13th July 2023

NewDepomod Modelling Report

Quanterness

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Summary

Cooke Aquaculture Scotland Ltd. (CAS) has undertaken biomass and in-feed chemotherapeutant modelling for the proposed Quanterness site. The pen layout uses 14, 120m circular pens, moored within 70m grids. The site was modelled using NewDepomod to determine the maximum biomass and in-feed chemical treatments. NewDepomod was ran using SEPA default values as a risk assessment tool to determine dispersion and depositional characteristics at the proposed site. A summary of the predicted footprints of the proposed site are given in Table 1.

Spatial contour plots and 2D transects quantifying the benthic footprints are presented for the default NewDepomod results. The majority of deposition occurs directly beneath the pens, specifically towards the southwestern region of the farm. In the default model, the predicted impact of the proposed Quanterness site is comfortably within the benthic EQS thresholds for a site with a high wave exposure index.

In-feed chemical modelling complies with environmental standards when using 30g of Emamectin Benzoate. This simulates an impact area equivalent to 83% of the 100m mixing area. This permits a treatable biomass of 85.7 tonnes.

Table 1. Summary of the recommended consent limits for the proposed Quanterness site.

Maximum biomass	1925T	**Stocking density**	14.99
Biomass modelling		**Default model**	
100m mixing zone area (m^2)		188,957	
Impact area (m^2)		0	
Percentage of 100m mixing zone (%)		0	
Cage edge threshold (g m^2 yr^{-1})		0	
In-Feed Treatments - EmBz		**Default model**	
Chemical quantity (g)		65	
100m mixing zone area (m^2)		188,957	
Predicted impact area of proposed site (m^2)		157,500	
Percentage of 100m mixing zone (%)		83.4	

1. Introduction

This report details the methodology and results for SEPA's default NewDepomod model for the proposed Quanterness aquaculture site. Modelled footprint area and intensity are then used to determine the maximum biomass and in-feed chemical mass that complies with all SEPA's environmental quality standards (EQS).

1.1 Site description

Quanterness is considered a new potential site and would replace the existing West Shargun Shaol (Wide Firth) site (CAR/L/1001931) operated by Cooke Aquaculture Scotland. The site is located off the northeast coastline of the Orkney mainland, within the Bay of Kirkwall, in Wide Firth. The existing site consists of a single group of 8 circular, 90m circumference pens with a net depth of 8m. These are arranged in a 2 x 4 layout with a 50 m separation, housing a maximum consented biomass of 600T at a maximum stocking density of 14.54kg/m^3. The site is aligned with a bearing of ~8^o. The licensed site is centred on 343220.24E, 1013947.6N, with a wave exposure index of 2.81.

The proposed development relinquishes the existing site and adds a new site ~1.1km towards the northwest. The proposed site has a site centre of 342733 E, 1014921 N and consists of 14 120m circumference pens in a 2 x 7 layout (see figure 1). The proposed site will house a maximum consented biomass of 1925T, providing a maximum stocking density of 14.99kg/m^3. Further information on the existing and proposed site infrastructure and pen layout is presented in Table 2.

