QUANTERNESS EIAR
EQUILIBRIUM CONCENTRATION ENHANCEMENT MODELLING

APPENDIX 3

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1. Introduction

As part of the screening and scoping process, in relation to proposed changes to the Quanterness 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 Quanterness site.

Cumulative impacts for the area will be assessed with three operational sites and one inactive site present in the waters to the north and east of the Quanterness site within the Wide Firth and Shapinsay Sound water bodies. The energetic nature of Wide Firth and Shapinsay Sound 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 Quanterness 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

Quanterness is an existing, consented site (CAR/L/1001931) operated by Cooke Aquaculture Scotland (CAS). The site is located off the north coastline of the Orkney mainland, within the Bay of Kirkwall, south of Wide Firth.

The existing site consists of a single group of 8 circular, 90m circumference cages with a net depth of 8m. These are arranged in a 2x4 layout moored within 50m grids. The maximum consented biomass for the site is 600t with a maximum stocking density of 14.54kg/m^3. The site is aligned on a bearing of 8°. The licensed site is centred on 343220.24E, 1013947.6N.

The proposal is to create a new site to replace the existing site, with the new site located approximately 1km NNW of the established site location. The new site would consist of 14 x 120m circular cages, arranged in a 2x7 layout. The cages would be moored within 70m grids, orientated on a bearing 0 °. A 200ft feed barge will be moored centrally to the south of the cage group, with a mooring containment area measuring 710m x 290m. The proposed maximum consented biomass for the new site would be 1925t providing a maximum stocking density of 14.99kg/m3. This is a net increase of 1325t 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.

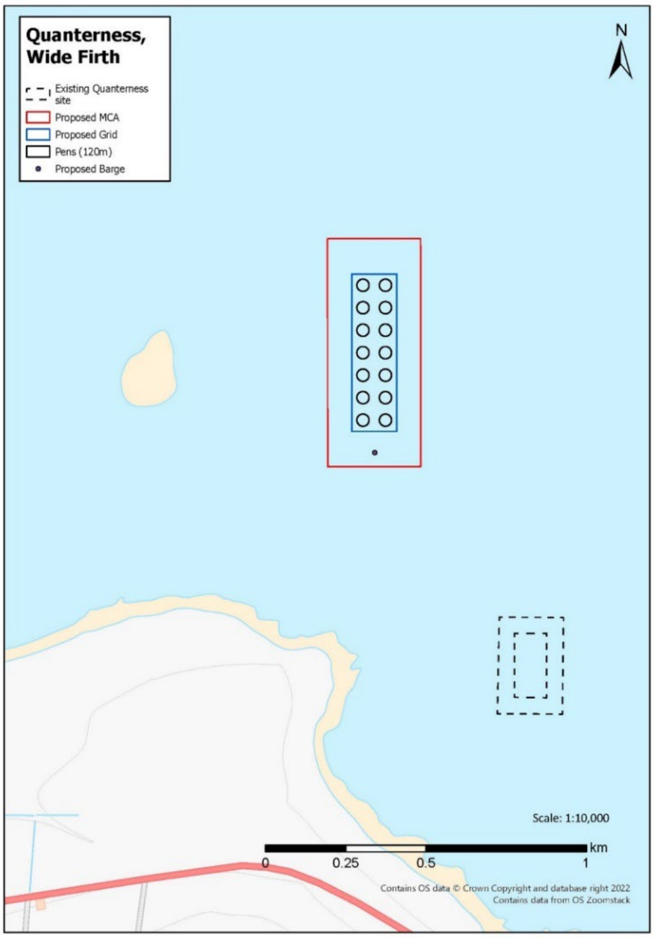

Figure 1. Existing Quanterness site location and proposed location and setup for the new Quanterness site.

