09th January 2026

Far-Field Benthic Modelling Report

Vementry

Table of Contents

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 Swarbacks Minn. 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 calibrated and validated hydrodynamic model and particle-tracking model, incorporating dispersion parameters derived from local drogue surveys, was used to predict the advection and dispersion of faeces and waste feed from the proposed Vementry site and 13 additional sites in the area. Operational conditions were simulated for one year, assuming constant maximum stocking and no decay of organic particles.

Deposited and suspended sediment pathways are shown for the proposed Vementry farm and the cumulative proposed site scenario. Deposition is shown to occur locally to the site, with thin, patchy areas of accumulation occurring in the surrounding channel. Cumulative effects show minimal overlap with other sites, resulting in very small increases in the spatial deposition. Suspended material pathways indicate minimal particle transportation routes.

The most priority marine features show no interaction with fish farm waste. One feature shows a brief interaction with material originating from Vementry, occurring over a single time step, negligible in magnitude, and immediately eroded. The result of this modelling indicates that the proposed development poses a very low far-field and cumulative environmental risk from dispersion of solid waste material.

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 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

Vementry is considered a new potential site to be operated by Cooke Aquaculture Scotland. The site is located off the northeast coastline of Vementry, in Swarbacks Minn, Shetland. The proposed site consists of a single group of 10 circular, 120m circumference pens with a net depth of 21m. These are arranged in a 2 x 5 layout with an 85 m separation, housing a maximum consented biomass of 1350T at a maximum stocking density of 5.61kg/m^3. The site is aligned with a bearing of 295.5° and has a wave exposure index of 3.52. The proposed development adds a new site ~0.3 off the north coastline of Vementry with the site centre located at 430285.52 E, 1161466.97 N as shown in figure 1. Further information on the proposed site infrastructure and pen layout is presented in Table 1.

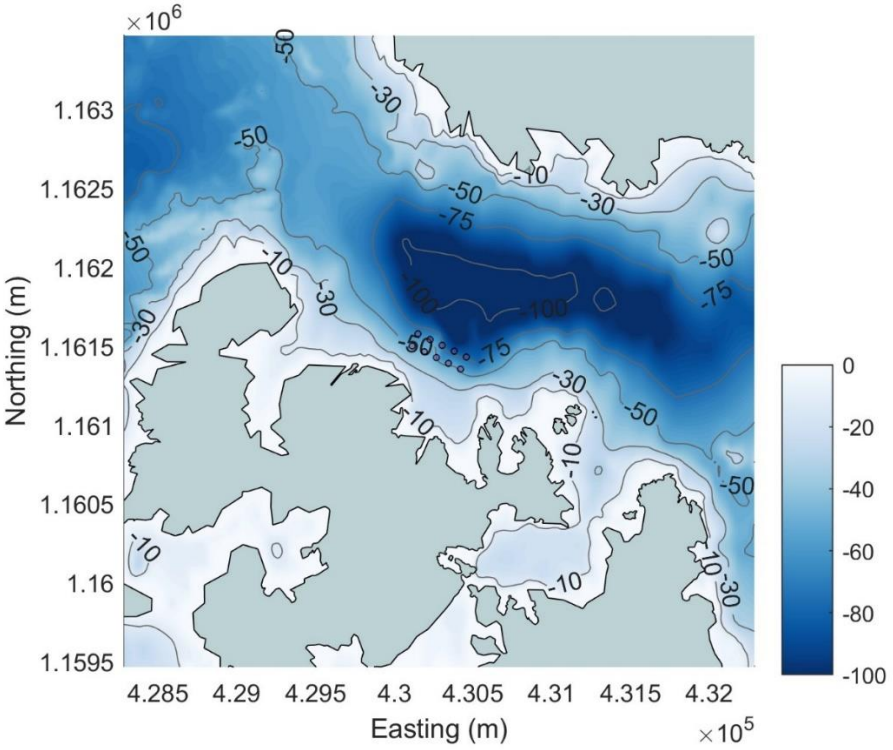

Figure 1. Proposed Vementry site infrastructure and bathymetry.

Table 1 – Proposed site infrastructure and pen layout.

	Vementry (Proposed)
Consent number	-
Company	Cooke Aquaculture Scotland
Receiving water	Swarbacks Minn
Site centre (OSGB36)	430285.52 E, 1161466.97 N
Current meter location (OSGB36)/year of deployment	430307E, 1161464N /2023
Distance to shore (km)	0.3
Average water depth (m)	58.2
Maximum biomass (t)	1350
Total number of pens	10
Number of pen groups	1
Formation	2 x 5
Pen group orientation (°)	295.5
Pen shape	Circular
Pen circumference (m)	120
Mooring grid (m)	85
Net depth	21
Wave exposure index	3.52

1.2 Surrounding Farms and Sensitive Marine Features

The Swarbacks Minn area hosts 14 fin fish aquaculture sites and 10 sensitive marine features. Table 2 outlines the additional farms that are included within the cumulative assessment and the marine features that are assessed within this study. These sites were specified in the Screening and Risk Identification Report (SEPA 2024).

Table 2. Farm and sensitive marine features identified within Swarbacks Minn and its surrounding waters.