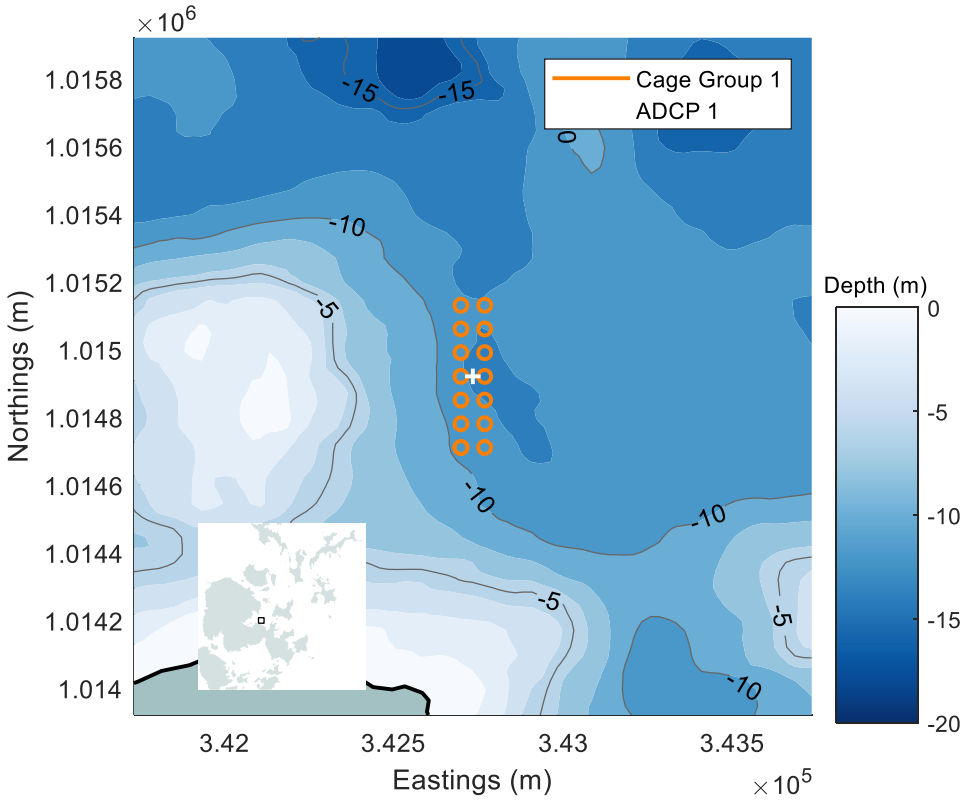

Figure 1. Proposed (orange) Quanterness site infrastructure, ADCP deployment location ('+') and bathymetry.

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

	West Shargun Shoal (Existing)	Quanterness (Proposed)
Consent number	CAR/L/1001931	CAR/L/5003381
Company	Cooke Aquaculture Scotland	Cooke Aquaculture Scotland
Receiving water	Bay of Kirkwall	Wide Firth
Site centre (OSGB36)	343220.24E, 1013947.6N	342733E, 1014921N
Current meter location (OSGB36)/year of deployment		342733E, 1014921N
Distance to shore (km)	0.56	0.9
Average water depth (m)	13.46	15.18
Maximum biomass (t)	600	1925
Total number of pens	8	14
Number of pen groups	1	1
Formation	2 x 4	2 x 7
Pen group orientation (°)	8	0
Pen shape	Circular	Circular
Pen circumference (m)	90	120
Mooring grid (m)	50	70
Wave exposure index	2.81	2.82

2. NewDepomod modelling methods

To determine maximum biomass and compliant in-feed chemotherapeutant quantities, a particle tracking model is applied. NewDepomod (version 1.3.2-rc01) simulates the release and deposition of waste feed and faecal material from farms to the seabed, from which the benthic impact is predicted. For in-feed treatments specific chemical characteristics are accounted for to determine chemical concentration and accumulation.

2.1 SEPA default model

The SEPA default model allows a cautionary estimate of the proposed site's depositional footprint. Parameters controlling particle settling, dispersion and erosion are set to SEPA's predetermined values.

2.1.1 Benthic

The benthic SEPA default model is used to determine maximum biomass based on Environmental Quality Standards (EQS). These methods and NewDepomod particle dispersion parameters are outlined in more detail in SEPA (2019a) and SEPA (2019b).

For the standard default model, the domain consists of a 2 km^2 area with grid cells at 25 m spacing. The coordinate system uses the cartesian Ordnance Survey of Great Britain 1936 system (OSGB 1936), with the site centred in the domain. Uniform bathymetry is applied, with the depth value set at the minimum ADCP measured depth (13.43m). Coastline data from Ordnance Survey (2022), is used to define the land boundary, which is set to 10 m above sea level.

The simulation uses 90-days of hydrographic data recorded within 150m of the proposed site centre. The processed hydrographic data uses three depth cells. These represent flow conditions at near bed, pen bottom and near surface depth intervals. Residual currents contribute 87.1% to the near-bed mean speed, therefore residual currents are removed in the SEPA default model forcing. The hydrographic data is presented in more detail in the Modelling Data Collection Report (CAS, 2022) and is summarised below in section 3.1.

