04th July 2024

Far-Field Benthic Modelling Report

Meil Bay

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Summary

Cooke Aquaculture Scotland Ltd. (CAS) have developed a particle tracking model, driven by a decoupled hydrodynamic model, to simulate the dispersion of solid waste released from all marine fish farm sites within Wide Firth and Shapinsay Sound. This identifies possible areas of sediment accumulation and suspended sediment pathways that may pose adverse environmental risk to large areas of seabed or sensitive marine features.

A multi-point calibrated and validated hydrodynamic model and calibrated particle-tracking model with dye and drogue surveys, were used to predict faeces and waste food particle advection and dispersion from the proposed Meil Bay site and 4 additional sites within the area. Operational conditions were simulated for 1 year assuming constant maximum stocking and no decay of organic particles.

Deposited and suspended sediment pathways are shown for the proposed Meil Bay farm and the cumulative proposed site scenario. Deposition is shown to occur beneath the site and within Meil Bay. Cumulative effects show very small amounts of deposition transported to the Bay of Kirkwall and Ingreness Bay. The suspension pathways are well scatted indicating high levels of dispersion. An assessment of the deposition and suspended materials at sensitive feature locations shows small infrequent quantities of waste material with no accumulation or prolonged exposure. This indicates that any potential benthic waste accumulation will remain localised to the site and during resuspension events, will be widely dispersed and assimilated with very low potential for environmental risk on sensitive marine features.

1. Introduction

This report details the results of the simulation of solid particulate waste from multiple aquaculture sites within a hydrodynamic and particle tracking model. The description of the hydrodynamic model, the calibration and validation, and the methods of simulating waste particles are presented in the Modelling Methods Statement. The measurement of the dispersion coefficient that is used within the particle tracking model is described in detail within the Dye and Drogue Release report. The results of the far-field benthic modelling are used to determine potential risk to sensitive marine features and cumulative impacts while maintaining compliance with the latest SEPA standards and guidance (SEPA, 2024)

1.1 Site description

Meil Bay is an existing, consented site (CAR/L/1003888) operated by Cooke Aquaculture Scotland. The site is located off the northeast coastline of the Orkney mainland, within the Bay of Meil, south of Shapinsay Sound (figure 1). The existing site consists of a single group of 10 circular, 100m circumference cages with a net depth of 6m. These are arranged in a 2 x 5 layout with a 60 m separation, housing a maximum consented biomass of 884T at a maximum stocking density of 18.5kg/m^3. The site is aligned with a bearing of 22.5^o (figure 1). The existing licensed site is centred on 348452.07E, 1012342.29N.

The proposed development adds a further six 100m circumference pens to the existing infrastructure, forming a site layout of 2x8 pens on a 60m grid, and repositions the site ~200m to the NW (348439.639E, 1012644.247N) in a deeper, less constrained location closer to the mouth of the bay (figure 1). The proposed site will house a maximum consented biomass of 1410T, providing a maximum stocking density of 18.4kg/m^3. Further information on the existing and proposed site infrastructure and pen layout is presented in table 2.

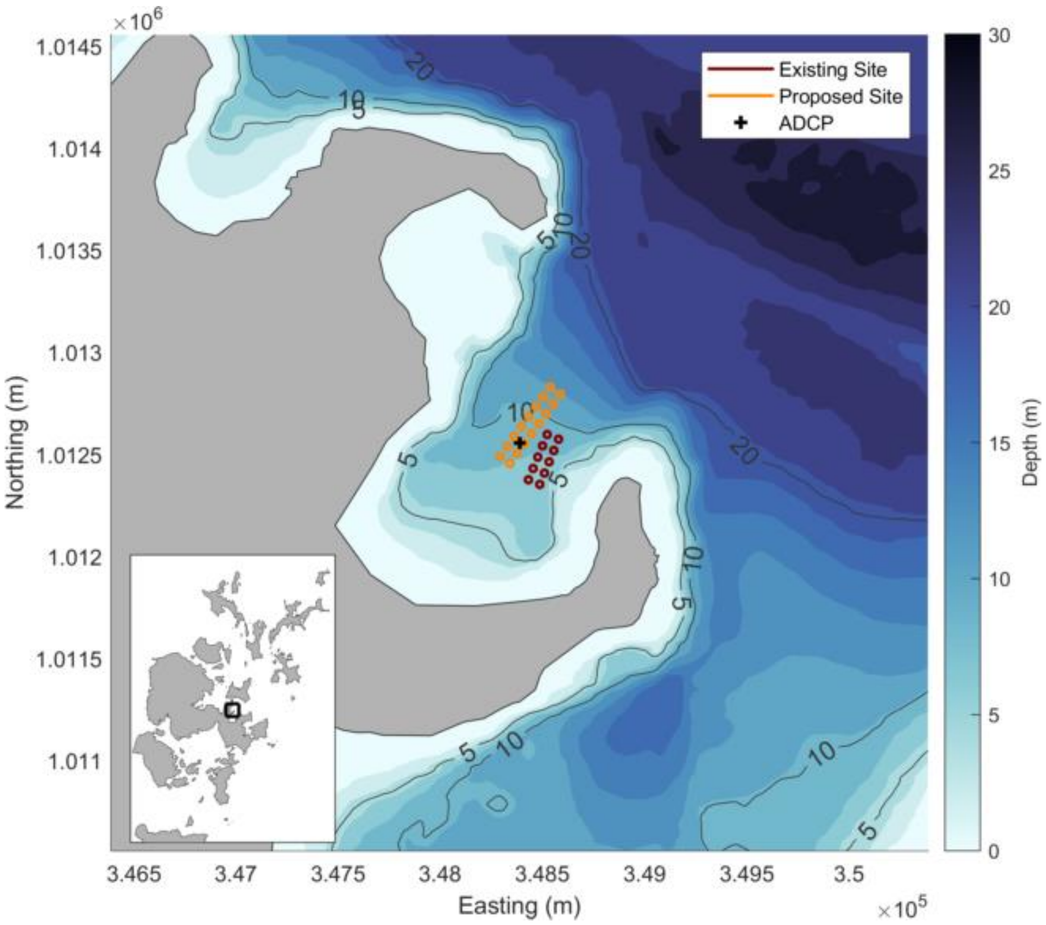

Figure 1. Existing (red) and proposed (orange) Meil Bay site infrastructure, ADCP deployment location ('+') and bathymetry.

Table 2 – Existing and proposed site infrastructure and pen layout.

