Deposition Marine Modelling Report
Fish Holm, Shetland Islands

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1 Summary

This report describes simulations of deposition based on the outputs of a hydrodynamic model which was developed for the East coast of Shetland. The aim of the investigation was to provide a risk assessment for deposition resulting from a proposed new development within the area (details in Table 1.1), in addition to potential interaction with footprints from other nearby sites. A single scenario involving feeding at a fixed rate while stocking at peak biomass for a full year was simulated. This provides an upper limit on the anticipated cumulative impact of all the sites licensed to be stocked in the area.

The report includes an assessment of impacts on documented sensitive features within the neighbourhood of the site (Priority Marine Features, shellfish farms, and other fish farms). A visual survey carried out identified a number of potential additional PMF locations. These are also included in the impact assessment.

Table 1.1: Summary of site details and model results.

Proposed Site Details	
Name	Fish Holm
SEPA ID	FISH1
Location	Yell Sound, Shetland
Site centre (Latitude, Longitude)	60.446001, -1.122585
Proposed Biomass (T)	6000 (applied for)
Configuration	
Number of Cages	12
Cage Circumference (m)	160
Pen Group Distance to Shore	610 m (centre)
Pen Orientation	27°
Depth (m)	60

2 Introduction

This report has been prepared by Scottish Sea Farms Ltd. to meet the requirements of the Scottish Environmental Protection Agency (SEPA) for an application for an expansion of the site at Fish Holm, on the East coast of Shetland ("FISH1"; Figure 2.1), and in particular to predict the dispersal of waste feed and faeces from the proposed site.

The report describes the application of a particle tracking model to estimate the spread of waste material from the proposed site and its neighbours. The particle tracking model is forced by the outputs of a hydrodynamic model which was developed specifically for this work. Full details of the development, calibration and validation of the hydrodynamic model are given in dedicated reports ([2] [6]).

The modelling procedure follows the current version SEPA marine modelling guidance as available at January 2024, as far as possible [5].

This configuration is composed of 12 160 m circumference pens, with centre-point of cage grid at OSGB 448381, 1173901 m. Key data relating to the site are summarised in Table 1.1.

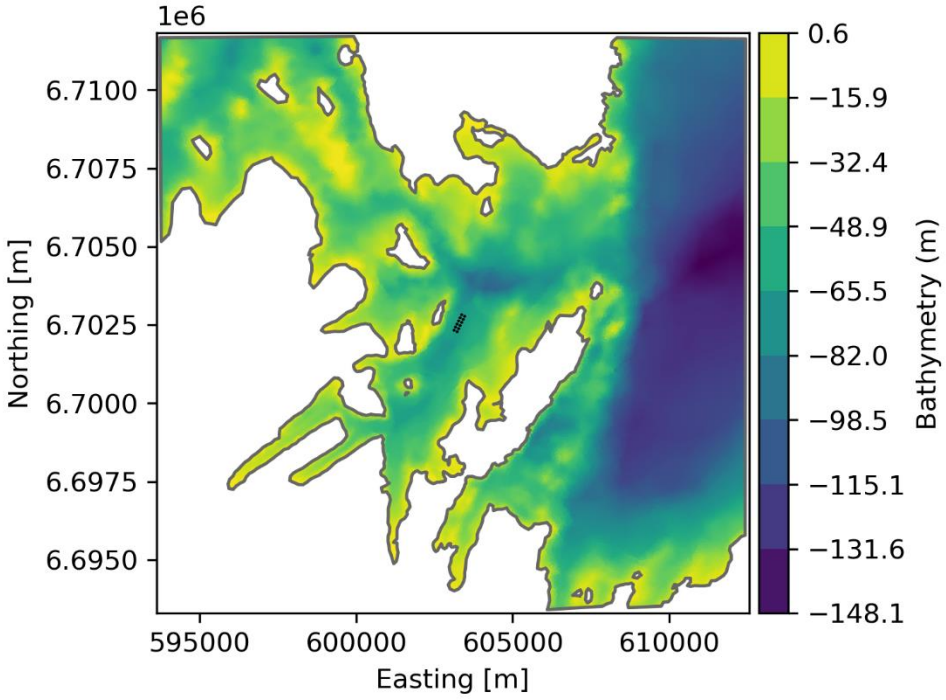

Figure 2.1: Location of the proposed Fish Holm development, overlaying MIKE mesh and bathymetry for the area. Map coordinates are UTM zone 30N.

3 Methodology

3.1 Hydrodynamic Model

The hydrodynamic model used in this work was the DHI MIKE 3 numerical modelling system, which has been developed for general simulation of water flows in estuaries, bays and coastal areas, in addition to wider ocean domains. MIKE 3 is a three-dimensional model which can account for density variation, currents and tidal elevation [3].

MIKE 3 is a finite volume hydrodynamic model, using an unstructured spatial mesh formulation which allows representation of fine scale features in coastline and bathymetry while retaining computational efficiency through a coarser mesh in simpler areas. Horizontal elements in the model can be triangular or quadrilateral; the model described here used exclusively triangular elements. This approach is particularly important for complex coastal regions such as the Shetland Islands. A similar method is used by other current hydrodynamic models such as FVCOM [1]. This allows simulation of spatial domains that were not possible with earlier regular-grid models such as POLCOMS and ROMS, which were developed with wider ocean regions in mind.

Hydrodynamic fields were derived from a climatological implementation of Scottish Sea Farms' East Shetland hydrodynamic model [2]. Model output covers the entirety of the Shetland Islands, with greater mesh resolution along the East Coast of the Shetland Mainland, and has been validated at multiple locations throughout the domain, including the proposed Fish Holm site. The hydrodynamic simulations covered two periods: i) a "climatological" year (25-year average meteorological and oceanographic forcing from 1990-2014), and ii) a 13-month period 01/06/2017-01/06/2018, which was validated against available current meter observations for the focal site and other nearby sites. The outputs of the former (climatology) simulation were applied here. The HD model output timestep was 30 minutes. Full details of the development, calibration and validation of the hydrodynamic model are given in [2] and the accompanying HD model validation report.

3.2 Particle Tracking Model

Particle tracking was also carried out using the DHI MIKE software suite ([3]). Flow fields (U/V/W velocities) generated by MIKE 3 were used to drive the movement of passive particles (no active horizontal or vertical movement) in the water column. Particles were subject to advection due to currents, and horizontal and vertical diffusion (described by a random walk formulation) at fixed rates of 0.1 and 0.001 $m^2 s^{-1}$ respectively. Separate simulations were carried out for waste feed and faeces, with specific sinking rates being applied to each class of particle:

- Waste feed = 0.095 m s^{-1}
- Waste faeces = 0.032 m s^{-1}

Particles were allowed to settle on the seabed, but no consolidation was included in the model. Erosion and resuspension from the seabed was modelled using a default critical erosion threshold of 0.02 N m^{-2}. The default bed roughness of 0.001 m was used for the main simulations (tuning and final).

A timestep of 180 s (3 minutes) was used for particle tracking. Half-hourly hydrodynamic model velocities were interpolated temporally horizontally onto the particle tracking model mesh by the software during the model simulation.

The model domain used for this study covers the East coast of Shetland Mainland (Figure 3.1). Resolution of hydrodynamic model mesh is constrained by computational processing capacity, and the need to obtain a balance between resolution and spatial extent of the model domain, which also has an impact on accuracy of predictions. High horizontal resolution in areas of deeper water requires a very short hydrodynamic model timestep, which is not feasible for a model of this spatial and temporal extent. The HD model mesh in this case was adapted to have a high resolution in the area around the proposed site, and lower resolution elsewhere. The mesh used for hydrodynamic modelling is shown in Figures 3.1 and 3.2.

Particle tracking was carried out using a higher resolution mesh representing the area around the proposed site development (Figure 3.3). This mesh has a fine resolution over an extended area in order to represent trajectories of particles more precisely. Median element area within a 3 km box centred on the proposed site location is 630.8 m^2 (95% interval = [399.3, 952.8] m^2).

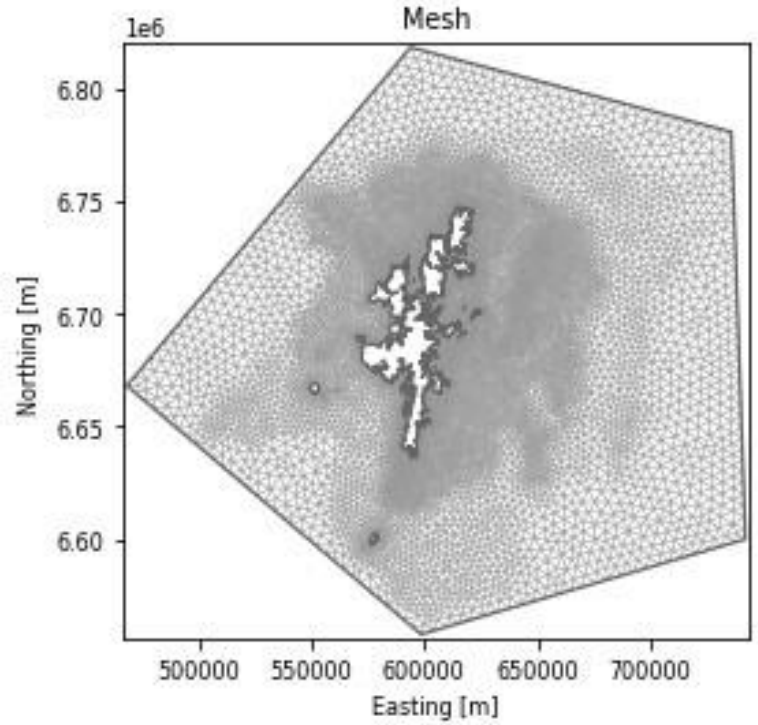

Figure 3.1: Mesh for hydrodynamic model, showing the full extent of the spatial domain, which covers the entirety of the Shetland Islands. [2]. Map coordinates are UTM zone 30N.

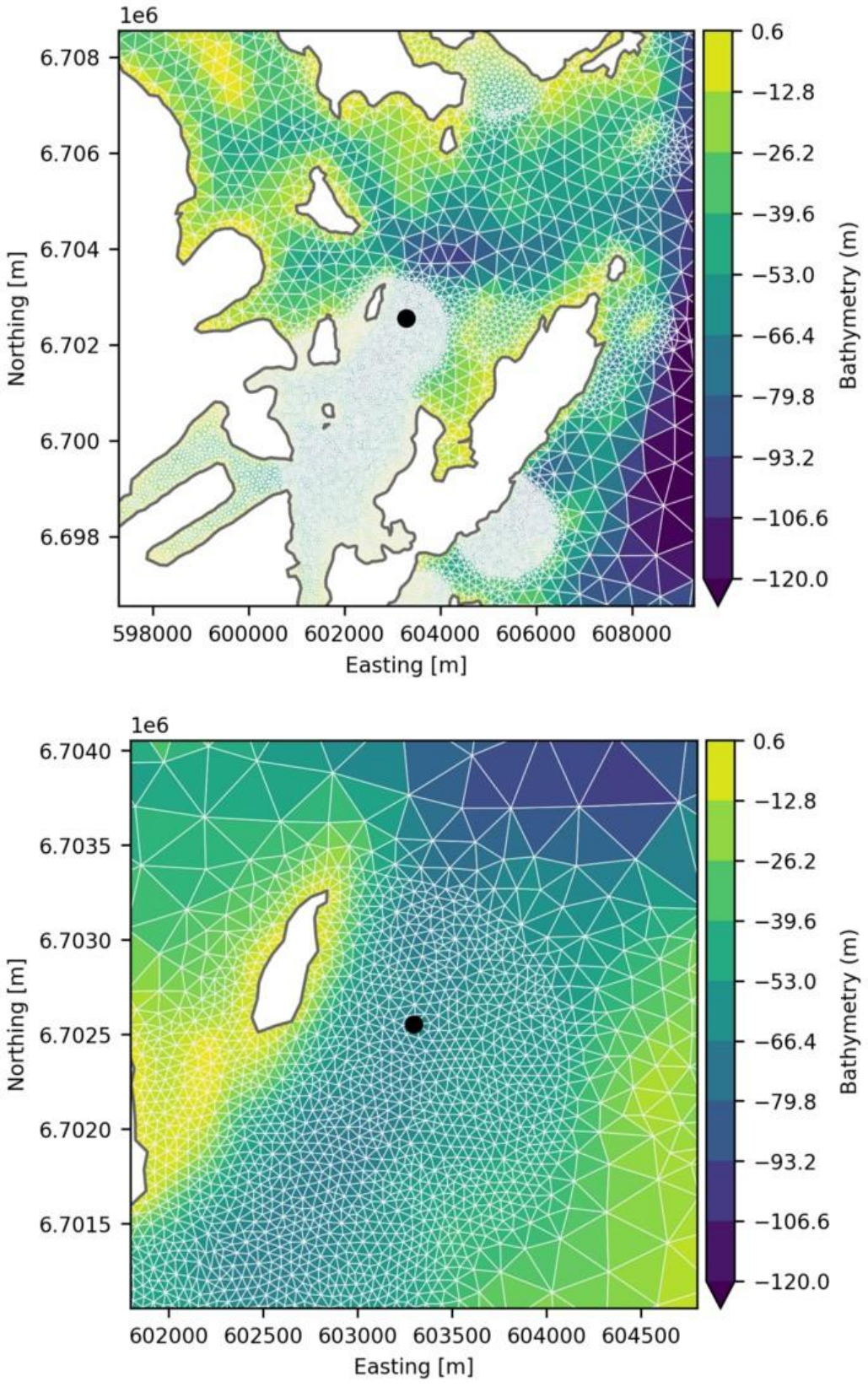

Figure 3.2: Close-up view of the area around Fish Holm and the mesh/bathymetry used for hydrodynamic modelling. Map coordinates are UTM zone 30N.

