8th April 2024

Nutrient Assessment Report

Meil Bay

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1. Introduction

As part of the screening and scoping process, in relation to proposed changes to the Meil Bay fish farm site in Orkney, Cooke Aquaculture Scotland were requested to carry out an assessment of the potential water column impacts. Details of the predicted nutrient enhancement likely to result from the discharge of the finfish site is to be provided, as well as taking into account any cumulative impacts from other sites in the surrounding area.

An Equilibrium Concentration Enhancement (ECE) assessment using the open water body model described by Gillibrand (2006) will be used to assess nutrient enhancement at the Meil Bay site.

Cumulative impacts for the area will be assessed with three operational sites and one inactive site present in the waters to the north west and south of the Meil Bay site within the Shapinsay Sound and Wide Firth water bodies. The energetic nature of Shapinsay Sound and Wide Firth could lead to increased nutrient loading in the area. The cumulative assessment will use the open water model to investigate nutrient loading from sites located near the Meil Bay site. This will compare the worst-case scenario to quantify the enrichment for the region and any potential adverse effects from the proposed changes to the site.

1.1 Background

Fish farms release nutrients as dissolved inorganic nutrients through excretion from the fish (ammonia and phosphate), particulate organic nutrients through defecation, and dissolved organic nutrients through resuspension from the particulate fractions. The majority of the nitrogen (N) wastes are released to open waters (68% of total) in the form of ammonia whereas the majority of the phosphorus (P) is accumulated in sediments (63%). Dissolved inorganic nutrients are rapidly assimilated by phytoplankton and bacteria and are then transferred to the higher trophic levels in the planktonic food web (Olsen and Olsen, 2008).

These nutrients can enhance the growth of marine plants and algae within the water column. High nutrient levels may lead to algal blooms and depletion of oxygen in the water column however it is not easy to identify the causal links of harmful algal blooms, with impacts from fish farms on productivity yet to be demonstrated, as dilution at marine sites is generally rapid. In the marine environment nitrogen is typically a limiting nutrient so its addition will dictate the amount of primary production (algal growth) however phosphorous is not considered a limiting nutrient for phytoplankton in marine waters and therefore is of less importance than nitrogen (Environmental Assessment Office, 1997). The Scottish Executive Review of environmental impacts of aquaculture concluded that the present level of fish farming is having only a small effect on the numbers and growth rate of phytoplankton and that this effect should not be a cause of concern except in poorly flushed areas or areas of high farm density (Scottish Executive, 2002). It is also recognised in many areas, especially rural areas, that nutrient inputs from agricultural land well exceeds those from fish farming operations.

A number of steps have been taken by the industry in recent years to reduce nutrient release into the marine environment through improvements in husbandry practices, feed technology and feed quality, however the continuing increase in total production means that the release of nutrients to the sea from aquaculture has also increased (Gubbins, 2003a). Therefore monitoring nutrient levels around fish farms is important to ensuring impacts on the water column and organisms present are reduced.

1.2 Site description

Meil Bay is an existing, consented site (CAR/L/1003888) operated by Cooke Aquaculture Scotland (CAS). The site is located off the north coastline of the Orkney mainland, within the Bay of Meil, south of Shapinsay Sound.

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 2x5 layout moored within 60m grids. The maximum consented biomass for the site is 884t with a maximum stocking density of 18.5kg/m^3. The site is aligned on a bearing of 23^o. The licensed site is centred on 348452.07E, 1012342.29N.

The proposal is to relocate and expand the existing site, moving the site approximately 0.3km NNW of the established site location. The new setup would consist of 16 x 100m circular cages, arranged in a 2x8 layout. The cages would be moored within 60m grids, orientated on a bearing of 36 ^{o}. A 200t feed barge will be moored centrally to the west of the cage group, with a mooring containment area measuring 630m x 270m. The proposed maximum consented biomass for the new site would be 1410t providing a maximum stocking density of 18.4g/m3. This is a net increase of 526t at the site.