	Meil Bay (Existing)	Meil Bay (Proposed)
Consent number	CAR/L/1003888	-
Company	Cooke Aquaculture Scotland	Cooke Aquaculture Scotland
Receiving water	Shapinsay Sound	Shapinsay Sound
Site centre (OSGB36)	348505E, 1012476N	348439.639E, 1012644.247N
Current meter location (OSGB36)/year of deployment	348388E, 1012558N /2021	348388E, 1012558N /2021
Distance to shore (km)	0.35	0.5
Average water depth (m)	9	12
Maximum biomass (t)	884	1410

Total number of pens	10	16
Number of pen groups	1	1
Formation	2x5	2x8
Pen group orientation (°)	22.5	36
Pen shape	Circular	Circular
Pen circumference (m)	100	100
Mooring grid (m)	60	60

1.2 Surrounding Farms and Sensitive Marine Features

The waters around Shapinsay Sound hosts numerous sensitive marine features. Table 3 outlines the marine features that are assessed within this study. These sites were specified in the Screening and Risk Identification Report (SEPA 2022).

Table 3. Farm and sensitive marine features identified within Shapinsay Sound.

Name	**Feature type**	**Location (OSGB)**		**Mesh resolution (m^2)**
		East (m)	**North (m)**	
Maerl beds	Marine habitat - Points	346907 347526 350250 351113 349210 349756 349865 351128 350773 351256 351506 352127 352147 352171	1015999 1015671 1015610 1015166 1011840 1012489 1012987 1012514 1012025 1012007 1012036 1011913 1011933 1011960	2000 (45m) - 2500 (50m)
Horse mussel beds	Marine habitat - Area	Shapefile		2000 (45m)
Horse mussel beds	Marine habitat - Points	348810	1015440	2000 (45m) - 4000 (63m)

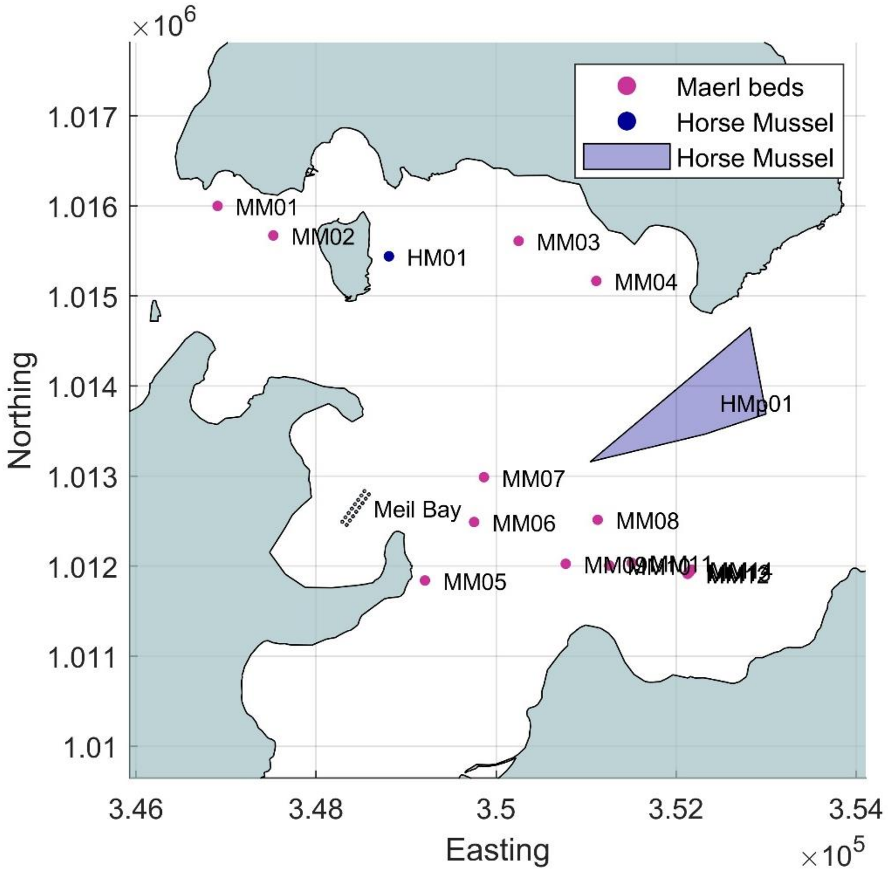

Figure 2. Farm locations and sensitive marine features identified within Shapinsay Sound.

2. Model Description

This study uses DHI's MIKE3 flexible mesh model to simulate free-surface flow in a coastal environment. The model uses an unstructured mesh to replicate tidal hydrodynamics, wind and wave driven currents, and storm surges.

2.1 Hydrodynamic model

DHI's MIKE3 flexible mesh model solves the three-dimensional incompressible Reynolds averaged Navier-Stokes equations, using the Boussinesq and hydrostatic pressure assumptions to simulate 3D hydrodynamics over the coastal domain of interest. Continuity of momentum, temperature, salinity and density are applied alongside the k-epsilon turbulent closure scheme. A cell centred finite volume approach is applied for the spatial discretion of the momentum equations over an unstructured triangular mesh.

2.1.1 Model domain

The model domain is created using the cartesian Ordnance Survey of Great Britain 1936 coordinate system (OSGB 1936). Coastline data is imported from Ordnance Survey (2020) and is used to define the land boundaries within the domain. Bathymetry data are taken from the UK Hydrographic Office (UKHO, 2021). The model mesh is unstructured, consisting of non-overlapping triangular elements covering a domain that extends from 229929E to 442733E, and 910599N to 1099869N (figure 3a). An unstructured mesh allows variation in element size, meaning near open boundaries the mesh resolution is relatively coarse (2km) to increase computational efficiency. In areas of specific interest, complex topography or complex bathymetry, the resolution is enhanced so that these features are adequately resolved (figure 3b). Horizontally the mesh comprises 73066 nodes and 139921 elements. In the vertical dimension, the model has 5 terrain following sigma layers, mostly concentrated within the upper part of the water column.