Name	Feature type	Location (OSGB)		Mesh resolution (m)
		East	North	
Vementry	Fish Farm	430363	1161477	31.0
BOB1	Fish Farm	434243	1157972	48.5
COLED1	Fish Farm	435782.1	1163170	35.2
COLEN1	Fish Farm	436350.9	1162387	47.7
CROSS1	Fish Farm	429526.9	1158439	66.6
EAIT1	Fish Farm	434906	1156578	45.6
LBUR1	Fish Farm	434749.1	1159483	36.3
LINB1	Fish Farm	428309.2	1158767	84.4
MUCE1	Fish Farm	434435	1165632	38.2
NEPL1	Fish Farm	434244.1	1162453	36.5
NOR1	Fish Farm	429200.2	1161211	31.6
OLN2	Fish Farm	437808.7	1164984	35.1
OLNA1	Fish Farm	437414.1	1164260	44.0
SOA1	Fish Farm	432188.9	1159966	35.0
Kelp Beds	PMF	429492	1164721	53.8
		430730	1162602	31.9
		429092	1162142	30.8
		431190	1160396	36.8
		430527	1167164	66.9
Horse Mussel	PMF	434994	1163509	39.0
		435549	1162602	36.9

Kelp and Seaweed Communities	PMF	435062	1163672	28.4
		434994	1163496	38.5
		435299	1163340	34.4

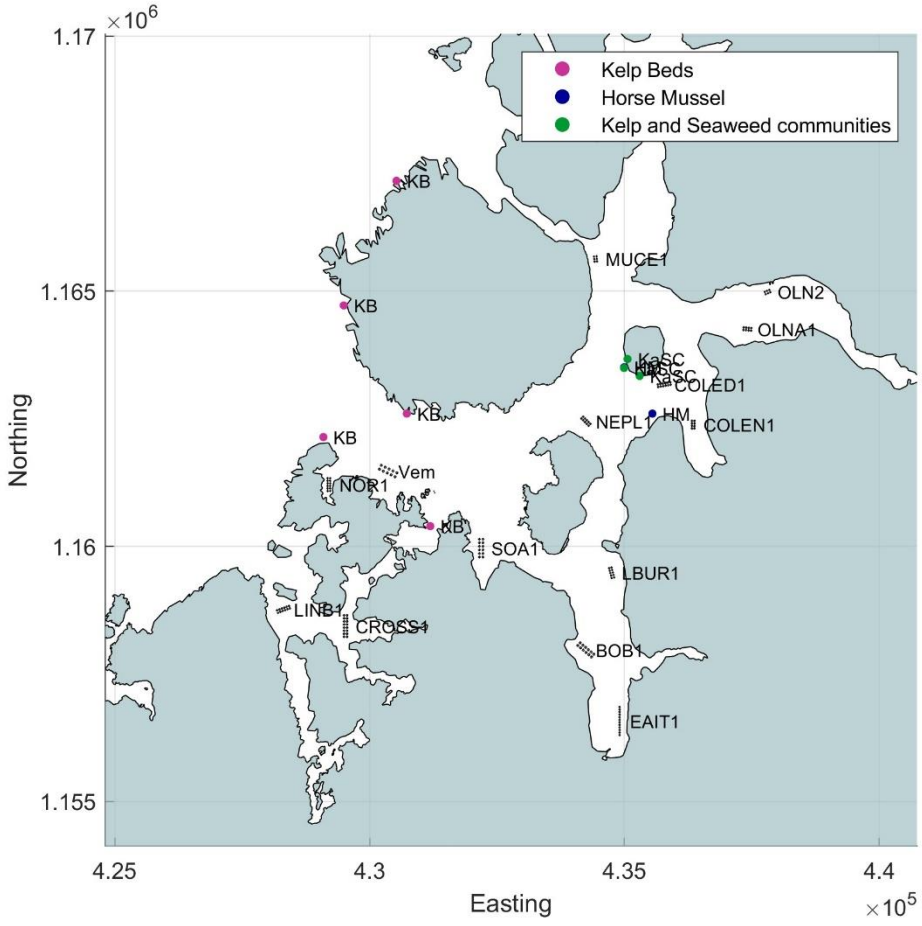

Figure 2. Fin fish farm locations and sensitive marine features identified in and around Swarbacks Minn.

2. Model Description

This study uses DHI's MIKE21/3 flexible mesh model to simulate free-surface flow and waste particle advection 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 Mike21/3 is used to simulate regional-scale hydrodynamic flow and waste feed and fish faecal matter dispersion and deposition. This uses a calibrated hydrodynamic and particle tracking model to replicate particle emissions from all farms specified within the Screening and Risk Identification report (SEPA, 2024b). This utilises better performing

spatially varying hydrodynamics to identify particle fate and accumulation near existing farms and sensitive marine features.

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 (2024) and is used to define the land boundaries within the domain. Bathymetry data are taken from the UK Hydrographic Office (UKHO 2021). A flexible mesh is applied where the peripheries of the model domain have a coarse resolution, with an approximate cell spacing of 250m. The mesh resolution for all identified farms and sensitive marine features is specified in table 1, where the area within Swarbacks Minn has a maximum mesh resolution of 1225-2000m^2 (35-45m). Due to the close proximity of finfish, shellfish and marine features in Swarbacks Minn, an extended area of increased mesh resolution was used. The computational mesh is shown in Figure 3, with an enlarged view of the identified areas of interest.

