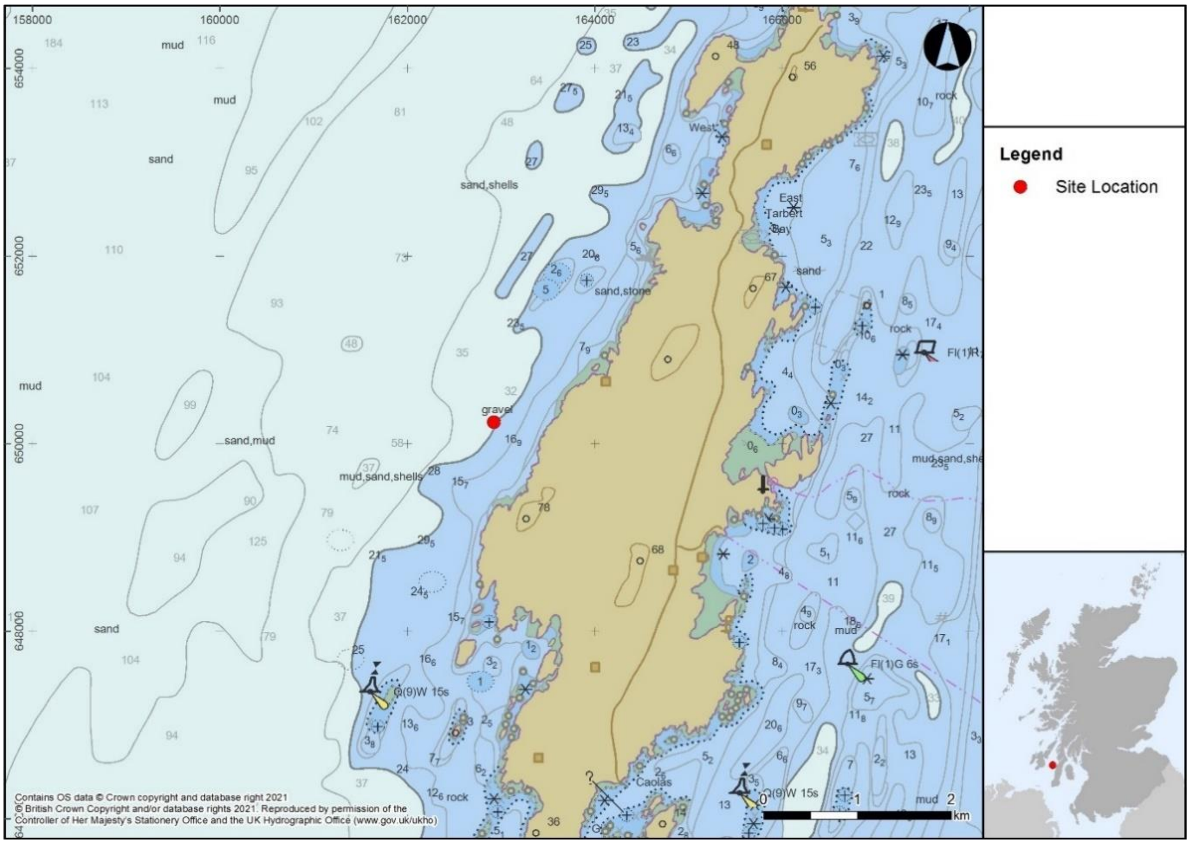

Figure 2.1: Location of the West Gigha site

2.2 Site Details

The site is proposed to have 8 x 160 m circular pens, held in a 120 m grid, in one group of eight (arranged in a 2 x 4 layout) and with a net depth of 15 m. The proposed biomass is 3,104 T. Details of the site are provided in table 2.1 with a graphical representation of the site provided in figure 2.2.

Table 2.1: Summary of West Gigha site information

Site Details	
Group Location	162,876 E, 650,258 N
Number of Pens	8
Pen Circumference (m)	160
Grid Matrix (m)	120 x 120
Net Depth (m)	15
Configuration	2 x 4
Orientation (°)	035
Distance from shore (m)	450 - 700
Depth at Site (m)	36 - 54

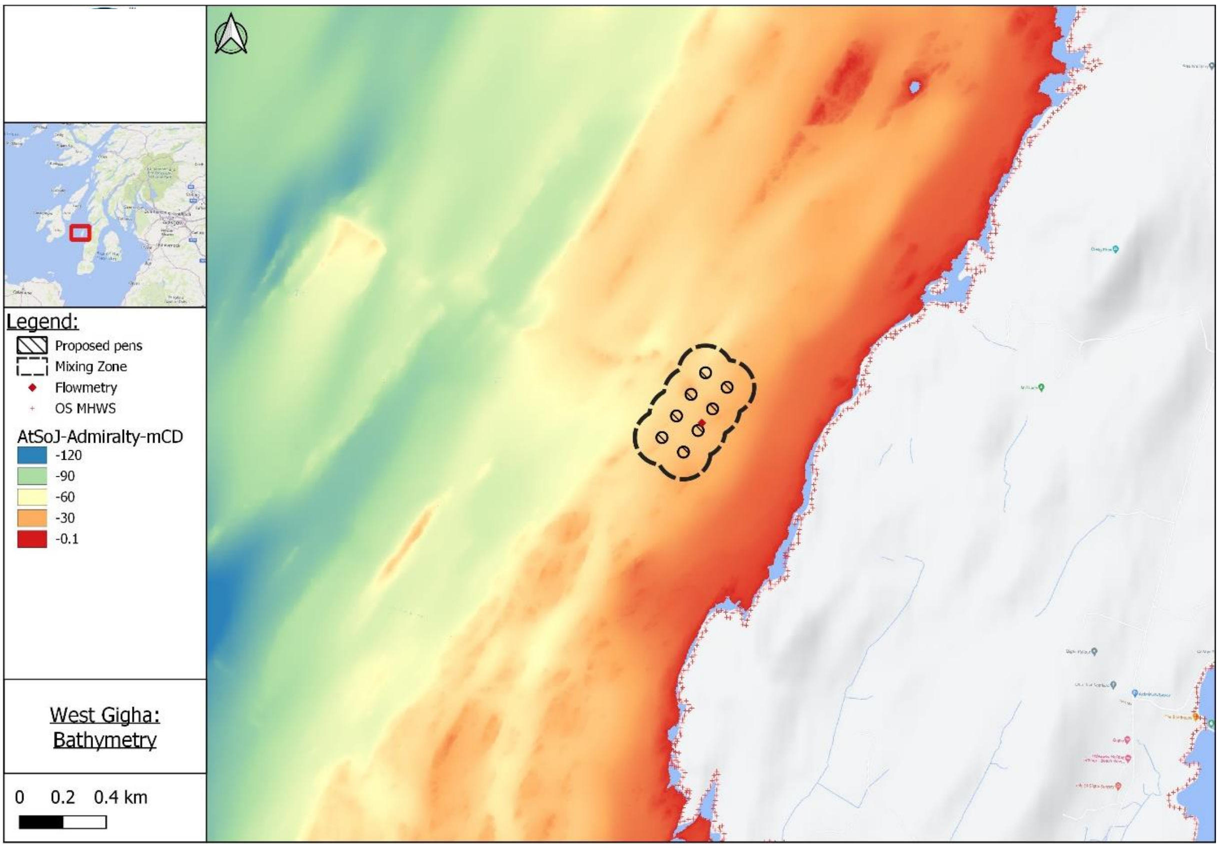

Figure 2.2: Proposed site layout and underlying bathymetry

2.3 Geographical Context

The assessment incorporates a primary area of interest (the area surrounding the proposed site) and a wider area of interest, reviewing interaction with receptors within the larger Sound of Jura and connectivity to Loch Shuna and the wider Loch Linnhe system. These areas are displayed in figure 2.3

The primary area is considered to be moderately exposed to significant Atlantic swells from the Malin Sea area and the Irish Sea. The Isle of Gigha offers significant protection from these Atlantic swells to the existing BFS sites of Druimyeon Bay and East Tarbert Bay. The tidal regime varies significantly within the domain, with an M_2 amphidromic point between Rathlin Island and the Sound of Islay. The tidal regime is semi-diurnal in nature with recorded tidal ranges varying from a 3 m spring range at Bangor, 0.8 m at Gigha/ Port Ellen and 4.3 m at Tobermory. The tidal regime in the primary and wider areas of interest is thus considered complex, with hydrodynamic flows perturbed and exacerbated by complicated geological formations, overwritten by a complex glacial history resulting in deep, narrow Fjordic sea lochs, shallow sills[2] and tidal velocities in excess of 5 kts (2.6 m/s) are commonly observed.

Freshwater inflows are significant within the wider area of interest, with freshwater bores observed at the Corran Narrows[2] and high freshwater concentrations observed at the Falls of Lora and within Loch Etive[3]. Significant freshwater inflows are also sourced from the North of Ireland, including Loch Foyle, the River Bush and Bann. It is, however, likely that these freshwater sources will be highly dissipated and not directly interact with farms in the primary area of interest.

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[2] Berx, B. Gallego, A. & Heath, M, (2015). *Loch Linnhe and Firth of Lorne MASTS Case Study Workshop Report.* Scottish Marine and Freshwater Science Vol 6 No 1.

[3] Hicks, N., Brand, T et al., (2016) *Loch Etive: MASTS Case Study Workshop Report* [Accessed online 10/05/2021: http://www.masts.ac.uk/media/36494/loch-etive-workshop-report_final-report.pdf]

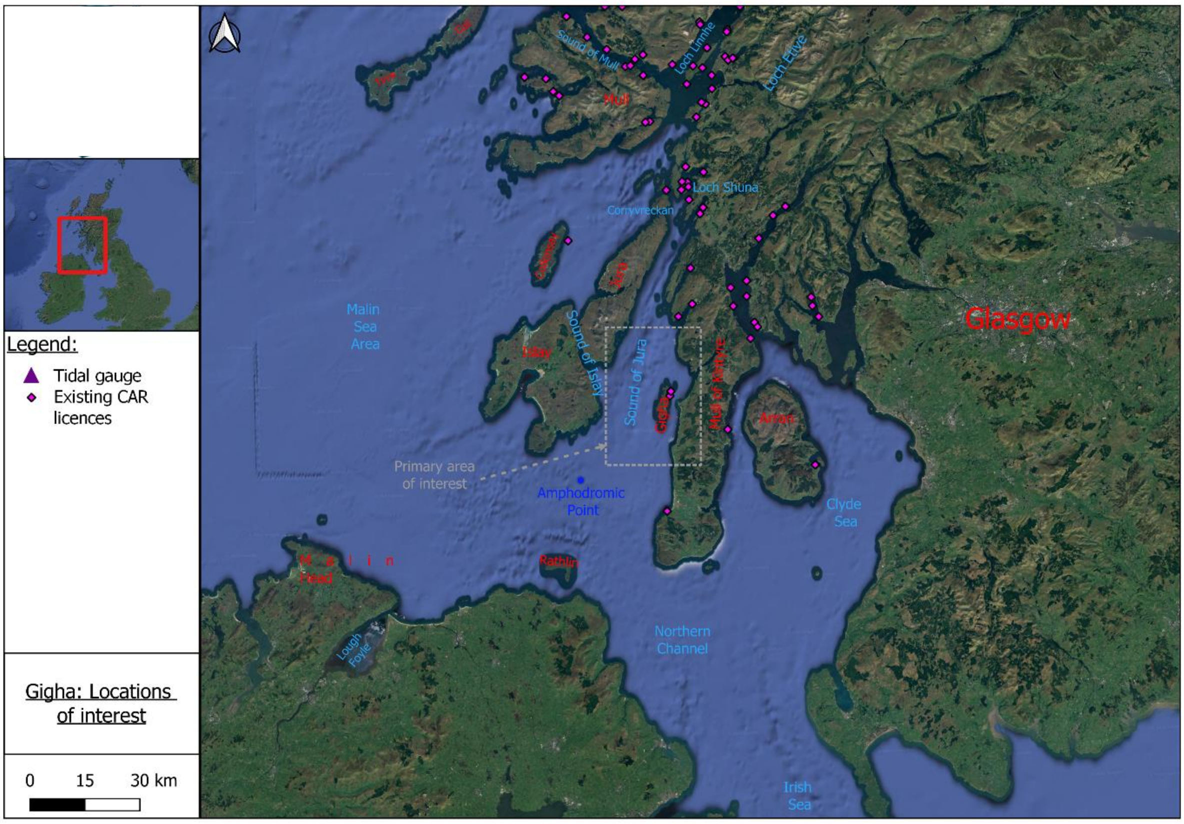


Figure 2.3: Geographical context of the primary area of interest

2.4 Project Aims

The aim of this report is to review the dispersion of three scenarios of aquaculture releases from the proposed West Gigha farm based on a stocked biomass of 3,104 T and risks associated with identified receptors.

The aim will be fulfilled via the following objectives:

- Review the impact of the release of feed and faeces from the proposed development at a medium and large scale, supplementing assessments undertaken in NewDepomod[4]
- Revise the outputs of BathAuto modelling[4] and assess the maximum permissible quantities of bath medicines (Azamethiphos and Deltamethrin) that satisfy SEPA's regulatory requirements.

2.5 Oceanographic Setting

Given the remit of the modelling, there are three dominant mechanisms that govern flow and exchange within coastal and estuarine environments. These are;

- Tidal forcing
- Meteorological forcing (wind stress, ambient temperature, precipitation and barometric pressure)
- Density driven interchange (stimulated by atmospheric interaction and temperature and salinity gradients).

The role of these mechanisms on the area surrounding the Isle of Gigha, the larger Sound of Jura and connected systems are outlined below.

[4] BFS (2023) West Gigha: Depositional modelling report

2.5.1 Tidal Levels

The tidal environment within the primary area of interest is a micro-tidal, semi-diurnal regime with a mean spring range of 0.8 m. Away from this area of interest, the tidal regime varies significantly with a macro-tidal regime observed at Bangor and Portpatrick to the south, Malin Head to the west and at Tobermory to the north. The area encompassing the primary area of interest can thus be considered a complex oceanographic environment, with the flood tide generally flooding from south to north, creating intricate flow patterns within the various sounds and fjordic systems, whilst being constrained by open inflows from the Irish Sea and the Eastern Atlantic and constrained inflows through the Corryvreckan and the Sound of Luing to the north.

2.5.2 Tidal Velocities

Currents within the area of interest are dominated by the tidal conditions, with high velocities elicited regularly with mean observed current speeds of between 0.12 m/s and 0.16 m/s at BFS farms and maximum observed speeds between 0.5 m/s to 0.7 m/s at the surface layers. Event driven velocities are present but are considered largely insignificant in comparison to the tidal component of water velocities. Average (depth and time) velocity roses observed at BFS hydrographic meter deployment locations are displayed in figure 2.4. The data collected by BFS remains the only known observational data in the primary area of interest.

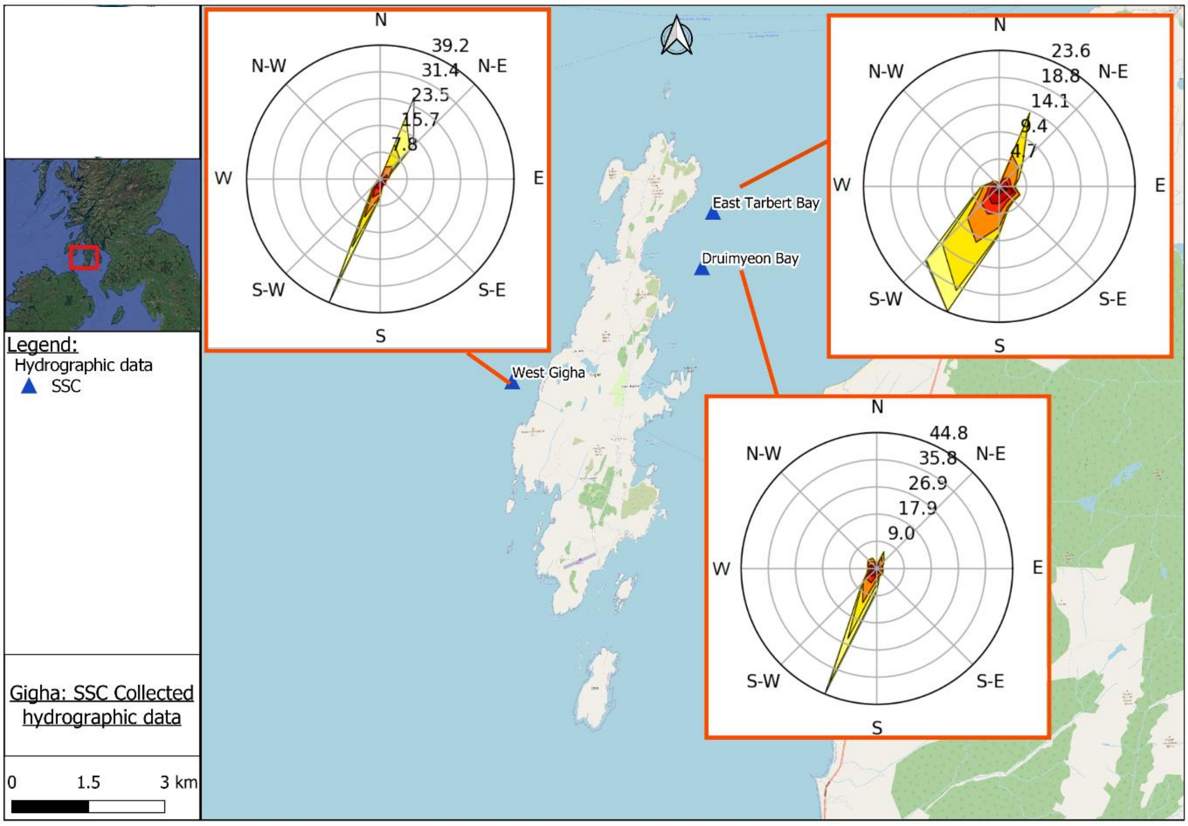


Figure 2.4: Observed current roses at hydrographic meter deployment locations.