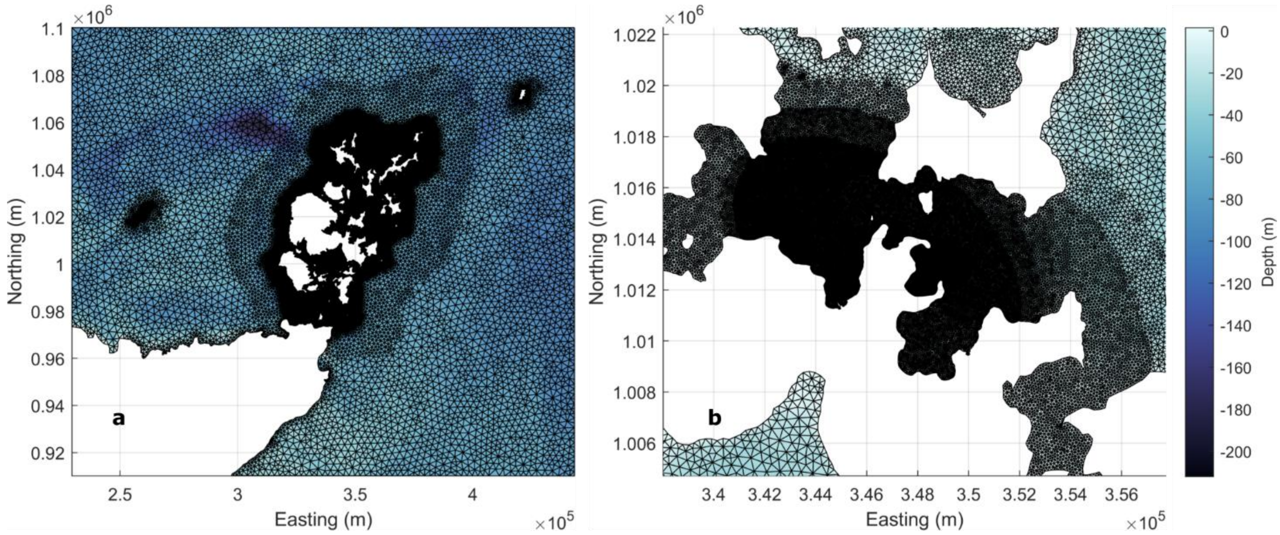

Figure 3. Hydrodynamic model mesh. a) wider computational mesh. b) Computational mesh around the proposed Meil Bay site.

2.1.2 Configuration and boundary forcing

Boundary conditions are taken from DHI's global tidal model, where tidal elevations are calculated from 10 principal astronomical constituents (semidiurnal M2, S2, K2, N2, Diurnal S1, K1, O1, P1, Q1 and Shallow water M4). The global tidal model has a resolution of 0.125°x 0.125° and interpolates data to the nearest boundary element. Temporal resolution outputted elevations every 12 mins. Wind data was taken from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 model (ECMWF, 2023). This provides wind velocity in U and V components, as well as surface pressure with a resolution of 0.25°x. 0.25° at an hourly interval.

A minimum and maximum model time step of 0.01 and 60 seconds was applied, with a critical CFL number of 0.95 ensuring model stability. Point data outputs were produced at 10-minute intervals and area data outputs at 30-minute intervals. Flooding and drying were included, with a drying depth of 0.005m and a wetting depth of 0.1m. The horizontal eddy viscosity applies Smagorinsky's formulation with a constant value of 0.28. Bed roughness in the form of the roughness height is used as the main calibration term. This parameter is adjusted to calibrate the model. The best model performance was achieved using a spatially variable bed roughness. A local (3km radius) bed roughness of 0.025m was applied at Quanterness and 0.15m at Meil Bay. The background bed roughness across the remainder of the mesh was set to 0.05m.

2.2 Particle tracking model

Particle release is simulated using DHI's MIKE 3 particle tracking model. The particle tracking (PT) model is run in 3-dimension, with 10 sigma layers. The model is run offline from the hydrodynamic model to reduce computational time. The time step remains identical to that used within the hydrodynamic model. The PT model is run for 365 days, where the start date is located out with the hydrodynamic model warm-up period.

Wind forces were removed for the driving hydrodynamic model to prevent storms causing misrepresentation of dispersion during winter months. This provides a more conservative model with lower dispersion rates.

2.2.1 Particle Configuration

To simulate waste feed and faeces, two particle classes are specified for each farm. This allows separate particle parameters to be applied to each particle type that match their settling and resuspension characteristics. Peak biomass is used to calculate the feed waste and faecal matter using the following equations and values in table 3. The calculated quantities of waste and excreted solids for each farm are given in table 4. It should be noted Berstane is assumed to be stocked, however, this site hasn't been operational within current records, and it is most likely obsolete.

Table 3. Input feed parameters

Parameter	Symbol	Value
Feed requirement	f_r	7kg per tonne biomass per day
Feed water (%)	f_h	9%
Feed waste (%)	f_w	3%
Feed absorbed (%)	f_a	85%
Feed carbon (%)	f_c	49%
Faeces carbon (%)	f_f	30%

The amount of waste solids (w_s) per day is calculated as

$$w_s = (1 - f_h).f_w.f_r$$

Waste carbon (w_c) is calculated as

$$w_c = (1 - f_h).f_c.f_w.f_r$$

Excreted solids (e_s) are calculated as

$$e_s = (1 - f_h).(1 - f_w).(1 - f_a).f_r$$

Excreted carbon (e_c) is calculated as

$$e_c = (1 - f_h).(1 - f_w).(1 - f_a).f_f.f_r$$

Table 4. Particle mass per model timestep.

Site	Biomass (t)	Waste feed (kg)	Excreted Solids (kg)
Meil Bay (Proposed)	1410	11.2	54.5
Meil Bay (Existing)	884	7.0	34.1
Qaunterness (Proposed)	1950	15.5	75.3
Qaunterness (Existing)	600	4.8	23.2
Puldrite	980	7.8	37.8
Carness	1000	8.0	38.6
Berstane	500	4.0	19.3

Particle properties are defined in table 5. Waste feed and faeces particle settling rates are defined using the SEPA default values. The results of the drogue and dye release model calibration study were used to determine representative horizontal dispersion coefficients (K_h). This applies a horizontal dispersion coefficient of 0.105 m^2/s for Meil Bay and Quanterness while the remaining sites use the default value of 0.1m^2/s. Vertical dispersion coefficient uses the default value of 0.001 m^2/s for all sites.

Table 5. Benthic model particle parameters

Particle class	Waste feed	Excreted solids
Decay (s)	0	0
Settling velocity (m/s)	0.095	0.032

Horizontal dispersion (m^2/s)	0.105 (Quanterness and Meil Bay) 0.1 (remaining sites)	0.105 (Quanterness and Meil Bay) 0.1 (remaining sites)
Vertical dispersion (m^2/s)	0.001	0.001
Erosion threshold ($N/m^2/s$)	0.02	0.02
Density (kg/m^3)	1027	
Bed Roughness (m)	0.001	

Throughout the model run period, 10 particles per hour were released from each particle class (feed and faeces) into the domain from an area source. As it is not feasible to define each individual pen manually, a rectangular area for each cage group is defined using the central locations of the corner pens. Particles are randomly released across this rectangular source area in a vertical layer spanning from the sea surface to the depth of the cage bottom. This offers the most representative particle dispersion where concentration and area coverage are most similar to the individual pen simulation.