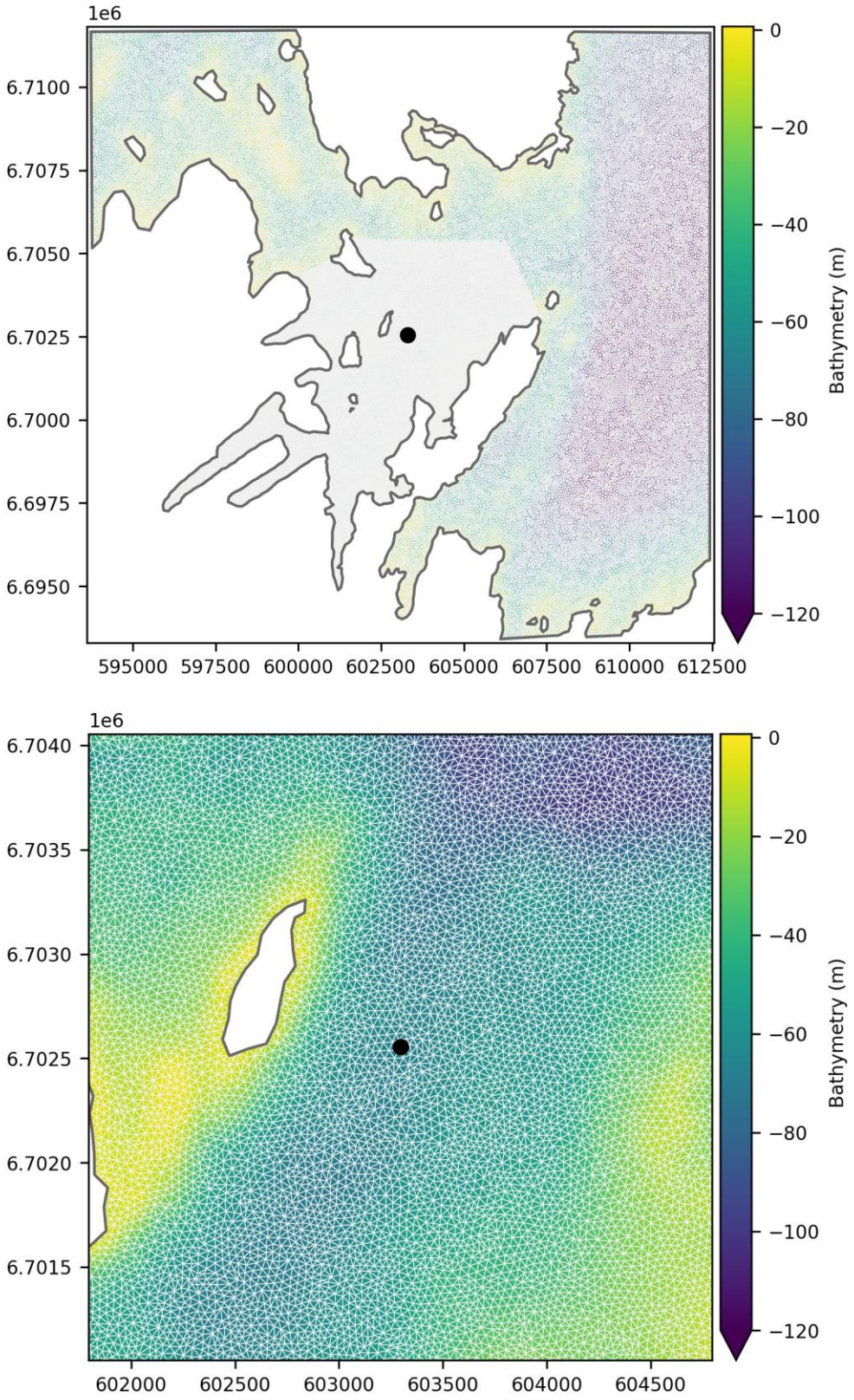

Figure 3.3: Close-up view of the area around Fish Holm and the mesh/bathymetry used for particle tracking. Map coordinates are UTM zone 30N.

3.3 Waste Deposition Model Study

3.3.1 Approach

For particle tracking simulations, separate results were stored for waste feed and faeces. Each simulation covered a period of 365 days, using HD model climatology output for the period 01/01/1993 00:00 to 31/12/1993 23:00.

Simulations were carried out for the proposed site FISH1, in addition to other existing sites identified in the SEPA risk screening report for the site ([4]).

Using the proposed site as an example, the quantity of material released per day was:

$$\begin{aligned}\text{Feed mass} &= \text{Biomass (kg)} \times \text{Feed requirement (proportion)} \times (1 - \text{Feed water content (proportion)}) \times \\ &\quad \text{Feed waste level (proportion)} \\ &= 6{,}000{,}000 \times 0.007 \times 0.91 \times 0.03 \\ &= 1{,}146.6 \text{ kg}\end{aligned}$$

$$\begin{aligned}\text{Faeces mass} &= \text{Biomass (kg)} \times \text{Feed requirement (proportion)} \times (1 - \text{Feed water content (proportion)}) \times \\ &\quad (1 - \text{Feed waste level (proportion)}) \times (1 - \text{Feed absorption level (proportion)}) \\ &= 6{,}000{,}000 \times 0.007 \times 0.91 \times 0.97 \times 0.15 \\ &= 5{,}561.0 \text{ kg}\end{aligned}$$

Where the values used for each parameter (other than biomass) are the SEPA default values as per the latest version of the guidance [5].

Details of the sites used, and the calculated mass release rates, are given in Table 3.1. For the Fish Holm site, polygons representing proposed and existing pen layouts were used to generate starting locations for particles. For all other sites, a single point representing the centre point of the site was used for particle release.

One particle was released at each particle tracking model timestep (once every 3 minutes; 20 particles per hour. The mass represented by each particle released was thus calculated as the daily feed (or faeces) mass, multiplied by 180/86400.

Carbon mass represented by each feed or faeces particle were calculated using multipliers of 0.49 and 0.30 respectively ([5]).

Assessment was made of the predicted cumulative impacts of all sites listed for inclusion in SEPA's risk assessment report. These are listed in Table 3.1.

Table 3.1: Sites simulated, with stocked biomass and calculated quantities for release (per day, and per model timestep).

Site Name	Site Name	Easting	Northing	Biomass (tonnes)	Active	Waste feed mass (/day)	Faeces mass (/day)	Waste feed mass (/step)	Faeces mass (/step)
FISH1	Fish Holm (proposed)	448381	1173899	6000	Proposed	1146.6	5561.0	2.389	11.585
FISH1	Fish Holm (existing)	448381	1173899	1910	Active	365.0	1770.3	0.760	3.688
LING1	South of Linga	446777	1172750	2299	Active	439.3	2130.8	0.915	4.439
HAML1	Hamnavoe	449519	1172542	1910	Active	365.0	1770.2	0.760	3.688
SETN1	Setterness North	448136	1172099	2500	Active	477.8	2317.1	0.995	4.827
SWI2	Foraness	445724	1172004	2100	Active	401.3	1946.4	0.836	4.055
SETW1	Setterness South	447236	1170873	2357.6	Active	450.5	2185.1	0.939	4.552
COL3	Swining Voe 3	446380	1169735	1920	Active	366.9	1779.5	0.764	3.707
COLL3	Collafirth 3	445455	1170490	1200	Active	229.3	1112.2	0.478	2.317
WATI1	West Taing	444100	1170950	500	Inactive	95.5	463.4	0.199	0.965
NWSCA1	Scarva Ayre	442750	1170600	250	Inactive	47.8	231.7	0.100	0.483
DAL1	South Side Dales Voe	443200	1170350	100	Inactive	19.1	92.7	0.040	0.193
NCH1	Ness of Copister	450308	1178936	2420.5	Active	462.6	2243.4	0.964	4.674
HMNV1	Hamnavoe, Yell	448900	1179400	190	Inactive	36.3	176.1	0.076	0.367
VIDJ3	Taing of Kelswick	450750	1169550	99	Inactive	18.9	91.8	0.039	0.191
VIDM2	Vidlin Outer	448622	1167794	916	Active	175.0	849.0	0.365	1.769
VIDM1	Vidlin Inner	448445	1167446	900	Active	172.0	834.2	0.358	1.738

3.3.2 Output Statistics

Output statistics were generated for all particle dispersion simulations in accordance with the current version of SEPA guidance [5]. Specifically, this included, for suspended and deposited solids:

- Plots showing the extent and concentration of impact, as an average, taken over the last 90 days of the model run, at the 250 g m^{-2} contour;
- Areal extent and average concentration, averaged over the last 90 days of the model run;
- Time series of maximum and average concentrations for the entire model run period;
- Time series of areal extent at the 250 g m^{-2} contour of deposited material.

Several points in the locality of the farm have been identified as Priority Marine Features, due to the presence of horse mussel, kelp, seaweed, algal communities and maerl (Table 3.2). Locations for these were provided by SEPA. A visual seabed survey was carried out as part of the risk assessment work for this site development, full results of which are detailed in a separate report. A number of potential PMF locations were identified during this survey [8]; these are detailed in Table 3.3.

Additional sensitive locations were identified during the risk screening [4], in the form of fish (Table 3.1) and shellfish farms (Table 3.4). For each of these locations, timeseries of concentration within were generated. Mean values and number of non-zero values over the last 90 days of the simulation were calculated, in addition to vertical profiles of concentration over the last 90 days, where concentration was sufficiently high.

Locations of PMFs, fish farms and shellfish farms identified in the SEPA risk identification report are shown in Figure 3.4. For the shellfish farms and one larger region identified as maerl, an assessment was made based on the total area covered by the sensitive feature rather than just a point feature, with output statistics relating to the highest concentration anywhere within a bounding polygon at each timestep. Shapefiles for these features were provided by SEPA for this assessment.

Table 3.2: PMF locations in the proximity of the proposed site, extracted from the NMPI database. Numbering here is used in later plots presenting results of impact calculations. (A further final maerl bed was determined as covering a region of greater spatial extent, and is defined by a shapefile - shown in Figure 4.3).

ID	Feature Name	Easting (OSGB)	Northing (OSGB)
1	Horse Mussel	444602	1178546
2	Kelp and seaweed communities	447475	1170225
3	Kelp and seaweed communities	449785.1	1173843
4	Kelp and seaweed communities	449757.3	1173916
5	Kelp and seaweed communities	453142.2	1173820
6	Kelp beds	452216.9	1172464
7	Kelp beds	452383.8	1172909
8	Kelp beds	453274.4	1173493
9	Kelp beds	453434.4	1173660
10	Kelp beds	453114.4	1173744
11	Kelp beds	453708.4	1177498
12	Kelp beds	453587.8	1179613
13	Tide swept algal communities	449747.8	1173926
14	Tide swept algal communities	449768	1173894
15	Tide swept algal communities	449825.4	1173829
16	Maerl/coarse shell gravel/burrowing sea cucumbers	450540.3	1173772
17	Maerl/coarse shell gravel/burrowing sea cucumbers	450609.9	1173760
18	Maerl/coarse shell gravel/burrowing sea cucumbers	453107.7	1173704

Table 3.3: PMF locations identified during the site visual survey. Transect number indicates that from the report from that study. Transect section length relates to the portion of transect summarised by the easting/northing point location (mid-point of transect section).