2.5.3 Wave Conditions

The wave conditions in the area were reviewed using the North-West Shelf Re-analysis (NWSR) from January 2019 to January 2021[5] and the simulated wave climate for the Mull of Cara (south of the Isle of Gigha) can be seen in Figure 2.5.

The model illustrates a moderate wave climate with the approximate 1 in 1-year Significant Wave Height (*Hs*) of approximately 4m. It also demonstrates that the dominant wave direction is west-south-westerly originating from the Malin Sea area. The model also demonstrates a small contribution from southerly waves originating from the Irish Sea. The significant proportion of waves from westerly directions and their magnitude result in waves from this origin being considered the dominant wave conditions at the west of Gigha, whilst the BFS sites to the east of Gigha are likely influenced from southerly swells.

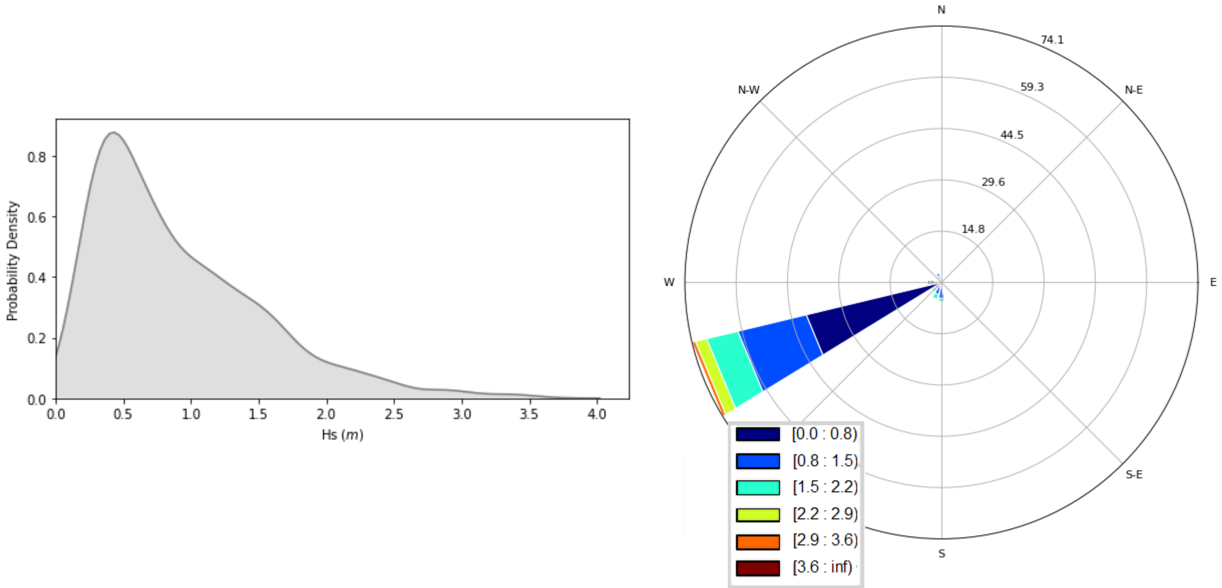


Figure 2.5: Wave conditions for Gigha. Data generated from CMEMS hindcast 2019-2020[5]

2.6 Modelling Approach

The dispersal of aquaculture related discharges was assessed in the MIKE3 simulaton package, with hydrodynamic forcing conditions derived from two independent modelling exercises, outlined below:

- **WESTCOMS**: A 3D baroclinic, hydrodynamic model used to force the dispersal of Feed and Faeces over a period of 365 days
- **BFS Gigha HD**: A bespoke 3D baroclinic, hydrodynamic model, with atmospheric heat exchange with high resolution within the area of interest. This will be used to force the dispersal of bath treatments.

The Particle Tracking model domain is a refined version of the BFS Gigha HD model with released particles taking a “superindividual” approach (each simulated particle is representative of multiple “real” particles). Five simulation scenarios were undertaken as outlined in table 2.2. These will apply SEPA default parameters[6] to model forcing (outlined in greater detail in Section 3.6).

[5] Tonani, M., Sykes, P., King, R. R., McConnell, N., Péquignet, A. C., O'Dea, E., ... & Siddorn, J. (2019). The impact of a new high-resolution ocean model on the Met Office North-West European Shelf forecasting system. *Ocean Science*, *15*(4), 1133-1158.
[6] SEPA (2022) Interim Marine Modelling Guidance_Draft _20211215_final.docx

Table 2.2: Proposed simulation scenarios

Particle assessed	Timespan (Days)	Dosage	Period assessed
Feed and Faeces	365	Assume 7kg/feed/tonne/day	Annual
Azamethiphos (AZA)	7	Reviewed to simulated EQS and MAC*	Peak *neap* tidal vectors
Azamethiphos (AZA)	7	Reviewed to simulated EQS and MAC*	Peak *spring* tidal vectors
Deltamethrin (Del)	7	Reviewed to simulated EQS*	Peak *neap* tidal vectors
Deltamethrin (Del)	7	Reviewed to simulated EQS*	Peak *spring* tidal vectors

** - This process is outlined in greater detail in Sections 3.7 and 3.8*

2.6.1 Simulation Package

The simulation package chosen to simulate the dispersal conditions of BFS sites in the vicinity of the Isle of Gigha is the MIKE suite of model packages, hosted by DHI Consulting. Given the role of three-dimensional (3D) processes in the dispersal of particles from the farms, 3D simulations were considered vital to accurately represent the process undertaken. MIKE 3 includes the simulation tools to model 3D free surface flows, density and heat driven interchange and associated sediment, ecology and water quality processes. The following module available within MIKE 3 was used during this study:

- ***HD – Hydrodynamics***: This module simulates the water level variations and flows in response to a variety of forcing functions according to the Reynolds averaged Navier-Stokes equations and their simplifications, conserving momentum, temperature, salinity and density. It includes a wide range of hydraulic phenomena in the simulations and provides the basis for simulations performed in subsequent modules. Modern flexible, triangular mesh was used to facilitate the interchange between locations using a semi-implicit simulation approach.

Hydrodynamic model output will then be applied to track particle dispersion using the MIKE3 Particle Tracking module, described briefly below:

- ***Particle tracking***: MIKE Particle tracking module can be run with 2D and 3D simulations and allows particles to be simulated as passive particles, carried within the water column. This module follows a Langrangian computational framework and is less computationally expensive than the alternative Eulerian framework.

The MIKE 3 Model used for the present study was version 2022.

3. Model Setup

As outlined in Section 2.6 there are five modelling tasks required to successfully simulate the dispersion of aquaculture relevant material, with additional model sensitivity testing. The setup of the MIKE3 particle tracking model is outlined in the following sections.

3.1 Model Runs

Three model simulations were performed using the parameters outlined in table 3.1. A single simulation was undertaken to simulate and assess the cumulative feed and faeces deposition, covering 365 days. Two additional simulations were undertaken to review the dispersion Azamethiphos and Deltamethrin under spring and neap tide conditions, respectively.

3.2 Particle Properties

Particle tracking was implemented to assess the medium scale (0.5-5 km) to far-field (<10 km) impact of farm associated releases of solids (Feed and Faeces) and Bath treatments, supplementing an additional risk assessment undertaken in NewDepomod, which assesses the near-field impact of feed and faeces, and superseding BathAuto simulations submitted at Pre-application stage.

A Lagrangian framework was adopted to track the diffusion, dispersion and ultimate fate of the simulated releases from the farm. It is proposed that four different types of particles are released from the proposed farm with their behaviour defined by physical properties or SEPA guidance where available; these are summarised in table 3.1 and discussed in greater detail below.

Table 3.1: Particle classes proposed for simulations.

Type	Particle	Buoyancy	Resuspension	Decay	Release type	Inputs	Simulation period
Waste Solids	Feed	No	Yes	No	Continuous	SEPA defined	1 year
	Faeces	No	Yes	No			
Bath Medicine	Azamethiphos	Neutral	-	Yes	Instantaneous	Vet Defined	Spring & Neap
	Deltamethrin	Neutral	-	No			

3.3 Model Mesh

The three-dimensional model was setup in MIKE 3, using a UTM-29 projection, with an unstructured mesh generated in BlueKenue. The mesh includes variable node spacing along the shoreline, element growth constrained by bathymetry and increased resolution close to existing farms and oceanographic features of interest. A representation of the model mesh can be seen in figure 3.1. The mesh includes 107,017 nodes and 200,320 elements.

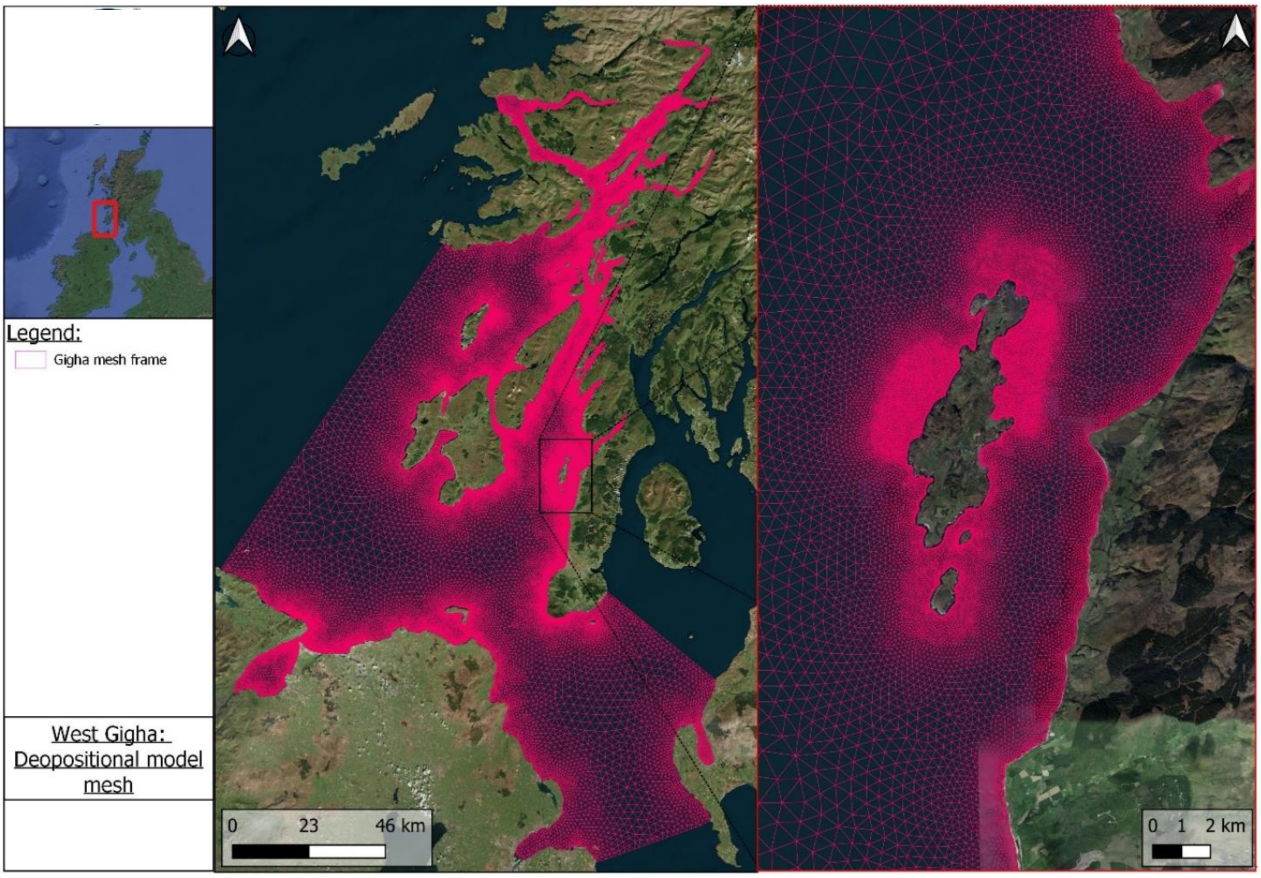
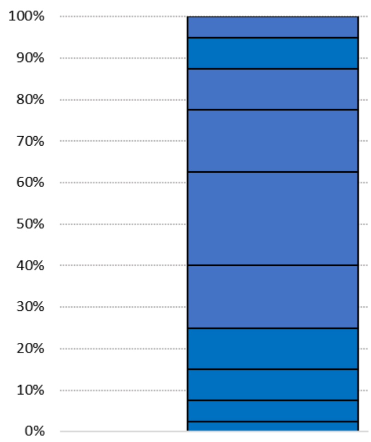


Figure 3.1: BFS Gigha Depositional Model Mesh used in simulations.

The model was vertically discretised into 10 variable sigma depth layers to better represent stratification throughout the domain. These divisions can be seen in table 3.2. Increased resolution of sigma layers was included at the surface and bed layers to better represent the interaction with atmospheric conditions and bed friction.

Table 3.2: Vertical discretising in Gigha domain

Layer	% of Water Column
1	0.05
2	0.075
3	0.1
4	0.15
5	0.225
6	0.15
7	0.1
8	0.075
9	0.05
10	0.025



3.4 Reference Systems

All model spatial data was converted to a UTM-29N (ESPG:32629) projection. All bathymetry data was maintained in Chart Datum (mCD) and converted to Mean Sea Level (MSL) based on a conversion of 0.6 m (based on the Admiralty TotalTide conversion at the Sound of Gigha).

Model output from version 2 of the West Scotland Coastal Ocean Modelling System (WeStCOMSv2) was transformed from WGS84 to UTM-29 using GDAL built-in functions, maintaining consistency with the bespoke modelling undertaken by BFS and the particle tracking mesh.

It is recognised that the conversion from CD to MSL varies throughout the model domain as the charted surface deviates from reference geoids. However, given the localised area of interest (Gigha), the conversion to MSL was considered to be within measurement error of the composite bathymetry used.

3.5 Bathymetry

Bathymetry was used from multiple public sources presented below, in order of priority. This priority list was devised based on the source accuracy of the data, the degree of interpolation in the spatial DTMs and the resolution of the data.

- UKHO /Admiralty online bathymetry portal (Crown copyright)[7]
- EMODnet DTM[8]
- OS Mean High-Water Springs (MHWS) polyline[9]
- GEBCO DTM[10]

It should be noted that GEBCO data was used solely in the vicinity of the shoreline, where alternative data was not available. Due to the poor accuracy of this data (as assessed against BFS spot-depths and Admiralty DTMs) and the absence of suitable terrestrial datasets (LiDAR), areas of GEBCO data were manually reviewed to assess the suitability of nearshore areas not covered by high quality EMODnet or UKHO bathymetry. BFS holds additional, localised single-beam bathymetry survey in the area, however this data was not included in the modelling as all datasets reviewed overlapped the extent and coverage of UKHO data, which is considered of greater accuracy and consistent with large areas of the domain.

3.6 General Model Setup

Two general model setups were applied to review the dispersal of the four simulated particles releases. These releases were simulated based on the output flow vectors and stratification properties generated from hydrodynamic simulations reviewed by model developers DHI. Some minor modifications were undertaken to increase the suitability of the model and to improve the simulation approach, bringing the methodology in line with regulatory requirements. Selected significant modifications are outlined briefly in table 3.3 along with selected parameters applied in the particle tracking module.

Table 3.3: General particle tracking model setup

Parameter	Modification
Mesh	Mesh developed and applied in the BFS Gigha domain for 3D HD simulations was refined, yielding an average cell size of 1,250m^2 (equivalent to an 35x35 m cartesian grid), within the vicinity of the farm.
Horizontal diffusion	Distribution of vertical sigma layers increases the resolution at the surface and bed.
Horizontal diffusion	Set to 0.1 m^2/s. *
Vertical diffusion	Set to 0.001 m^2/s.

[7] Admiralty Maritime Data Solutions (2020), Bathymetry Data Service, Crown Copyright 2020, UK hydrographic office/ [Accessed online 14/01/2021 - https://datahub.admiralty.co.uk/portal/apps/webappviewer/index.html?id=bd7cb85270ce4366bf0db9f515c37fae]
[8] EMODnet (2020) EMODnet Bathymetry portal. [Accessed online 15/01/2021 - https://portal.emodnet-bathymetry.eu/]
[9] OS (2021) MHWS vector layer. [Accessed online 15/01/2021 https://osdatahub.os.uk/downloads/open]
[10] GEBCO Compilation Group (2020), GEBCO 2020 Grid [Accessed online 15/01/2021 https://www.gebco.net/data_and_products/gridded_bathymetry_data/]

3.7 Feed and Faeces Simulations

The rate of feed and faeces input into the model will be defined according to NewDepomod iterations that were reviewed by SEPA at the pre-application stage. The dispersal of waste particles will be assessed against Mixing Zone requirements (as with NewDEPOMOD assessments and SEPA requirements) and the dispersal of waste feed and faeces will be reviewed at the location of known benthic Priority Marine Features (PMF) and active CAR licences in the area (discussed in Section 0).

The influence of feed and faeces will be reviewed “in combination” with discharges from Marine Pen Fish Farms outlined in SEPA’s Screening Report, assumed to be at peak biomass for 365 days, using standard feed rates (7kg/t/d) and feed conversion ratios. These existing farms and their consented biomass are outlined in table 3.4.

Table 3.4: Farms included in Feed and Faeces simulations.