3.2.3 Environmental Standards (EQS)

Benthic impact area is determined using the Infaunal Quality Index (IQI), where a relationship between sediment flux and IQI is defined as a proxy for environmental impact. SEPA (2024) states that an average solid flux calculated from the last 90 days of a simulation should be used as the representative flux. For NewDepomod modelling this suggests that a flux value of $250g/m^2$ is equivalent to an IQI of 0.64 and acts as the far field EQS. Therefore, any deposition above the $250g/m^2$ is defined as having a significant impact on the seabed. This EQS and the intensity parameter used within NewDepomod are outlined in table 6. While these EQS parameters were calibrated and validated within NewDepomod, there has been no assessment in the applicability of this method and optimal particle parameters within a larger scale hydrodynamic and particle tracking model. This suggests that the application of the $250g/m^2$ within a marine model offers a more appropriate tool in determining geographical distribution of sediment rather than attempting to accurately forecast the magnitude of deposition.

Table 6. Benthic EQS parameters

Benthic		
Pen-edge	Intensity	Mean deposited mass within the 250 g/m^2 impact area should not exceed 2000 g/m^2 where wave

		exposure is less than 2.8, and 4000 g/m^2 where wave exposure is more than 2.8.
Mixing zone	Area	Total area (m^2) with a mean deposited mass in excess of 250 g/m^2 should not exceed the 100 m composite mixing zone area (m^2). If wave exposure is 2.8 or above, the mixing area may occupy 120% of the 100m mixing zone.

3. Results

3.1 Far-field Sediment and Suspension

The average deposition from the proposed Meil Bay farm is shown in figure 4. The concentrations displayed represent the mean of the final 90 days of the particle tracking model run. Concentration values of less than 1g/m^2 have been excluded from the map and all subsequent figures. Such low concentrations are not considered to be representative of the main influence of a discharge. Highlighted predicted impact areas are defined as those with deposited concentrations of 250g/m^2 or higher. This shows the majority of the deposition occurs around the site and is contained within the bay. Other patches of deposited sediment are shown to occur within the domain at much lower concentrations.

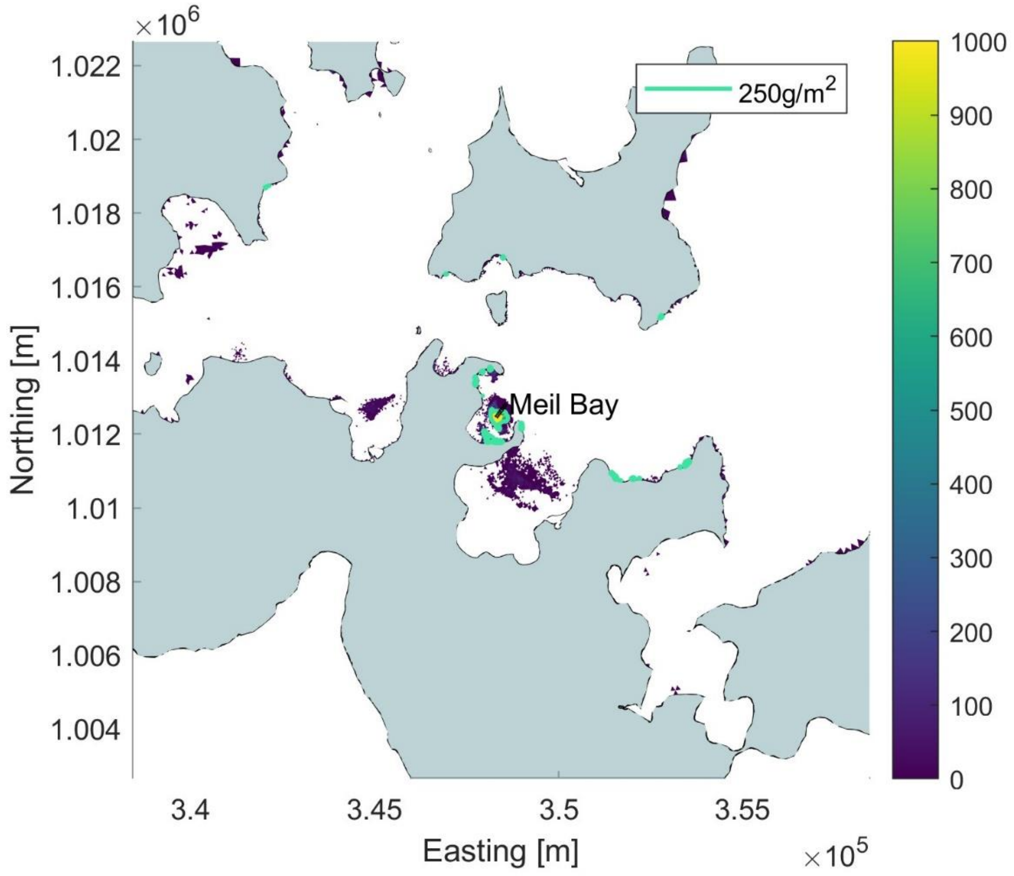

Figure 4. Average far field deposition (g/m^2) from the last 90 days of the simulation for the proposed Meil Bay development.

The average deposition from all proposed sites including the Proposed Meil Bay and Quanterness farms are shown in figure 5. The cumulative assessment of deposition shows sediment accumulations beneath Carness, Meil Bay and Berstane. The joint deposition shows cumulative effects from Meil Bay contributing small quantities of deposition to accumulations within the Bay of Kirkwall and Ingerness Bay.