If the proposal is consented, the existing site would be removed to allow the seabed to recover naturally. Figure 1 shows the existing and proposed site locations.

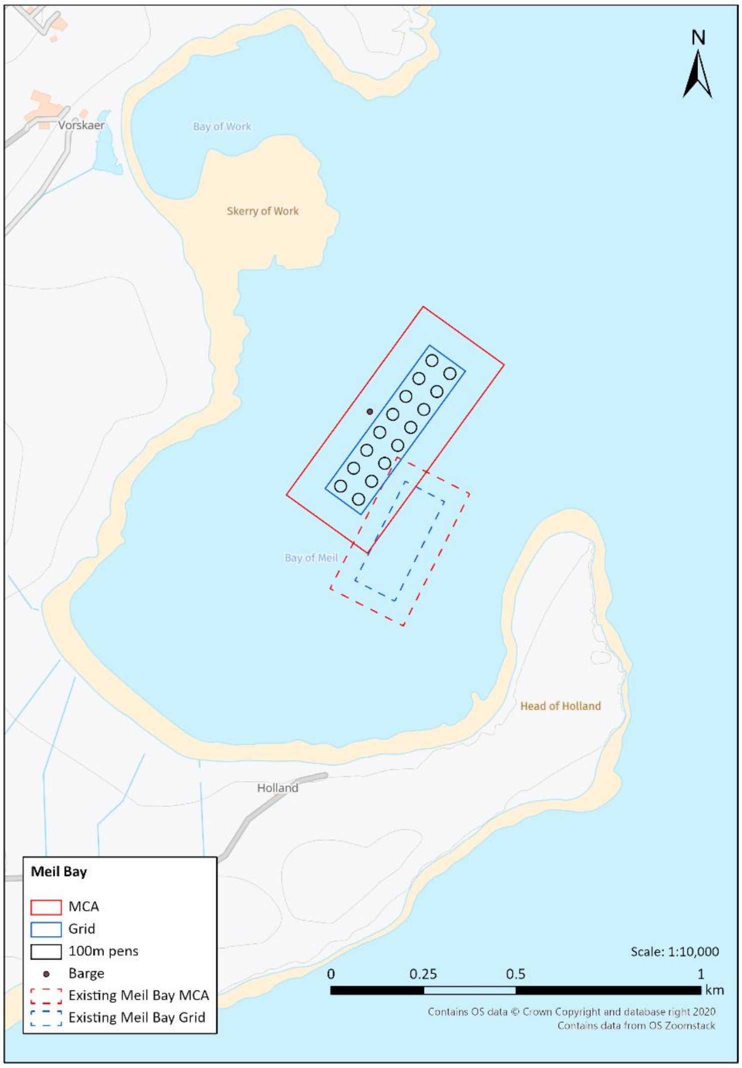

Figure 1. Existing Meil Bay site location and proposed location and setup for the new Meil Bay site.

Details of the Meil Bay site and the other fish farm sites in the surrounding area can be found in Table 1, with their locations illustrated in Figure 2.

Table 1 Details of the fish farm sites.

CAR licence number	Site name	Operator	Maximum biomass (tonnes)	Site centre position		Distance (Bearing) from Meil Bay
				WGS 84	NGR	
CAR/L/1003888	Meil Bay	CAS	1,410[1]	59°59.866'N 02°53.948'W	348439 1012644	-
WPC/N/70199	Berstane Bay[2]	S&W[3]	500	58°58.872'N 02°54.067'W	348300 1010800	1.85km (S)
CAR/L/1003899	Carness Bay	CAS	1,000	59°00.637'N 02°55.374'W	347093 1014093	1.98km (NW)
CAR/L/1001931	Quanterness	CAS	1,925[1]	59°01.050'N 02°59.941'W	342733 1014921	6.14km (WNW)
CAR/L/1003954	Puldrite	SSF[4]	980	59°02.976'N 03°00.199'W	342540 1018500	8.31km (NW)