Details of the Quanterness 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 Quanterness
				WGS 84	NGR	
CAR/L/1001931	Quanterness	CAS	1,925[1]	59°01.050'N 02°59.941'W	342733 1014921	-
CAR/L/1003954	Puldrite	SSF[3]	980	59°02.976'N 03°00.199'W	342540 1018500	3.58km (N)
CAR/L/1003899	Carness Bay	CAS	1,000	59°00.637'N 02°55.374'W	347093 1014093	4.44km (E)
CAR/L/1003888	Meil Bay	CAS	1,410[1]	59°59.866'N 02°53.948'W	348439 1012644	6.14km (ESE)
WPC/N/70199	Berstane Bay[2]	S&W[4]	500	58°58.872'N 02°54.067'W	348300 1010800	6.93km (SE)

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

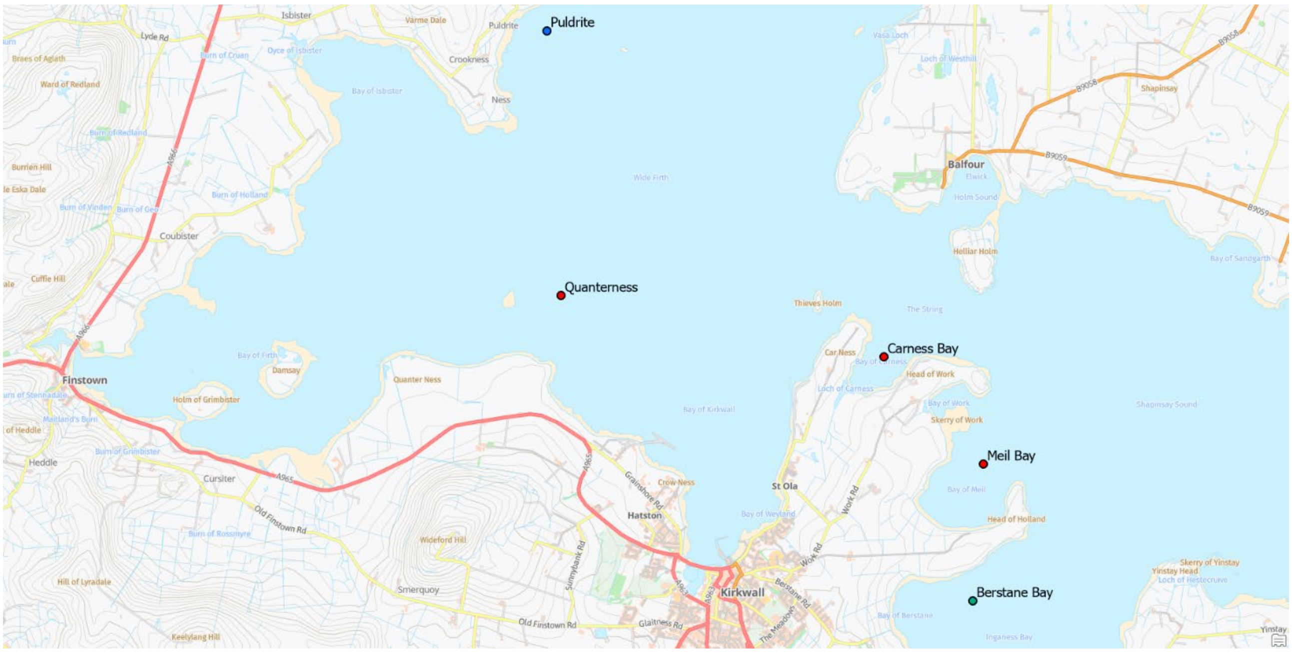

Figure 2. Locations of the fish farms present within the Wide Firth and Shapinsay Sound water bodies.

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 Quanterness 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).

For the Quanterness site the open water model is more appropriate to use to assess nutrient enhancement. The site is classed as highly resupensive, strongly flushed and highly dispersive with a large proportion of the material released from the site being exported in a south east direction towards the Bay of Kirkwall.