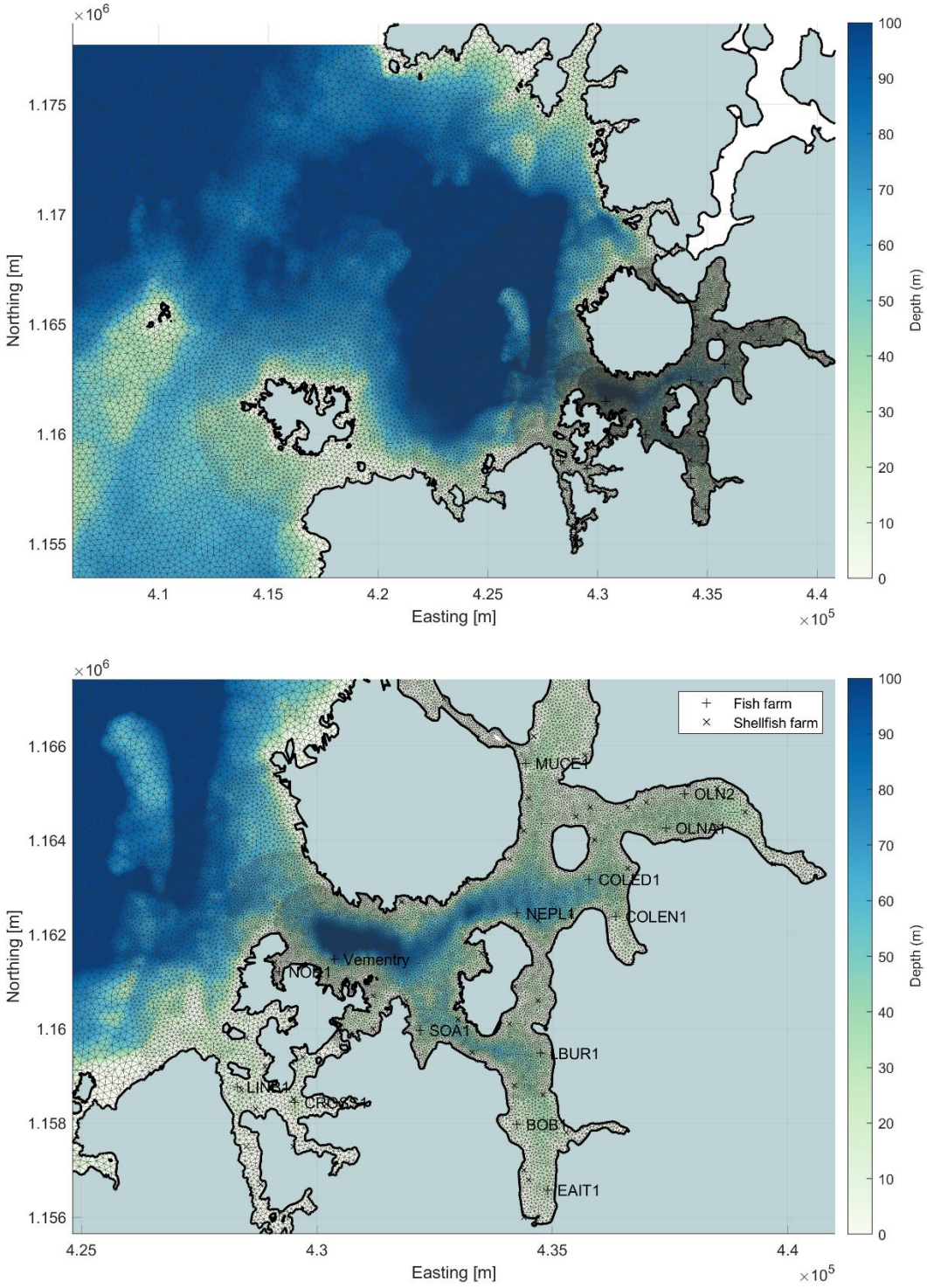

Figure 3. Hydrodynamic model mesh and bathymetry (top), enlarged view of the computational domain around the Swarbacks Minn area (bottom).

2.1.2 Configuration and boundary forcing

Boundary conditions are taken from E.U Copernicus Marine Service Atlantic - European North West Shelf - Ocean Physics Analysis and Forecast (CMEMS, 2025). This is taken from a

larger scale domain consisting of 50 depth layers and a horizontal resolution of 0.027° at a 15-minute time step. Surface elevation output was interpolated onto boundary nodes on the smaller-scale mesh shown in figure 3. Wind data was taken from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5 model (ECMWF 2025). This provides wind velocity in U and V components, as well as surface pressure with a resolution of 0.25°x. 0.25° at a 3-hourly interval.

A 2-dimensional domain is proposed with a time step interval of 60 s. Outputs are specified with point data frequency of 10 min (600s) and area data outputs at 60 min (3600s) intervals. The model is run for 365 days, plus an additional 5 days to allow the hydrodynamic model to stabilise. The governing equations use the shallow water equations with high order time integration and spatial discretization. Minimum and maximum timesteps were relaxed to 0.01s and 60s with a critical CFL number of 0.95. This has minimal effects to the output values but reduces computational time. Flooding and drying were included, with a drying depth of 0.005 and a wetting depth of 0.1. The horizontal eddy viscosity applies Smagorinsky's formulation with a constant value of 0.15.

Bed roughness is specified in the form of the Manning number and is used as the main calibration term for the HD model. The best result applies a uniform value of 20 $m^{1/3}/s$ over the entire domain.

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.

2.2.1 Particle Configuration

Each farm specified in Table 1 is modelled at peak biomass for the entire model duration. 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. The quantities of waste and excreted solids use the same formulation specified in the SEPA default model (SEPA, 2019a). Default particle properties are specified in Table 3. Where calibration data is available, these parameters may be adjusted.

Table 3. Particle mass per model timestep.

Site	Biomass (t)	Waste feed (kg)	Excreted Solids (kg)
Vementry	1350	10.75	52.13
BOB1	962	7.66	37.15

COLED1	2178	17.34	84.11
COLEN1	752	5.99	29.04
CROSS1	995	7.92	38.43
EAIT1	750	5.97	28.96
LBUR1	962	7.66	37.15
LINB1	1171	9.32	45.22
MUCE1	350	2.79	13.52
NEPL1	1750	13.93	67.58
NOR1	500	3.98	19.31
OLN2	300	2.39	11.59
OLNA1	1000	7.96	38.62
SOA1	2442	19.44	94.31

Particle properties are defined in table 4. Waste feed and faeces particle settling rates are defined using the SEPA default values. The results of the drogue survey were used to determine representative horizontal dispersion coefficients (K_h). This applies a horizontal dispersion coefficient of 0.0531 m^2/s for all sites. Vertical dispersion coefficient uses the default value of 0.001 m^2/s for all sites.