Farm	Consented Biomass (T)
Druimyeon Bay	2,499
East Tarbert Bay	2,500

3.7.1 Model Setup

The feed and faeces particles will be simulated as released weighted particles. The model conditions will be representative of the annual deposition of the farm, as if stocked at peak biomass throughout the simulation period, and specific setups of the two particle classes proposed are outlined in table 3.5 with select parameters applied presented in table 3.5.

Table 3.5: Solids input

	Feed	Facies
Release position	Pen midpoint	Pen midpoint
Release mass	0.8582 g/second	4.1622 g/second
Simulation period	365 days	
Particle representation	1	5
Total particles released	3.154×10^{7}	1.577×10^{8}
Settling velocity	0.095 m/s	0.032 m/s
Erosion threshold	0.02 N/m²/s	

3.7.2 Hydrodynamics – FVCOM: WESTCOMSv2 Domain

The dispersal of Feed and Faeces is required over a period of 365 days to satisfy SEPA licencing requirements. To assess this, hydrodynamic output from WeStCOMSv2 was converted from NetCDF to dfsu format and input to MIKE to force a 365 day simulation of the dispersal of feed and faeces on the WeStCOMSv2 grid resolution. WeStCOMS was developed by The Scottish Association of Marine Science (SAMS), and is a 3D baroclinic hydrodynamic model, developed using the Finite Volume Community Ocean Model (FVCOM) and forced by the NE-Atlantic ROMS model and atmospheric data from an inhouse implementation of the Weather Research and Forecasting model (WRF), which uses atmospheric boundary forcing derived from the Global Forecast System (GFS) weather forecast model. The model mesh can be seen in figure 3.2.

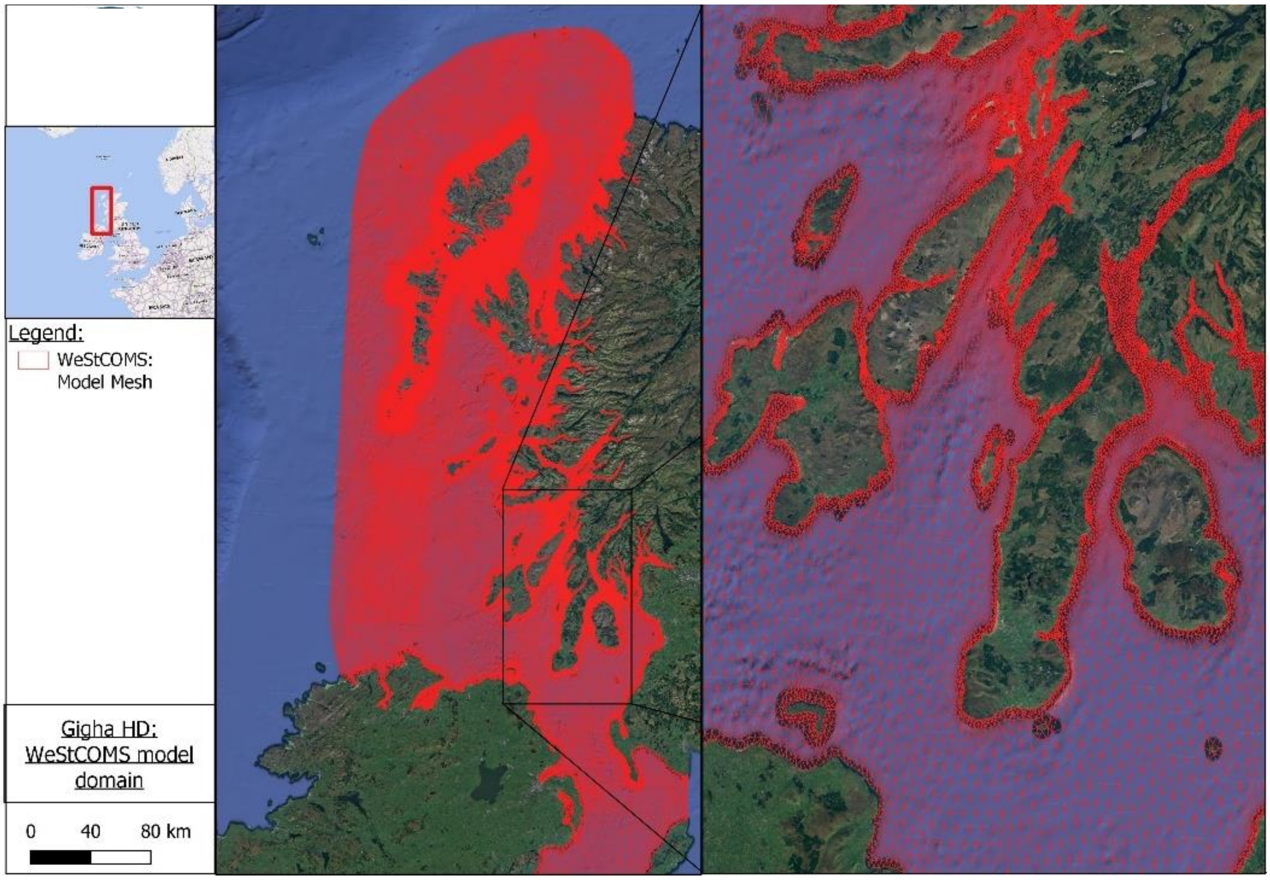


Figure 3.2: WESTCOMS model domain extent

365 days of model output were extracted and merged to generate a seamless timeseries of water level and hydrographic conditions from 30/09/2020 to 30/09/2021.

Validation

WeStCOMSv2 hydrodynamics were validated against the 92-days of observed hydrographic data at the West Gigha location. This validation exercise indicates that the model poorly replicates observed water level records but well approximates velocity shear throughout the water column and accurately predicts surface and bed velocities. The figures in table 3.7 demonstrate that WeStCOMS flow vectors closely replicate observed conditions in both datasets and throughout the water column. The model predicts higher velocities than observed (13.7% & 11.4%, respectively) but reproduces a similar velocity probability distribution. Velocity vectors are also well replicated within the model domain, approximating the observed flow pattern.

The poor performance of water level at this location is attributed to the micro-tidal regime and the proximity to an amphidromic point. Given that the model well replicates the observed velocity conditions at the site, the impact of water level predictions on the ultimate horizontal fate of released particles is not considered significant.

The WeStCOMSv2 model is considered to replicate observed velocity vectors well at both BFS hydrographic meter deployments (totalling 92 days). The application of these simulated conditions to force dispersal of feed and faeces is considered a good approximation of annual depositional patterns and will produce a detailed, robust and accurate simulation of the ultimate fate of particles released from the proposed farm location and from the two existing farms at Druimyeon Bay and East Tarbert Bay.

Model Credibility

This model has been developed independently of BFS and has been made available under licence for the review of the dispersal of aquaculture related discharges from BFS farms. The model is used extensively throughout the industry and by SEPA for the assessment of particle dispersal from aquaculture sites. Consequently, WeStCOMSv2 3D hydrodynamic model output was chosen to drive particle tracking simulations of solid dispersal in the remainder of this report.

3.7.3 Review

As with prior NewDepomod simulations, the average deposition over the final 90-days of simulation will be taken to review the impact of the annual deposition of the farm and mitigate the impact of any migratory depositional features.

3.8 Bath Treatments Simulations

The impact of bath treatments will be reviewed in combination with congruent releases from existing BFS farms at Druimyeon Bay and East Tarbert Bay. The existing sites will be simulated based on previous releases of bath treatments at BFS farms.

3.8.1 Model Setup

Bath treatment scenarios simulating the releases from all farms will be reviewed in two scenarios with treatment of all pens occurring over a Peak Spring and a Peak Neap tidal cycle. Table 3.6 outlines the general model setup, specifically for bath treatments.

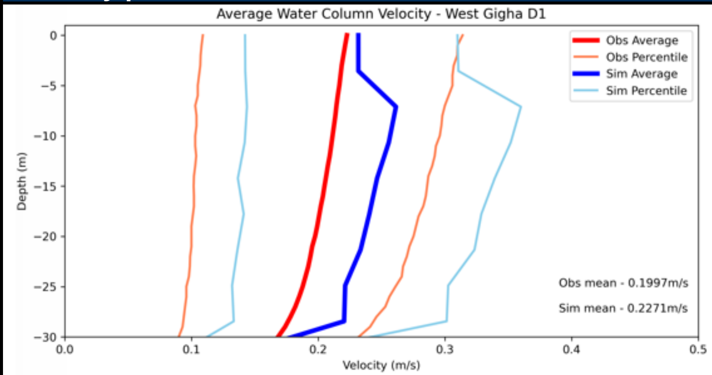
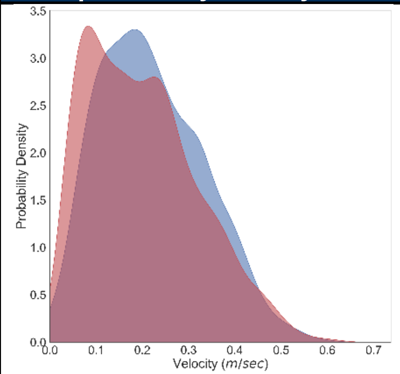
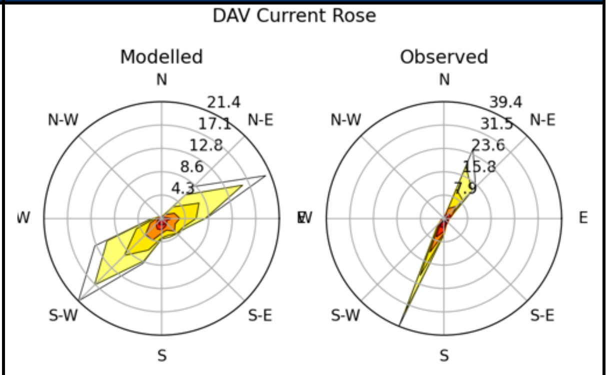
Table 3.6: Bath treatment model setup

	Proposed Site
Release position	Pen centres, 3 m below surface
Dosage	Released as a medicinal dose based on tarpaulin volume at specified depth
Releases	Three releases per day at three-hour intervals during daylight: 1100, 1400, 1700
Particle representation	1000 particles/ 1 gram Azamethiphos 5000 particles/ 24 gram Deltamethrin
Release format	Instantaneous release of treatment quantity at pen centre
Simulation period	Six days
Azamethiphos decay	5.6 days Half-Life[11]
Deltamethrin decay	Not applied

[11] DEFRA (2020) Summary of Product Characteristics: Vet, 500 mg/g Powder for Suspension for Fish Treatment. [Available online 25/01/2022: https://www.vmd.defra.gov.uk/productinformationdatabase/files/SPC_Documents/SPC_720682.PDF]

Table 3.7: WESTCOMSv2 model validation over the two observed ADCP deployments at West Gigha

<table>
<tr><th></th><th>Velocity profile</th><th>DAV probability density</th><th>Directional Roses</th></tr>
<tr><td>Deployment 1:
17/03/2021 -
07/05/2021

51 Days</td><td>
</td><td>
</td><td>
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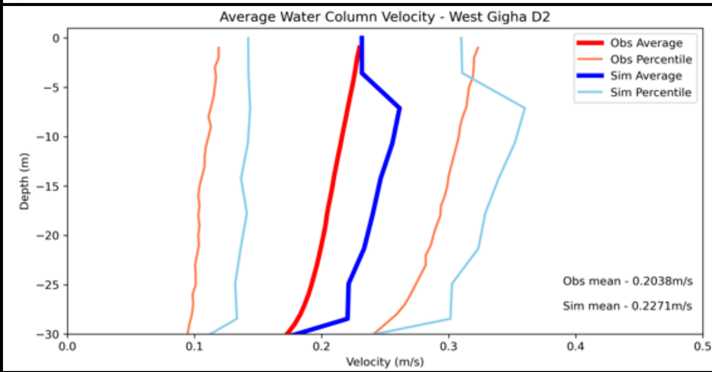
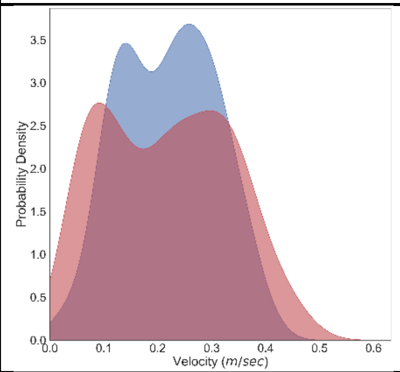
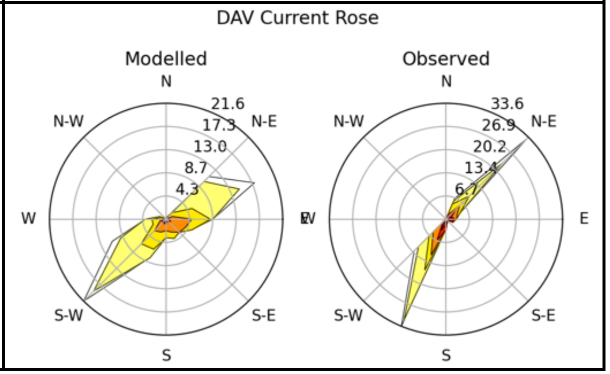
17/06/2021

41 Days</td><td>
</td><td>
</td><td>
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3.8.2 Hydrodynamics - MIKE3: BFS_Gigha Domain

BFS maintains a validated 3D hydrodynamic (HD) model for the Sound of Jura and the Isle of Gigha as displayed in figure 3.3. The model was developed using the MIKE3 simulation suite. The mesh was developed using BlueKenue and covers an area from Loch Sunart to Malin Head, east to Belfast Lough / the Rinns of Galloway and north to Campbeltown, including Loch Linnhe, the Sound of Mull and Lough Foyle. Using 10 sigma layers, the model is forced from the North-West Shelf Reanalysis (NWSR) [12,13 & 14] model, developed by the UK Met Office and hosted by the Copernicus Marine Service.

The 3D hydrodynamic simulations were developed in-house by BFS and a full report itemising model setup, the datasets applied, and calibration/validation of the model is provided in **APPENDIX A: BFS Gigha HD** modelling report.

Validation

The model was validated against 92 days of hydrographic ADCP data recorded at West Gigha and at four BODC water-level gauges within the model domain. Four additional ADCP deployments were also used to validate the model in the vicinity of the Isle of Gigha.

The model was found to replicate the observed hydrodynamic flow conditions well at West Gigha, accurately simulating the velocity vectors throughout the water column and closely replicating observed temperature conditions at the bed. The model performance over the two deployment periods at West Gigha, the four additional deployments and at the four water level gauges are outlined in detail in **Appendix A: BFS Gigha HD** modelling report.

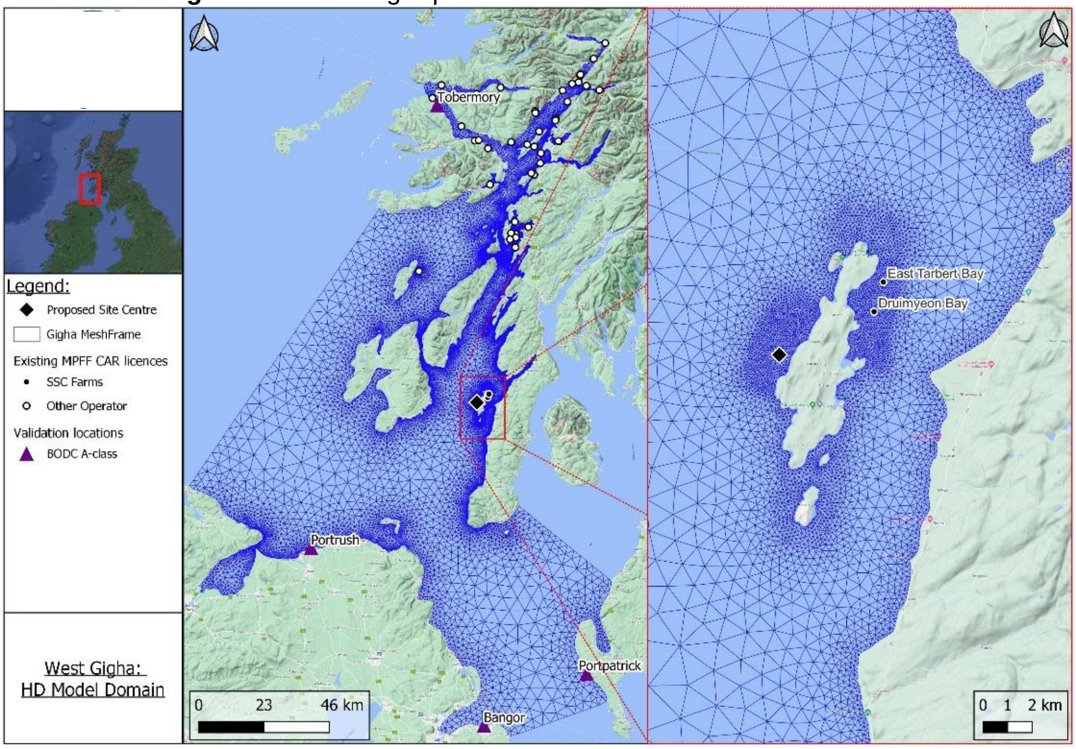

Figure 3.3: BFS Gigha Hydrodynamic Domain in MIKE3 with proposed West Gigha location

[12] Tonani, M., Sykes, P., King, R.R., McConnell, N., Péquignet A-C., O'Dea, E., Graham, J.A., Polton, J., Siddorn, J.: The impact of a new high-resolution ocean model on the Met Office North-West European Shelf forecasting system], Ocean Sci., '''15''', 1133–1158, 2019. https://doi.org/10.5194/os-15-1133-2019

13 Lewis, H., Castillo Sanchez, J. M., Siddorn, J., King, R., Tonani, M., Saulter, A., Sykes, P., Péquignet, A.-C., Weedon, G., Palmer, T., Staneva, J., and Bricheno, L.: Can wave coupling improve operational regional ocean forecasts for the North-West European Shelf], Ocean Sci., '''15''', 669–690. https://doi.org/10.5194/os-15-669-2019

14 Crocker, R., Maksymczuk, J., Mittermaier, M., Tonani, M., and Péquignet A-C.: An approach to the verification of high-resolution ocean models using spatial methods], Ocean Sci., '''16''', 831–845, 2020. https://doi.org/10.5194/os-16-831-2020

3.8.3 Review

The particle dispersal from the proposed farm is assessed against the calculated Environmental Quality Standard (EQS) and Maximum Allowable Concentration (MAC) and will be reviewed and solved according to the specification in table 3.8 to identify the maximum permissible treatment quantity at each of the relevant time periods will be reviewed. The permissible quantity will then be identified as the smallest quantity that satisfies all standards for both hydrographic climates.