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 Wide Firth and Shapinsay Sound 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 Quanterness 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 E_x and E_y 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 Quanterness ECE

2.2.1 Model inputs

An acoustic profiling current meter was deployed at the proposed site centre location for 103 days, from the 2nd September 2021 to the 15th December 2021. From this a 90-day subset was selected, spanning from 2nd September 2021, 15:40 to 1st December 2021, 15:40.

The reported hydrographic data for the near surface (NS), cage bottom (CB) and near bed (NB) layers for the proposed Quanterness 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
0.160	0.152	0.115	0.161	0.158	0.129	0.065	0.0567	0.0495

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)
0.142	0.149	0.057	149

The production cycle for the Quanterness 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 Quanterness 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)	1,925
Nitrogen output (kg/yr)	92,785
Nitrogen output (kg/s)	**2.942×10^{-3}**

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

Table 6 ECE model inputs

Semi-diurnal tidal period (s)	T	45,000
Water depth (m)	H	15.7
Residual flow (m/s)	U_R	0.142
Standard deviation "along-shore" flow (m/s)	σ_u	0.149
Standard deviation "across-shore" flow (m/s)	σ_v	0.057
Nutrient decay rate (s-1)	k	0
Nitrogen output (kg/s)	S	2.942×10^{-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 Quanterness site.

Table 7 Zone B dimensions

Length (m)	3,025.7
Width (m)	1,155.7
Area (m^2)	3,496,651.8
Volume (m^3)	54,897,433.2

Exchange rates and flushing times for the Quanterness 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}	4.70875×10^{-5}
Median exchange rate (s-1)	E_{MEDIAN}	4.73411×10^{-5}
Maximum exchange rate (s-1)	E_{MAX}	4.79988×10^{-5}
Minimum flushing time (hrs)	Tf_{MIN}	5.79
Median flushing time (hrs)	Tf_{MEDIAN}	5.87
Maximum flushing time (hrs)	Tf_{MAX}	5.9

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

Table 9 Equilibrium Concentration Enhancement

		(kg/m^3)	(µmol l-1)
Minimum ECE	C_{MIN}	1.11658×10^{-6}	0.07976
Median ECE	C_{MEDIAN}	1.13209×10^{-6}	0.08086
Maximum ECE	C_{MAX}	1.13819×10^{-6}	**0.0813**

The predicted maximum nutrient enhancement value for the Quanterness site is 0.0813 µmol l-1, equivalent to nutrient enhancement index category 1.

2.3 Quanterness ECE – Cumulative effects

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

There are four other fish farms in the surrounding area of Wide Firth and Shapinsay Sound, 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 Quanterness site.

2.3.1 All sites - 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**
Puldrite	0.078	0.069	0.058	0.28	0.263	0.233	0.071	0.076	0.078
Carness Bay	0.036	-	0.035	0.077	-	0.077	0.06	-	0.061
Meil Bay	0.02	0.018	0.005	0.036	0.037	0.045	0.031	0.03	0.042
Berstane Bay	0.036	-	0.017	0.059	-	0.038	0.048	-	0.025

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 (σu)	"across shore" flow (σv)	Water depth (m)	Vector Average Residual Direction (Degrees)
Puldrite	0.0681	0.2586	0.0749	14.0	203
Carness Bay	0.0352	0.077	0.0602	7.64	182
Meil Bay	0.0146	0.0392	0.0347	12.1	184
Berstane Bay	0.0267	0.0484	0.0366	10.0	2

2.3.2 All sites - Model outputs

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

Table 12 Zone B plume dimensions

	Length (m)	Width (m)	Area (m^2)	Volume (m^3)
Puldrite	5,238.6	1,517.5	7,949,307.7	111,290,308.1
Carness Bay	1,560.1	1,219.1	1,901,931.5	14,530,756.9
Meil Bay	794.5	702.6	558,152.3	6,753,642.8
Berstane Bay	979.4	742	726,745.6	7,267,456.5