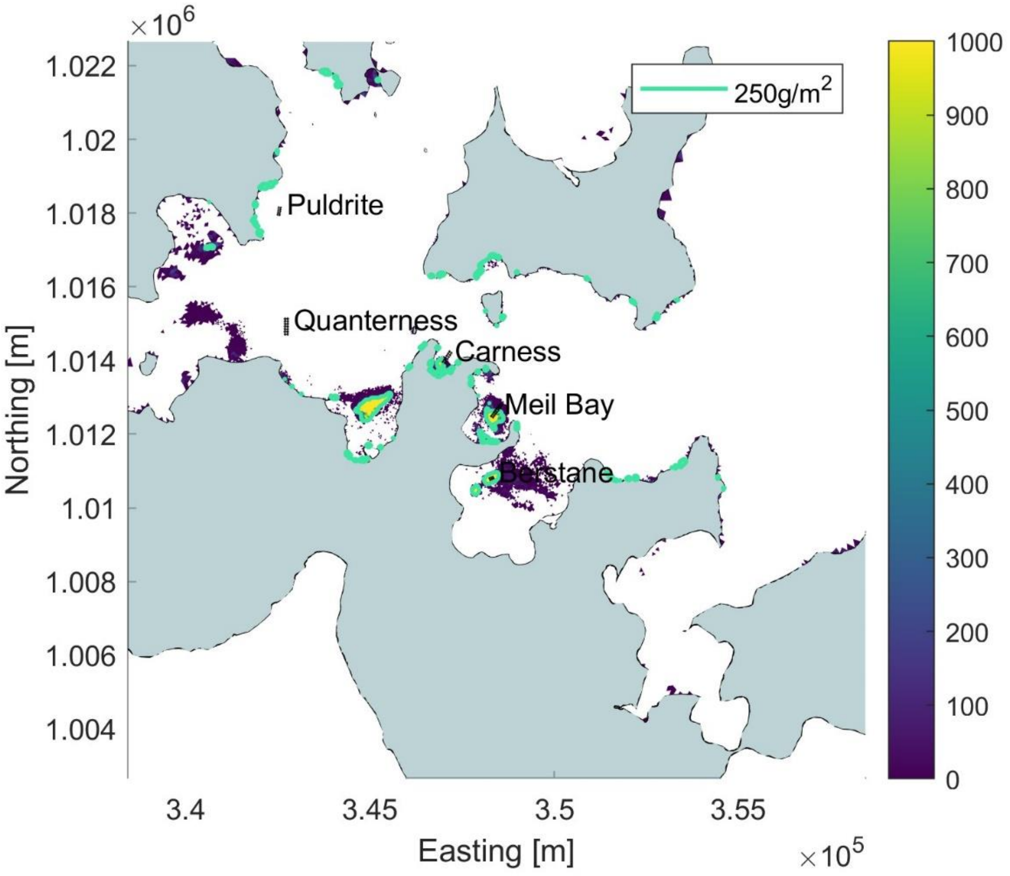

Figure 5. Average far field deposition (g/m^2) from the last 90 days of the simulation for all sites including the proposed Quanterness and Meil Bay developments.

The suspended sediment pathway for all proposed developments is shown in figure 6. Suspension around the proposed Meil Bay development occurs mostly at the southern headland of the bay. This sediment is scattered to the east and west in low concentrations.

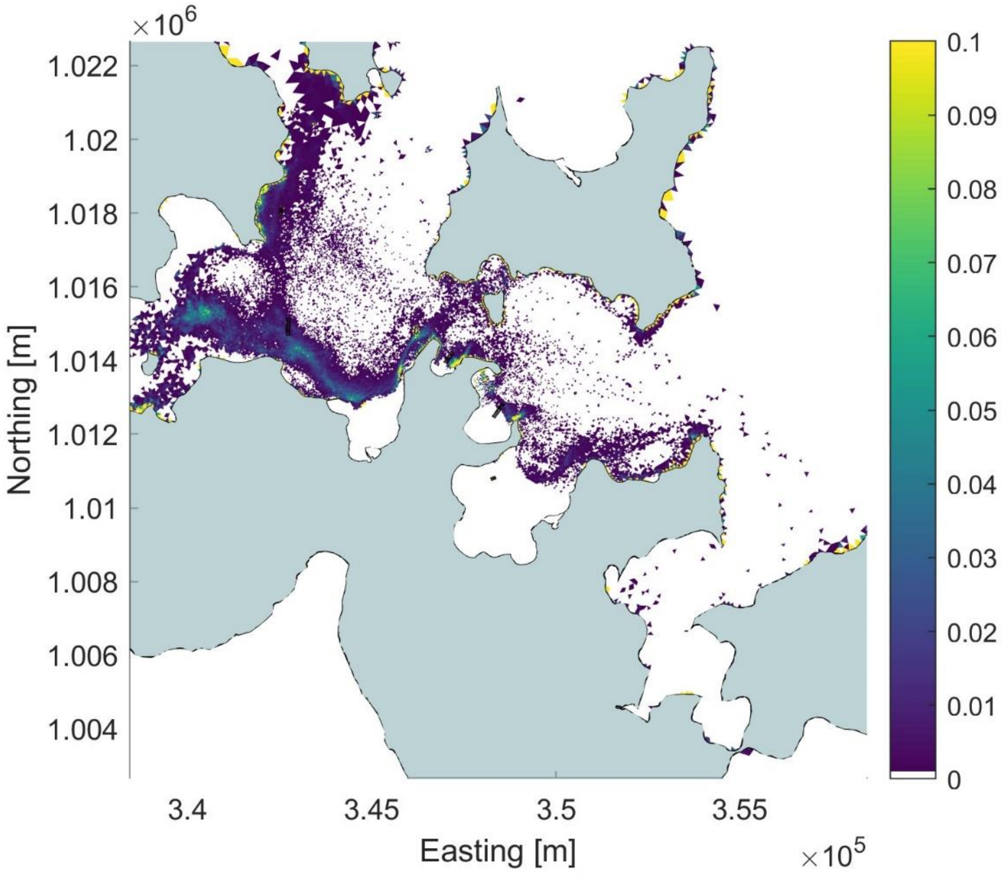

Figure 6. Average far field suspension pathway (g/m^3) of the last 90 days of the simulation for all sites including the proposed Quanterness and Meil Bay sites.

A time series of the area exceeding 250 g/m^2 and the intensity for the sedimented material originating for each farm is shown for the last 90 days of the simulation in Figures 7 and 8. All sites show a gradual increase in sediment accumulation in both area extent and intensity. This is due to sustained maximum biomass and non-decaying particles used within the simulation. Fluctuations within the area assessment show larger variation within spring tides where resuspension events are more common.