Peak biomass is simulated for the entire model duration, this is equal to 365.25 days for the benthic model. Maximum biomass is then used to calculate the feed waste and faecal matter using the values in table 3 and the equations below.

Table 3. Input feed parameters

Parameter	Symbol	Value
Feed requirement	f_r	7kg per 1000kg biomass per day
Feed water (%)	f_h	9%
Feed waste (%)	f_w	3%
Feed absorbed (%)	f_a	85%
Feed carbon (%)	f_c	49%
Faeces carbon (%)	f_f	30%

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

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

Waste carbon (w_c) is calculated as

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

Excreted solids (e_s) are calculated as

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

Excreted carbon (e_c) is calculated as

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

To ensure consistent particle dispersion characteristics within the default model, specific parameters are defined. These are outlined in Table 4. These parameters are set to the predetermined figures defined by SEPA, with the exception of the resuspension dispersion coefficient Z which uses the mean bed velocity ($\bar{u}$) to calculate the vertical resuspension coefficient.

Table 4. SEPA default model parameters.

Parameter	**Value**
tauEcritmin	0.02
Expansion T50	1
Particle release height	0
Bed roughness	0.001273
Resuspension dispersion coefficient Z	$0.0003\bar{u}^{-0.762}$
Resuspension dispersion coefficient XY	0.1
Suspension dispersion coefficient X	0.001
Suspension dispersion coefficient XY	0.1
dLayer mass	3375
Particles per area	0.0016
Density of mud	1400

The default model uses the 3 hourly outputs averaged over the last 90 days of the simulation as a risk assessment tool for the benthic environment. The EQS values and descriptions that are used to define a maximum acceptable impact are provided in Table 5. To determine potential risk to the seabed, the Infaunal Quality Index (IQI) provides a numerical value that corresponds to the health of the seabed. As NewDepomod does not model IQI directly, a relationship between sediment flux and IQI is used as a proxy for environmental impact. For the SEPA default model, this states that a solid

flux of 250g/m^2 is equivalent to an IQI of 0.64. Therefore, any deposition above the 250g/m^2 is defined as having a significant impact on the seabed. The 100m composite mixing zone is defined as the pen area plus an additional 100m buffer zone. An additional intensity standard is applied that restricts the mean concentration of the impacted area, where the permitted average is based on the sites wave exposure. The proposed Quanterness site has a wave exposure value greater than 2.8.

Table 5. Default benthic EQS parameters

Pen-edge	Intensity	Mean deposited mass within the 250 g/m^2 impact area should not exceed 2000 g/m^2 where wave exposure is less than 2.8, and 4000 g/m^2 where wave exposure is more than 2.8.
Mixing zone	Area	Total area (m^2) with a mean deposited mass in excess of 250 g/m^2 should not exceed the 100 m composite mixing zone area (m^2). If wave exposure is 2.8 or above, the mixing area may occupy 120% of the 100m mixing zone.

2.1.2 In-feed treatment

In-feed chemical compliance determines the maximum quantity of Emamectin Benzoate (EmBz) to be used on site. The chemical model settings are identical to the default benthic model, with the exception of a handful of variables that control particle consolidation and decay (table 6). Settling, erosion and dispersion parameters are defined in table 4.

For the treatment of EmBz, simulation duration is reduced to 223 days, where the EQS is recorded at 118 days. This is based on the average chemical concentration from the 48 hours leading up to the 118th day, sampled at 3-hour intervals. The model domain is consistent with that of the benthic model, providing a 2km^2 domain.

Table 6. Infeed parameter specific to chemical modelling.

Parameter	**Benthic (solids input)**	**In-feed (EmBZ input)**
Consolidation time of faeces	0	345600
Consolidation time of feed	0	345600
Degrade T50 chemical (s)	Infinity	21600000

In-feed chemical EQS values are defined using the most recent guidelines from SEPA (2022) and the UK Technical Advisory Group (2022). These values and descriptions are given in table 7. This uses the 100m mixing zone principle, with a chemical contour value of 272 ng/kg of dry sediment. This is equivalent to 0.136 µg/kg of wet sediment.