[1] Proposed biomass, [2] Inactive fish farm, [3] Sutherland & Wylie, [4] Scottish Sea Farms

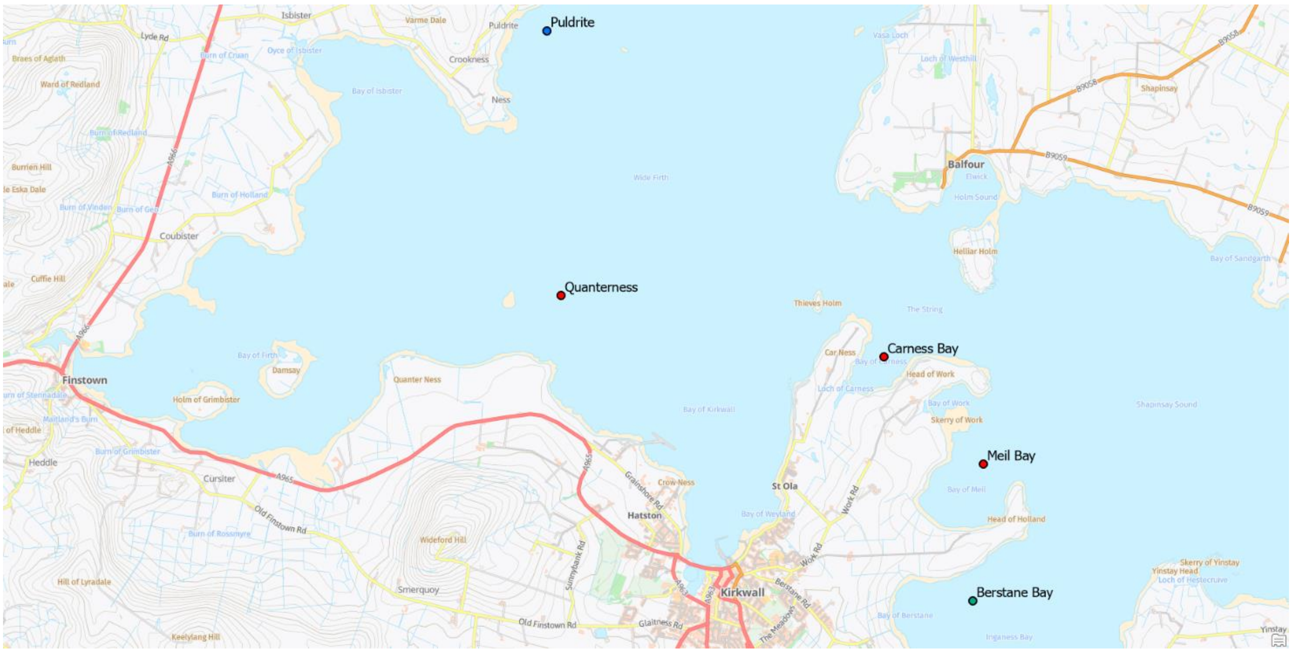

Figure 2. Locations of the fish farms present within the Shapinsay Sound and Wide Firth water bodies.

2. Nutrient modelling

Nutrient enhancement of a water body can be estimated by using two types of models. The first is used for assessing semi enclosed water bodies, described by Gillibrand (2002). This model is a technique used by Marine Scotland in the 'Locational Guidelines for Authorisation of Marine Fish Farms in Scottish Waters' issued to aid marine fish farm planning. This model is based on a semi enclosed loch scenario, with exchange of the water body achieved through the ebbing and flooding tide. This flushing allows a constant nutrient input, while maintaining a steady state concentration. The standard ECE model described by Gillibrand (2002) is designed for enclosed loch systems and is not suited to open water and large water bodies.

The second model is used to assess sites which are located in open water (Gillibrand 2006). Length and width of nutrient plumes are defined by parameters extracted from hydrographic survey data, where current velocities have been resolved to along shore and across shore components.