Table 4. Benthic model particle parameters

Particle class	**Waste feed**	**Excreted solids**
Decay (s)	0	0
Settling velocity (m/s)	0.095	0.035
Horizontal dispersion (m^2/s)	0.0531	0.0531
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 5. 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 5. 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 Vementry farm within Swarbacks Minn is shown in figure 4. The concentrations displayed represent the mean of the last 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 occurring beneath the site with small patchy accumulations throughout the channel.

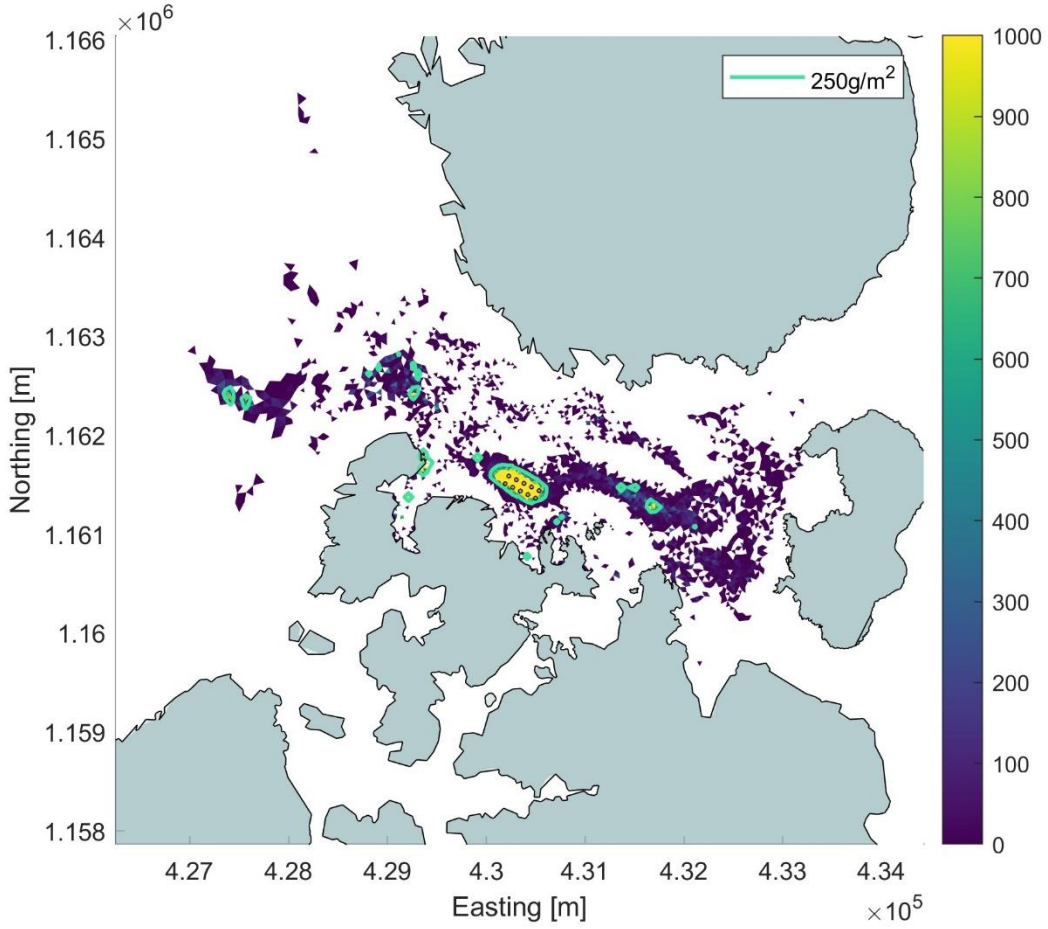

Figure 4. Average far field deposition (g/m^2) from the last 90 days of the simulation for the proposed Vementry development.

The average deposition from all sites, including the proposed Vementry development are shown in figure 5. The cumulative assessment of deposition shows sediment accumulations throughout Swarbacks Minn. The deposition of the proposed sites shows minimal overlap with existing developments, resulting in minimal increase in cumulative impact, where

deposition from Vementry and neighbouring sites only results in minor increases in deposition values.