Table 3.8: Bath treatment review partitions and standard assessed against

Time since last treatment:	3 hr	6 hr	72 Hr
Azamethiphos	EQS	-	EQS & MAC
Deltamethrin	-	EQS	-

Model Credibility

The hydrodynamic model was reviewed by software developers at DHI Consulting, assessing model setup, performance and suitability for the proposed application, of evaluating the dispersal of aquaculture related discharge within the model domain. DHI's summary of the hydrodynamic modelling package concluded that the model is "considered very good for risk-based assessments at the vicinity of the development area" (C.Mitsis, DHI, 2022).

The model is therefore considered appropriate for the proposed application in reviewing particle dispersal from farms within the area surrounding the Isle of Gigha. Subsequently, outputs from this 3D Hydrodynamic model were used to drive particle tracking simulations of bath treatments for two, six-day periods, corresponding to Spring tide (starting 26/04/2021) and Neap tide (starting 19/04/2021).

3.9 Sensitive Features

The SEPA Screening Report outlines a limited list of PMFs that should be included in the hydrodynamic modelling undertaken. These features are presented in Table 3.9, along with existing CAR licences within the area, including two within Loch Caolisport. The impact of the four released particle classes will be reviewed at these sensitive features and presented within the final modelling report.

Table 3.9 : Sensitive features within the area

Feature Name	Distance to proposal (km)	Feature Type	Brief Reason For Identification
Northern Sea Fan and Sponge Communities	1.2	PMF	At risk from bath and sediment influence
Maerl Beds	2.9 5.2 7.5	PMF	At risk from sediment influence
East Tarbert Bay	4.3	Marine Pen Fish Farm	At risk from bath and sediment influence
Druimyeon Bay	5.2	Marine Pen Fish Farm	At risk from bath and sediment influence
Horse Mussel Beds	5.6	PMF	At risk from bath and sediment influence
Laith Eilean	24.6	Marine Pen Fish Farm	At risk from bath and sediment influence
Eilean Fada	28.9	Marine Pen Fish Farm	At risk from bath and sediment influence

BFS also undertook a public consultation online on 05/04/2022 and in Gigha Village Hall on 06/04/2022. No additional PMFs were identified as part of this consultation.

3.10 Model Conservatism

The modelling undertaken and presented in this report was considered a conservative estimate of the conditions at the site. Where possible, cautious modelling assumptions were employed to reduce the risk of non-compliance. Conservative assumptions included:

- *Releases are simulated as a point source from a single m^3*: In reality, releases of medicines and solids will occur in the tarpaulin/cage area and subsequently will be significantly more diffuse at the initial timestep and be subject to greater velocity shear, encouraging accelerated diffusion and lower concentrations.
- *Tarpaulin treatments simulated:* It is likely that bath treatments will be undertaken in well-boats with a lower volume and an extended discharge period. This will result in less medicament required and releases in lower quantities.
- *Additional Deltamethrin modelled:* 2g more deltamethrin were modelled than would likely be used in treatment.
- *Feed and Faeces releases based on peak tonnage throughout the year in all farms*: Biomass within a farm grows over a production cycle, with harvesting occurring close to consented biomass. It is therefore improbable that all three farms simulated in combination will be maintained at peak biomass simultaneously for a year period. The Feed and Faeces simulated is in excess of any probable scenario.
- *Simulation of Spring and Neap conditions:* The simulation of Spring and Neap tidal conditions reviews two extreme hydrodynamic conditions and allows the assessment of conditions under high velocities.
  - Spring: Maximum velocity shear, tidal excursion and widespread dispersal.
  - Neap: Reduced velocity shear and tidal excursion, limiting dispersal and increasing local concentrations.

4. Model Outputs

The outputs of the two modelling exercises are presented below. All assessments were undertaken using a combination of GIS, script-based packages and MIKE Zero. As requested by SEPA, the following model outputs were presented to SEPA with the application. File formats are provided:

- Time series of concentrations of Azamethiphos over Spring period *(.dfsu)*
- Time series of concentrations of Deltamethrin over Neap period *(.dfsu)*
- Bath treatment element areas, relevant to EQS *(.shp)*
- Averaged deposition over final 90 days for West Gigha, Druimyeon Bay and East Tarbert Bay. *(.dfsu)*
- Averaged deposition over final 90 days for West Gigha, Druimyeon Bay and East Tarbert Bay *(.shp)*

NB: SEPA additionally requested a timeseries of the 250g/m^2/year contour of solid releases. Once coastal elements deemed to be model artefacts were removed from the analysis, no cells exceeded the 250g/m^2/yr threshold.

4.1 Feed and Faeces

The release of waste feed and faeces (solids) from the proposed farm was simulated to review the potential fate of these products on the benthic environment and on selected sensitive features. The impact of solid releases were reviewed using a “developed” scenario (West Gigha releases in simulated isolation) and an “in combination” scenario (West Gigha releases simulated with existing significant discharges). Both scenarios are outlined in greater detail below.

4.1.1 Developed: West Gigha Solid Dispersal

The feed and faeces representative particles released from the site are dispersed over a very large area, generally accumulating in small quantities on the seabed or in higher quantities at the shoreline. The high levels of dispersal simulated here indicate minimal deposition and consolidation based on SEPA’s recommended particle properties. A timeseries of maximum and average total solids and average suspended and sedimented solids over the model domain during the simulation is shown in figure 4.1 which shows a steady accumulation of solids within the domain without reaching equilibrium during the course of the simulation.

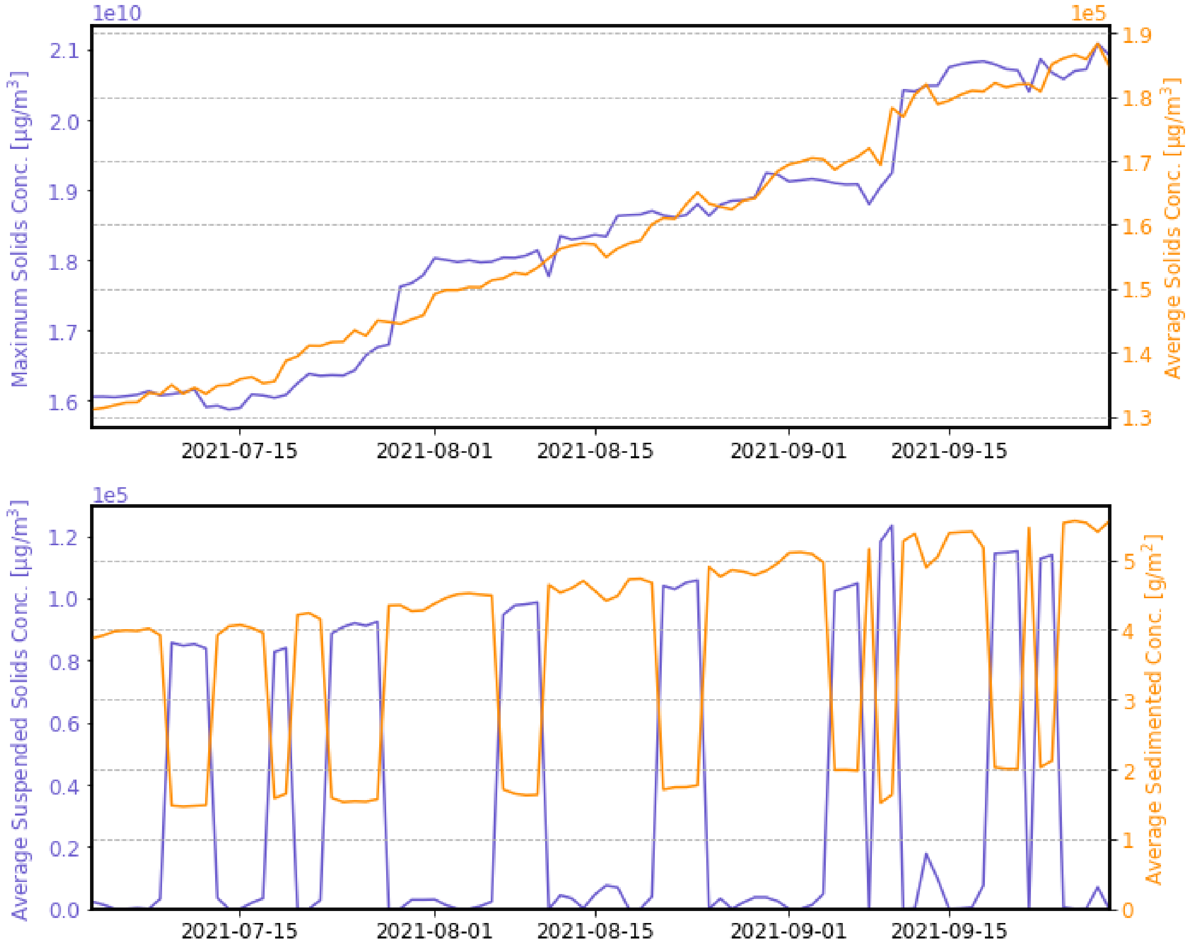

Figure 4.1: Time series of maximum and average total solids (top) concentration [µg/m^3] and average suspended [µg/m^3] and sedimented [g/m^2] solids (bottom) concentrations over the model run period.

The spatial pattern of solid dispersal for the West Gigha site is displayed in figure 4.2. It demonstrates the dispersion of feed and faeces over an extensive area, stretching from south of the Mull of Kintyre to the northern Sound of Jura and Western Islay. The extent of this dispersion is generally through the resuspension phase as, with the 0.02N/m^2 erosion threshold specified by SEPA, the deposition rarely remains deposited on the bed.

Figure 4.2 shows the simulated deposition of solids releases from the proposed farm. These releases cover a wide area and rarely exceed 0.5 g/m^2/yr. The primary area of deposition is along the west of Gigha, parallel to the shoreline and dominant flow vectors here. We also see some limited deposition to the east of the island, within the channel. The model simulates some localised exceedances of 2 g/m^2/yr next on the shoreline or within shallow bays where velocities are less and sediment is retained by the shoreline. The deposition rates here are several orders of magnitude below SEPA's Mixing Zone threshold of 250 g/m^2/yr and are thus the solid dispersal from this site is anticipated to have minimal impact on the benthic environment beyond 1km from the proposed farm.

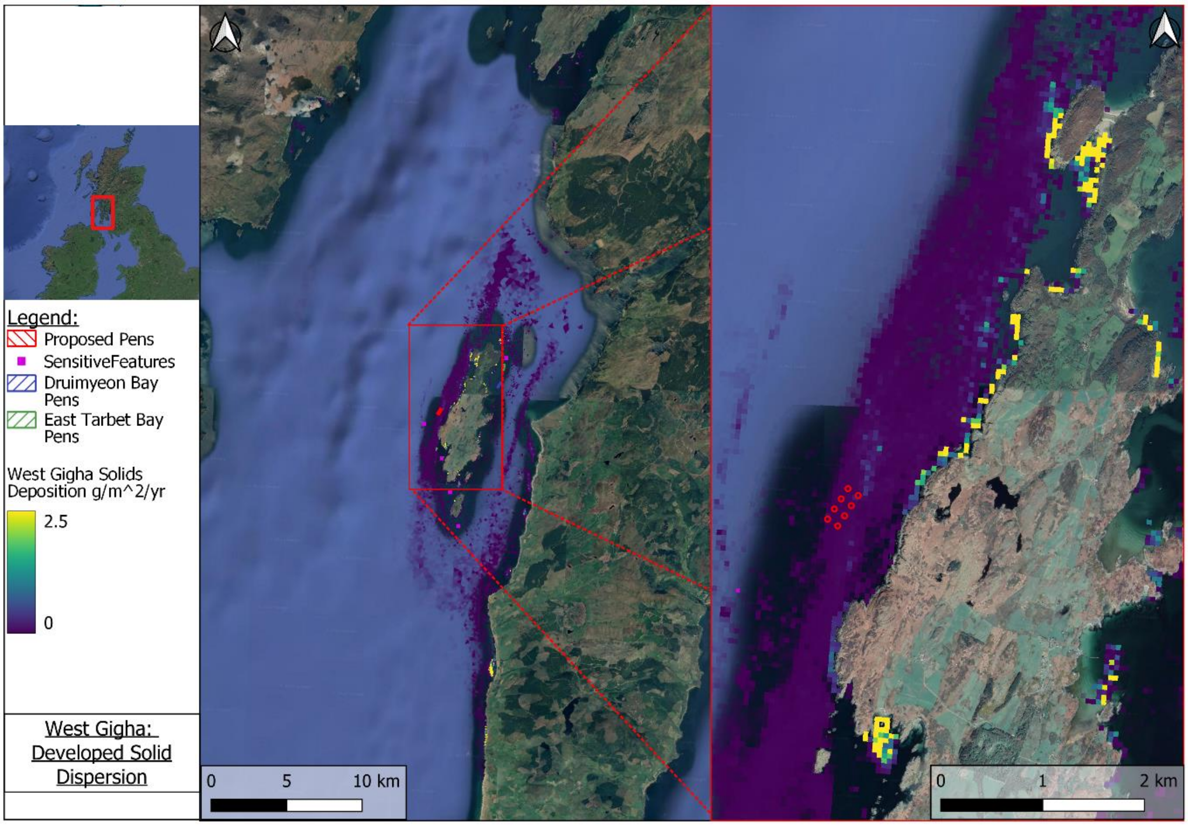

Figure 4.2: Solids deposition [g/m^2/year] from the West Gigha farm site. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features close to the farm site.

Based on the simulated deposition rates in the area, the impact of the proposed farm on the benthic environment at the medium to large scale is considered minimal and the Mixing Zone is not breached.

It should be noted that a formal Risk Assessment of waste solids has been undertaken in NewDepomod, applying SEPA's Standard Default Method (outlined in an accompanying report). This exercise found the proposed tonnages and associated benthic impact was deemed acceptable.

4.1.2 In Combination: West Gigha and Existing Site Solid Dispersal

The proposed site was simulated in combination with East Tarbert Bay and Druimyeon Bay with all sites simulated at peak biomass with default feed rates for 365 days. The ultimate accumulation of Feed and Faeces was averaged over the final 90-days of the simulation. The spatial distribution of the releases is visible in 3. As anticipated, with the addition of farms to the East of Gigha, deposition of waste solids is more significant here. As with the "Developed" scenario, the model simulates deposition along bathymetric features, along the shoreline and within bays where sediment is trapped by eddies and deposited by slower currents. The impacted area is bigger, largely due to the additional 4,999T of stocked biomass.

It should be noted that the depositional patterns around Druimyeon Bay and East Tarbert Bay are not corroborated by long term benthic sampling exercises undertaken at these farms which outlines much greater deposition under the pens. This is likely a result of the low critical shear stress for erosion advised by SEPA modellers. The dispersion simulated here is thus considered unrealistic.

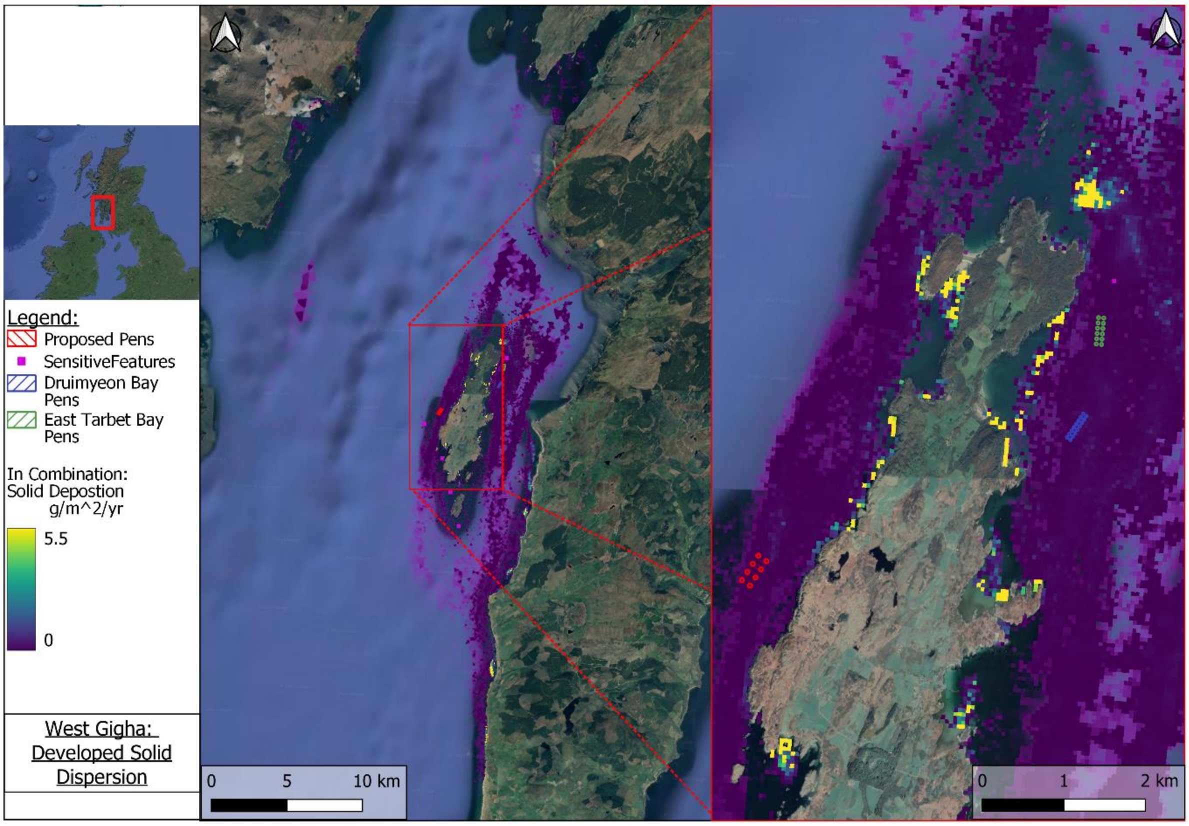

Figure 4.3: In combination Solids deposition [g/m^2/year] from West Gigha, Druimyeon Bay and East Tarbert Bay. Blue and green circles indicate the pen locations at existing farms, Druimyeon Bay and East Tarbert Bay. Red circles indicate the proposed pen locations at the West Gigha farm site. pink dots indicate the location of identified Priority Marine Features.