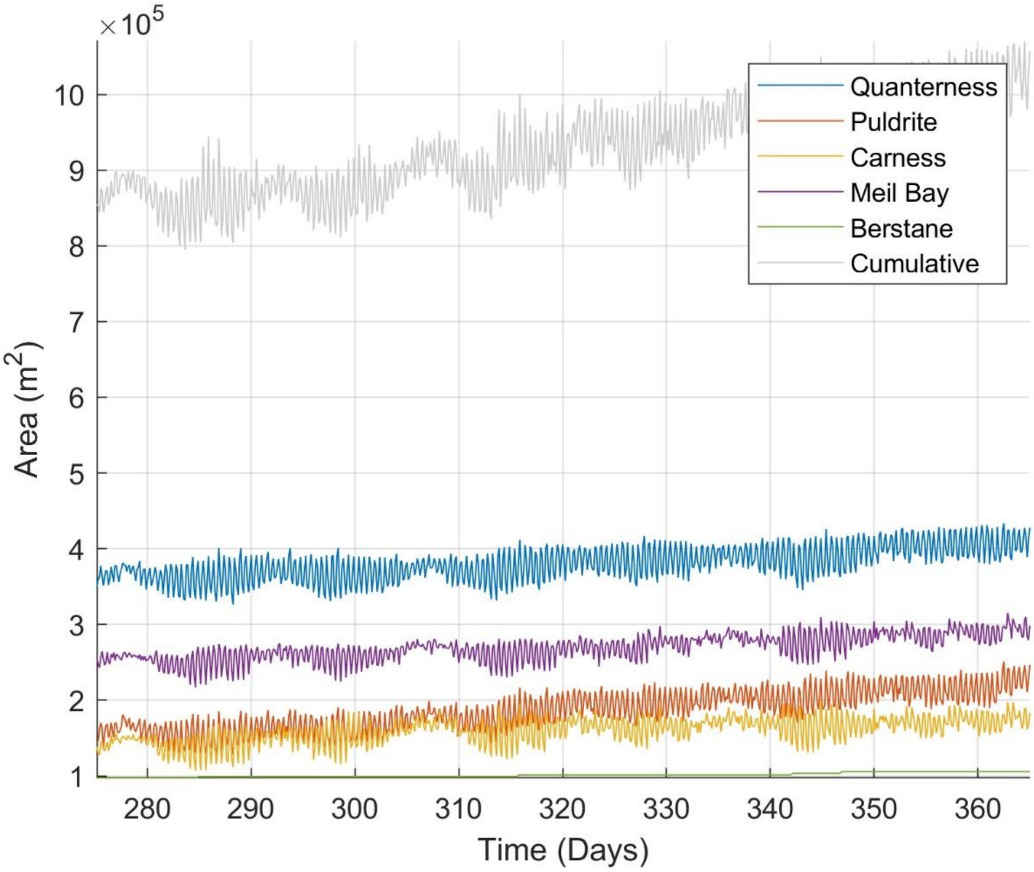

Figure 7. Average area exceeding 250g/m^2 for the cumulative and independent sites over the last 90 days of the simulation.

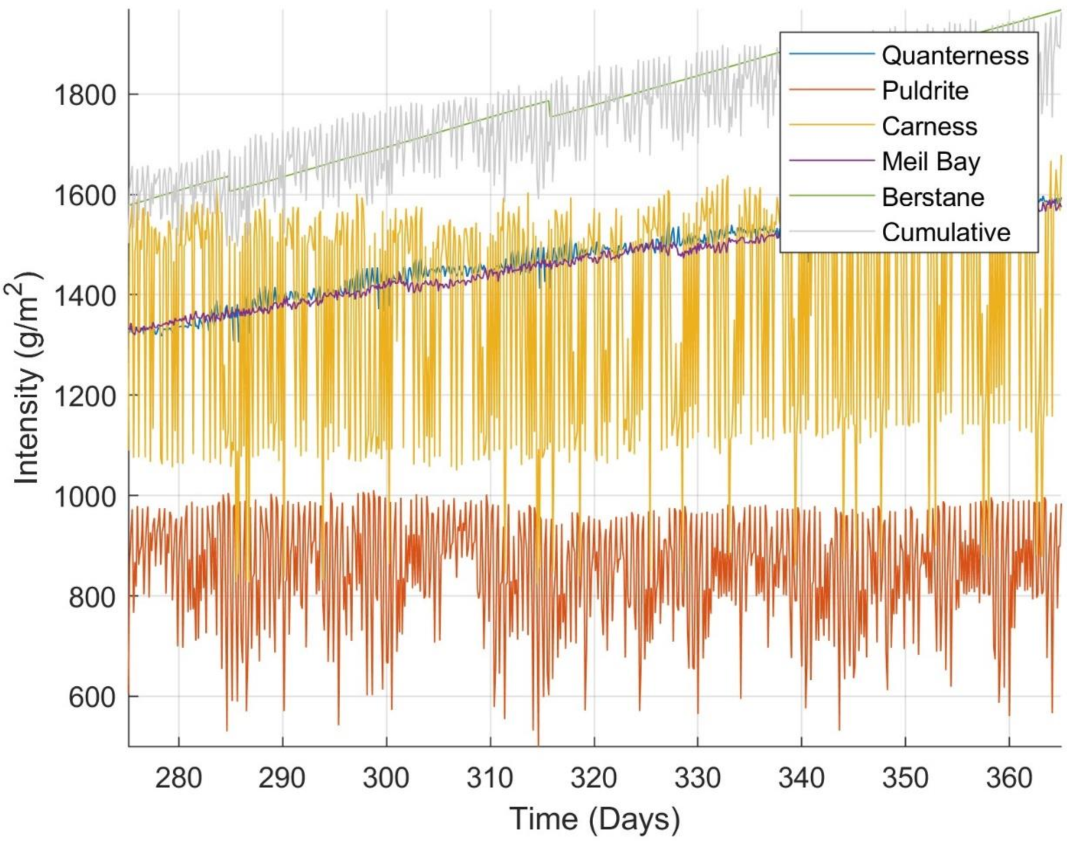

Figure 8. Average deposition intensity for areas exceeding 250g/m^2 for the cumulative and independent sites for the last 90 days of the simulation.

The average individual and cumulative area exceeding 250 g/m^2 for the last 90 days of the simulation is shown in table 7.

Table 7. Average concentration at 250g/m^2 contour, averaged over the last 90 days of simulation.

	Area (m^2)
Meil Bay (Proposed)	269,665
Qaunterness (Proposed)	380,753
Puldrite	186,525
Carness	160,228
Berstane	101,075

Cumulative	**926,543**

3.2 Sensitive Marine Features

Waste feed and feaces particles released from all aquaculture farms are monitored in the form of deposition and suspended flux. These values are assessed at identified sensitive marine feature locations to determine potential environmental risk. Figure 9 shows the average cumulative deposition flux for all proposed sites. The results indicate that no sediment accumulation occurs at any point or area based sensitive feature.