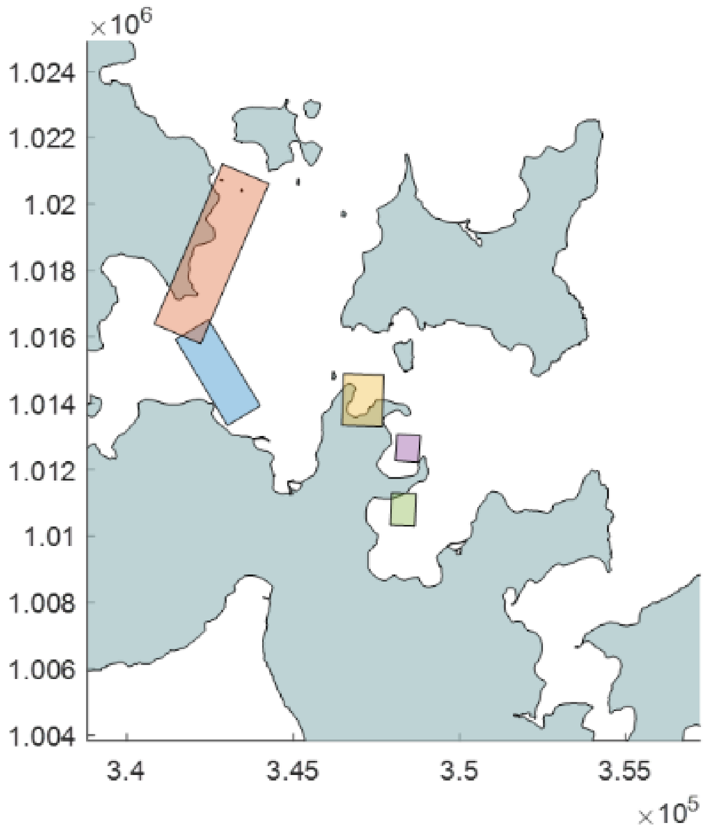

Figure 3. Nutrient plumes for all sites, including the proposed Quanterness site (blue).

The Quanterness (blue) and Puldrite (orange) nutrient plumes are shown (Figure 3) to overlap therefore a total enrichment for the Wide Firth area is to be calculated.

2.3.3 Wide Firth - Model inputs

The total enrichment of the Wide Firth area is considered, this uses the open water model combined with the cumulative effects from the Quanterness and Puldrite farms to quantify the total ECE concentration. The area is calculated from the unified cumulative area of the Quanterness and Puldrite sites modelled previously. The volume is calculated using an average depth of 14.85m. The plume length and width are extracted from the impact area as shown in Figure 4. The model input parameters are shown in Table 13 and 14.

Table 13 below shows the nitrogen data used to calculate the nitrogen output value for the Wide Firth area to include the Quanterness and Puldrite sites.

Table 13 Nitrogen data

Nitrogen (kg per tonne salmon)	48.2
Combined proposed maximum biomass on site (t)	2,905
Nitrogen output (kg/yr)	140,021
Nitrogen output (kg/s)	**4.44×10^{-3}**

Table 14 outlines the data inputs required for the open water ECE model for the Wide Firth area.

Table 14 Wide Firth ECE model inputs

Semi-diurnal tidal period (s)	45,000
Average water depth (m)	14.85
Length (m)	6,835
Width (m)	1,685
Area (m^2)	11,516,975
Volume (m^3)	171,027,079
Average Residual flow (m/s)	0.105
Average Standard deviation "along-shore" flow (m/s)	0.204
Average Standard deviation "across-shore" flow (m/s)	0.066
Nutrient decay rate (s-1)	0
Nitrogen output (kg/s)	4.44×10^{-3}