At the time of writing, no criteria exists for the assessment of "in combination" runs and so no formal assessment was undertaken.

4.1.3 Impact on Sensitive Features

A 500m buffer was imposed around the charted locations of the nine PMFs and sensitive features outlined in Table 3.9. The simulated average and maximum deposition from West Gigha and all farms are presented in table 4.1. The table shows that solids (waste feed and faeces) released from the proposed development at West Gigha will have a very small impact at all sensitive features outlined, with average deposition rates less than 0.005 g/m^2/yr with a peak simulated deposition less than 0.4 g/m^2/yr (with the exception of East Tarbert Bay). No deposition was predicted to occur at the Northern Sea Fan and sponge communities). The simulated deposition rates outline slightly elevated deposition rates at the three Mearl Bed communities, but these increases are considered low and well within natural sediment movement patterns. The impact at the Horse Mussel Beds, Laith Eilean, Druimyeon Bay and East Tarbert Bay are a small proportion of the existing depositional pressure on these features from the existing farms at Druimyeon Bay and East Tarbert Bay.

Table 4.1: Solids impact on sensitive features

PMF/ Sensitive features	West Gigha: Deposition ($g/m^2/yr$)		In Combination: Deposition ($g/m^2/yr$)	
	Average	Max	Average	Max
Northern Sea Fan and Sponge Communities	0.0000	0.0000	0.0000	0.0000
Maerl Beds-1	0.0026	0.1209	0.0026	0.1209
Maerl Beds-2	0.0041	0.3827	0.0046	0.4354
Maerl Beds-3	0.0009	0.0197	0.0011	0.0238
East Tarbert Bay	0.0320	10.7355	1.7284	592.2344
Druimyeon Bay	0.0014	0.0688	0.0630	1.2135
Horse Mussel Beds	0.0032	0.2751	0.0826	1.9502
Laith Eilean	0.0032	0.2327	0.0430	1.7189
Eilean Fada	0.0000	0.0000	0.0000	0.0000

The proposed 3,104T farm at West Gigha is not considered to have a significant impact on PMFs and Sensitive features outlined by SEPA for impacts from waste feed and faeces.

4.2 Azamethiphos Dispersion

A single dose of Azamethiphos was simulated within the model, corresponding to an in-tarp concentration of 0.2 ppm of *Salmosan®* or similar (with 50% active ingredient). This dosage is a single prescribed dose required for the treatment of fish at the site. The dosage of Azamethiphos from each pen was subsequently calculated at 589.69 g and represented by 235,876 particles, cumulating in the release of 4,717.5 g of Azamethiphos across eight pens, over a 52-hour treatment cycle (assuming three treatments per day). In total 1,887,008 particles were released. Details of the calculations are presented in table 4.2 and the 3-Hour and 72-Hour EQS/MAC were taken following the final treatment of all pens. Timeseries of maximum Azamethiphos and Deltamethrin concentrations during the Neap and Spring tidal simulations are shown in figure 4.4.

It should be noted that the simulation strategy applied here assumes medicine administration via a tarpaulin with a volume of 5,897m^3. Given the size of the proposed pens at the site (160m *C*) it is unlikely that tarpaulin treatments will be undertaken, and bath treatments are likely to be undertaken in well boats. Well-boat treatments generally use less volume to treat and discharge water over a defined time period (varying from the instantaneous releases simulated here). Both these factors will decrease the amount of treatment released and increase the rate of diffusion of the treatment.

The instantaneous releases of bath treatments simulated here are thus considered highly conservative and demonstrate an extreme impact of the release of Azamethiphos from the farm.

An additional simulation was undertaken to review the impact of Azamethiphos at the 72-hour MAC. This is presented to explore modelling artefacts.

Table 4.2: Calculation of bath treatment quantities

Parameter		Value per pen	Additional Info
C* - Pen circumference *(m)		160	-
Treatment type		Tarpaulin	-
Cage Volume *(m³)*		20,371.8	-
Treatment Volume *(m³)*		5,897	29% of pen volume
Single Dose *(g)*	**0.2 ppm**	1,179.38	Dose of medicament, calculated based on medicine concentration and tarpaulin volume
Azamethiphos *(g)* *eg: Salmosan®*	**Single dose**	589.69	Active ingredient (AZA) is 50% of medicament
Deltametherin *(g)* *eg: Alphamax®*	**Single dose**	24	Per vet recommendation for 160m pen

These calculated treatment inputs are within the limits set for the site in bathauto.

Table 4.3: BathAuto standards and model results

Treatment Tarpaulin	BathAuto Mixing Zone (m²)	Permitted Treatment (g)
AZA	3.56E+5	890.95
DEL	1.01E+6	60.48

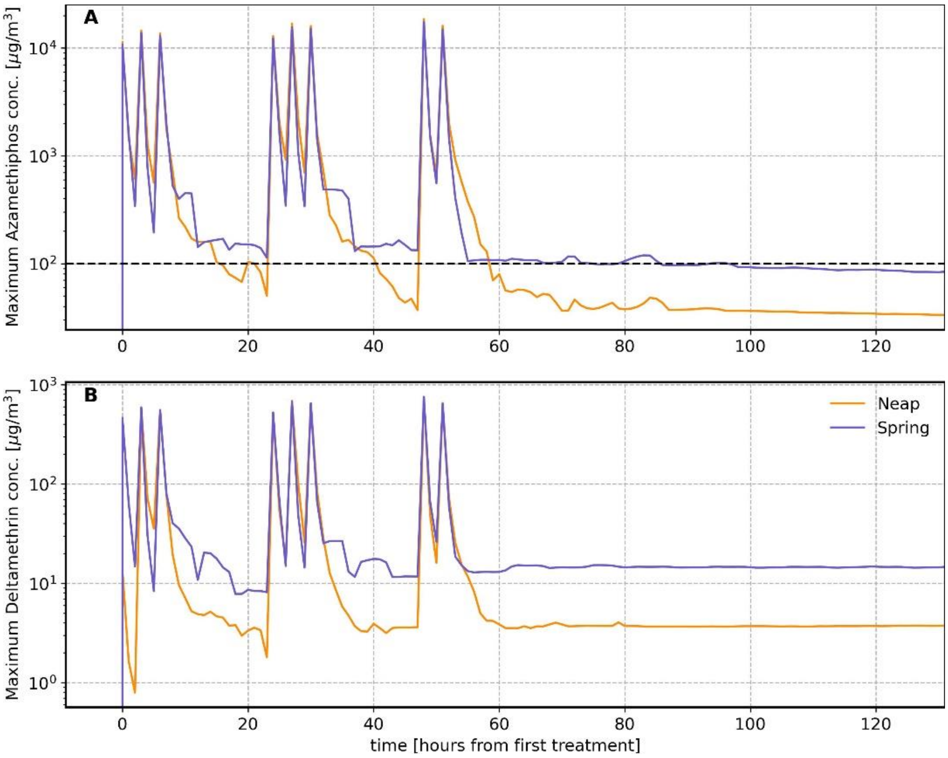

Figure 4.4: Timeseries of maximum Azamethiphos (A) and Deltamethrin (B) concentrations [µg/m³] during the Neap and Spring tidal simulations. Horizontal dashed line in (A) indicates the 72-hour MAC of 100 µg/m³. Timeseries ends 72 hours after final treatment. Elements highlighted as model artefacts in Table 4.5 have been removed before plotting.

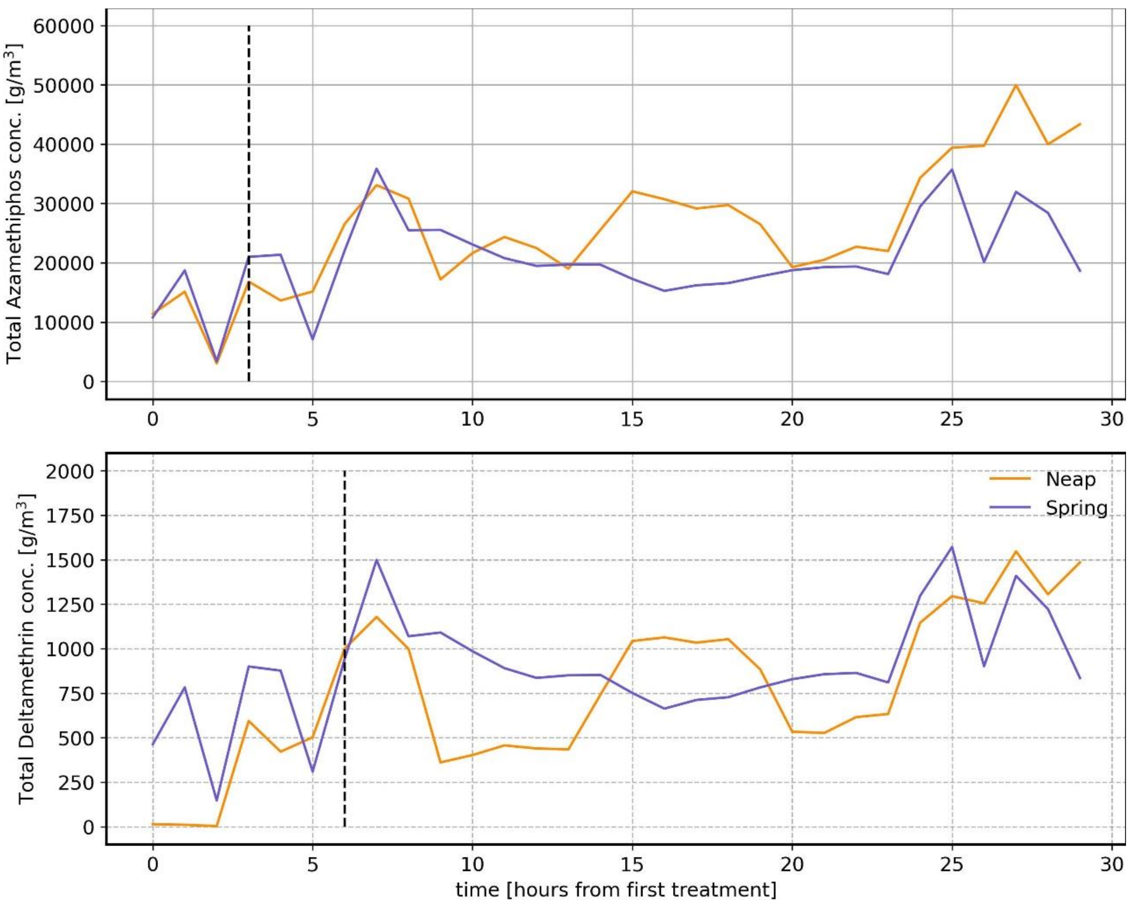

Figure 4.5: Timeseries of Azamethiphos (A) and Deltamethrin (B) concentrations [ng/l] summed across the domain for the initial 30 hours after first treatment. Vertical dashed line indicates the 3 hour EQS point for Azamethiphos (A) and 6 hour EQS point for Deltamethrin (B).

4.2.1 3-hour EQS

Under current guidance, the 3-hour EQS threshold for Azamethiphos is 250 ng/l. This was assessed at 20:00 on the first and second days of treatment and at 17:00 on the final day of treatment (with the treatment of the final site at 14:00). The peak concentration of each assessment time is presented in Table 4.4 and an image of the highest concentration (Neap hydrographic conditions 20:00, Day 1) is visible in 5.

Table 4.4: Azamethiphos concentrations for 3- hour EQS

Treatment day	Spring		Neap	
	EQS Area (km^2)	Max concentration (ng/l)	EQS Area (km^2)	Max concentration (ng/l)
Day 1 – 20:00	0.019819	846.48	0.005270	263.59
Day 2 – 20:00	0.001840	728.00	0.003848	280.60
Day 3 – 17:00	0.000760	275.56	-	575.44

NB: Modelled outputs were simulated in µg/m³. This is directly comparable to the ng/l specified in SEPA's guidance (1,000 l in a m³).

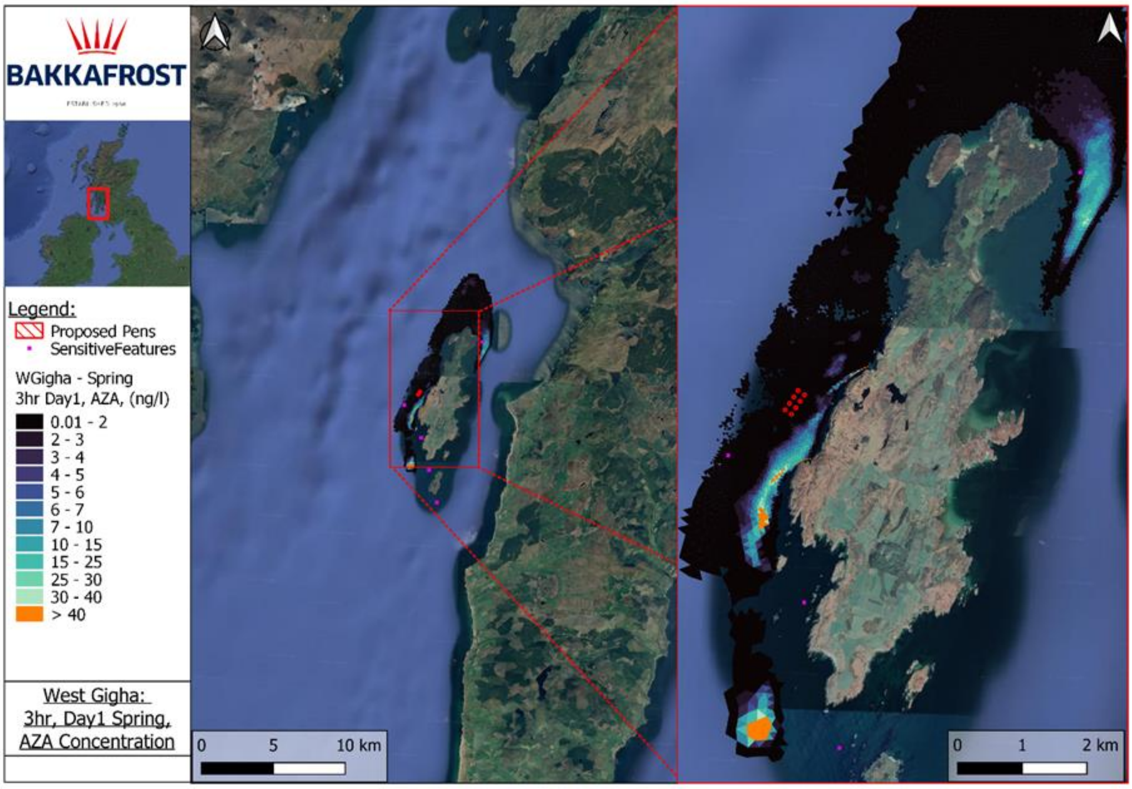

Figure 4.6: Azamethiphos concentration [ng/l] 3 hours after treatment during Spring tidal conditions. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features.