ID	Transect	Type	Easting (UTM30N)	Northing (UTM30N)	Transect section length (m)
1	3N	Brittle star	603526	6702932	103.5
2	3S	Brittle star	603029	6701970	91.4
3	4S	Brittle star	602866	6702195	64.2
4	4N	Brittle star	603291	6703033	9.3
5	4N	Brittle star	603286	6702993	72.2
6	5	Brittle star (possible horse mussels)	603234	6703369	83.6
7	5	Brittle star (possible horse mussels)	603226	6703298	62.6
8	5	Brittle star (possible horse mussels)	603209	6703224	88.0
9	5	Brittle star (possible horse mussels)	603195	6703144	76.5
10	5	Brittle star (possible horse mussels)	603178	6703073	67.9
11	5	Brittle star (possible horse mussels)	603162	6703022	40.2
12	6	Brittle star	603576	6702565	102.0
13	6	Brittle star	603623	6702656	102.5

Table 3.4: Shellfish farms identified as sensitive features at risk from sediment interaction in the SEPA risk screening report.

ID	Feature Name	Easting (OSGB)	Northing (OSGB)
1	Cul Ness	447700	1169300
2	North West of Cul Houb	446500	1168200
3	Inner Collafirth, Delting	443600	1169400
4	West Taing	444000	1170900
5	South Side, Dales Voe	443000	1170200
6/7	Scarva Ayre 1	442100	1169900
8	Scarva Ayre 2	442800	1170600

Figure 3.4: Map showing all sensitive features identified in the SEPA risk screening report, including fish farms (dark blue discs, SEPA ID label), PMF points (orange discs, small number labels), and shellfish/maerl polygons (dark grey, large number labels). Numbering on PMFs and polygons relates to the number within the summary Tables 3.2 and 3.4.

4 Results

4.1 NewDepomod Results

Results from the final NewDepomod simulation for the Fish Holm site are shown in Figure 4.1. The allowable mixing zone (AMZ) (120% of basic AMZ due to the site lying at a location with wave exposure over 2.8) for the site is 324,116 m^2. The impacted area above the 250 g m^{-2} contour for this final passing simulation was estimated as 71250 m^2 (counting cells), and the mean flux within this zone was 284.2 g m^{-2} yr^{-1}. Results are described in more detail in the accompanying NewDepomod modelling report [7].

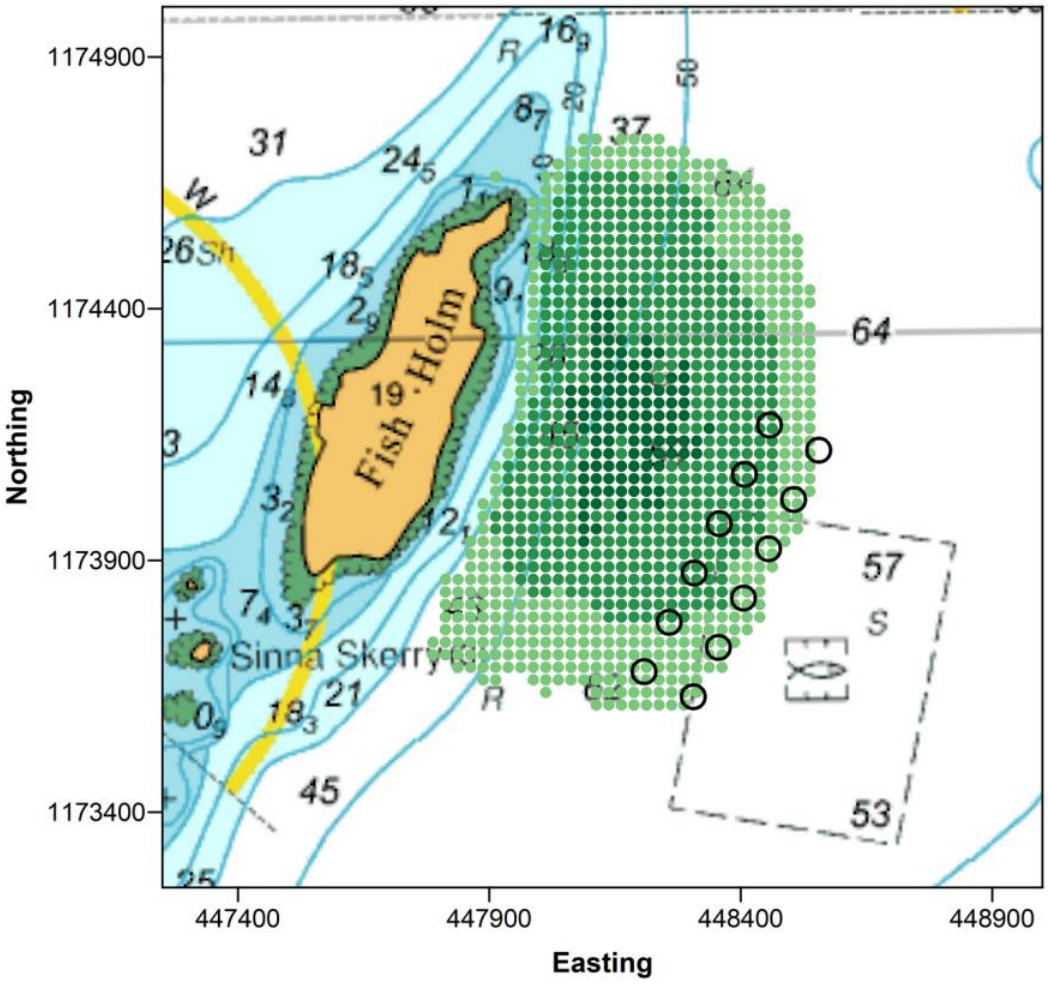

Figure 4.1: Map of deposition predicted by NewDepomod using the standard default configuration. Black circles: proposed pen layout. Green discs: predicted solid deposition 50-100 (light), 100-250 (mid) and over 250 (dark) g m^{-2} yr^{-1}. Map coordinates are OSGB 1936.

4.2 Extent and concentration of impact over final 90 days

4.2.1 Suspended sediment

A map of suspended sediment concentration, averaged over the last 90 days of the simulation, is shown in Figure 4.2. A corresponding map for the Fish Holm (proposed) site in isolation is given in Figure 4.3.

The concentration is generally predicted to be low throughout the domain, only reaching any notable level on some coastlines of nearby islands to the sites, where some accumulations are predicted. Similar aggregations have been observed in previous projects, and may be an artefact of model configuration and the manner in which particles interact with the coastline.

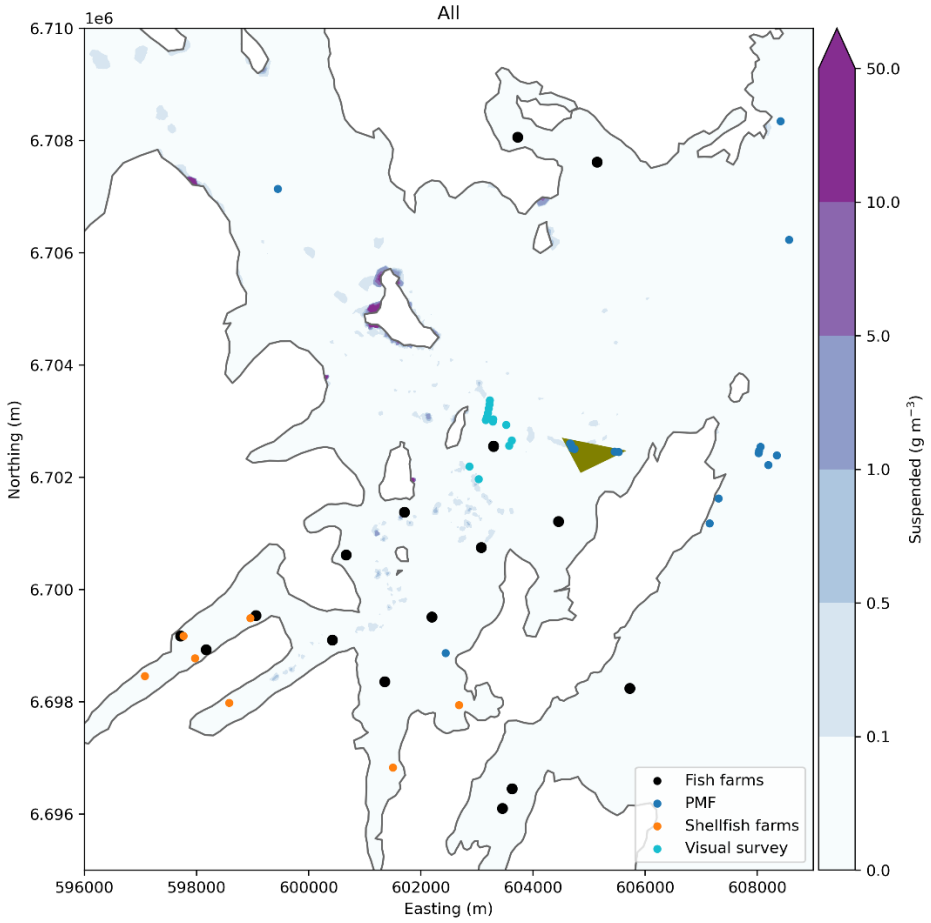

Figure 4.2: Map of average suspended sediment concentration of the final 90 days of the simulation, released from ALL sites in Table 3.1. Black points indicate fish farm locations. Blue points indicate PMFs identified by SEPA, and orange points shellfish farms identified for impact assessment. The area of maerl defined by SEPA is indicated by the dark yellow triangle.

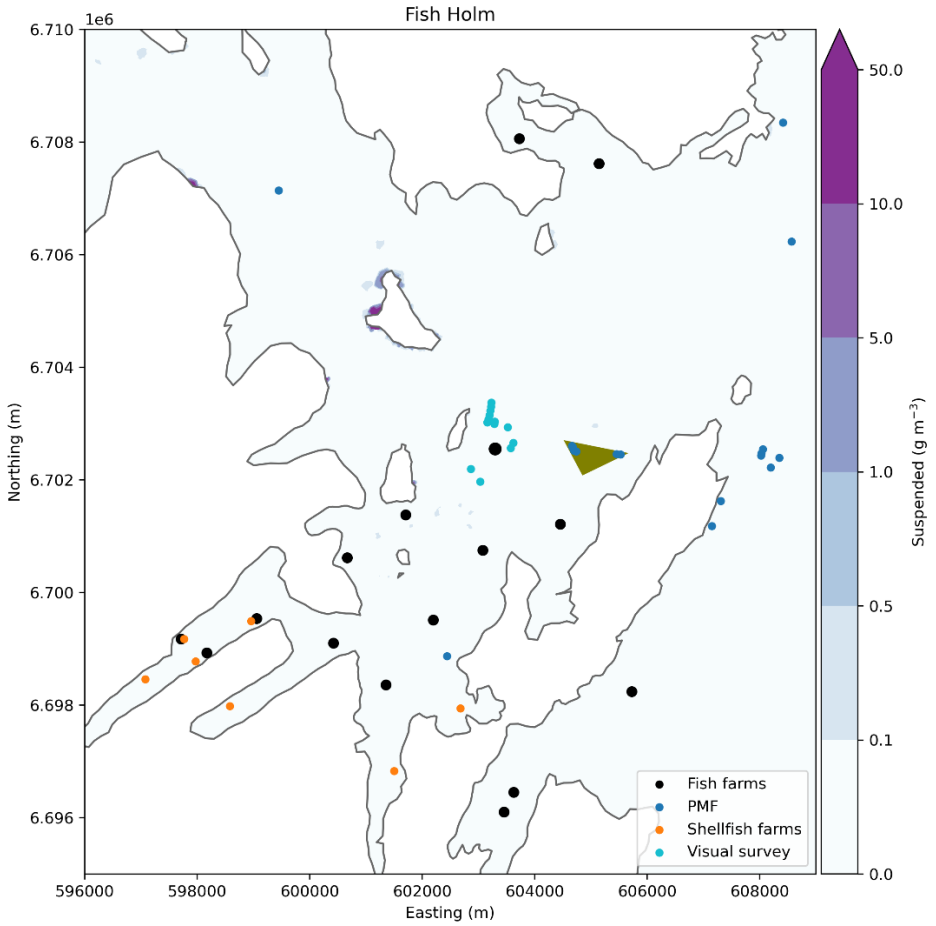

Figure 4.3: Map of average suspended sediment concentration of the final 90 days of the simulation, **released from Fish Holm (proposed biomass) only**. Black points indicate fish farm locations. Blue points indicate PMFs identified by SEPA, and orange points shellfish farms identified for impact assessment. The area of maerl defined by SEPA is indicated by the dark yellow triangle.