Table 7. In-feed chemical EQS parameters

Mixing zone	Area	Total area which exceeds the pertinent EQS (0.0655 µg/kg) should not exceed the 100 m mixing zone area.

3. Input data

3.1 Hydrographic data

An acoustic profiling current meter was deployed at the proposed site centre location for 103 days, from the 2nd of September 2021 to the 15th of December 2022. From this a 90-day subset was selected, spanning 02/10/2021 15:40 to 01/12/2022 15:40. Within this 90-day subset, no pitch and roll exceedances or water column errors were identified. A summary of the flow statistics over the 90-day deployment are given in Table 8.

Table 8. Hydrographic input information.

	Near Surface	Cage Bottom	Near Bed
Height from seabed (m)	10.62	8.62	1.62
Depth Cell	10	8	1
Mean Speed (m/s)	0.176	0.171	0.132
Ranked Percentage at 0.03m/s (%)	3.90	3.83	5.02
Ranked Percentage at 0.045m/s (%)	8.37	8.51	11.15
Ranked Percentage at 0.095m/s (%)	25.68	27.29	37.75
Maximum Speed (m/s)	0.476	0.471	0.387
Residual Speed (m/s)	0.160	0.155	0.115
Residual Direction (°)	149.2	150.3	146.8

Typically, the site experiences high flow speeds, with mean velocities >0.13m/s. This suggests the site is strongly dispersive, where sediment resuspension will occur on a regular basis. Peak flow speeds of 0.47m/s occur within the water column and 0.37m/s towards the seabed. Little vertical structure is observed in velocity magnitudes, indicative of shallow well-mixed sites.

Residual currents at the site centre are shown to be very strong throughout the water column. At the near bed depth layer, residual currents contribute ~87% to the overall mean velocity. As residual currents exceed 35% of the mean bed speed, they are excluded from the flowmetry data for use

within the SEPA default NewDepomod model. The direction of the residual currents is predominantly towards the south east near the bed.

The vertical (z) resuspension dispersion coefficient used in the SEPA default model is calculated based on the mean bed velocity ($\bar{u}_z$). For Quanterness the mean bed velocity is 0.132m/s.

3.2 Bathymetry and coastline

For the SEPA default NewDepomod models, a uniform bathymetry is applied based on the minimum recorded depth by the ADCP during the 90-day subset. This produces a uniform depth value of -13.43m. The model domain is shown in figure 2. A regular structured grid with a 25m resolution is used to represent bathymetry and coastlines. Coastline data is taken from the ordinance survey (Ordnance Survey, 2022).

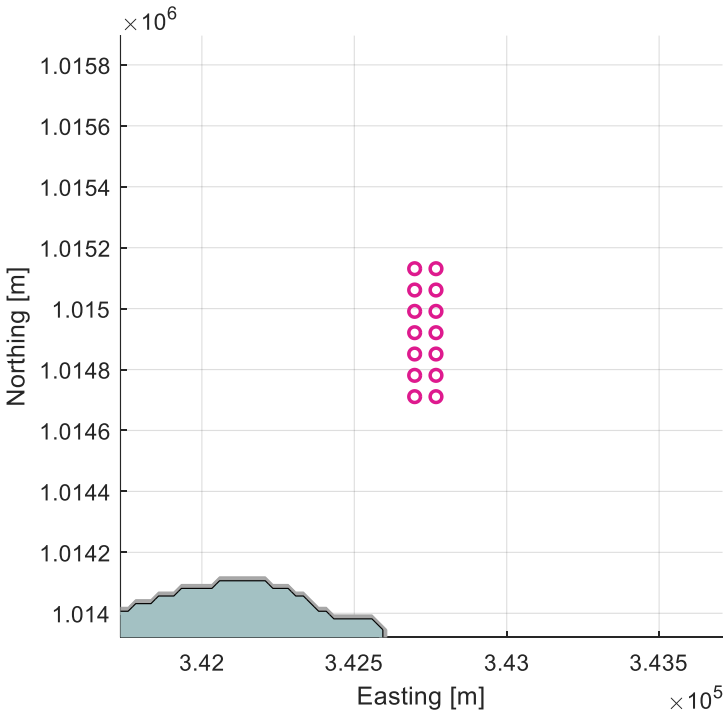

Figure 2. NewDepomod domain for the proposed Quanterness Site.