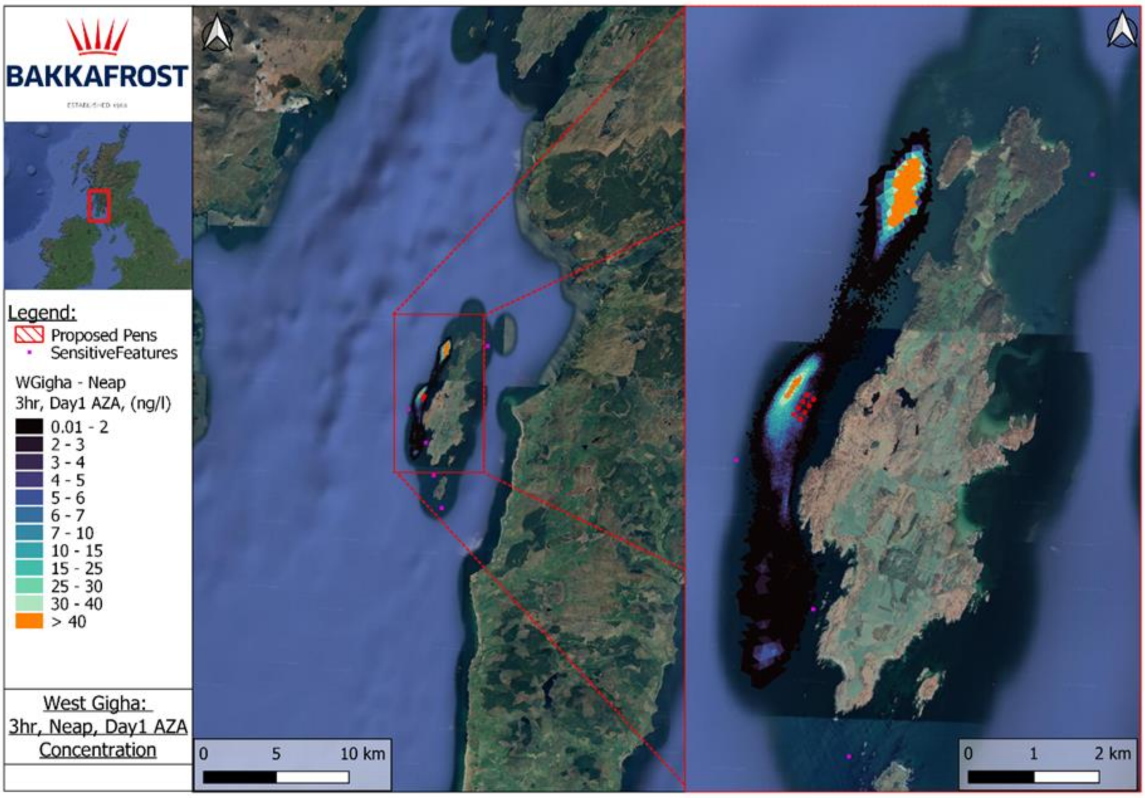

Figure 4.7: Azamethiphos concentration [ng/l] 3 hours after treatment during Neap tidal conditions. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features.

The simulations outline that the release of AZA rarely breaches the 3hr EQS standards outlined by SEPA and where the 250ng/l threshold is exceeded it is by a limited number of model cells, corresponding to low total areas, with seven cells simulated in excess of 250 ng/l at 20:00 on Day 1 of the Spring simulation and 1 cell in excess of 250 ng/l at the same time in the Neap simulation, located in the centre of the northward mass.

The simulated dispersion of AZA indicates small areas exceeding the 250 ng/l threshold three hours post treatment on any day assessed. The most significant impact produced an EQS area 5.96% of the permissible 0.5km2, based on a treatment schedule of three pens per day. The simulated conditions therefore outline the conditions at West Gigha are suitable for the licencing of 4,717.5g of Azamethiphos for treatment of the proposed 3,104 T under the three hour EQS.

24-hour EQS and MAC

Figures 4.7,8 show the concentration of Azamethiphos 24 hours after the end of all treatments, at 14:00:00 on day 3 of the simulation.

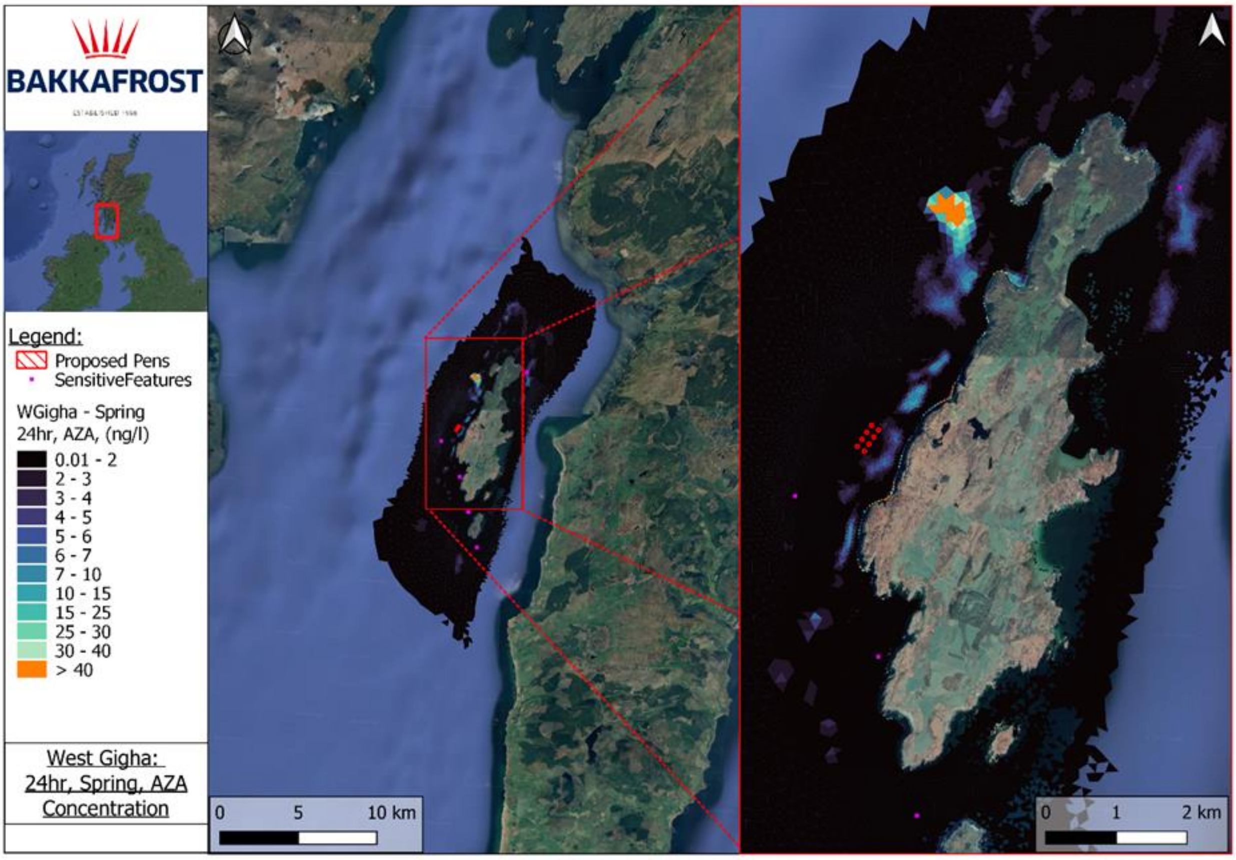

Figure 4.8: Azamethiphos concentration [ng/l] 24 hours after treatment during Spring tidal conditions. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features.

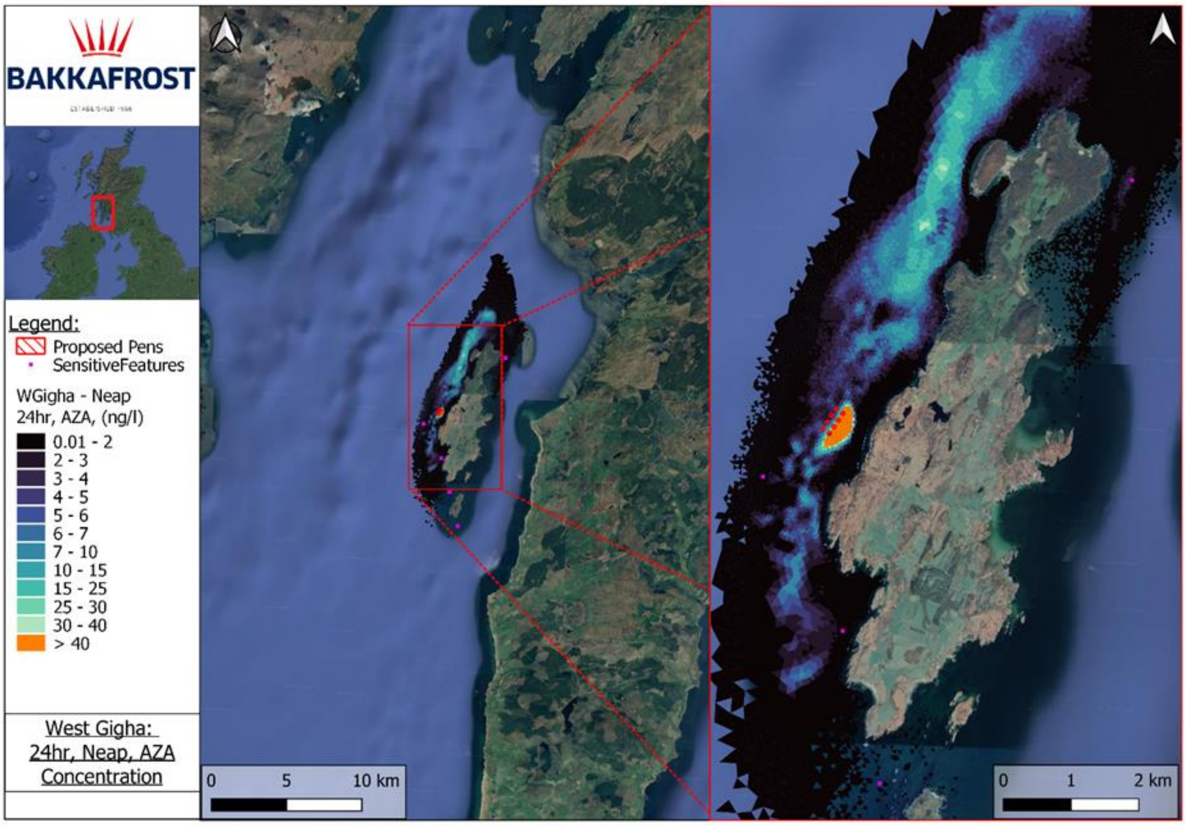

Figure 4.9: Azamethiphos concentration [ng/l] 24 hours after treatment during Neap tidal conditions. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features.

4.2.2 72-hour EQS and MAC

Under current guidance, the 72-hour EQS for Azamethiphos is for the area encompassed by the 40 ng/l contour to be less than 0.5km^2. This was assessed at 14:00 on Day 5 of the simulation. It is also required that the a concentration of 100 ng/l not be exceeded.

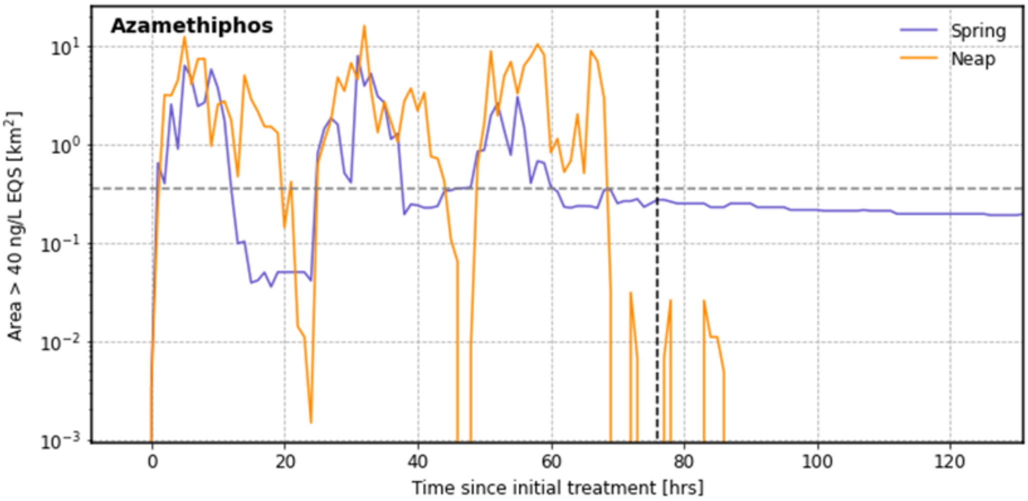

Figure 4.10: Time series of the area [km^2] exceeding the Azamethiphos EQS of 40 ng/l. Vertical dashed line indicates the point 24-hours after the final treatment and the horizontal dashed line indicates the mixing zone calculated using BathAuto.

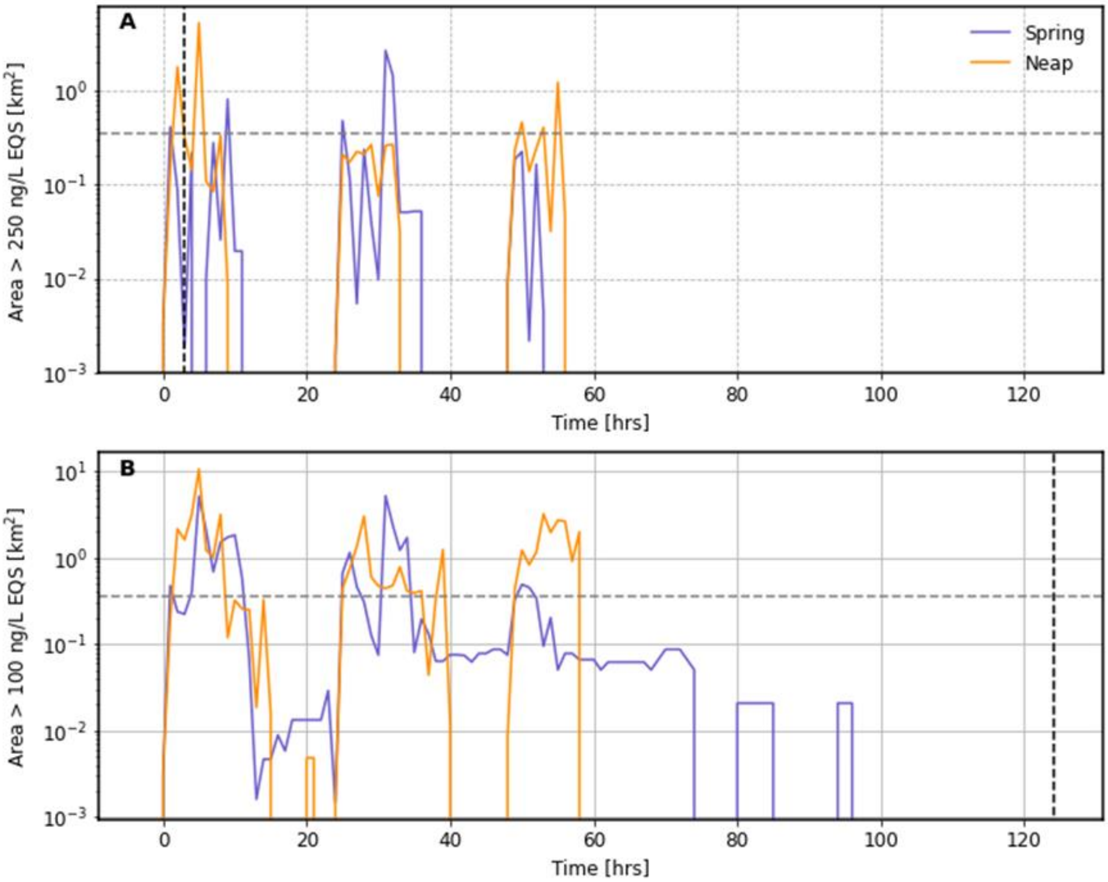

Figure 4.11: Time series of the area [km^2] exceeding the Azamethiphos (A) EQS of 250 ng/l and (B) MAC of 100 ng/l. Horizontal dashed lines indicates the mixing zone calculated using BathAuto. Vertical dashed lines indicate (A) 3-hours after initial treatment and (B) 72-hours after final treatment.

Figure 4.12 demonstrates the EQS zone for a release under peak spring conditions. The simulated output is demonstrated to comply with current regulations, with the 40 ng/l contour covering 2.14% of the permissible 0.5km^2. The dispersion of Azamethiphos extends south toward the southern Mull of Kintyre and is dispersed north eastward toward West Loch Tarbert.

Figure 4.13 demonstrates the EQS zone for a release under peak Neap tidal conditions. The simulated output is demonstrated to rarely exceed concentrations greater than 20 ng/l with higher concentrations along the western and northwest coast of Gigha. Concentrations less than 1 ng/l extend north along the shoreline toward the Isle of Dana. The variation between the ultimate dispersion footprint between Spring and Neap tidal conditions is attributed to variation between the tidal ebb and flood at the time of snapshot.

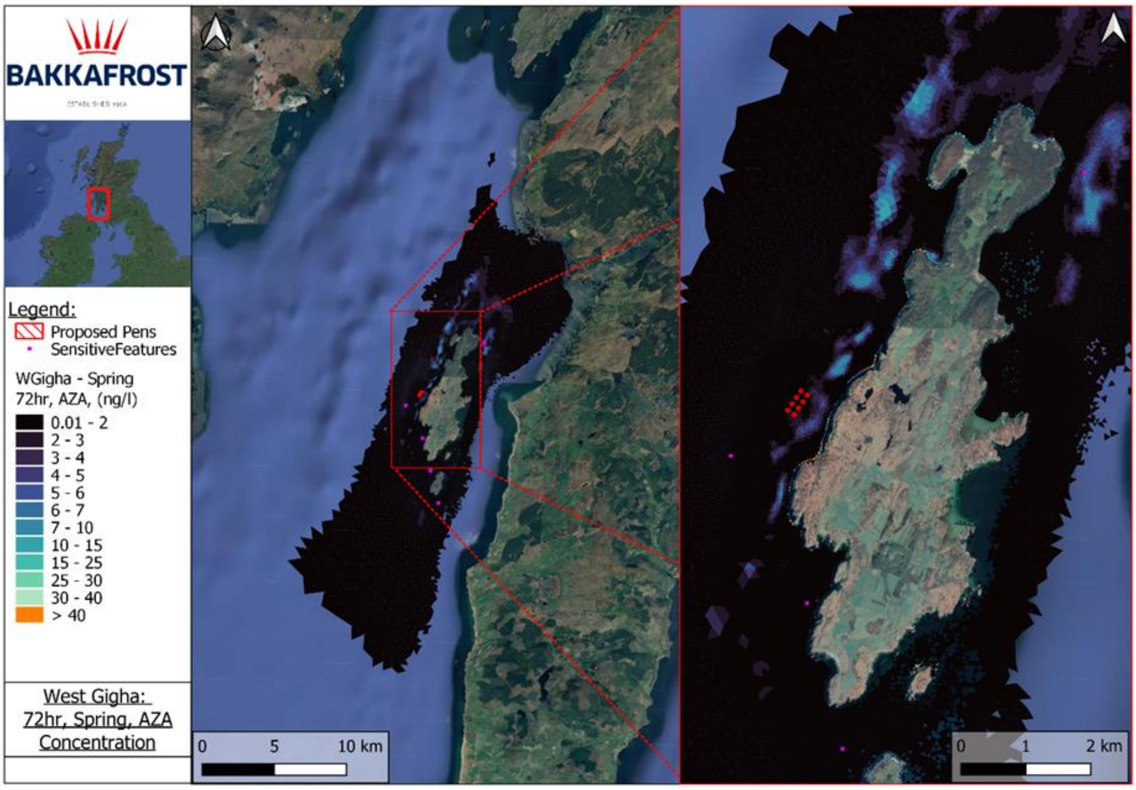

Figure 4.12: Azamethiphos concentration [ng/l] 72 hours after treatment during Spring tidal conditions. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features.