2.1 ECE model

The proposed Meil Bay site is located in the Kirkwall coastal water body (ID: 200234) in the Scottish Water Framework Directive (WFD) and is 73.6 square kilometres in area. It is an un-categorised waterbody as per MSS Locational Guidelines (December 2023).

With the proposed changes to the Meil Bay site including the movement of the site to the mouth of the bay, the site now borders the highly dispersive water body of Shapinsay Sound. The proposed site also experienced several higher energy events during the hydrographic data collection period. Shapinsay Sound will be having more on an effect on the dispersal of nutrients from the proposed Meil Bay site due to its close proximity to the energetic water body therefore the open water model was deemed appropriate to assess nutrient enhancement.

Due to the presence of other fish farm sites located within a nearby proximity (<10km) to the proposed site and the dynamic nature of the surrounding waters, fish farms located in the Shapinsay Sound and Wide Firth water bodies will be considered in the cumulative impact assessment.

2.1.1 ECE modelling methodology

The ECE model is a simple box model used to predict the level of enhancement of soluble nutrient nitrogen from fish farming sources, treating nitrogen as a conservative substance. The model is a function of the flushing rate of a sea loch or voe, nitrogen source rate and total consented biomass within a defined area.

The nutrient considered by the model is nitrogen, mainly in the form of dissolved ammonia, however, nitrogen emitted as particulate waste is also considered as it is re-dissolving into the water column from the seabed. The combined source of nitrogen from dissolved and particulate wastes is 48.2kg N per tonne of salmon produced. This value is derived from a mass balance model used to estimate the release of dissolved and particulate nitrogenous waste from cultivated salmon (Davies, 2000). Such an estimate is dependent on details such as stocking, feeding and harvesting strategies employed during cultivation. This information was derived from the records of a major salmon producer in Scotland averaged over a large number of their on-growing sea cage sites. Total nitrogen discharge rate is therefore the sum of the dissolved and particulate rates.

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

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

Predicted ECE for nitrogenous nutrients arising from fish farming (µmol l-1)	Nutrient enhancement index
>10	5
3-10	4
1-3	3
0.3-1	2
<0.3	1
0	0

2.1.2 ECE calculations

The calculations to determine the ECE values for the proposed Meil Bay site and the cumulative assessment using the open water model are detailed in Gillibrand, 2006. A summary of the calculations used to assess nutrient impact are detailed below.

Nitrogen output (S) in kg/s is calculated using the equation –

$$S = \frac{\text{Max harvested biomass} * 48.2}{31{,}536{,}000}$$

Where:

-48.2kg is the value given to the combined source of nitrogen from dissolved and particulate wastes per tonne of salmon produced.

-31,536,000 is the number of seconds in a year to convert the nitrogen output from kg/yr to kg/s.

For the open water model, impacts resulting from nutrient discharges are considered over three spatial scales: Zone A is a region very close to the nutrient source; Zone B is the near field region, with residency times in the order of a few days and typically of the same spatial scale as a tidal excursion; Zone C is the far field region where residence time is the order of weeks to months. In Zone B phytoplankton may grow if conditions are favourable, therefore the model considers the exchange of water in the Zone B scale region. The model aims to predict the concentration of nutrients within Zone B, which represents the volume of water into which nutrients are released from the source and are rapidly mixed within a tidal cycle. The concentration in the body of water depends on the rate at which it is replaced or exchanged by uncontaminated water.

We must assume the flow at the site contains a tidal component and that the dominant tide is the semi diurnal lunar constituent. We also must assume that the vertical extent of the nutrient plume is bounded either by seabed or by a pycnocline and that the contaminant mixes evenly vertically through this surface layer.

The model uses site specific data from hydrographic surveys to calculate the rate of change of water within Zone B. The basic method of calculating the rate of change of water within Zone B is a simple calculation based on the current velocities of an average tide.