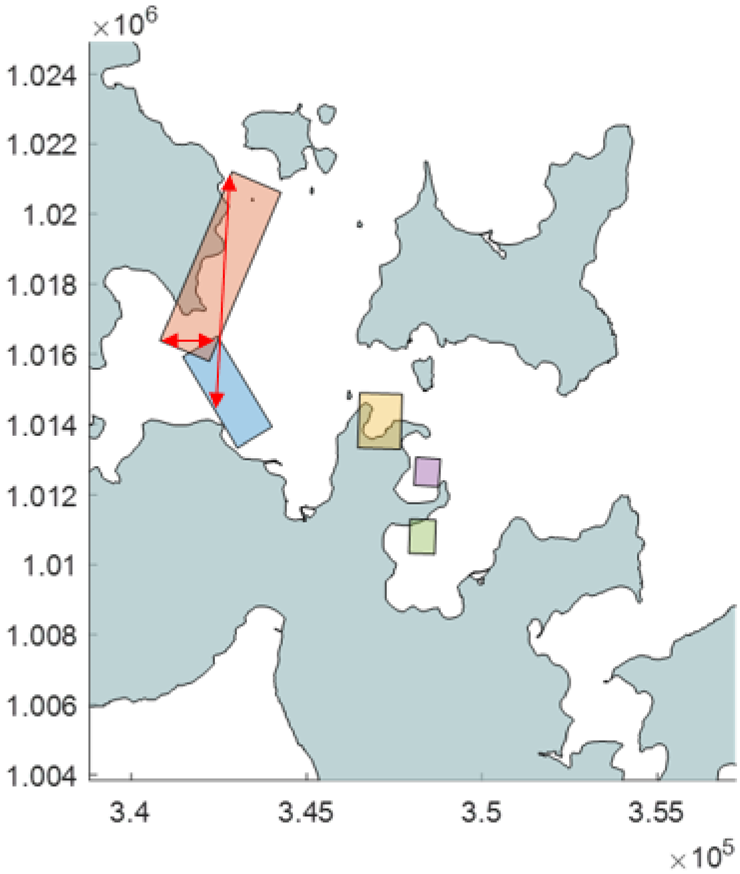

Figure 4. Wide Firth total enrichment area (orange and blue box), red arrows illustrating the length and width of the impact area.

2.3.4 Wide Firth - Model outputs

Exchange rates and flushing times for the Wide Firth area are detailed in Table 15. 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 15 Exchange rates and Flushing times

Minimum exchange rate (s-1)	E_{MIN}	1.54081×10^{-5}
Median exchange rate (s-1)	E_{MEDIAN}	1.54837×10^{-5}
Maximum exchange rate (s-1)	E_{MAX}	1.56884×10^{-5}
Minimum flushing time (hrs)	Tf_{MIN}	17.71
Median flushing time (hrs)	Tf_{MEDIAN}	17.94
Maximum flushing time (hrs)	Tf_{MAX}	18.03

The resultant open water ECE model outputs are detailed in Table 16 below for the Wide Firth area.

Table 16 Equilibrium Concentration Enhancement

		(kg/m³)	(µmol l-1)
Minimum ECE	**C_{MIN}**	1.65479 x 10^{-6}	0.1182
Median ECE	**C_{MEDIAN}**	1.67666 x 10^{-6}	0.1198
Maximum ECE	**C_{MAX}**	1.68489 x 10^{-6}	**0.1203**

The predicted maximum nutrient enhancement value for the Wide Firth area, to include the Quanterness and Puldrite sites, is 0.1203 µmol l-1, equivalent to nutrient enhancement index category 1.

3. Discussion

3.1 Quanterness ECE

For the ECE calculations the open water model was deemed to be the most appropriate to calculate nutrient enhancement at the proposed Quanterness site. This was due to the location of the site within the dynamic uncategorised waterbody of Wide Firth and the hydrographic data recorded at the site presenting the site as highly resuspensive and highly dispersive.

Using the open water ECE model, the Quanterness site has a maximum nutrient enhancement value of 0.081 µmol l-1. When stocked to the proposed maximum biomass this provides a nutrient enhancement index of 1. This remains at the lower end of the level 1 index with a range of <0.3 µmol l-1. When comparing to the current Quanterness site, using hydrographic data from the existing location, the maximum nutrient enhancement value was calculated as 0.084 µmol l-1, with a nutrient enhancement index of 1.