4. Results

4.1 Benthic

The SEPA default model was run to determine the maximum compliant biomass at the proposed site. Compliance was achieved with a biomass of 1925 tonnes, providing a stocking density of 14.99kg/m^3. A summary of the proposed site's environmental performance using the SEPA default model is given in table 9.

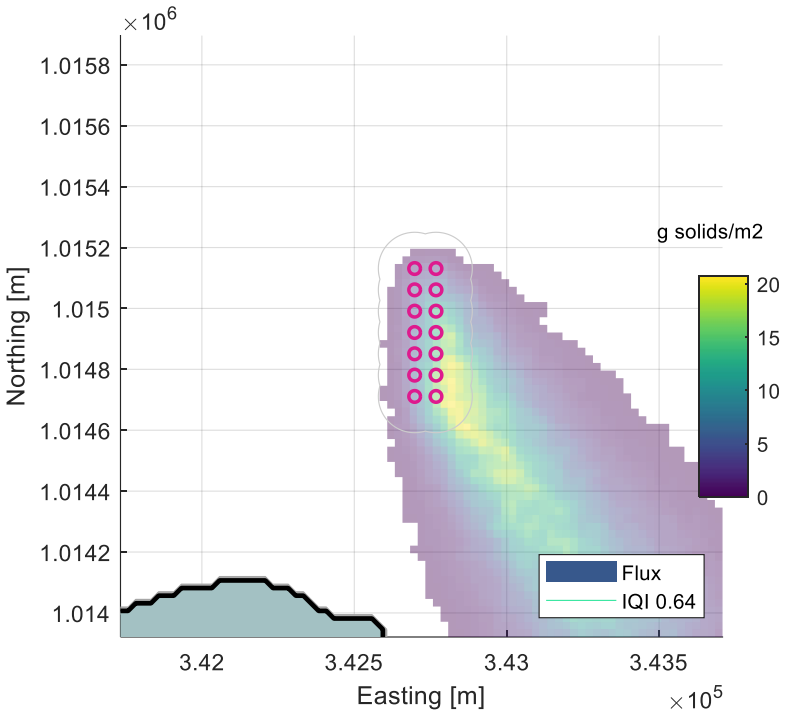

Figure 3. Modelled benthic footprint for the proposed Quanterness site (1925T) using the default model (residual currents included).

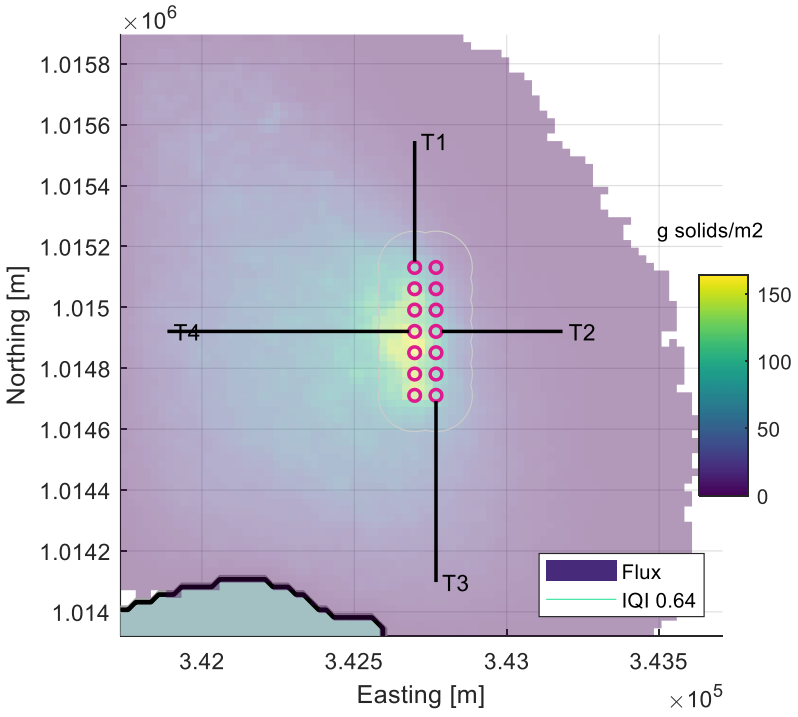

Figure 4. Modelled benthic footprint for the proposed Quanterness site (1925T) using the default model (residual currents removed). Transects locations 1-4 are also shown.