Zone B is determined by its length (L) and width (W) in metres, which are based on tidal excursion and calculated using the equations –

$$L = \frac{(\sqrt{2})\sigma_u T}{\pi} \qquad W = \frac{(\sqrt{2})\sigma_v T}{\pi}$$

Where:

σ_u is the standard deviation of “along shore” flow (m/s)

σ_v is the standard deviation of “across shore” flow (m/s)

T is the semi diurnal tidal period (s)

π=3.1415

We assume for simplicity that Zone B is rectangular with area (m^2) and volume (m^3) calculated using the equations –

$$A=LW \qquad V=AH$$

Where:

H is the water depth or pycnocline depth (m)

The concentration of effluent within the box (Zone B) is determined by the exchange rate (E), which is the inverse of the flushing time (Tf). The flushing time is defined as the time after which the mean concentration (C) in the box would have fallen to a value which is 37% of the initial concentration due to the action of physical exchange processes only.

In the model we define the exchange rate in seconds as:

$$E = E_A + E_x + E_y$$

Where:

E_A is the exchange rate due to advection (residual flow - U_R) and Ex and Ey are due to along shore and across shore diffusion respectively.

The exchange rate due to advection (E_A) is calculated by –

$$E_A = \frac{U_R}{L}$$

Where:

U_R is the residual flow (m/s)

Exchange rates due to diffusion are calculated by –

$$Ex = \frac{Kx}{2L^2} \qquad Ey = \frac{Ky}{2W^2}$$

Where:

Kx is the along shore diffusion coefficient

Ky is the across shore diffusion coefficient

The derivations of these equations to calculate the coefficients can be found in Sherwin (2001). This will give a Minimum (Min), Median and Maximum (Max) exchange rate. These exchange rates are then used to calculate Min, Median and Max flushing times (Tf) and effluent concentration (C) in Zone B.

Flushing time in hours is calculated using the equation –

$$Tf = ((1/E)/60)/60$$

Where the:

E_{MAX} value is used to calculate the Tf_{MIN} value

E_{MEDIAN} value is used to calculate the Tf_{MEDIAN} value

E_{MIN} value is used to calculate the Tf_{MAX} value

The effluent concentration in kg/m^3 is calculated by the equation –

$$C = \frac{S}{V(E+k)}$$

Where:

S is the nitrogen output or effluent source (kg/s)

k is the nutrient decay rate (s)

And the:

E_{MAX} value is used to calculate the C_{MIN} value

E_{MEDIAN} value is used to calculate the C_{MEDIAN} value

E_{MIN} value is used to calculate the C_{MAX} value

To convert the ECE value (C) from kg/s to µmol/l the following equation is used –

$$\frac{C*1000000}{14}$$

2.2 Meil Bay ECE

2.2.1 Model inputs

An acoustic profiling current meter was deployed approximately 100m from the proposed site centre location for 112 days, from the 15th September 2021 to the 5th January 2022. From this a 90-day subset was selected, spanning from 7th October 2021, 10:30 to 5th January 2022, 10:30.

The reported hydrographic data for the near surface (NS), cage bottom (CB) and near bed (NB) layers for the proposed Meil Bay site are shown in Table 3, with the averaged hydrographic data required for the model shown in Table 4 below.

Table 3 Hydrographic data at the three reported water depths

Residual Current (U_R)			"along shore" flow (σ_u)			"across shore" flow (σ_v)		
NS	**CB**	**NB**	**NS**	**CB**	**NB**	**NS**	**CB**	**NB**
0.0202	0.0183	0.00545	0.0361	0.0369	0.0447	0.0313	0.0304	0.0423

Table 4 Averaged hydrographic data for input into the model

Residual Current (U_R)	"along shore" flow (σ_u)	"across shore" flow (σ_v)	Vector Average Residual Direction (Degrees)
0.0146	0.0392	0.0347	184

The production cycle for the Meil Bay site is 22 months with 2 months fallowing. To adopt a precautionary approach and to follow the methods detailed in Gillibrand (2002) the source of nitrogen from dissolved and particulate wastes was set at 48.2kg Nitrogen per tonne of salmon produced.