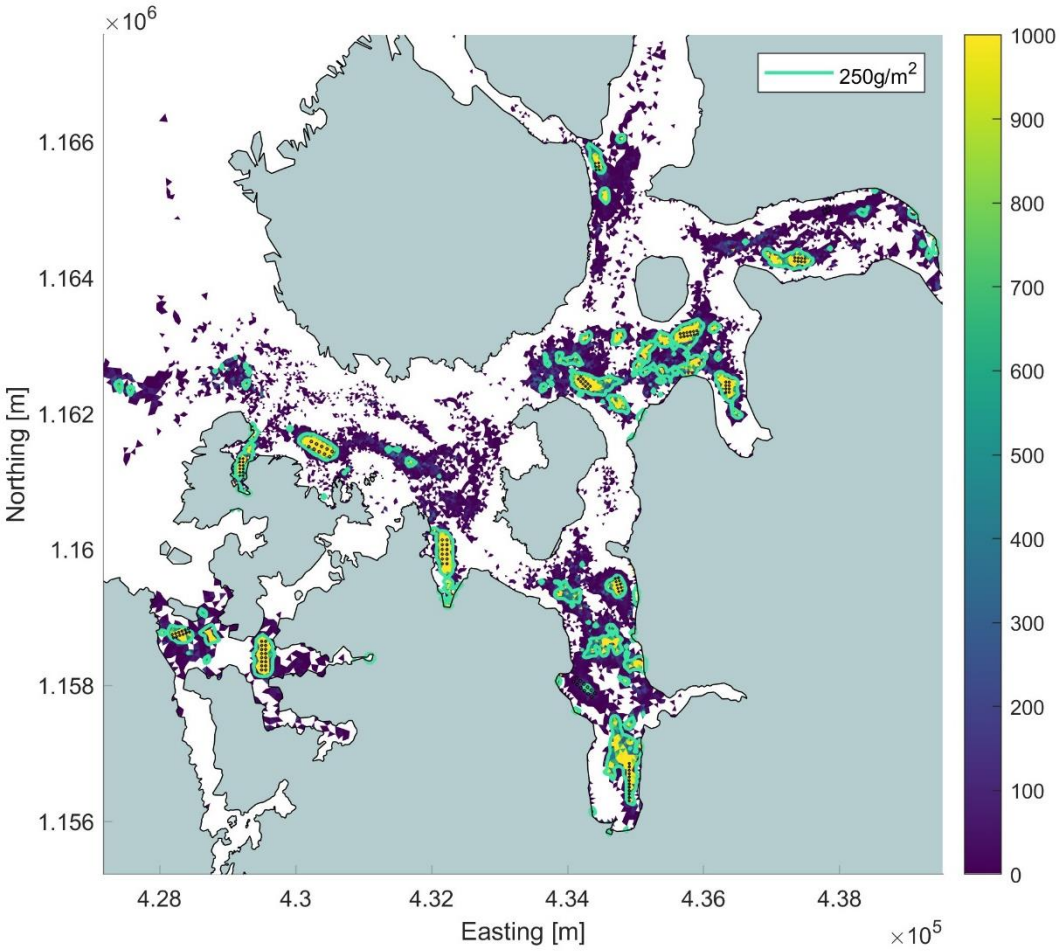

Figure 5. Average far field deposition (g/m²) from the last 90 days of the simulation for all sites.

The suspended sediment pathway for all sites is shown in figure 6. Suspension around the proposed Vementry development occurs mainly beneath the farm, with patchy values around the site. This indicates lower resuspension, where particles spend most of their time in contact with the seabed. The lack of clear suspension pathways around the farm indicates limited sediment transport routes and highlights a lack of cumulative interaction with neighbouring sites.

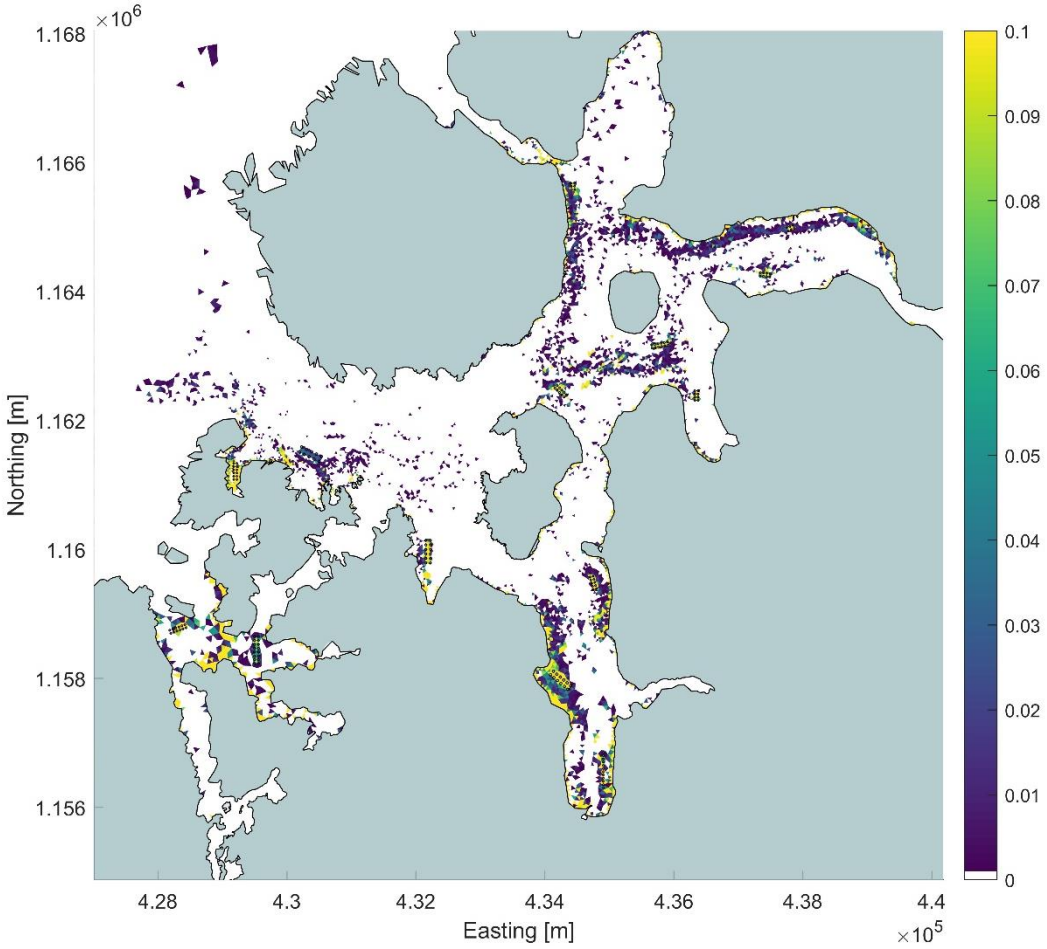

Figure 6. Average far field suspension pathway (g/m^3) of the last 90 days of the simulation for all sites.

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.