Table 9. EQS results from benthic NewDepomod model run.

Model type	SEPA default (residual currents included)	SEPA default (residual currents removed)
Residual currents	Included	Removed
Feed input	Maximum biomass	Maximum biomass
Sediment flux equivalent to IQI=0.64 (g/m^2)	250	250
Biomass (tonnes)	1,925	1,925
Stocking density (kg/m^3)	14.99	14.99
100m mixing zone (m^2)	188,957	188,957
Predicted impact area (m^2)	0	0
Area of 100m mixing (%)	0	0
Mean deposited mass ($g\ m^{-2}\ yr^{-1}$)	0	0

The average spatial coverage of the deposited solids is shown in figures 3 and 4, where the residual currents are included and removed respectively. When the residual currents are included, deposition occurs in the south easterly direction with low intensity values. Due to large sustained current velocities, organic waste is continually resuspended and dispersed over a large area. When residual currents are removed, the deposition is more centred on the site, providing increased intensity values. However, as the site still remains very dispersive, no flux values exceed 250 g/m^2, thus no impacted area occurs. As no impact occurs, the mean deposited mass value also equals 0 g/m^2. This complies with all specified benthic EQS values.

To further illustrate the variability in sediment flux with distance from the farm, four transects are extended radially outwards from the pen edges. The locations of these are shown in figure 4. All transects are arranged orthogonally to the farm. Figure 5 shows the changing deposition along these transects. As distance from the cage edge increases, flux values are shown to reduce. For T1 and T2, sediment flux values reach 0g/m^2within 400m of the pen edge, indicating a tightly constrained footprint in the north and east directions. T3 and T4 show material extending 600m and 900m, respectively towards the south and westerly direction. However, the concentrations on these transects remains low with no values exceeding the 250g/m^2 threshold, indicating that there is a very low risk for benthic impact to occur. Cage edge values from all transects remain below 170g/m^2.

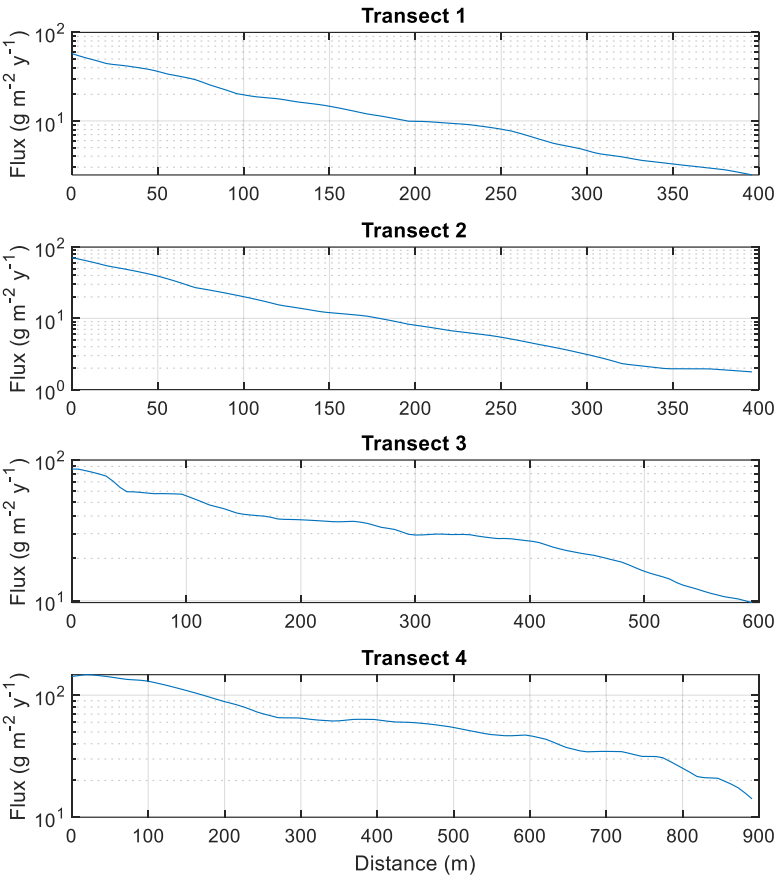

Figure 5. Transects (T1-T4) of organic solids depostion with distance from cage edge for the proposed Quanterness site using the default model.