Table 5 below shows the nitrogen data used to calculate the nitrogen output value for the Meil Bay site which is subsequently used in the ECE model.

Table 5 Nitrogen data

Nitrogen (kg per tonne salmon)	48.2
Proposed maximum biomass on site (t)	1,410
Nitrogen output (kg/yr)	67,962
Nitrogen output (kg/s)	**2.155×10^{-3}**

Table 6 outlines the data inputs required to run the open water ECE model for the Meil Bay site.

Table 6 ECE model inputs

Semi-diurnal tidal period (s)	T	45,000
Water depth (m)	H	12.1
Residual flow (m/s)	U_R	0.0146
Standard deviation "along-shore" flow (m/s)	σ_u	0.0392
Standard deviation "across-shore" flow (m/s)	σ_v	0.0347
Nutrient decay rate (s-1)	k	0
Nitrogen output (kg/s)	S	2.155×10^{-3}

2.2.2 Model outputs

Area of impact (Zone B) is calculated using the hydrographic data. Table 7 details the area of impact for the Meil Bay site.

Table 7 Zone B dimensions

Length (m)	794.5
Width (m)	702.6
Area (m^2)	558,152.3
Volume (m^3)	6,753,642.8

Exchange rates and flushing times for the Meil Bay site are detailed in Table 8. The model determines a flushing time by calculating a refreshment rate. This is based on the size of Zone B and the residual currents in the area.

Table 8 Exchange rates and Flushing times

Minimum exchange rate (s-1)	E_{MIN}	1.85265×10^{-5}
Median exchange rate (s-1)	E_{MEDIAN}	1.99384×10^{-5}
Maximum exchange rate (s-1)	E_{MAX}	2.73721×10^{-5}
Minimum flushing time (hrs)	Tf_{MIN}	10.15
Median flushing time (hrs)	Tf_{MEDIAN}	13.93
Maximum flushing time (hrs)	Tf_{MAX}	14.99

The resultant open water ECE model outputs are detailed in Table 9 below for the Meil Bay site.

Table 9 Equilibrium Concentration Enhancement

		(kg/m³)	(µmol l-1)
Minimum ECE	C_{MIN}	1.16577 x 10^{-5}	0.8327
Median ECE	C_{MEDIAN}	1.60041 x 10^{-5}	1.1432
Maximum ECE	C_{MAX}	1.72238 x 10^{-5}	**1.2303**

The predicted maximum nutrient enhancement value for the Meil Bay site is 1.23 µmol l-1, equivalent to nutrient enhancement index category 3.

2.3 Meil Bay ECE – Cumulative effects

An assessment of the cumulative effects of nutrients released from the sites in the waters surrounding the Meil Bay site was undertaken.

There are four other fish farms in the surrounding area of Shapinsay Sound and Wide Firth, however one of these sites is inactive. The cumulative assessment is carried out using the open water model (Gillibrand 2006). The sites considered in the cumulative assessment are not located within areas categorised in the Locational Guidelines. This combined with their current regimes and topography, mean the open water model is applicable. Using the most recent hydrographic data for the sites, plume dimensions were calculated. The plumes were mapped using the vector averaged residual current directions to assess potential influence on nutrient loading at the proposed Meil Bay site.

2.3.1 Model inputs

Three current velocity inputs are required to calculate the nutrient plume dimensions, with data obtained from hydrographic surveys at the four sites. Data from two or three reported water depths (NS-near surface, CB-cage bottom & NB-near bed layers) are shown in Table 10.

Table 10 Hydrographic data at the two or three reported water depths.