4.2.2 Deposited Sediment

Maps of deposited sediment concentration, including all source sites in the SEPA risk assessment and averaged over the last 90 days of the simulation, are shown in Figure 4.4. A corresponding map for the Fish Holm (proposed) site in isolation is given in Figure 4.5.

Summary statistics for the extent and intensity of the 250 g m^{-2} impacted area are given in Table 4.1. FISH1 has the largest predicted area over 250 g m^{-2}, but with average intensity within this area lower than any of the other sites.

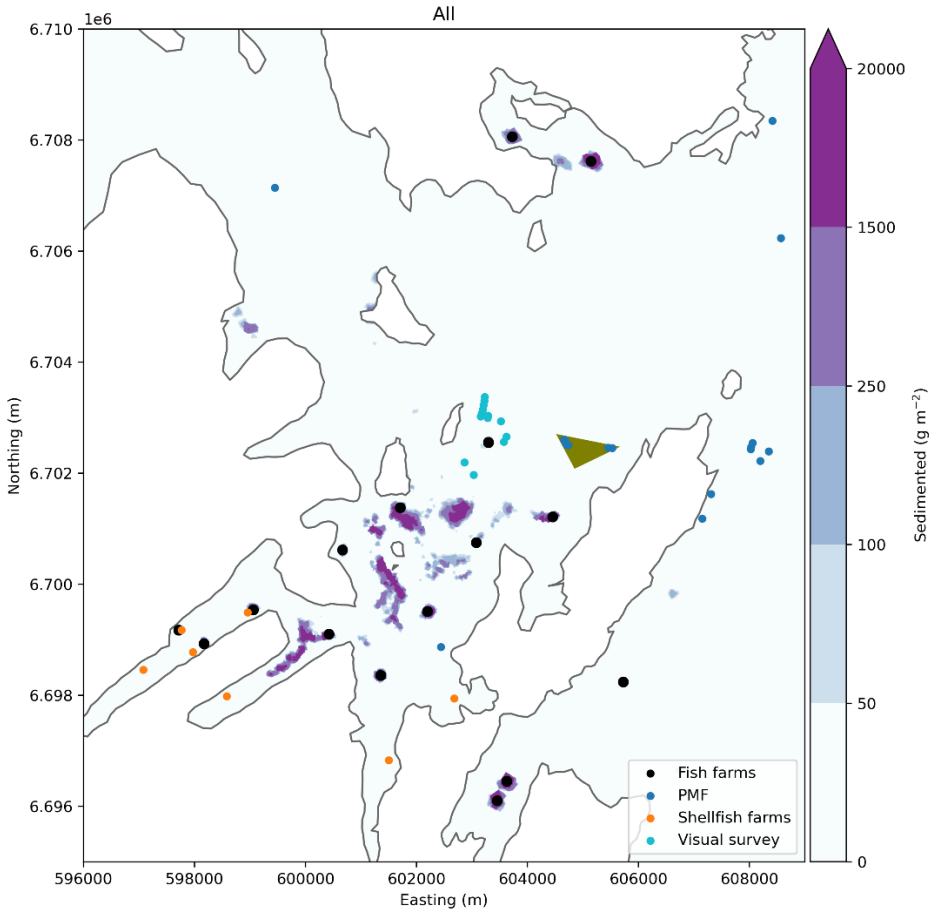

Figure 4.4: Map of average deposited sediment concentration of the final 90 days of the simulation, released from ALL sites in Table 3.1. Black points indicate fish farm locations. Blue points indicate PMFs identified by SEPA, and orange points shellfish farms identified for impact assessment. The area of maerl defined by SEPA is indicated by the dark yellow triangle.

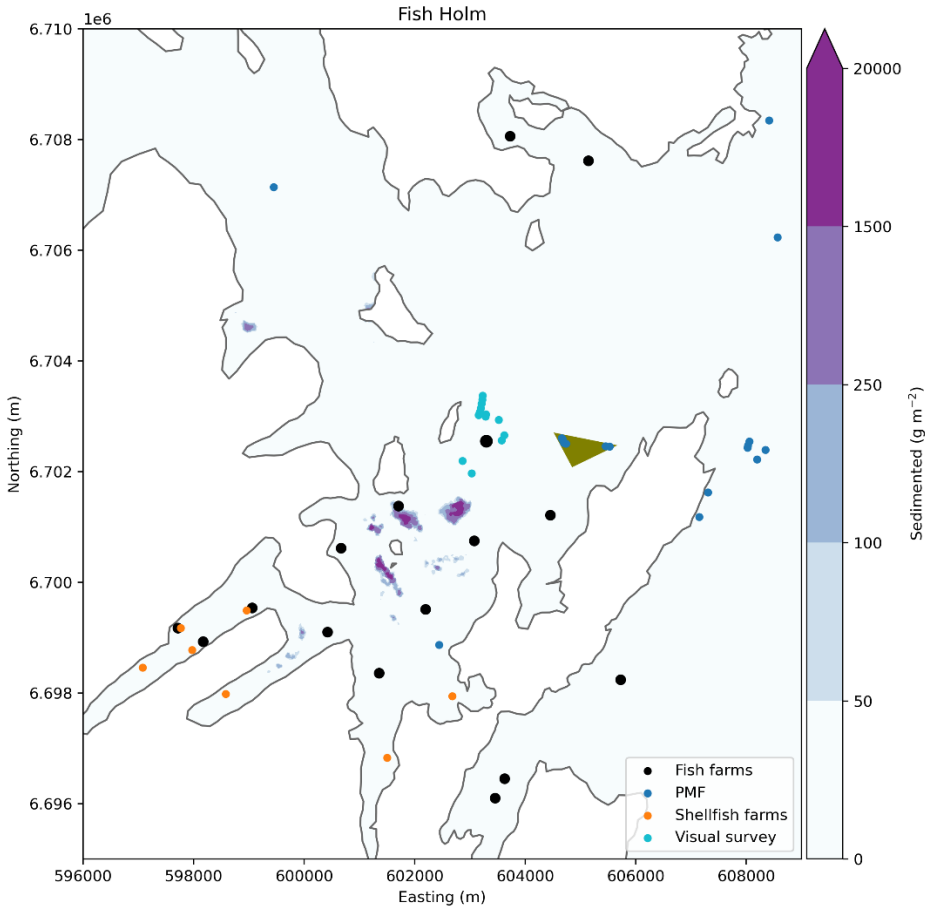

Figure 4.5: Map of average deposited sediment concentration of the final 90 days of the simulation, **released from Fish Holm (proposed biomass) only**. Black points indicate fish farm locations. Blue points indicate PMFs identified by SEPA, and orange points shellfish farms identified for impact assessment. The area of maerl defined by SEPA is indicated by the dark yellow triangle.

Table 4.1: Summary statistics for individual site releases, showing the size and average intensity of the area above 250 g m^{-2}, over the last 90 days of the simulation.

Site Name	Extent >250 g m^{-2}	Average >250 g m^{-2}
Fish Holm	206,894	1,271.0
Fish Holm existing	103,546	1,260.8
South of Linga	58,374	7,433.5
Hamnavoe	44,149	12,106.4
Setterness North	139,318	2,028.4
Foraness	70,330	5,411.6
Setterness South	29,010	15,117.7
Swining Voe 3	20,050	17,703.2
Collafirth 3	20,833	11,114.2
West Taing	13,230	6,961.5
Scarva Ayre	5,225	8,822.5
South Side Dales Voe	4,546	3,955.0
Ness of Copister	39,347	10,025.7
Hamnavoe, Yell	15,220	2,342.8
Taing of Kelswick	13,865	615.8
Vidlin Outer	22,648	7,357.8
Vidlin Inner	22,941	7,474.3

4.3 Maximum concentrations (full run)

4.3.1 Suspended Sediment

Suspended sediment concentrations in the simulation are broadly increasing over the first half of the year, before becoming more stable. Maximum concentration at a given time is highly dependent on the state of the tide, and this is reflected in the raw timeseries which indicate a high level of short term variability (not shown). The overall pattern of maximum concentration (and the conservative upper bound) also experiences strong variability over a longer period of time for each individual site, seen more clearly in the timeseries of the 72 hr rolling maximum (Figure 4.6), though for the cumulative sites the impact shows a much more consistent increase with less variability, reaching a point of stability towards the end of the year run.

Due to the relatively large biomass, the proposed site is at the upper end of the modelled sites in terms of the maximum concentration of suspended sediment resulting from its operation.

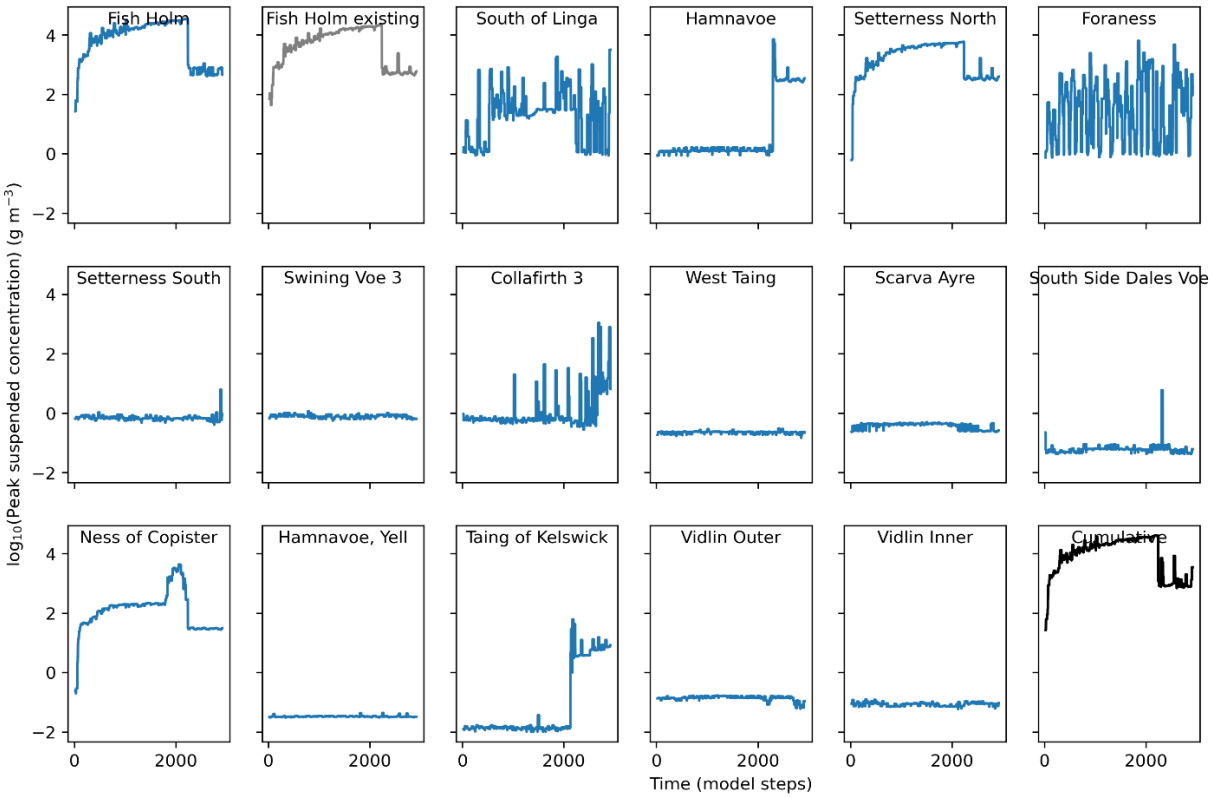

Figure 4.6: Maximum concentration of suspended sediment (rolling maximum over 72 hrs) in relation to each source farm, and cumulative total. Sites included in the cumulative total are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.