There will be some nutrient enrichment in the vicinity of the development due to nutrient release from the fish farm. However, when comparing the nutrient enhancement of the current and new Quanterness sites there has been no change in the nutrient enhancement index value of 1 and there has been a slight reduction in the maximum nutrient enhancement value. This is most likely due to the movement of the site further north into the more energetic waters of Wide Firth. The nutrient enhancement of the area from the new Quanterness site is not considered to be significant in terms of the current regime of the Wide Firth waterbody. The proposed site is unlikely to lead to any environmental impacts with the majority of the effluent from the site dispersed in the active waters around the site.

3.2 Cumulative assessment

Due to the presence of other fish farm sites located within close proximity (<10km) to the proposed site and the dynamic nature of the surrounding water bodies, fish farms located in the Wide Firth and Shapinsay Sound water bodies were 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 Quanterness 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 Quanterness and Puldrite nutrient plumes located within Wide Firth did overlap therefore a total nutrient enrichment value was calculated for the Wide Firth area. The other three sites which are located in Shapinsay Sound had nutrient plumes which were localised within the bays they are located and are greater distances from the Quanterness nutrient plume. The potential for cumulative nutrient loading from the sites within Shapinsay Sound is low.

Using the open water ECE model, the Wide Firth area has a maximum nutrient enhancement value of 0.1203 µmol l-1. When both sites are stocked to the proposed maximum biomass this provides a nutrient enhancement index of 1. This remains at the lower end of the level 1 index with a range of <0.3 µmol l-1. The energetic nature of the Wide Firth water body, where both sites are located, would 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.

Nutrient modelling of the proposed site showed low nutrient loading. The Quanterness nutrient plume did overlap with the Puldrite nutrient plume however after calculations of nutrient enhancement levels within the Wide Firth area, the nutrient levels remained low. Due to the hydrodynamic conditions at the site and the surrounding 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 Quanterness 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

Davies, I.M. (2000). Waste production by farmed Atlantic salmon (*Salmo salar*) in Scotland. ICES CM 2000/O:01, 12 pp.

Environmental Assessment Office (1997). Nitrogen as the limiting nutrient for eutrophication in coastal marine ecosystems. Evolving views over three decades 1997 Robert W. Howarth1 and Roxanne Marino.

Gillibrand P.A. (2006) Improving Assimilative Capacity Modelling for Scottish Coastal Waters: II. A Model of Physical Exchange for Open Water Sites. SAMS Marine Physics Report No. 168

Gillibrand P.A., Gubbins M.J., Greathead C. & Davies I.M. (2002) Scottish Executive Locational Guidelines for fish farming: predicted levels of nutrient enhancement and benthic impact. Scottish Fisheries Research Report Number 63. FRS, Aberdeen.

Gubbins, M.J., Gillibrand, P.A., Sammes, P.J., Miller, B.S. and Davies, I.M. 2003a. OSPAR eutrophication assessment of aquaculture hotspots in Scottish coastal waters. FRS Marine Laboratory Collaborative Report 07/03, 149 pp.

Olsen Y., Olsen L.M. (2008) Environmental impact of aquaculture on coastal planktonic ecosystems. In:Tsuka -moto K, Kawamura T, Takeuchi T, Beard TD Jr, Kaiser MJ (eds) Fisheries for global welfare and environment. Proc 5th World Fisheries Congress 2008, Terrapub, Tokyo, p 181−196.

Scottish Executive, (2002). Review and Synthesis of the Environmental Impacts of Aquaculture, The Scottish Association for Marine Science and Napier University.

Sherwin, T.J. (2001) The significance of residual currents in the interpretation of the EU Urban Wastewater Treatment Directive in coastal locations. Marine Pollution Bulletin, 40, 17-21.