	Residual Current (U_R)			"along shore" flow (σ_u)			"across shore" flow (σ_v)		
	NS	CB	NB	NS	CB	NB	NS	CB	NB
Berstane Bay	0.036	-	0.017	0.059	-	0.038	0.048	-	0.025
Carness Bay	0.036	-	0.035	0.077	-	0.077	0.06	-	0.061
Quanterness	0.160	0.152	0.115	0.161	0.158	0.129	0.065	0.0567	0.0495
Puldrite	0.078	0.069	0.058	0.28	0.263	0.233	0.071	0.076	0.078

Table 11 outlines the data inputs required to calculate the nutrient plume dimensions including the averaged hydrographic data, depth and residual direction. Additional data inputs required to calculate the plume dimensions include the semi diurnal tidal period of 45,000 seconds which remains the same for all sites.

Table 11 Plume calculations - model inputs

	Residual Current (UR)	"along shore" flow (σ_u)	"across shore" flow (σ_v)	Water depth (m)	Vector Average Residual Direction (Degrees)
Berstane Bay	0.0267	0.0484	0.0366	10.0	2
Carness Bay	0.0352	0.077	0.0602	7.64	182
Quanterness	0.142	0.149	0.057	15.7	149
Puldrite	0.0681	0.2586	0.0749	14.0	203

2.3.2 Model outputs

Table 12 details the plume dimensions of the area of impact (Zone B) for the sites to the south and north west of the Meil Bay site within Shapinsay Sound and Wide Firth. Figure 3 illustrates the nutrient plumes for all the sites including the proposed Meil Bay site.

Table 12 Zone B plume dimensions

	Length (m)	Width (m)	Area (m^2)	Volume (m^3)
Berstane Bay	979.4	742	726,745.6	7,267,456.5
Carness Bay	1,560.1	1,219.1	1,901,931.5	14,530,756.9
Puldrite	5,238.6	1,517.5	7,949,307.7	111,290,308.1
Quanterness	3,025.7	1,155.7	3,496,651.8	54,897,433.2

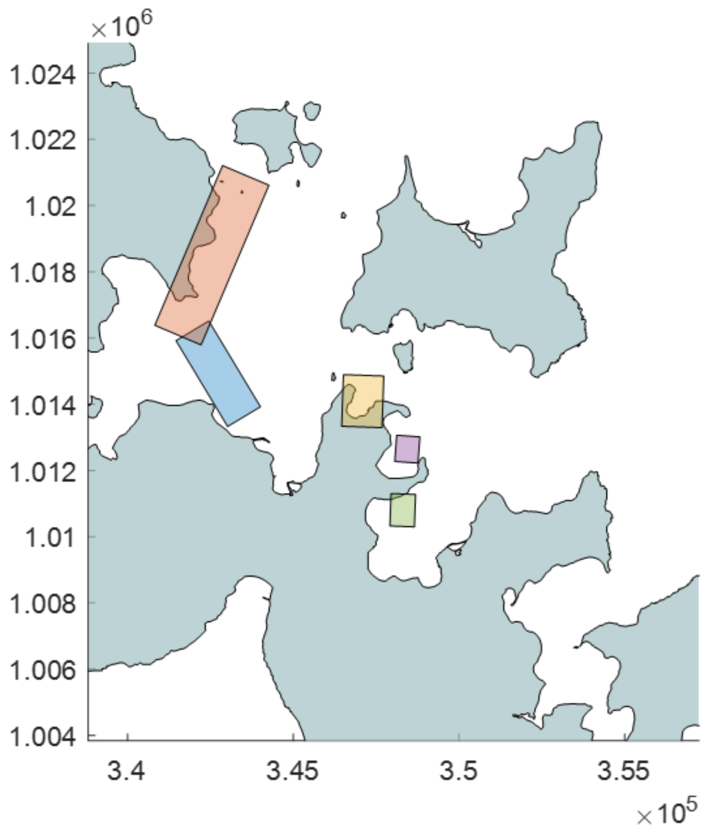

Figure 3. Nutrient plumes for all sites including the proposed Meil Bay site (purple).