4.3.2 Deposited Sediment

For most of the simulated sites, maximum concentration of deposited sediment fluctuates somewhat less than does maximum suspended sediment, with a more consistent increase over time in deposition until a point of stability is reached later during the modelled year. Timeseries of individual site and overall (cumulative) maxima are shown in Figure 4.7. The proposed Fish Holm site has similar maximum concentration of deposited sediment to many of the other sites assessed.

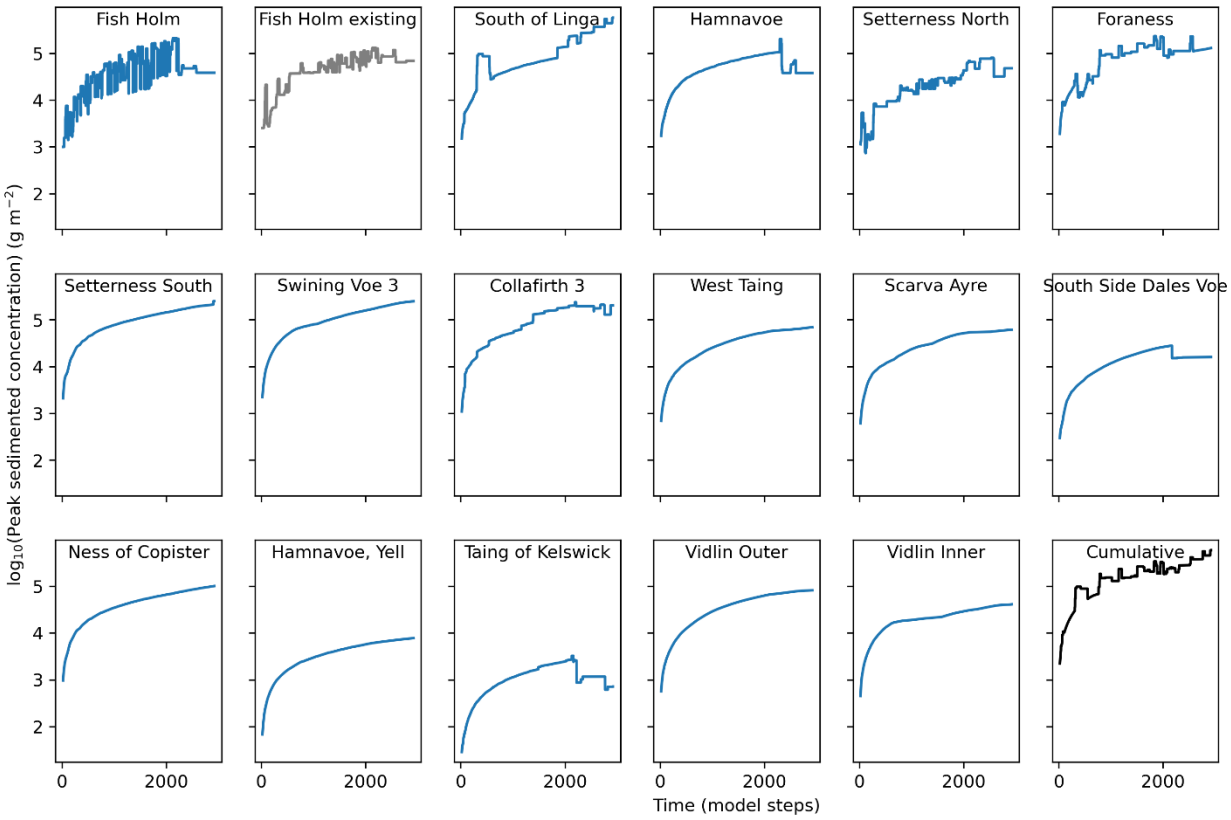

Figure 4.7: Maximum concentration of deposited sediment (raw values) in relation to each source farm, and cumulative total. Sites included in the cumulative total are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.

4.4 Average concentrations (full run)

4.4.1 Suspended Sediment

The patterns of average suspended sediment concentration predicted over the duration of the simulation are similar to those seen in the maximum concentrations, though at certain sites there is a peak in concentration before the end of the simulation, followed by a significant drop to a lower level. Again there are high levels of fluctuation in concentration in the short term, and the proposed site is comparable to the others included in the simulation (Figure 4.8).

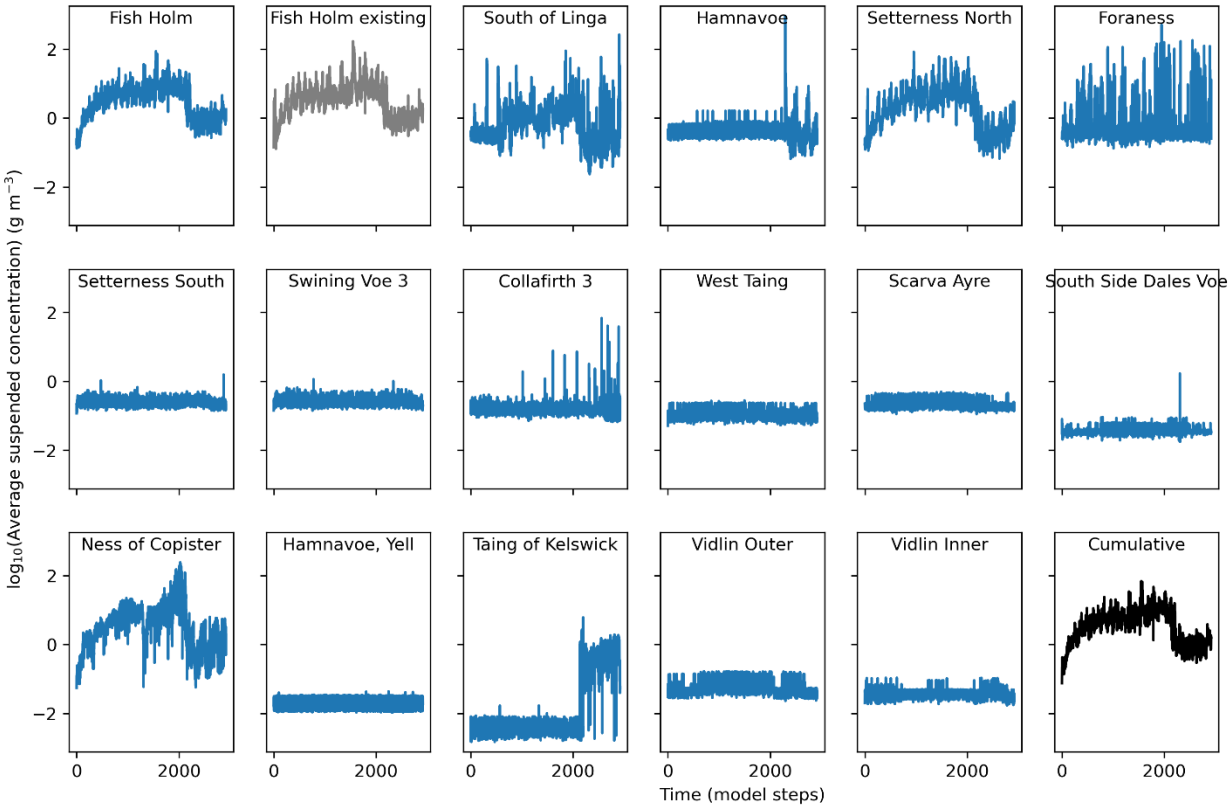

Figure 4.8: Average concentration of suspended sediment (raw values) in relation to each source farm, and cumulative total. Sites included in the cumulative total are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.

4.4.2 Deposited sediment

The patterns of average deposited sediment concentration predicted over the duration of the simulation are similar to those seen in the maximum concentrations, though again with high peaks in concentration towards the beginning of the run at certain sites. These could correspond to an initially intense footprint of waste in proximity to the site where material is then resuspended and distributed over a wider area over time. After these peaks, ongoing deposition again increases the average sedimented concentration over time, though this appears to level out towards the end of the run. Moderate levels of fluctuation were observed (generally lower than for suspended sediment), and the proposed site is one of the lowest included in the simulation (Figure 4.9), due to having higher current speeds and therefore being more dispersive than the other sites.

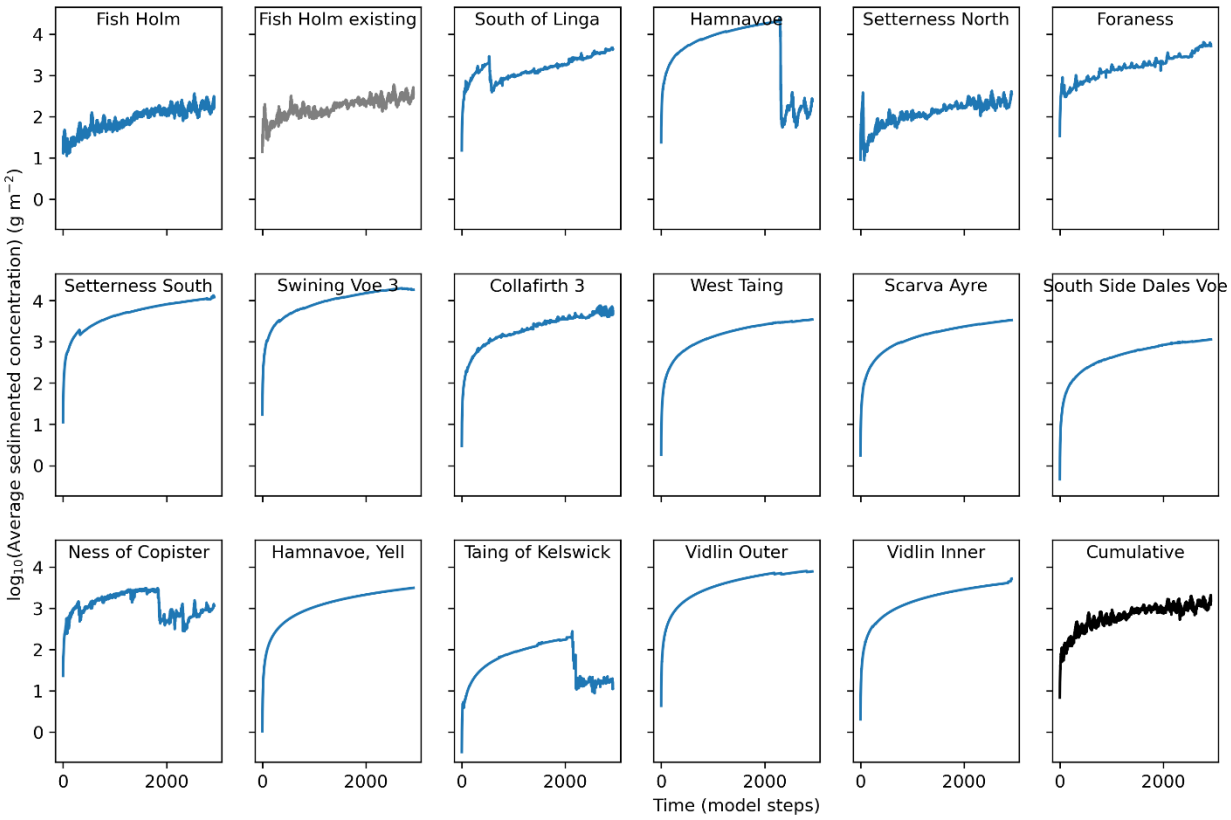

Figure 4.9: Average concentration of deposited sediment (raw values) in relation to each source farm, and cumulative total. Sites included in the cumulative total are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.

4.5 Areal extent of 250 g m^{-2} contour (full run)

The areal extent of the 250 g m^{-2} sedimented material contour generated by most individual sites was fairly small, due to the high levels of resuspension and dispersion occurring in the model runs as a result of the default settings. Due to its large spatial extent and release levels, FISH1 generated a larger area over the threshold deposited mass than did other sites in the assessment (Figure 4.10), though as seen in the maps this was not co-located with the farm itself.