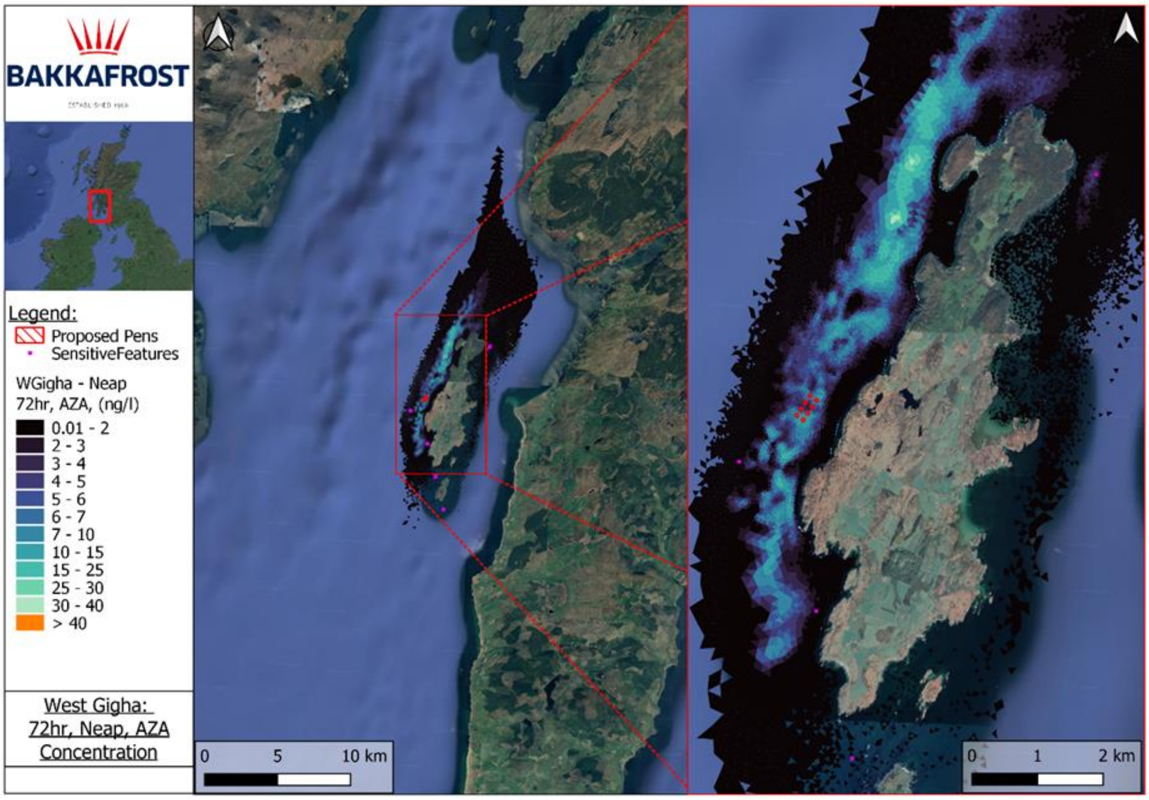

Figure 4.13: Azamethiphos concentration [ng/l] 72 hours after treatment during Neap tidal conditions. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features.

The model outputs a single cell with a high concentration of AZA for the 72-hour timestamp of 244.94 ng/l during Spring tidal conditions. Seven cells in total are simulated to breach the MAC under the Spring scenario, with all cells less than 1,200m^2, adjacent to the shoreline and adjoined by cells with concentrations less than 10 ng/l. These model outputs are considered to be a model artifact where the concentration is several orders of magnitude in excess of the surrounding cell averages as displayed in figure 4.14. It is anticipated that this artifact is encouraged by entrapment in the coastline and sedimentation and is a product of modelling approach associated with cell wetting and drying and not representative of physical conditions.

Further interrogation outlines that these seven cells are consistently the highest concentration from Day 2, suggesting particles become trapped here within the model, outlining high concentrations and loosing mass through decay. This is supported by the negligible amounts of suspended AZA concentrations in these cells, corresponding to a true concentration outlined in Table 4.5 (based on particles in suspension). It should also be noted that all nodes in the table below have consistently high concentrations indicating particles are retained throughout the simulation.

Table 4.5: Model Artefacts: Maximum concentration and suspension phase (spring)

Cell ID	Day1 - 2000	Day2 - 2000	Day3 - 1700	72- hour	Suspended particles
111051	0	119.0726	275.5641	244.9446	0.0132%
108930	0	200.8894	208.1032	169.2076	0%
109215	846.4761	202.4575	155.8444	125.5573	0%
106623	0	727.9959	153.9505	122.3662	0%
111266	53.59106	118.0573	179.1207	119.2256	0.0346%
111232	1.03358	66.23383	127.1016	116.0978	0.0944%
108929	0	120.9311	136.8149	111.6179	0 %

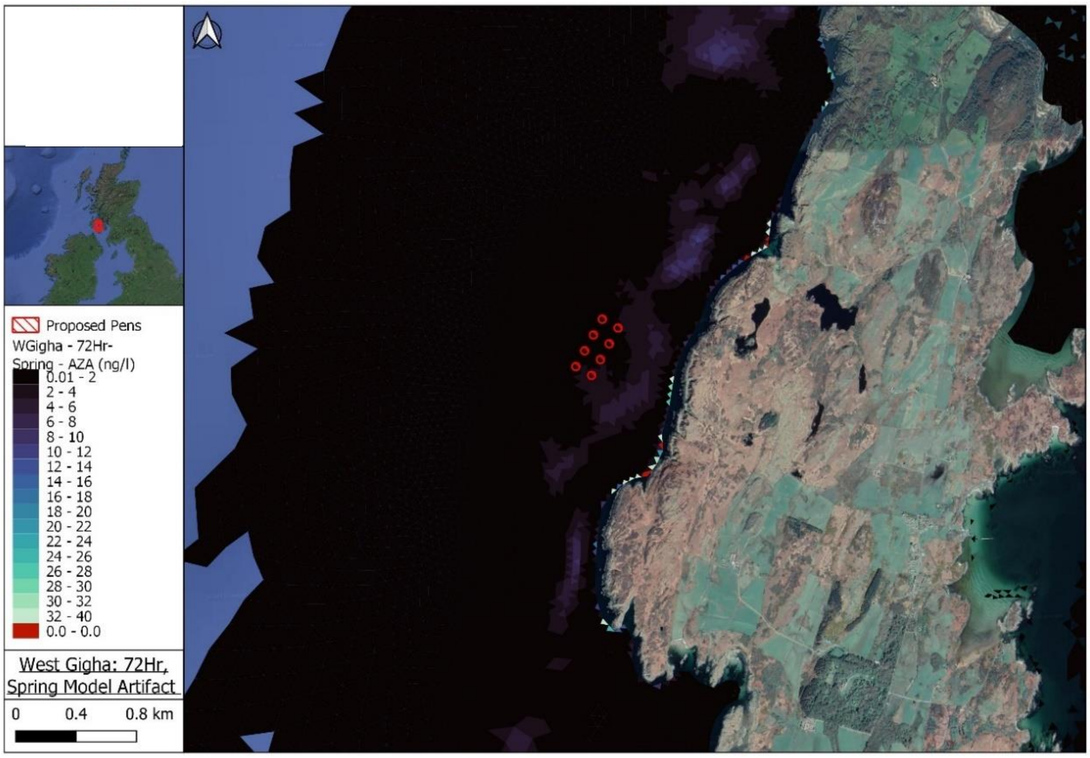

Figure 4.14: Azamethiphos concentration [ng/l] 72 hours after treatment during Spring tidal conditions. Model artifacts are indicated as anomalously high shoreline cell values. Red circles indicate the pen locations.

The model has simulated the additional particles becoming entrained within the bed at the shoreline. This is not considered realistic of physical process (as Azamethiphos remains in solution) Thus these high values, associated with entrained particles (where entrained particles is >90% of total particles) were excluded from the analysis.

In the absence of these artifacts, the compliance of the modelled conditions was reviewed against SEPA's EQS, presented in table 4.6 They demonstrate small areas where the EQS threshold of 40 ng/l is exceeded and a peak concentration that is well within the MAC concentration. The simulation of the dispersion of 4,717.5g of Azamethiphos demonstrates that the proposed treatment quantity released over three days is permissible under current CAR licence requirements.

Table 4.6: Azamethiphos compliance, 72 hours following final treatment.

	Spring: Compliance	Neap: Compliance
EQS *(km^2)*	0.19618	-
Max *(ng/l)*	85.9*	34.06

* model artefacts have been omitted from this assessment

4.2.3 Number of treatments per day

The model simulations presented herein have primarily assessed three treatments per day with the complete treatment spanning three days. This is considered a very conservative treatment schedule, with three hours between tarpaulin treatments in 160m *C* pens. To review sensitivity to this assumption, the degree of conservatism applied, and highlight the role of model artifacts in retaining high, artificial concentrations of Azamethiphos in the vicinity of the western Gigha shoreline, the treatment of two pens per day, with a four-hour treatment schedule (12:00 and 16:00) was simulated (starting 25/04/2021). In this scenario treatment of all pens was undertaken over a period of four days and the Spring hydrographic conditions were assessed.

The modelling was found to be highly sensitive to the assumption of three treatments per day, with the two treatments per day producing a significantly lower concentration for SEPA's EQS standards and MAC, as displayed in Table 4. and visible in Figure 4.12.

The model artifacts visible in figure 4.11 are also visible in Figure 4.15 but the accumulation of particles within the bed model is significantly less and the overall concentrations are substantially lower for the 72 hour MAC (3.40ng/l). Supporting the conclusion that the high values present at this timestep are a product of modelling assumptions (model artifact) and not indicative of "real" conditions.

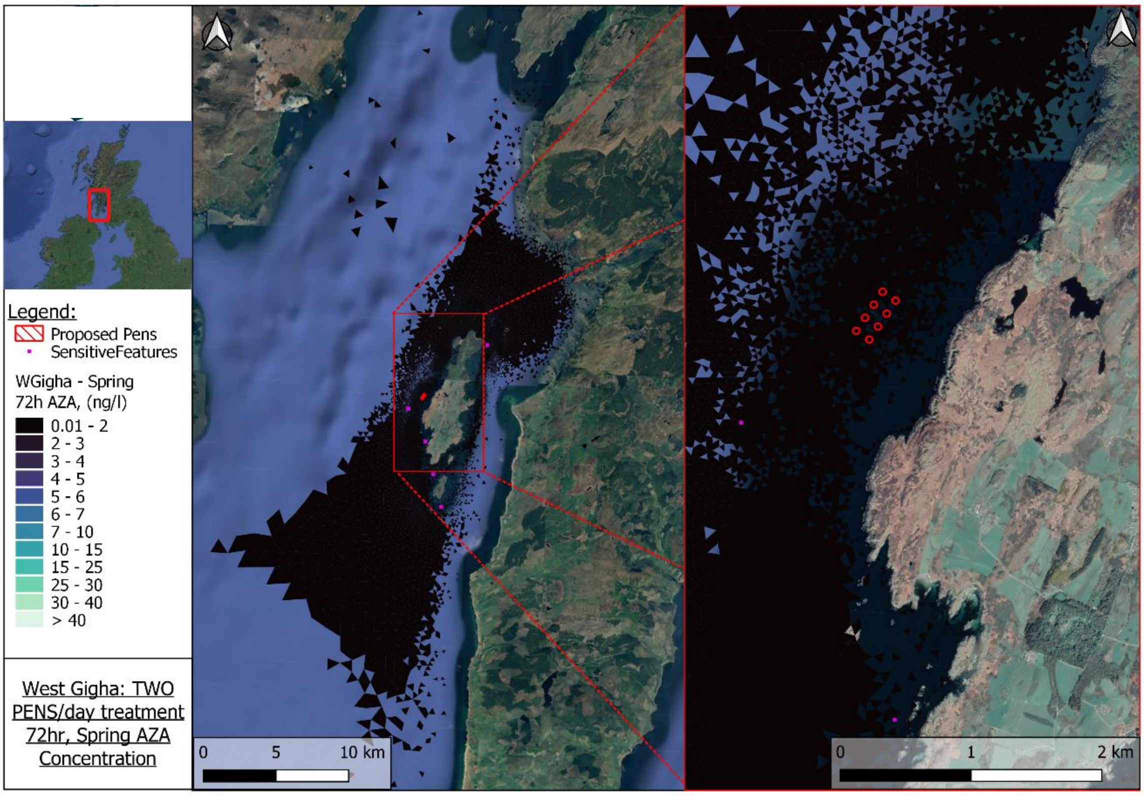

Figure 4.15: Azamethiphos concentration [ng/l] 72 hours after two pen per day treatment pattern during Spring tidal conditions. Red circles indicate the pen locations.

Table 4.7: Two pen/day treatment scenario: Azamethiphos EQS

Azamethiphos EQS: Two pens treated per day		Spring	
		EQS Area (Km^2)	Max concentration (ng/l)
3 – hour EQS	Day 1 – 1900	~	4.76
	Day 2 – 1900	~	7.84
	Day 3 – 1900	~	5.62
	Day 4 - 1900	~	5.77
72 - hour	Day 7 - 1400	~	3.40

4.3 Deltamethrin Dispersal

A single dose of Deltamethrin was simulated within the model, corresponding to an in-tarp concentration of 0.2ppm of Alphamax®. The dosage of Deltamethrin from each pen was subsequently calculated at 24 g and represented by 5,000 particles, cumulating in the release of 192 g of Deltamethrin across eight pens, over the 52-hour treatment cycle. In total 40,000 particles were released. Details of the calculations are presented in Table 4.2. The 6-Hour EQS was taken at three intervals, following the final treatment of each pen each day. Timeseries of maximum Deltamethrin concentrations during the Neap and Spring tidal simulations are shown in the lower panel of figure 4.4.

It should be noted that the simulation strategy applied here assumes medicine administration via a tarpaulin with a volume of 5,879m3, (29% of the pen volume). Given the size of the proposed pens at the site (160m C) it is unlikely that tarpaulin treatments will be undertaken, and bath treatments are likely to be undertaken in well boats. This treatment mechanism requires less volume to treat and discharges water over a defined time period (varying from the instantaneous releases simulated here). Both these factors will decrease the amount of treatment released and increase the rate of diffusion of the treatment.

The instantaneous releases of bath treatments simulated here are thus considered highly conservative and demonstrate an extreme impact of the release of Deltamethrin from the farm.

4.3.1 6-hour EQS

Under current guidance, the 6-hour EQS for Deltamethrin is 6 ng/l. This was assessed at 23:00 on the first and second days of treatment and at 20:00 on the final day of treatment (with the treatment of the final site at 14:00). The peak concentration and the EQS area of each assessment time is presented in Table 4.7 with the most significant concentration visible in figure 4.18.

Table 4.7: Deltamethrin concentrations for 6- hour EQS

Treatment day	Spring		Neap	
	EQS Area (Km^2)	Max concentration (ng/l)	EQS Area (Km^2)	Max concentration (ng/l)
Day 1 – 2300	0.002	10.84	-	4.91
Day 2 – 2300	0.007	13.11	-	4.75
Day 3 – 2000	0.003	13.01	-	4.98

NB: Modelled outputs were simulated in µg/m^3. This is directly comparable to the ng/l specified in SEPAS guidance (1,000l in a m^3).

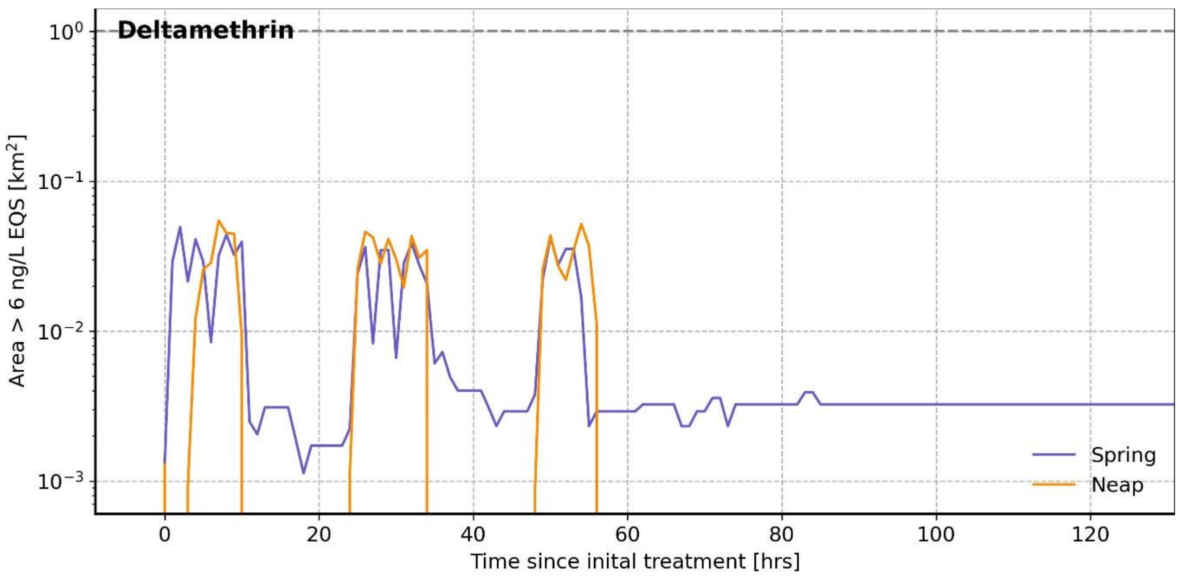

Figure 4.16: Time series of the area [km^2] exceeding the Deltamethrin EQS of 6 ng/l. Horizontal dashed line indicates the mixing zone calculated using BathAuto.