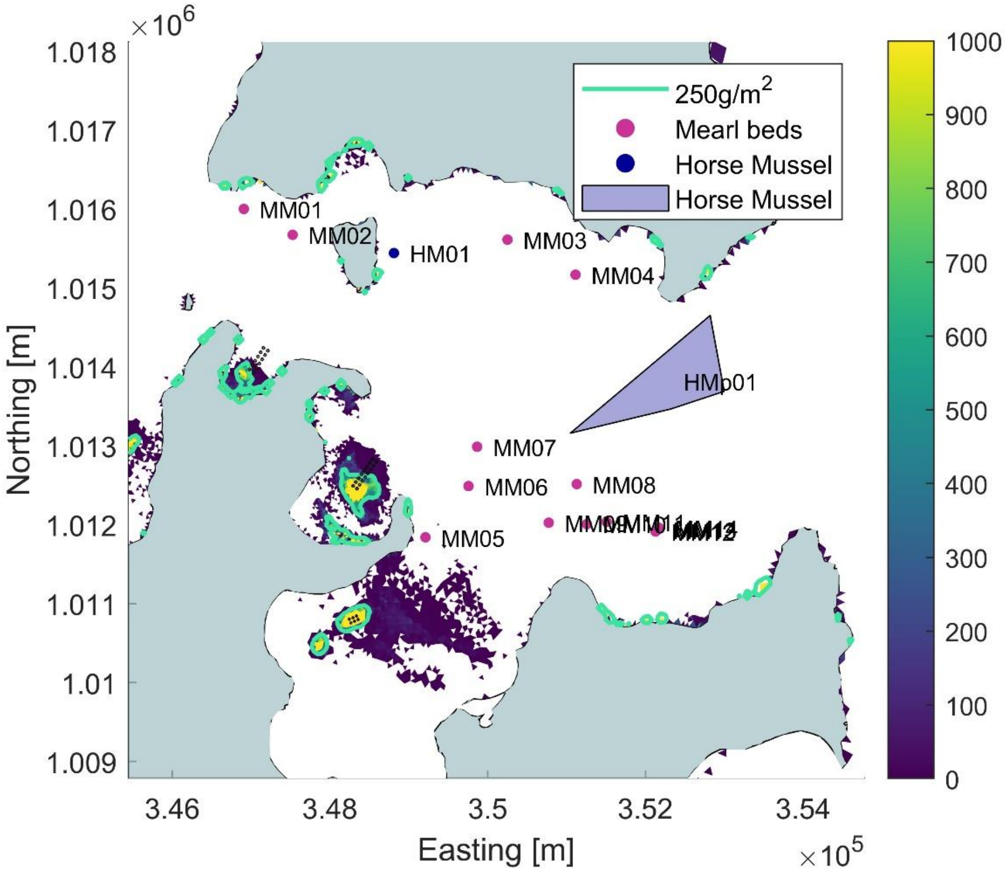

Figure 9. Average far field deposition (g/m^2) of the last 90 days of the simulation for all sites including the proposed Meil Bay development. All sensitive marine features identified in the screening report are shown.

Suspended sediment from the cumulative assessment is shown relative to the sensitive marine features within figure 10. This indicates no sensitive features are located within the main sediment pathway for any of the farms included within the assessment. The low concentrations and granular nature of the spatial average suggest a very low potential risk to sensitive features, even with enhanced sediment traps caused by complex seabed structures from marine features.

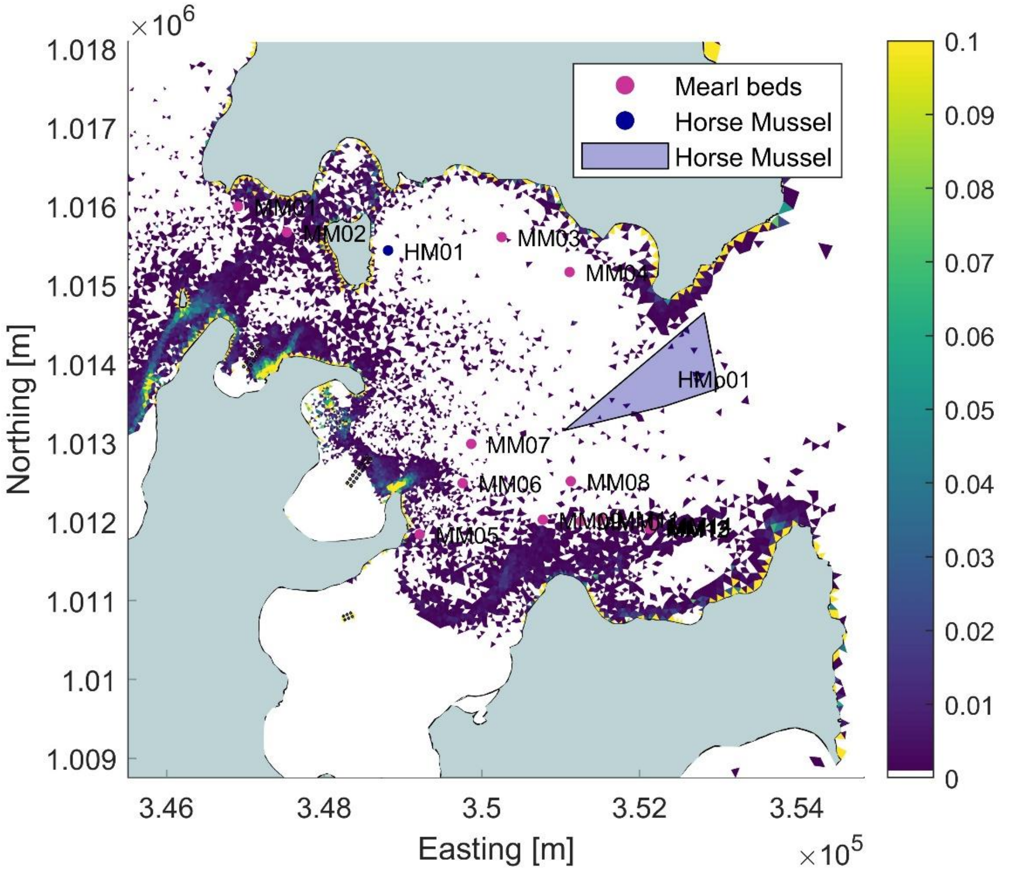

Figure 10. Average far field suspension (g/m^3) of the last 90 days of the simulation for all sites including the proposed Meil Bay development. All sensitive marine features identified in the screening report are shown.

Table 8 shows the average deposited and suspended values for each sensitive feature, where the polygon centres are used for area-based features. For all sensitive features, the suspension and deposition values are zero or negligible, this is less than 2 decimal places for sediment and 3 decimal places for suspended material. Within the area polygons HM01p, no deposition exceeds 250g/m^2.

Table 8. Average deposition and suspension at the location of each sensitive marine feature.