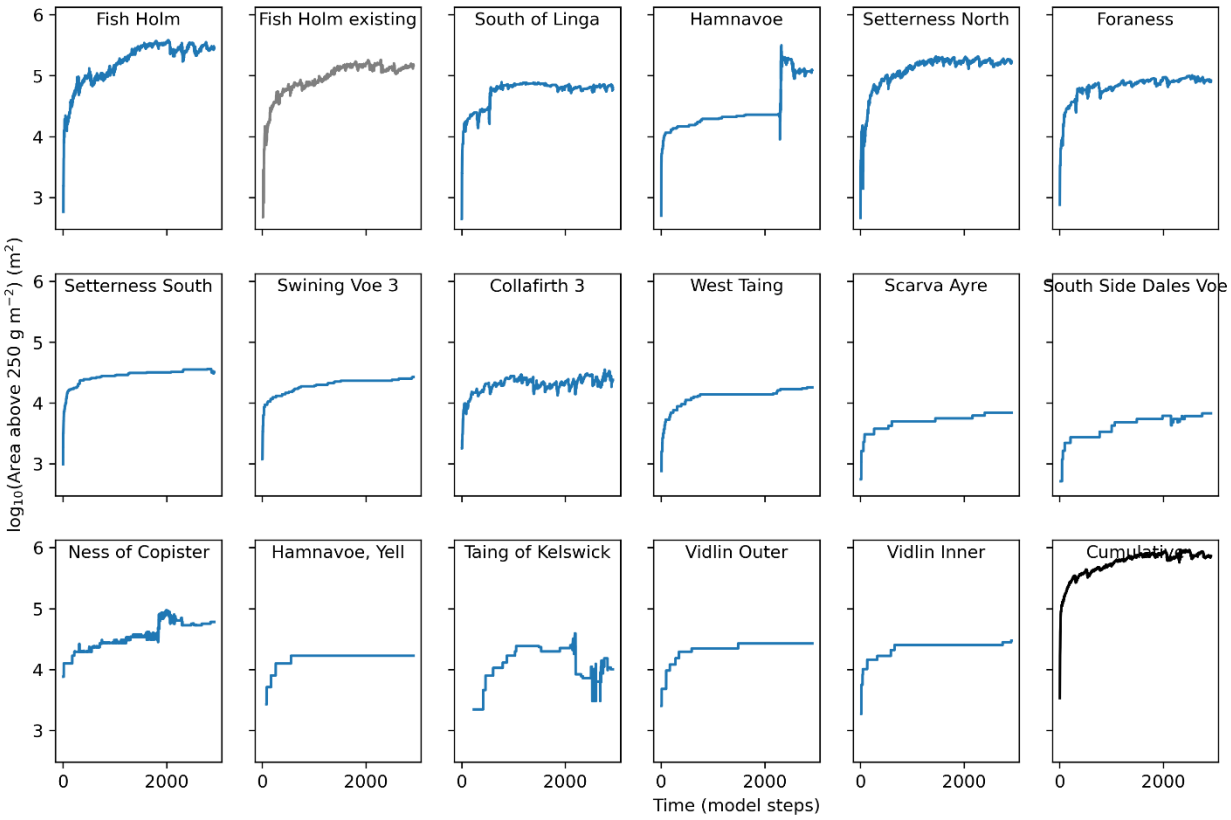

Figure 4.10: Areal extent of suspended sediment concentration over 250 g m^{-2}, in relation to each source farm, and cumulative total. Sites included in the cumulative total are shown with blue lines, and those excluded with grey. Values are plotted on a logarithmic scale.

4.6 Concentration at sensitive features

Within this section, suspended and sedimented concentrations are considered together for each feature type.

Non-zero concentrations at specific feature locations can be classified in two ways: i) a sustained concentration which is present over a long duration, and ii) a momentary "spike" in concentration, present only for a short time.

Momentary spikes are considered to be of lower concern than sustained concentration. The level of spikes is found to increase as mesh resolution is made finer, due to the reduced area over which the concentration of isolated patches is averaged. Additionally, such isolated peaks are considered to be of relatively low confidence in the model output when compared to sustained concentrations, due to variability in current patterns over time and space, and the ability of any model (whether based on climatology, or a hindcast) to reflect the current patterns and seabed interactions actually taking place in any future time scenario.

4.6.1 PMF database locations

At the database PMF locations, average concentrations of suspended sediment were predicted to be close to zero (Table 4.3). This is evident in the timeseries plot (Figure 4.11), which indicates concentrations were zero for the entire duration of the simulation, with only small short spikes at a small number of locations.

Concentrations of deposited sediment were also close to zero at all PMF locations throughout the last 90 days of the simulation, with the timeseries plot again indicating that there were only short spikes of concentration at a small number of locations, and only two of these exceeding 50 g m^{-2} (Figure 4.12). The most impacted locations were those closest to the Fish Holm site.

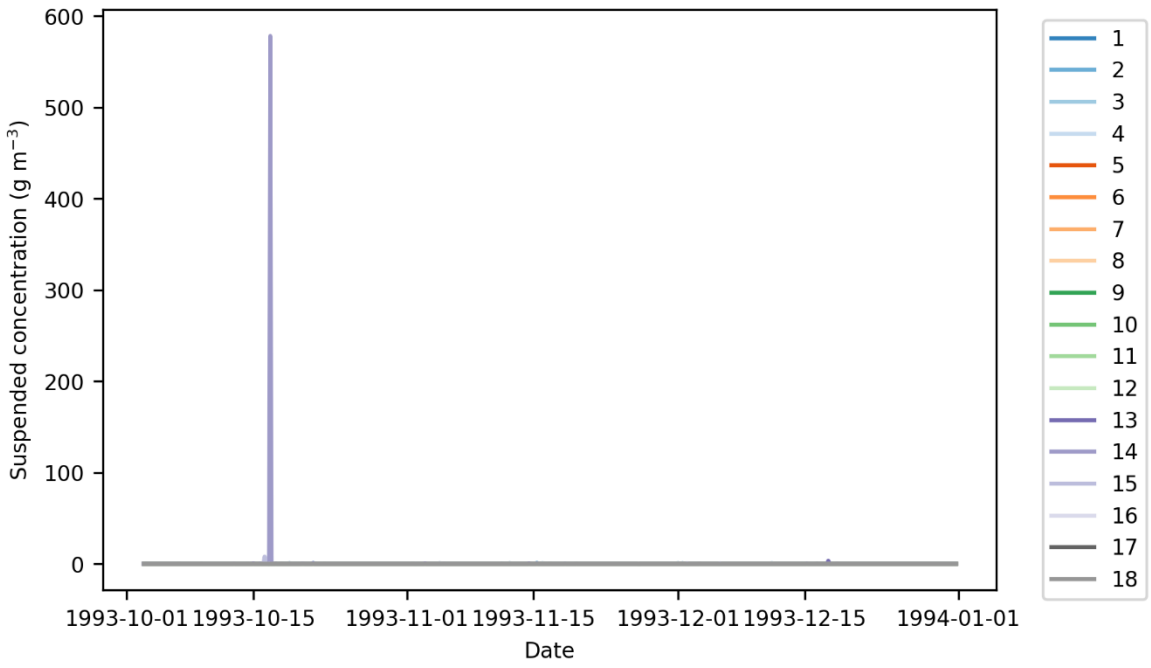

Figure 4.11: Timeseries of suspended sediment concentration at database PMF locations, extracted from the nearest element centre location on the model mesh for each point, including all farm sites as sources.

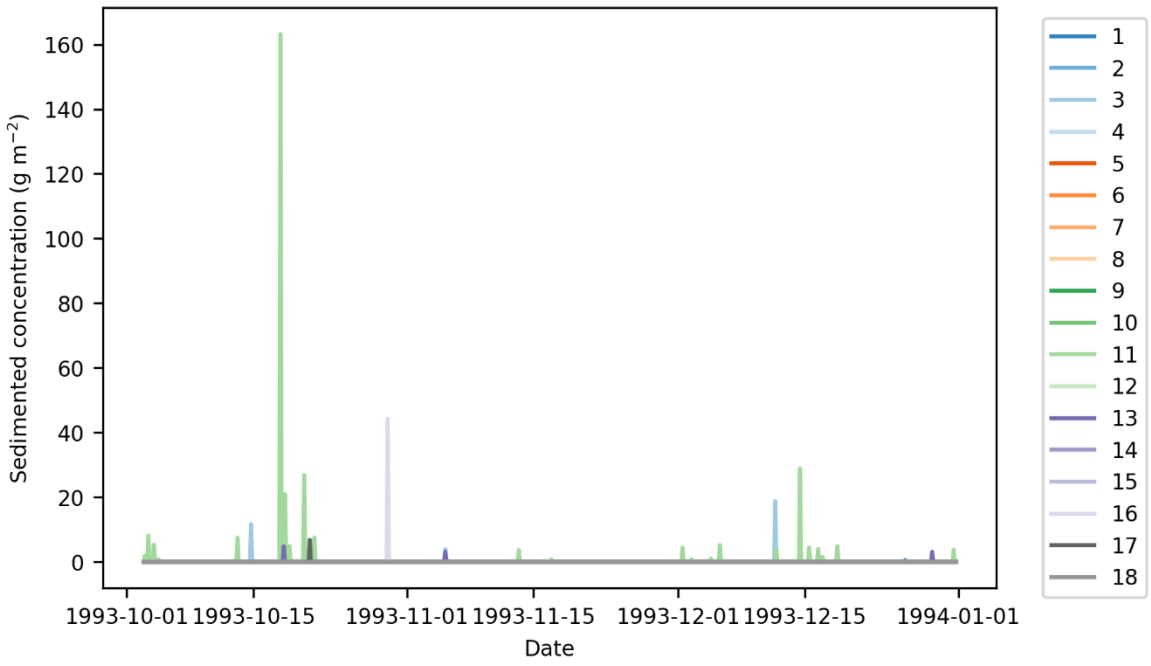

Figure 4.12: Timeseries of deposited sediment concentration at database PMF locations, extracted from the nearest element centre location on the model mesh for each point, including all farm sites as sources.

Table 4.2: Summary of average suspended/sedimented concentrations at database PMF locations, in addition to the proportion of individual time points at which concentration was non-zero over the last 90 days of the simulation. Concentrations are given to the nearest 0.001 g, and proportions to the nearest 0.001 (0.1%). Columns are shown for all sites operating together, and Fish Holm (applied for biomass) in isolation. Averages are over all timesteps within the window.

ID	Suspended average (g m^{-3})		Suspended maximum (g m^{-3})		Suspended non-zero proportion		Sedimented average (g m^{-2})		Sedimented maximum (g m^{-2})		Sedimented non-zero proportion	
	All	FH	All	FH	All	FH	All	FH	All	FH	All	FH
1	0.004	0.002	0.444	0.278	0.028	0.019	0.001	0.001	0.482	0.482	0.001	0.001
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0.013	0.010	2.292	1.907	0.014	0.011	0.048	0.037	18.749	18.749	0.004	0.004
4	0.113	0.005	77.206	0.964	0.013	0.010	0.014	0	9.760	0	0.001	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0.002	0.001	0.353	0.179	0.021	0.010	0.437	0.155	163.225	18.263	0.033	0.028
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0.011	0.002	3.312	1.316	0.019	0.010	0.015	0.009	4.781	3.097	0.004	0.003
14	0.805	0	578.269	0.553	0.008	0.001	0	0	4.33	0	0	0
15	0.013	0.004	7.781	4.723	0.010	0.007	0	0	0	0	0	0
16	0.001	0.003	0.288	0	0.003	0	0.061	0	44.261	0	0.001	0
17	0	0	0	0	0	0	0.009	0	6.772	0	0.001	0
18	0	0	0	0	0	0	0	0	0	0	0	0

4.6.2 PMF visual survey locations

At the visual survey PMF locations, average concentrations of suspended and deposited sediment were predicted to generally be near-zero, with occasional peaks (Table 4.3). Due to the proximity of these locations to the proposed site, there is a little more noise and fluctuation of small non-zero values than at the database PMF locations. Many of the locations exhibit spikes in deposited sediment, but spikes of any significant size are short-lived and are limited to a few occurrences for any given location (Figures 4.13 and 4.14).