4.2 In-feed treatment

In-feed treatments are used to control sea lice numbers in salmon farms. Slice™, active ingredient Emamectin Benzoate (EmBZ), is applied as a coating to the daily feed quota. To better understand the environmental effects of chemotherapeutants, the in-feed SEPA default model was applied, where residual currents have been removed.

The predicted chemical footprints for the proposed Quanterness site are shown in figures 6. Applying a mixing zone EQS of 0.0655 µg/kg, a maximum consented treatment quantity of 65g results in a 157,500m^2 impact area (83.4% of the 100m mixing zone). These values are presented in table 10.

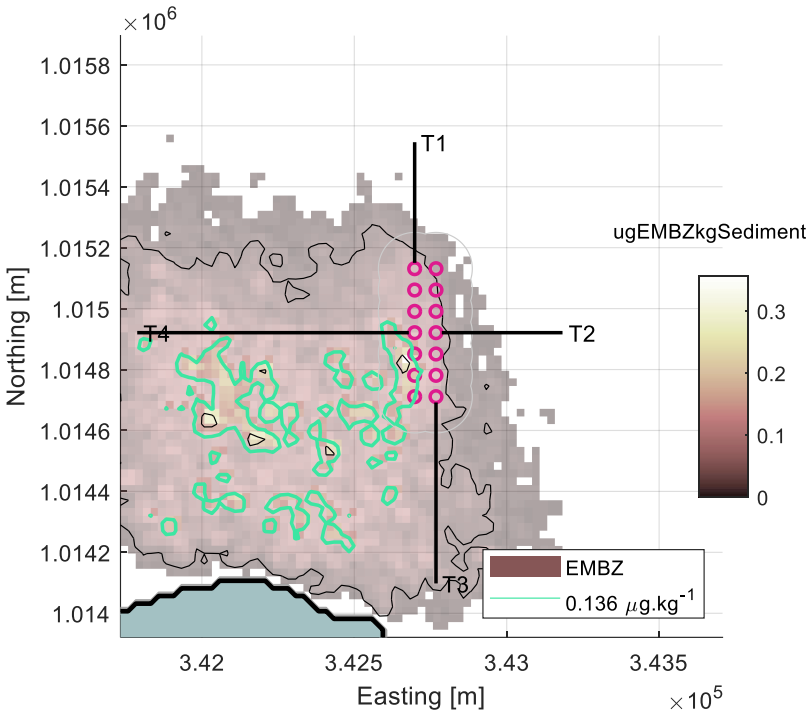

Figure 6. EmBz impact area for the proposed Quanterness site using the default NewDepomod model where residual currents are removed and an EQS of 0.136 µg/kg. Transects locations 1-4 are also shown.

Table 10. EQS results from the EmBz SEPA default model

	Proposed
Model type	SEPA default (residual currents removed)
Biomass (tonnes)	1925
Stocking density (kg/m^3)	14.99
Chemical quantity (g)	65
100m mixing zone (m^2)	188,957
Predicted impact area (m^2)	157,500
Area of 100m mixing zone (%)	83.4

The in-feed chemical footprint shows a patchy distribution of the impacted area towards the southwest of the farm. Chemical concentrations are plotted along the transects presented in figure 6. Transects 1 and 2 show very small quantities of EmBz present at the pen edge, these quickly reduce as the distances increase from the site. Transects 3 and 4 show a more variable concentration in chemical distribution, with values slightly below the EQS at the pen edge. For

Transect 3, there is a general reduction as distance increases. Transect 4 shows an increase in accumulation that exceeds 0.136 µg/kg around 70m from the pen edge, this is short lived and quickly drops to below the EQS value.