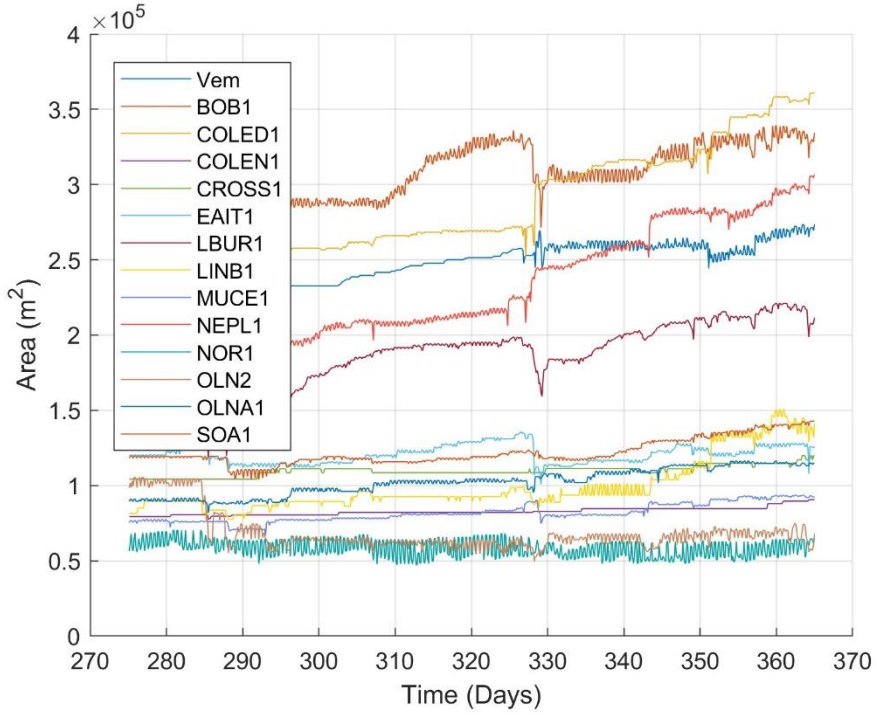

Figure 7. Average area exceeding 250g/m^2 for all independent sites over the last 90 days of the simulation.

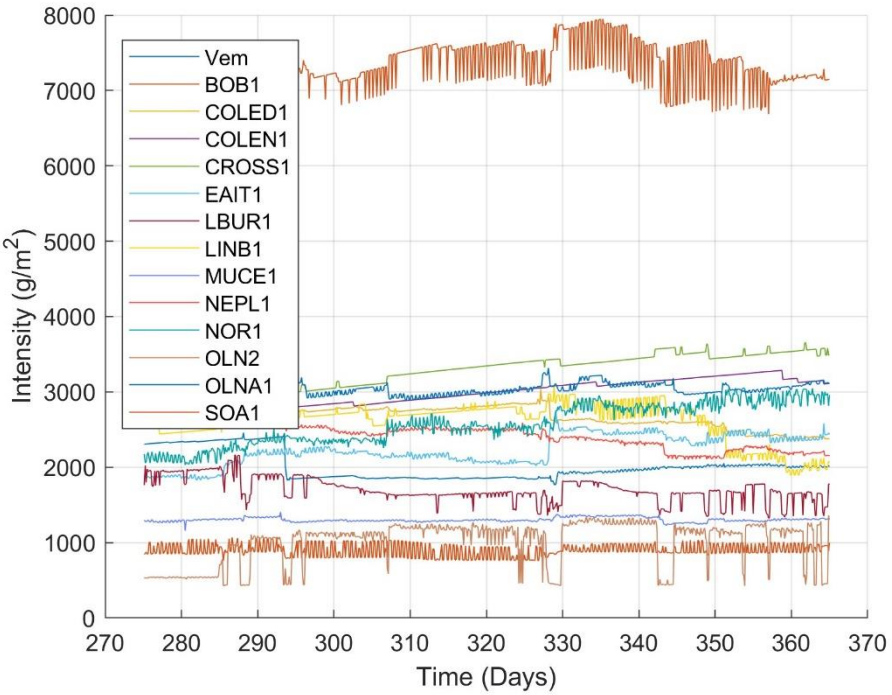

Figure 8. Average deposition intensity for areas exceeding 250g/m^2 for all independent sites for the last 90 days of the simulation.

The average individual and cumulative area exceeding 250 g/m^2 for the last 90 days of the simulation is shown in table 6.

Table 6. Average concentration at 250g/m^2 contour, averaged over the last 90 days of simulation.

	Area (m^2)
Vementry	234,328
BOB1	301,610
COLED1	283,116
COLEN1	82,779
CROSS1	109,735
EAIT1	120,797
LBUR1	183,647
LINB1	99,336
MUCE1	81,658
NEPL1	222,326
NOR1	58,348
OLN2	68,804
OLNA1	102,258
SOA1	122,009
Cumulative	2,052,450

3.2 Sensitive Marine Features

Waste particulates released from all aquaculture farms in the form of deposition and suspended flux are calculated at previously identified sensitive marine feature locations. Figure 9 shows the average cumulative deposition flux, where all point sensitive features experience very low or no deposition.