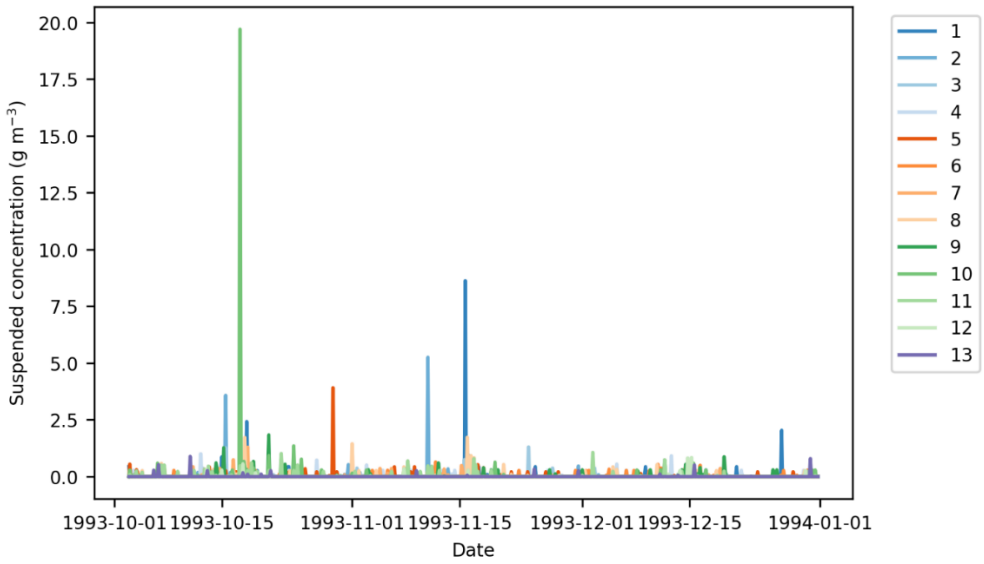

Figure 4.13: Timeseries of suspended sediment concentration at visual survey PMF locations, extracted from the nearest element centre location on the model mesh for each point, including all farm sites as sources.

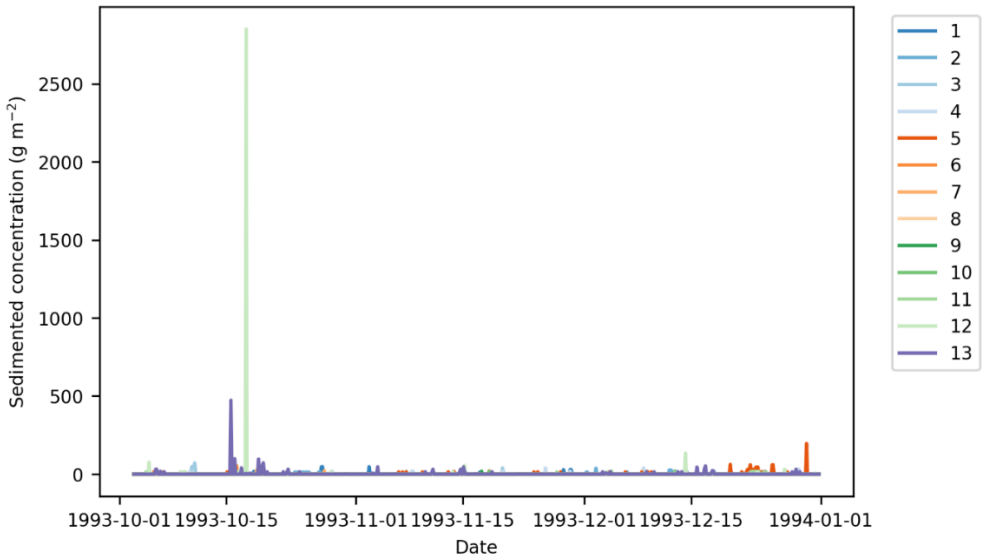

Figure 4.14: Timeseries of deposited sediment concentration at visual survey PMF locations, extracted from the nearest element centre location on the model mesh for each point, including all farm sites as sources.

Table 4.3: Summary of average suspended/sedimented concentrations at visual survey PMF locations, in addition to the proportion of individual time points at which concentration was non-zero over the last 90 days of the simulation. Concentrations are given to the nearest 0.001 g, and proportions to the nearest 0.001 (0.1%). Columns are shown for all sites operating together, and Fish Holm (applied for biomass) in isolation. Averages are over all timesteps within the window.

ID	Suspended average ($g\ m^{-3}$)		Suspended maximum ($g\ m^{-3}$)		Suspended non-zero proportion		Sedimented average ($g\ m^{-2}$)		Sedimented maximum ($g\ m^{-2}$)		Sedimented non-zero proportion	
	All	FH	All	FH	All	FH	All	FH	All	FH	All	FH
1	0.026	0.017	8.627	4.451	0.029	0.026	0.449	0.341	47.160	35.052	0.019	0.014
2	0.018	0.007	5.254	3.218	0.029	0.015	1.093	0.998	36.895	26.044	0.121	0.121
3	0.008	0.008	1.302	1.277	0.025	0.025	0.432	0.416	71.135	71.135	0.011	0.010
4	0.019	0.016	1.279	0.885	0.072	0.067	0.885	0.885	38.590	38.590	0.042	0.042
5	0.020	0.012	3.909	0.430	0.081	0.075	1.634	1.393	196.055	59.589	0.064	0.064
6	0.016	0.014	0.647	0.647	0.071	0.065	0.098	0.068	54.062	32.671	0.003	0.003
7	0.014	0.010	1.296	0.580	0.054	0.047	0.099	0.099	26.693	26.693	0.004	0.004
8	0.027	0.021	1.734	1.412	0.078	0.068	0.000	0.000	0.000	0.000	0.000	0.000
9	0.023	0.020	1.834	1.615	0.072	0.067	0.059	0.059	19.357	19.357	0.004	0.004
10	0.046	0.015	19.699	1.352	0.065	0.053	0.051	0.051	18.429	18.429	0.003	0.003
11	0.022	0.019	1.061	1.013	0.078	0.068	0.358	0.358	17.683	17.683	0.024	0.024
12	0.006	0.005	0.842	0.842	0.017	0.014	4.800	4.214	2850.220	2516.157	0.033	0.032
13	0.007	0.005	0.888	0.888	0.025	0.015	2.266	1.808	473.111	420.803	0.061	0.054

4.6.3 Fish Farm Locations

As might be anticipated, concentrations of deposited sediment are higher at fish farm centre locations than at PMF locations (Table 4.4), though suspended concentrations were still generally low. Within the last 90 days of the simulation, peaks of suspended sediment concentration remain fairly low, but non-zero values are observed consistently at most sites. In general, any significant level of suspended sediment tends to be dominated by occasional peaks rather than persistent presence (Figure 4.15).

With respect to sedimented concentration, many fish farm sites have non-zero values at a high proportion of time points, with concentration governed more by accumulation over time. Fish Holm itself is not predicted to be strongly impacted by accumulation of sediment, suggesting most material originating at this site will be exported (Figure 4.16).

It is worth noting that FISH1 site has lower average, maximum and proportion of non-zero values for both suspended and deposited sediment than almost all other sites considered here.

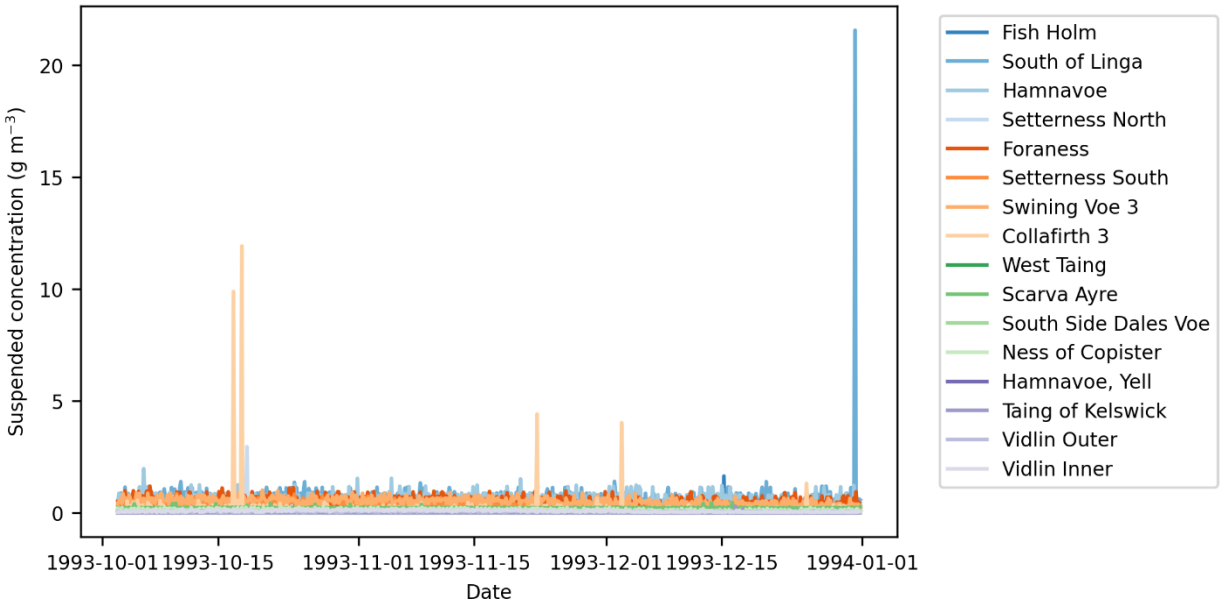

Figure 4.15: Timeseries of suspended sediment concentration at fish farm locations, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.

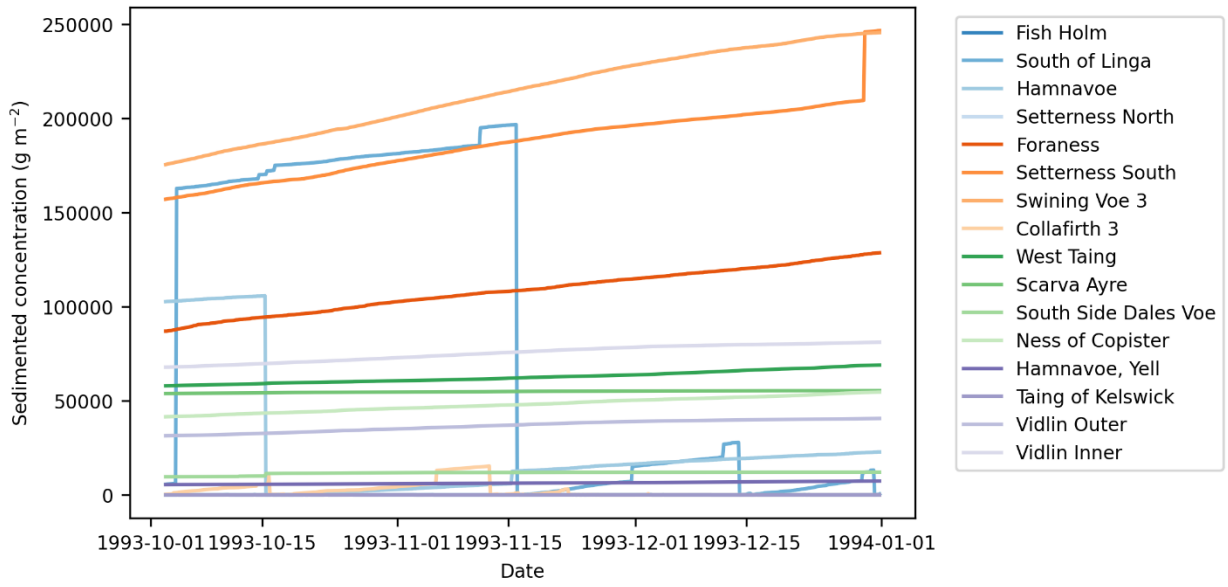

Figure 4.16: Timeseries of deposited sediment concentration at fish farm locations, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.

Table 4.4: Summary of average and maximum suspended/sedimented concentrations at fish farm locations, in addition to the proportion of individual hourly time points at which concentration was non-zero over the last 90 days of the simulation. Concentrations are given to the nearest 0.001 g, and proportions to the nearest 0.001 (0.1%). Columns are shown for all sites operating together, and Fish Holm (applied for biomass) in isolation. Averages are over all timesteps within the window.