3. Discussion

3.1 Meil Bay ECE

For the ECE calculations the open water model was deemed to be the most appropriate to calculate nutrient enhancement at the proposed Meil Bay site. This was due to the site being located in an uncategorised water body and also the proposed relocation of the Meil Bay site to the mouth of the Bay of Meil, is moving the site closer to the dynamic water body of Shapinsay Sound, aiding nutrient dispersal.

Using the open water ECE model, the Meil Bay site has a maximum nutrient enhancement value of 1.23 µmol l-1. When stocked to the proposed maximum biomass this provides a nutrient enhancement index of 3. This is at the lower end of the level 3 index with a range of 1-3 µmol l-1. When comparing to the current Meil Bay site, using hydrographic data from the existing location, the maximum nutrient enhancement value was calculated as 0.56 µmol l-1, with a nutrient enhancement index of 2.

There will be some nutrient enrichment in the vicinity of the development due to nutrient release from the fish farm and there has been a slight increase in the nutrient enhancement value and index at the Meil Bay site but this could be explained due to the increase in the proposed tonnage at the new site. With the Meil Bay site being moved towards the mouth of the Bay of Meil this is not considered to be significant in terms of the current regime of the Shapinsay Sound waterbody which borders the Bay of Meil. The proposed site is unlikely to lead to any environmental impacts with the majority of the effluent from the site dispersed in the energetic waters of Shapinsay Sound.

3.2 Cumulative assessment

Due to the presence of other fish farm sites located within a close proximity (<10km) to the proposed site and the dynamic nature of the surrounding waters, fish farms located in the Shapinsay Sound and Wide Firth water bodies will be considered in the cumulative impact assessment.

Due to a number of sites in the water bodies around the Kirkwall area and the energetic nature of the waters surrounding the Meil Bay site, there could be potential for nutrient plumes to overlap and lead to increased nutrient loading. To address this, the cumulative effects of all sites in the area were investigated using the open water model.

There are four sites in this area, however one site, Berstane Bay has been inactive for a long period of time, therefore, the addition of nutrients from this site is unlikely.

The Meil Bay nutrient plume does not overlap with any other site’s nutrient discharge and is localised within the bay where it’s located, therefore the potential for cumulative nutrient loading is low.

The closest site to the Meil Bay fish farm is the Berstane Bay site, which is 1.85km south of the proposed site. However, the Berstane Bay site has been inactive for a number of years therefore its unlikely to have an effect on nutrient input to the area. The next closest site is Carness Bay, which is 1.98km north west, and is also owned by CAS therefore it would be unlikely to have neighbouring sites operated by the same company stocked and reaching maximum biomass at the same time. The energetic nature of Shapinsay Sound, the water body which borders both bays where the sites are located will be having an impact on water movement in the bays, which should lead to rapid dispersal of nutrients in this area.

The modelling assumptions have considered a worst-case scenario. It has assumed that all sites are producing salmon and are at maximum biomass at one time. It is very unrealistic and impractical to have all sites running at maximum biomass. Therefore, the actual amount of salmon harvested will be significantly lower than that of the modelled assumptions. This will result in less feed used and less nitrogen enrichment in the area than predicted.

Relocation and expansion of the Meil Bay site shows some localised nutrient loading, however nutrient discharges from the other four sites in the area do not overlap with the Meil Bay plume therefore cumulative nutrient loading is unlikely. Due to the hydrodynamic conditions of the waterbodies in the area, any plumes that are created are quickly dispersed, allowing this site to be considered as low risk.

4. Mitigation

In order to minimise nutrient input from the Meil Bay site, measures are in place to reduce the amount of waste feed entering the water column and settling on the seabed. Improvements in feeding efficiency and feed quality could reduce waste entering the water column lowering the environmental impact.

Monitoring will be carried out in accordance with SEPA water quality monitoring procedures throughout the production cycle to detect nutrients entering the water column and to act as early warning of a potentially harmful bloom.

5. References

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