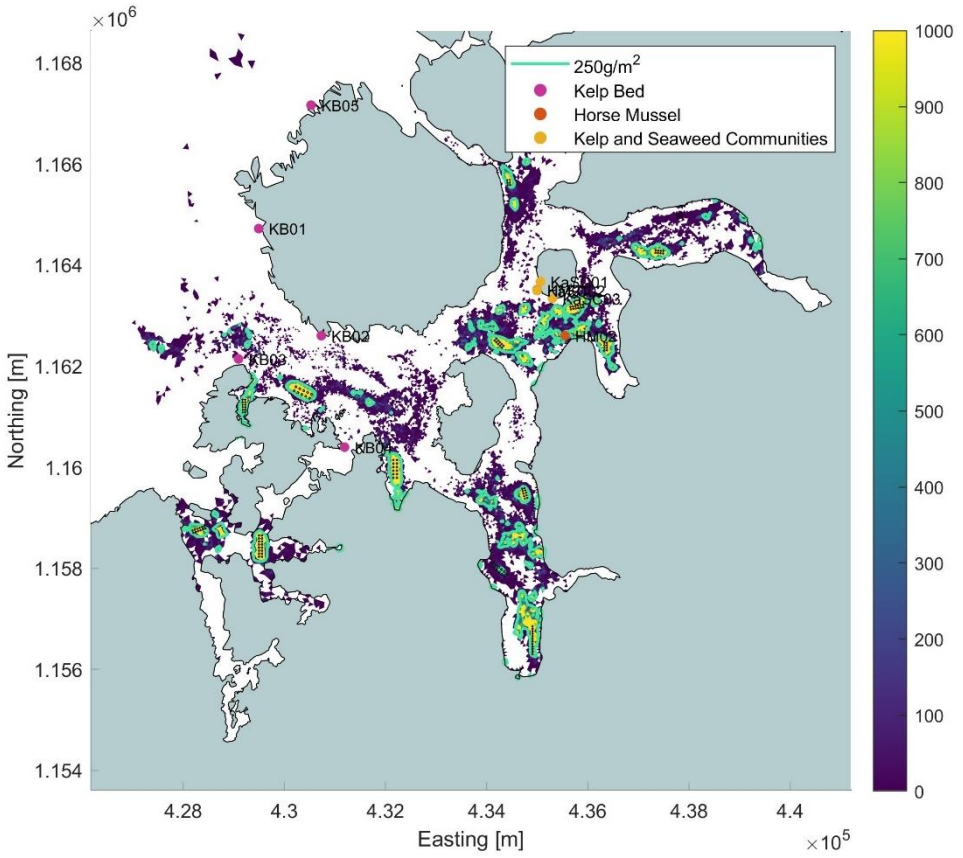

Figure 9. Average far field deposition (g/m^2) of the last 90 days of the simulation for all sites. All sensitive marine features identified in the screening report are shown.

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.

Table 7 shows the average deposited and sedimented values for each sensitive feature. For the majority of these features, the suspension and deposition values are zero. HM02 shows very small values for deposition of 9.07g/m^2. However, as no deposition and suspension from the proposed site accumulates at this location this is not relevant to the proposed development.

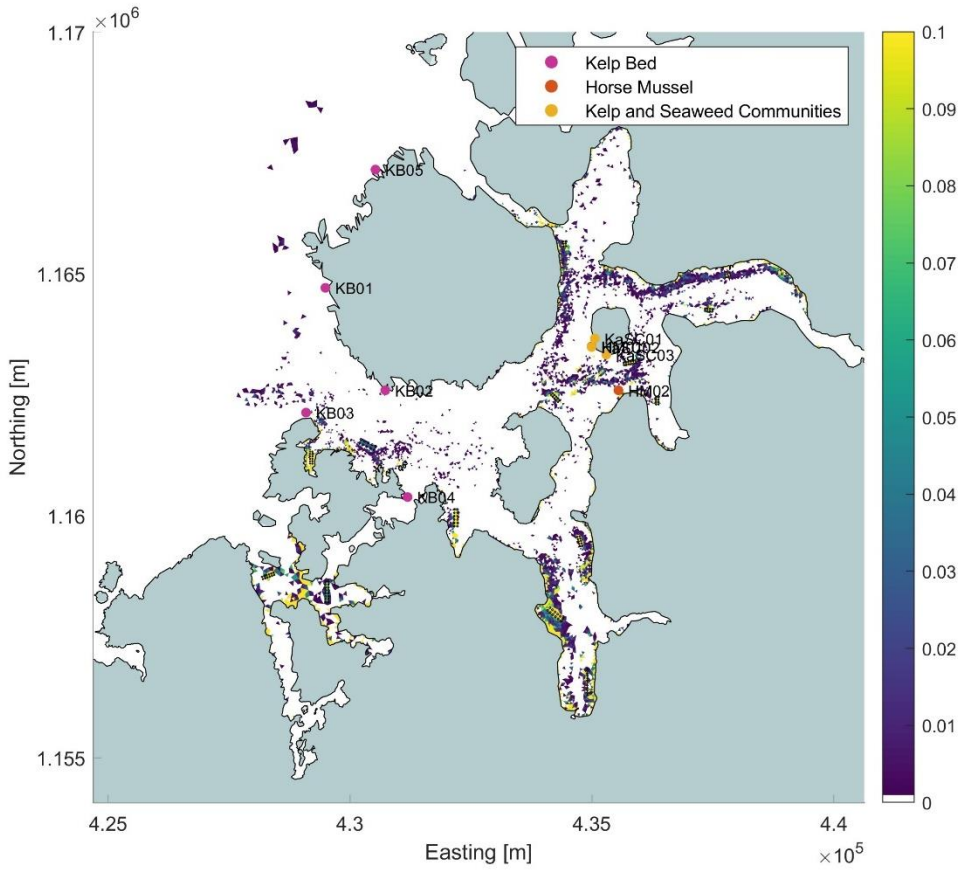

Figure 10. Average far field suspension (g/m³) of the last 90 days of the simulation for all sites. All sensitive marine features identified in the screening report are shown.

Table 7. Average deposition and suspension at the location of each sensitive marine feature.

	Name	Easting (m)	Northing (m)	Sediment Flux (g/m²)	Suspended Flux (g/m³)
Kelp Beds	KB01	429492	1164721	0.00	0.000
	KB02	430730	1162602	0.03	0.000
	KB03	429092	1162142	0.00	0.000
	KB04	431190	1160396	0.00	0.000
	KB05	430527	1167164	0.00	0.000
Horse Mussel	HM01	434994	1163509	0.00	0.000

	HM02	435549	1162602	9.07	0.00
Kelp and Seaweed Communities	KaSC01	435062	1163672	0.00	0.000
	KaSC02	434994	1163496	0.00	0.00
	KaSC03	435299	1163340	0.00	0.00

A time series of deposition and suspension for each point based sensitive feature is shown in figure 11. For the majority of features, no aquaculture waste interaction occurs throughout the simulation duration. Only two locations show particle interactions with cumulative farm waste. KB02 shows a single time step for deposition and suspension, where a single event occurs and is eroded with no lasting deposition. HM02 shows a very small and irregular amount of deposition accumulation. The magnitude of this deposition is below the 250g/m^2 EQS, indicating no environmental risk. This is caused by the farms neighbouring the feature and is not related to any particle release from the proposed Vementry site.