	Name	Easting (m)	Northing (m)	Sediment Flux (g/m^2)	Suspended Flux (g/m^3)
Mearl - points	MM01	346907	1015999	0	0
	MM02	347526	1015671	0	0
	MM03	350250	1015610	0	0
	MM04	351113	1015166	0	0

	MM05	349210	1011840	0	0
	MM06	349756	1012489	0	0
	MM07	349865	1012987	0	0
	MM08	351128	1012514	0	0
	MM09	350773	1012025	0	0
	MM10	351256	1012007	0	0
	MM11	351506	1012036	0	0
	MM12	352127	1011913	0	0
	MM13	352147	1011933	0	0
	MM14	352171	1011960	0	0
Horse Mussel - points	HM01	348810	1015440	0	0
Horse Mussel - area	HMp01	352282	1013818	0	0

	Polygon Area (m^2)	**Area exceeding 250g/m^2 (m^2)**	**Percentage Area of Polygon (%)**	**Area exceeding 1g/m^2 (m^2)**	**Percentage Area of Polygon (%)**
Horsel Mussel	1,023,467.5	0	0	0	0

A time series of deposition and suspension for each point based sensitive feature is shown in figure 11. For all features the presence of deposited or suspended particles is shown to be infrequent and transient. For sedimented particles, no accumulation occurs, where any deposition is quickly resuspended, this shows no sustained periods of deposition. The suspended material shows a similar sporadic distribution at low concentrations. This identifies that all features are not located in areas of sediment accumulation or within potential suspended sediment pathways.

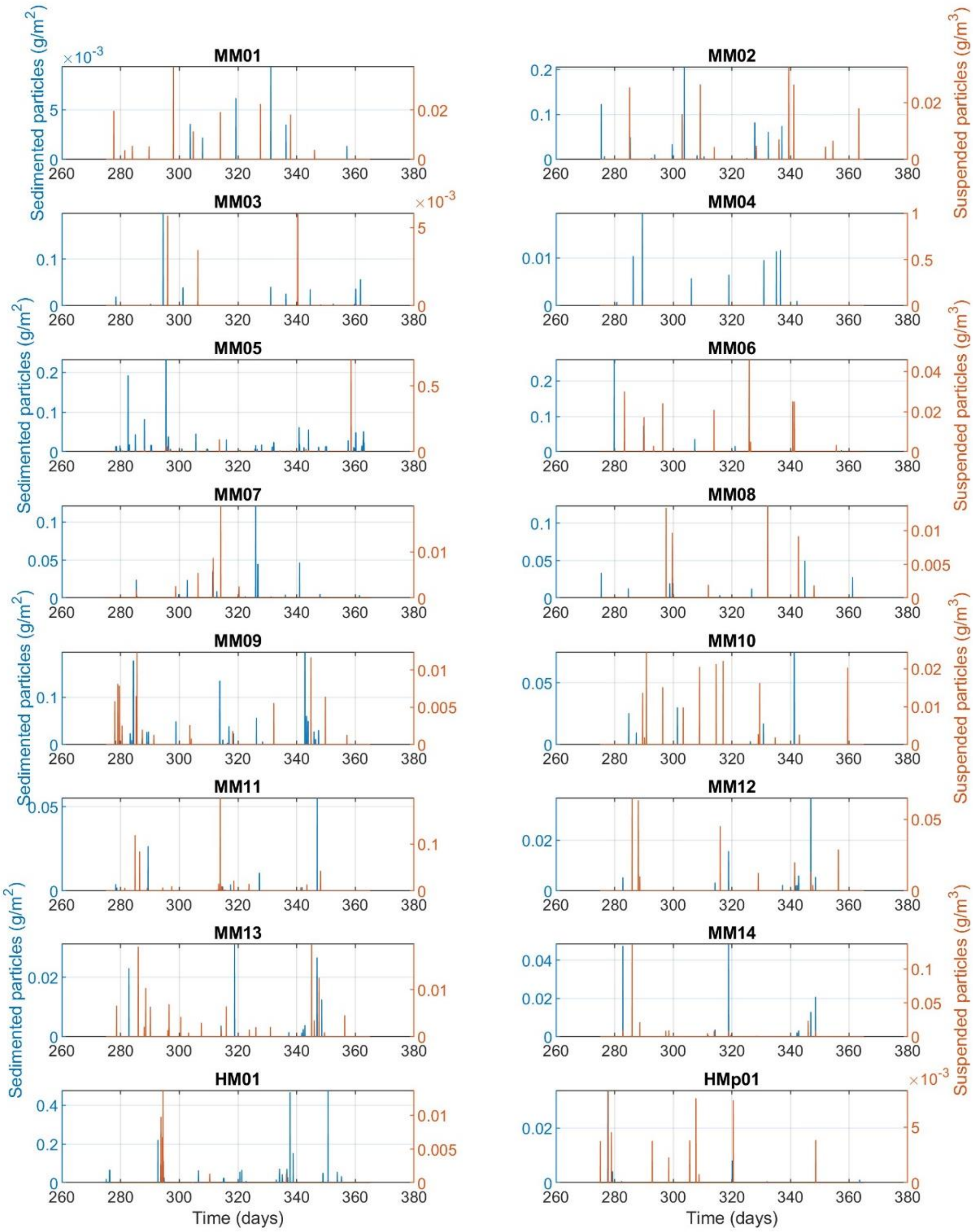

Figure 11. Timeseries of sedimented (left axis) and suspended (right axis) particles over the last 90 days for all identified point sensitive features.

4. Conclusions

This report outlines the hydrodynamic and particle tracking model for the distribution of solid waste particles from all surrounding aquaculture farms. This is used to help regulate development when considering cumulative deposition and potential risk towards sensitive marine features.

The proposed Meil Bay development shows the majority of accumulation of deposited material beneath the farm and towards the southern part of the bay. The cumulative effects show very little overlap with surrounding farms, with very small quantities transported to the Bay of Kirkwall and to Ingerness Bay. Average suspension pathways indicate a weak scattered distribution suggesting no single clear or concentrated pathway.

Deposition and suspension values were output for 16 sensitive point features and 1 area-based feature within the waterbody. No accumulation of deposited material occurred at any sensitive feature. A timeseries of deposited and suspended material indicated that infrequent and short-lived events occur. However, these were quickly resuspended or passed over the locations and further dispersed.

This study provides a very cautious approach at predicting the dispersal of solid waste from all fish farm developments within the area. The results show that while the site is situated in relatively sheltered conditions, the surrounding waters are very dispersive. Waste material released from the site is widely dispersed and assimilated. Both Suspended and deposited sediment pathways show little to no interactions with marine sensitive features and therefore pose no additional environmental risk.

5. References

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