ID	Suspended average (g m^{-3})		Suspended maximum (g m^{-3})		Suspended non-zero proportion		Sedimented average (g m^{-2})		Sedimented maximum (g m^{-2})		Sedimented non-zero proportion	
	All	FH	All	FH	All	FH	All	FH	All	FH	All	FH
FISH1	0.020	0.017	1.634	0.987	0.075	0.071	6.036	5.291	148.006	97.670	0.271	0.265
LING1	0.616	0.001	21.554	0.667	1	0.001	89037.836	326.752	196668.120	826.718	0.994	0.644
HAML1	0.577	0	1.968	0	1	0	24795.473	0	105722.660	0	0.993	0
SETN1	0.213	0.001	2.949	0.643	1	0.001	12.260	0	108.881	0	0.503	0
SWI2	0.467	0	1.191	0	1	0	108598.086	0	128546.640	0	1	0
SETW1	0.330	0	0.848	0	1	0	187007.060	0	246573.950	0	1	0
COL3	0.500	0	1.013	0	1	0	214159.160	0	245566.080	0	1	0
COLL3	0.231	0.000	11.915	0.316	1	0.001	2260.126	0	15274.873	0	0.606	0
WATI1	0.132	0	0.238	0	1	0	62647.844	0	68953.240	0	1	0
NWSCA1	0.223	0	0.458	0	1	0	54810.870	0	55370.355	0	1	0
DAL1	0.034	0	0.089	0	1	0	11555.270	0	12000.293	0	1	0
NCH1	0.117	0	0.291	0	1	0	48047.430	0	54621.820	0	1	0
HMNV1	0.023	0	0.044	0	1	0	6277.422	0	7368.974	0	1	0
VIDJ3	0.006	0	0.288	0	1	0	7.890	0	42.914	0	0.886	0
VIDM2	0.053	0	0.107	0	1	0	36741.340	0	40575.086	0	1	0
VIDM1	0.076	0	0.164	0	1	0	75341.914	0	81078.164	0	1	0

4.6.4 Shellfish Farms and larger Maerl bed

Concentrations of suspended sediment are predicted to be zero at all shellfish farm locations (Figure 4.17, Table 4.5). At the larger maerl bed PMF (assessed as a polygon region alongside the shellfish farms) a small non-zero concentration was observed at a significant proportion of time points in the last 90 days of the simulation, but significant concentrations were only reached on two specific occasions (Figure 4.17, Table 4.5).

Significant non-zero concentrations of deposited sediment over the last 90 days of the simulation were predicted at several shellfish farms (West Taing, South Side Dales Voe, and Scarva Ayre 2, Figure 4.18 a). These locations are also included in the list of fish farms in SEPA's risk identification report, and including them as particulate release sites means that they generate deposited sediment around themselves. Removing these sites from the list of release locations means that concentration of deposited sediment in the last 90 days of the simulation is predicted to be zero at all shellfish farms, while the Maerl bed region experienced short spikes in deposition (Figure 4.18 b).

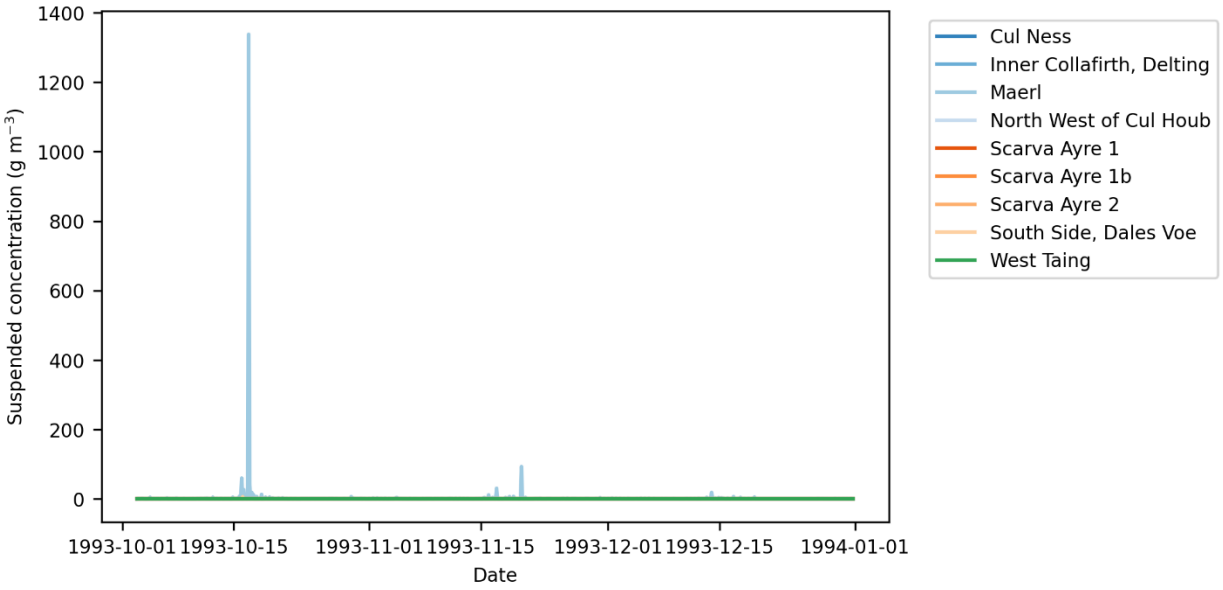

Figure 4.17: Timeseries of suspended sediment concentration at shellfish farm locations and maerl bed area PMF, extracted from the nearest element centre location on the model mesh for each point, including all specified farm sites as sources.

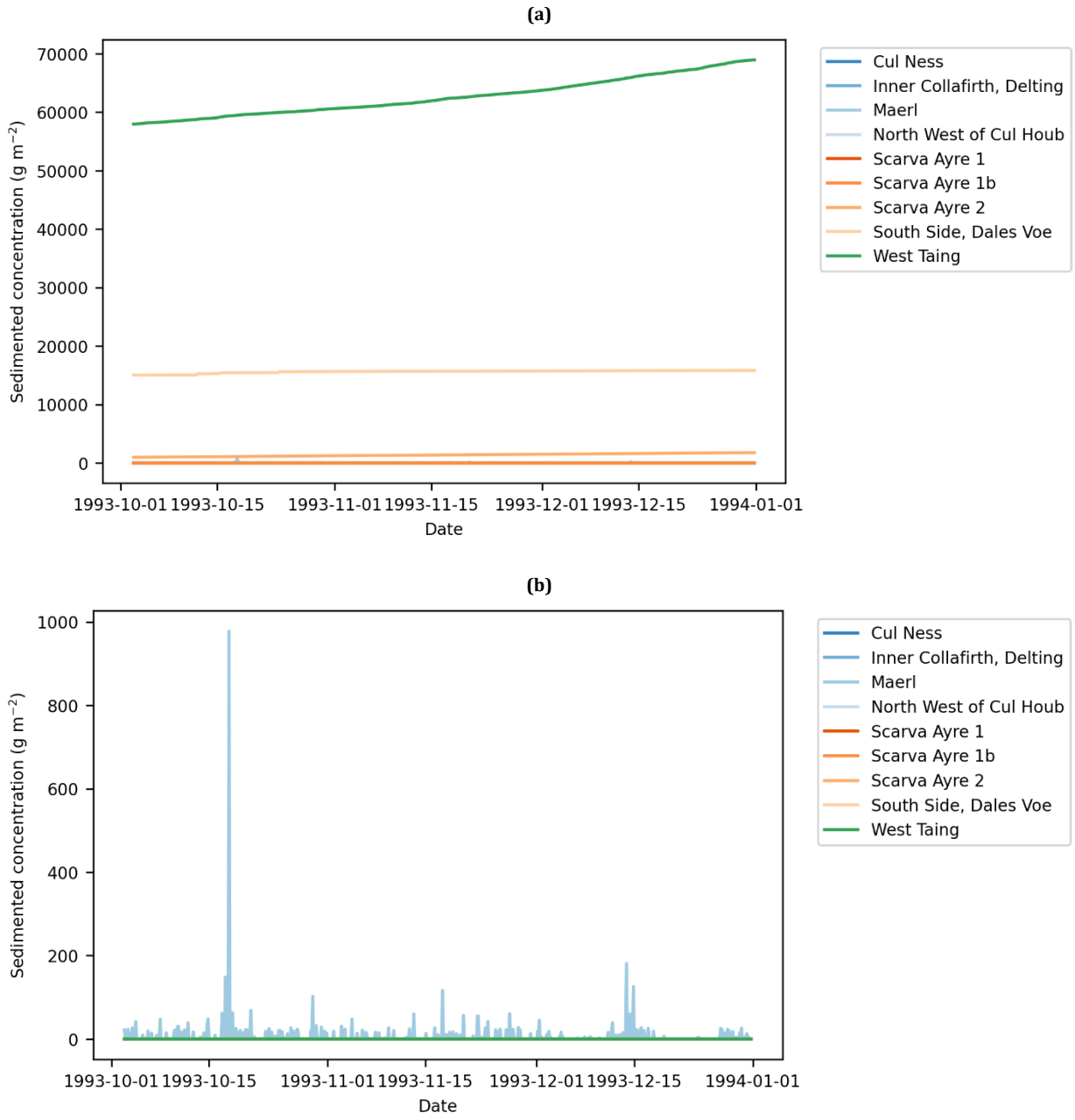

Figure 4.18: Timeseries of deposited sediment concentration at shellfish farm locations and maerl bed area PMF, extracted from the nearest element centre location on the model mesh for each point, (a) including all specified farm sites as sources, and (b) omitting particulate release from inactive sites (including those which are now shellfish farms, in particular West Taing, Scarva Ayre and South Side Dales Voe).

Table 4.5: Summary of average suspended/sedimented concentrations at shellfish farm locations and the maerl bed region, in addition to the proportion of individual time points at which concentration was non-zero over the last 90 days of the simulation. The concentration at each timestep was taken as the area's maximum concentration at that timestep. Concentrations are given to the nearest 0.001 g, and proportions to the nearest 0.001 (0.1%). Locations with an asterisk (*) are those which were also included as "fish farm" sources of waste material; removing these as sources reduced concentrations at these locations to zero. Columns are shown for all sites operating together, and Fish Holm (applied for biomass) in isolation. Averages are over all timesteps within the window.

ID	Suspended average ($g\ m^{-3}$)		Suspended maximum ($g\ m^{-3}$)		Suspended non-zero proportion		Sedimented average ($g\ m^{-2}$)		Sedimented maximum ($g\ m^{-2}$)		Sedimented non-zero proportion	
	All	FH	All	FH	All	FH	All	FH	All	FH	All	FH
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4*	0.150	0	0.304	0	1	0	62647.851	0	68953.242	0	1	0
5*	0.050	0	5.916	0	1	0	15608.567	0	15831.326	0	1	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8*	0	0	0	0	0	0	1374.260	0	1766.348	0	1	0
9	2.815	0.565	1337.981	44.413	0.435	0.389	7.067	5.175	977.649	911.267	0.257	0.190

5 Discussion and Conclusions

The proposed site is larger than other sites presently within the Yell Sound area. Due to this, and to its location in a more tidally influenced area, it has a larger predicted impacted area but low sediment intensity relative to other sites in the vicinity.

The NewDepomod model predicted a high degree of export of waste material from the vicinity of the site, predominantly directed towards the NW. In the HD model, material is also dispersed from the site, either N into the highly tidal environment of Yell Sound, or SW into more sheltered areas. The (default) model erosion settings applied in the far-field assessment mean that material is eroded from the seabed at a lower near-bed velocity than in NewDepomod. This generates little or no sedimented accumulation in Yell Sound or NW of the site, but to the SW of the site only.

The predicted influence of farm sites (including that proposed) on PMF and shellfish farm locations was minimal, with almost zero impact from suspended sediment, and any impact occurring only for short spikes in time. Once sites included as both fish farm sources and shellfish farm receptors were removed from the source list, no shellfish farms were influenced by high levels of suspended of deposited sediment. Only one PMF point location (a kelp bed), and the maerl polygon, were predicted to be influenced by any deposited sediment peaks of note from the cumulative impact of the proposed Fish Holm site and other sites in the area.

At fish farm locations themselves, deposition was predicted to be higher and more consistent, and in general this can be accounted for by the impact generated by the individual sites themselves. Suspended sediment was predicted to be present at many salmon farm sites with a fairly high frequency, but at a very low intensity.

6 References

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[6] SSF. *Fish Holm Hydrodynamic Model Validation Report*. Tech. rep. 2024.

[7] SSF. *Fish Holm NewDepomod Modelling Report*. Tech. rep. 2024.

[8] Tritonia Scientific. “Fish Holm, Shetland Isles: baseline seabed survey using multibeam echosounder and georeferenced 3D photogrammetry”. Report No: SSF-077075.