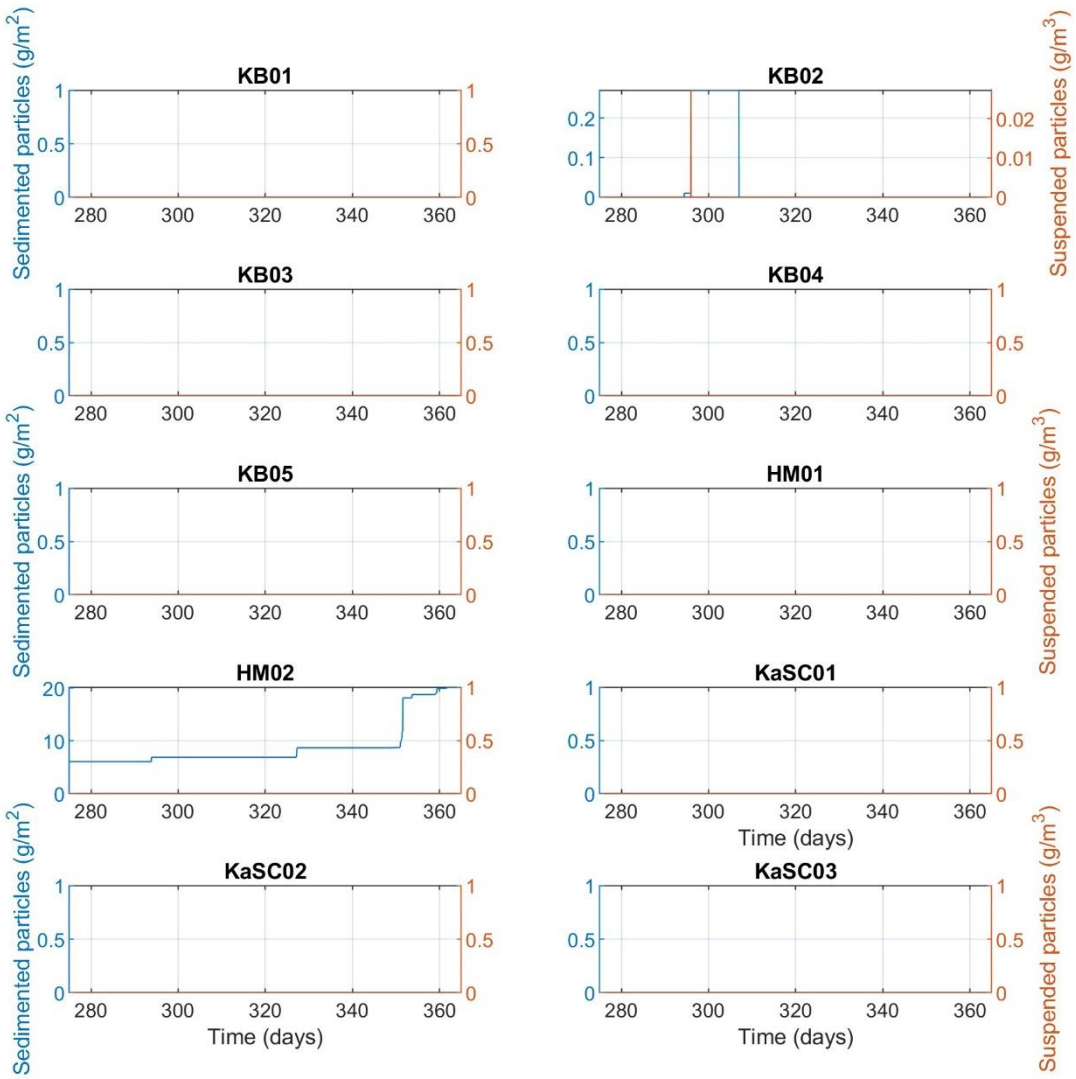

Figure 11. Timeseries of sedimented (left axis) and suspended (right axis) particles over the last 90 days for all identified point sensitive features.

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 Vementry development shows an isolated and self-contained footprint, with the majority of deposition occurring under the site. Small remote pockets of deposition occur within the main channel with few accumulations exceeding 250g/m2 and only occurring over a very small area. Cumulative impact from all CAR licenses within Swarback Minn show a complex distribution of deposition. Due to the location of the proposed

Vementry farm, there is little to no interaction with most farms within the waterbody. This suggests the inclusion of the proposed site will not result in any adverse cumulative impacts.

Deposition and suspension values were assessed at 10 sensitive feature locations, where only 2 locations showed any interactions. Vementry was shown only to contribute to one of these locations, where a single event occurred at extremely low levels that was immediately eroded.

The modelling adopts a highly precautionary approach, with all CAR-licensed sites simulated at maximum biomass and with no allowance for organic matter breakdown. These assumptions do not reflect actual operational farms in the region, realistic stocking practices, or natural assimilation processes, and therefore are not representative of the current deposition within the waterbody. The results show that the waste distribution from the proposed Vementry site remains relatively self-contained with small cumulative deposition that has a negligible effect on the waterbody and identified sensitive features. Therefore, the operation of the site poses no additional far-field environmental risk or additional risk to identified sensitive marine features.

5. References

Ordnance Survey (2020) “Data Downloads” (Accessed September 2020) Available at: https://osdatahub.os.uk/downloads/open

SEPA (2018) “Supporting Guidance (WAT-SG-53): Environmental quality standards and standards for discharges to surface waters”.

SEPA (2024) “Aquaculture Modelling Screening &Risk Identification Report: Vementry (VMNT1)” May, 2022

SEPA (2024) “Marine Modelling Guidance for Aquaculture Applications” January, 2024.

UK Hydrographic Office (2021) Marine Data Portal (Accessed May 2021) Available at: https://datahub.admiralty.co.uk/portal/apps/sites/#/marine-data-portal