Figure 4.16 demonstrates the Deltamethrin is present in significantly lower quantities than the Azamethiphos outlined in Section 4.2, with high dispersion of releases into the natural environment causing a “patchwork” concentration. Only 5 mesh elements were simulated to be in excess of 6 ng/l at the critical timestep on day 2 of the spring tide simulation. The EQS area does not exceed 0.1km^2 on any of the critical timesteps assessed. The administration of 24g of Deltamethrin or a single dose of *Alphamax®* in each of the eight pens, with three treatments per day (totalling 192g of Deltamethrin) was thus considered permissible under contemporary SEPA guidance.

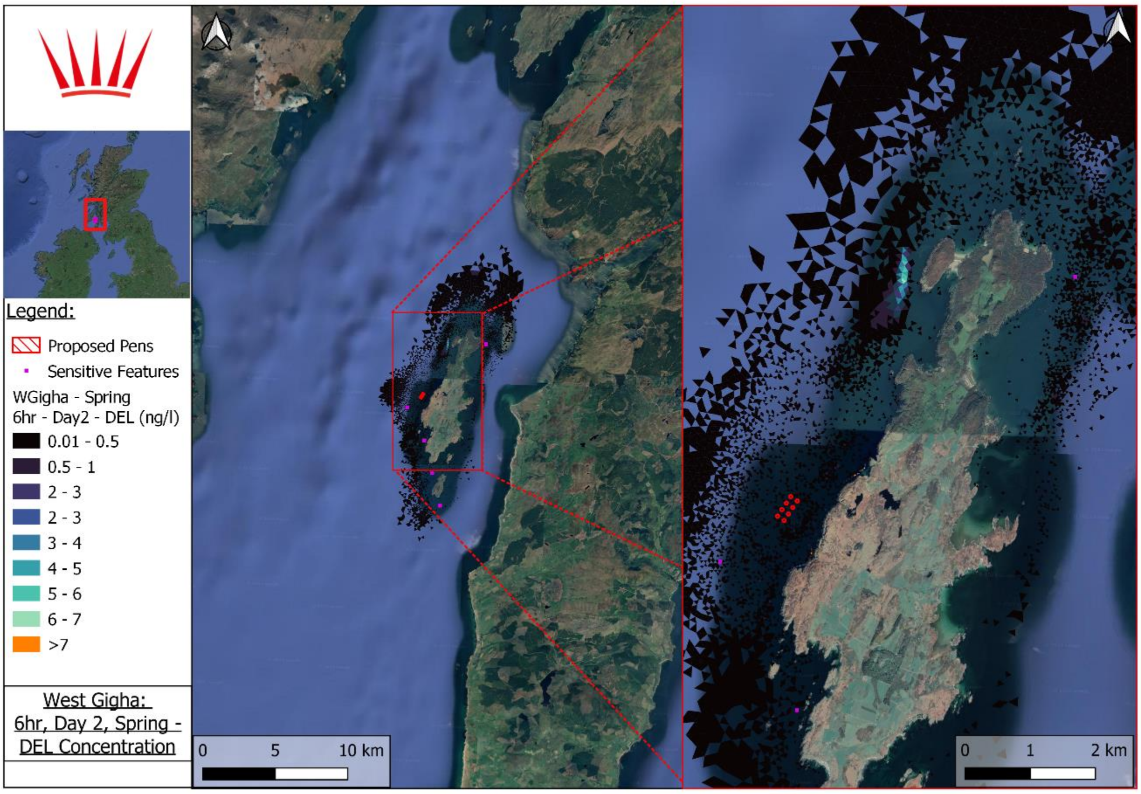

Figure 4.17: Deltamethrin concentration [ng/l] 6 hours after treatment during Spring tidal conditions. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features.

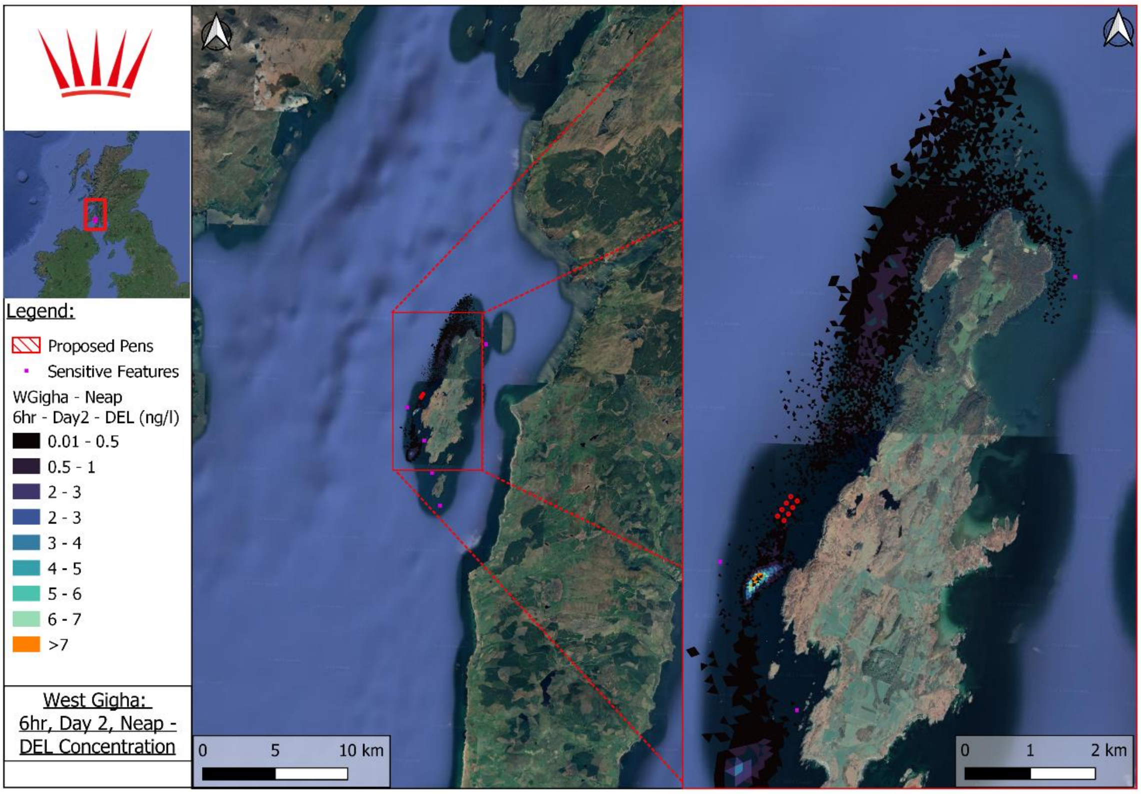

Figure 4.18: Deltamethrin concentration [ng/l] 6 hours after treatment during Neap tidal conditions. Red circles indicate the pen locations. Pink dots indicate the location of identified Priority Marine Features.

4.4 Bath Treatment: Impact on Sensitive Features

The concentration of Deltamethrin and Azamethiphos was reviewed at sensitive features deemed to be at risk from these releases. Average and maximum concentrations were assessed throughout the simulation time period, as well as the peak concentration in an area of 500m surrounding the features. Timeseries of Deltamethrin and Azamethiphos concentrations at the PMFs over the simulation are shown in Figure 4.19 and the highest simulated values (under Spring and Neap conditions) are listed in Table 4.8. The table demonstrates that while the peak concentration may exceed 10ng/l (below the 72hr EQS of 40ng/l), the average concentration within the area surrounding these sensitive features is extremely low and the peak concentrations are unlikely to impact the PMFs outlined below with the low residency times, elicited by the high current speeds. The proposed bath treatment quantities are thus considered to have minimal impact on the PMFs outlined below.

Table 4.8: Impact of Bath treatments on sensitive features

PMF/ Sensitive features	West Gigha: Azamethiphos concentration (ng/l)		West Gigha: Deltamethrin concentration (ng/l)	
	Average	Max	Average	Max
Northern Sea Fan and Sponge Communities	0.967	9.600	0.0296468	0.325
Maerl Beds-1	1.049	9.691	2.5004e-05	0.00352557
Maerl Beds-2	0.072	0.378	0.000951322	0.0597344
Maerl Beds-3	0.052	0.162	0.000457907	0.0277482
Horse Mussel Beds	4.045	17.050	0.270124	0.773956

NB: Existing Marine Pen Fish Farms were excluded from this analysis as they are not considered sensitive to bath treatments.

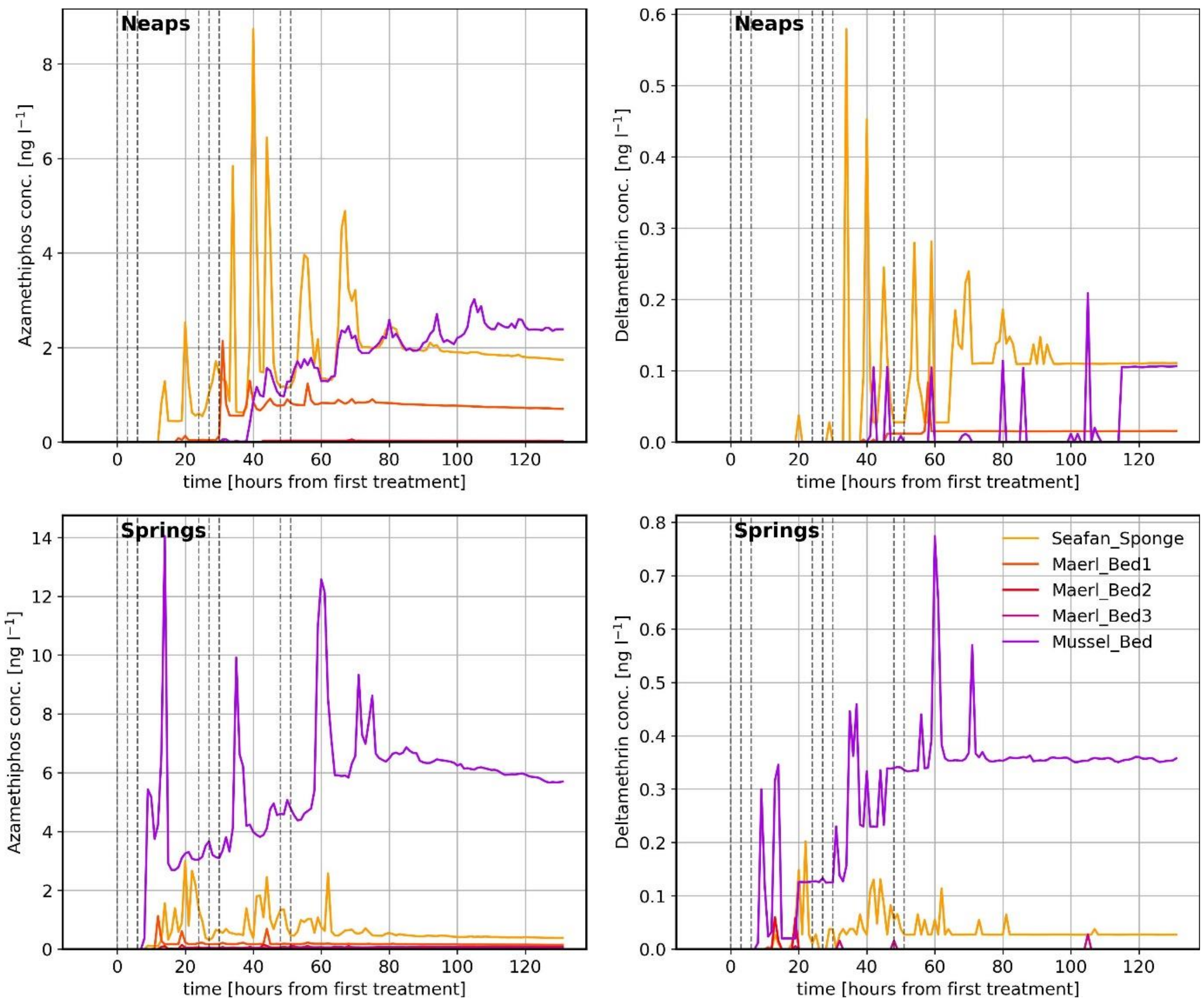

Figure 4.159: Timeseries of Deltamethrin and Azamethiphos concentrations [ng/l] at five Priority Marine Features during Neap (top panels) and Spring (bottom panels) tidal conditions during the simulation. Vertical dashed lines indicate timings of treatments.

4.5 Model Sensitivity

During model development, it was necessary to employ some assumptions on the representation of parameters within the model. Two of these assumptions were reviewed and assessed, using the existing model of the Neap hydrographic scenario simulating the treatment of Azamethiphos in three pens per day for bath treatments.

4.5.1 Horizontal Diffusion

The baseline diffusion rate was 0.1 m^2/s and employs a random walk variation in particle position to represent sub-cell scale hydrodynamic processes such as diffusion and turbulence and larger scale eddies. To review the sensitivity of the model to this assumption, the diffusion coefficient for Azamethiphos was varied between 0.07m/s and 0.15m/s and the results are visible in table 4.9. The table demonstrates the standard deviation and maximum concentration were sensitive to the variation in the diffusion parameter with lower diffusion rates producing less standard deviation and a higher peak concentration (84.924 ng/l). Higher diffusion rates produced largely comparable results to the baseline condition and the model is not considered sensitive to increased diffusion.

Table 4.9: Summary statistics for Horizontal diffusion sensitivity test. *NB: Only cells <0 were assessed.*

	Horizontal Diffusion		
72Hr AZA	0.07 m^2/s	Baseline (0.10m^2/s)	0.15 m^2/s
Cell count (<0)	100.90%	19435	101.46%
Mean (ng/l)	102.89%	2.215	99.02%
Std (ng/l)	116.80%	3.410	98.53%
25% (ng/l)	100.45%	0.093	98.68%
50% (ng/l)	100.52%	0.743	99.21%
75% (ng/l)	93.18%	3.006	98.88%
Max (ng/l)	249.32%	34.062	102.83%
Area <40 ng/l	0.010313 km^2	0 km^2	0 km^2

Whilst the assessment above outlines the model is sensitive to the selection of horizontal diffusion rate, the 0.10m^2/s selected and applied in the modelling is considered an appropriate rate of diffusion. This diffusion rate aligns with current hydrodynamic and particle tracking modelling paradigms and is deemed an appropriate estimation of sub-cell scale hydrographic processes. The model sensitivity to the diffusion parameter has no impact on compliance for the two additional conditions assessed and the baseline condition is considered a good estimation of sub-cell processes.

4.5.2 Particle Release Depth

Particle release depth was assumed to be 3m in simulations, corresponding to the approximate depth of tarpaulin at release. Model sensitivity to this parameter selection was reviewed at SEPA's request, with releases of Azamethiphos simulated at the base of the cage (15m depth). A comparison between the two conditions can be seen table 4.10. The variability between the two conditions is considered negligible with all statistics within 5% of the baseline condition. The model was thus considered insensitive to particle release depth.

Table 4.10: Summary statistics for particle release depth sensitivity test. NB: Only cells <0 were assessed.

72Hr AZA	Baseline (3 m)	15 m
Cell count (<0)	19435	98.80%
Mean (ng/l)	2.215	100.90%
Std (ng/l)	3.410	101.18%
25% (ng/l)	0.093	104.39%
50% (ng/l)	0.743	100.15%
75% (ng/l)	3.006	101.08%
Max (ng/l)	34.062	100.57%
Area <40 ng/l	0 km^2	0 km^2

5. Conclusion

The Isle of Gigha is located within a highly complex hydrographic environment, a short distance from an amphidromic point and influenced by water bodies in the Inner Hebrides, the Irish sea and the Malin Sea area. SSC employed a high quality, calibrated and validated hydrodynamic model to review the fate of Aquaculture related discharges from a proposed Marine Pen Fish Farm (West Gigha) to the west of the Isle of Gigha. A high-resolution mesh was used to review the ultimate fate of aquaculture related discharges (Feed, Faeces, Azamethiphos and Deltamethrin) on the benthic environment

Simulated releases of feed and faeces from the eight pens simulated were dispersed rapidly and at low concentrations within the greater Sound of Jura, where they were deposited at low concentrations (< 1g/m^2/yr), comparable to background biotic sedimentation rates. Additionally, no significant impact was found at nine sensitive features reviewed.

The modelling assessed releases of two bath treatment formats over Peak Spring and Peak Neap tidal cycles. The assessment outlines that a single dose of Azamethiphos (4,717.5 g) and Deltamethrin (192 g) at all pens on a treatment schedule of three pens per day is permissible. While the model displayed localised high concentrations of Azamethiphos in the vicinity of the shoreline, these are considered to be model artefacts and were not present for the simulation of two pens per day, which satisfied SEPAs MAC at the 72-hour timestep comfortably (7.8% of the permissible).