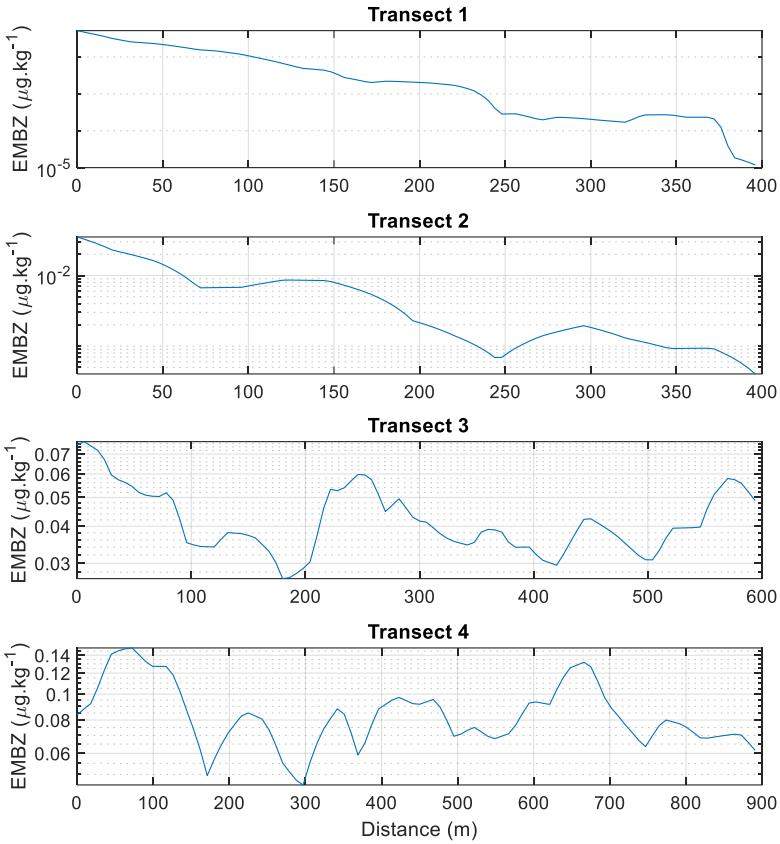

Figure 7. Transects (T1-T4) of EmBz depostion with distance from cage edge for the proposed Quanterness site using the default model.

The compliant treatable chemical mass is used to determine the maximum treatable biomass. The total amount of Slice required is calculated using the chemical quantity multiplied by 0.5. Treatable biomass is calculated by dividing the chemical quantity by 0.35. This provides a treatable biomass of 187.7 T, requiring 32.5 Kg of SLICE.

5. Conclusion

Results for the SEPA default model have been presented in this report for benthic impact and in-feed chemical treatments. The high current velocities at the site provide a very dispersive sediment transport process that leads to small quantities of organic waste and chemical accumulation around the site.

The risk-assessment (default) benthic modelling approach shows a maximum biomass of 1925 tonnes at the proposed Quanterness site, this complies with all EQS thresholds. When residual currents are removed, no flux values exceed 250g/m^2 and therefore no impacted area occurs. This is therefore equivalent to 0% of the 100m mixing area.

In-feed chemical compliance was also determined using the default model, where residual currents were subtracted from raw current data. Results from the model determined a compliant EmBz quantity of 65g, this provided an equivalent impact area of 83.42% of the 100m mixing zone. This permits a treatable biomass of 185.7 tonnes. In the event that sea lice infection requires treatment, preference will be given to mechanical non-chemical treatment options such as a thermolicer and hydrolicer treatments, alternatively bath treatments may also be used.

6. References

Ordnance Survey (2022) "Boundary-Line" Available at https://osdatahub.os.uk/downloads/open (Accessed 03/02/2022)

Scottish Environment Protection Agency (SEPA) (2019a) "Regulatory Modelling Guidance for the Aquaculture Sector" Version 1.1. Available at https://www.sepa.org.uk/media/450279/regulatory-modelling-guidance-for-the-aquaculture-sector.pdf. (Accessed on 01/08/22).

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