NewDepomod Modelling Report East Moclett

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Table of Contents

1. Summary

Cooke Aquaculture Scotland Ltd. (CAS) has undertaken biomass and in-feed chemotherapeutant modelling for the proposed East Moclett site. The pen layout uses 6, 160m circular pens, moored within 110m grids. The site was modelled using NewDepomod to determine the maximum biomass and in-feed chemical treatments. A summary of these values is shown in Table 1. Transects quantifying benthic footprints are presented, where predominant deposition occurs along transect 1 (T1) on a bearing of 350°G. As the site's hydrographic data records large proportional residual currents, the level of accuracy of the default model is uncertain. In this location, the default model is shown to either over or under predict dispersion. Therefore, the default model parameters may not be suitable for these conditions. EQS values permits a treatable biomass of 4.57 tons, when using Emamectin Benzoate.

Table 1 Summary of the recommended consent limits for the Chalmers Hope site.

Maximum Biomass	3,850t	Stocking density	15 kg/m^3
	Biomass modelling		
100m Mixing Zone Area (m^2)	153,708		
Impact area (m^2)	386,250		
Percentage of 100m mixing zone (%)	251.3		
Cage edge threshold (g m^2 yr^{-1})	779.7		
	In-Feed Treatments		
	Emamectin Benzoate		
Chemical Quantity (g)	1.5		
100m Mixing Zone Area (m^2)	153,708		
Predicted Impact area (m^2)	136,250		
Percentage of 100m mixing zone (%)	88.6		

2. Introduction

Site Details

The proposed East Moclett site is situated 2.8 km to the east of the southern end of Papa Westray in the North Sound, Orkney (Figure 1). This site is situated in relatively exposed waters with little shelter to the north.

The proposed site consists of 6 (2x3) pens with a circumference of 160m, a pen depth of 21m, and mooring grids of 110m. When stocked with a peak biomass of 3,850T, a stocking density of 15 kg/m^3 is achieved. Further information on the proposed site infrastructure and pen layout is presented in Table 2.

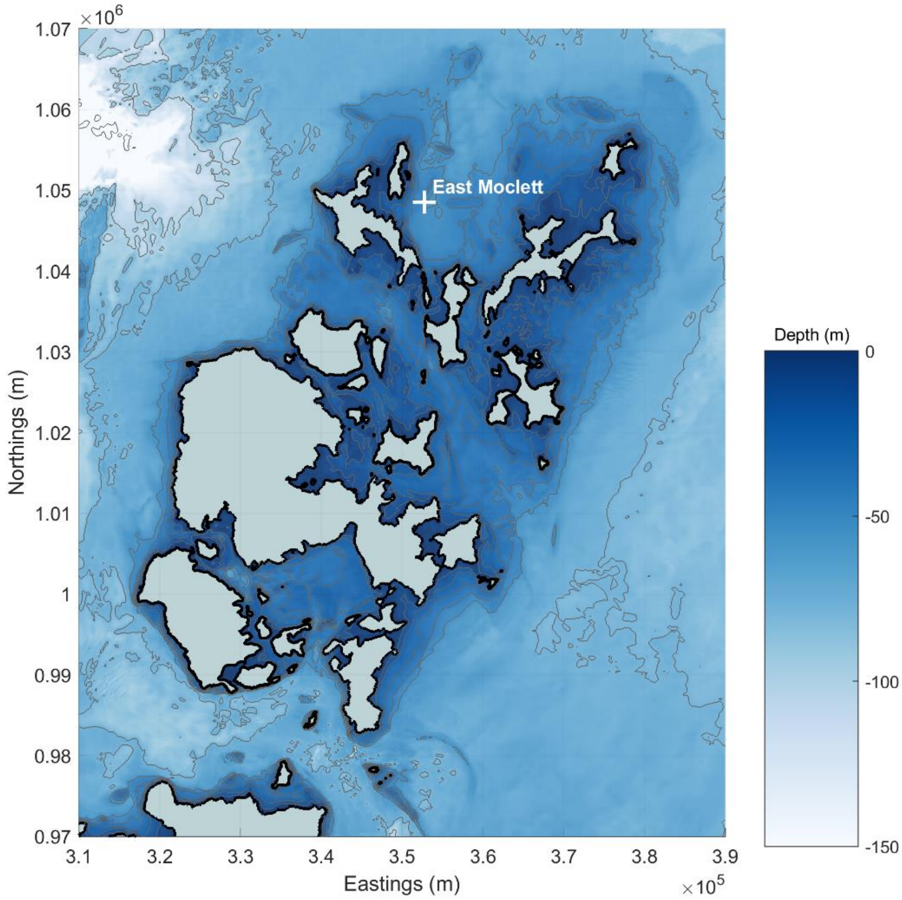


Figure 1. Site location and bathymetry with depth contours at 10 m intervals.

Table 2. Site Infrastructure and pen layout

Site name	East Moclett
Consent number	N/A
Company	Cooke Aquaculture Scotland
Receiving water	North Sound
Site center - (OSGB36)	352756.5 E, 1048514.6 N
Current meter location – OSGB36 (year of deployment)	352756.5 E, 1048514.6 N (2021)
Distance to shore (Km)	2.8
Average water depth (m)	54
Total number of pens	6
Number of pen groups	1
Formation	2 x 3
Pen group orientation (°)	0
Pen circumference (m)	160

3. 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 a similar process is used, however, specific chemical characteristics are accounted for to determine chemical concentration and accumulation.

3.1 Benthic – SEPA default model

As the proposed East Moclett site is a new site, with no existing benthic data, the SEPA default model is applied. The benthic SEPA default model is used to determine maximum biomass based on Environmental Quality Standards (EQS). These methods and NewDepomod particle dispersion parameters (see Table 5) are outlined in (SEPA 2019a) and (SEPA 2019b).

Peak biomass is simulated for the entire model duration, this is equal to 365 days for the benthic model. This value is used to calculate the feed waste and faecal matter using the following values, see Table 3.

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. This provides a small subset of controllable model parameters, and while there are other adjustable values, these are considered as the main calibration terms. These values are set to predetermined figures, with the exception of the resuspension dispersion coefficient z. This 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 z	0.001
Suspension dispersion coefficient xy	0.1

dLayer mass	3375
Particles per area	0.0016
Density of mud	1400

SEPA's default model is known to overpredicts particle dispersion in the presence of large residual currents. This can cause impacted footprints to be overly elongated and exist completely separated from the site. To account for this, a second model run is required for sites that record residual current speeds exceeding 35% of the mean bed velocity. This model uses adjusted current meter data, where the mean residual currents have been subtracted from the bed cell. This results in a less directionally weighted flow, which leads to the centralisation of benthic impacts beneath the pens.

3.1.1 Benthic EQS

The default model uses the outputs as a risk assessment tool for the benthic environment. The EQS values and descriptions are provided in Table 5. Benthic impact is determined using Infaunal Quality Index (IQI), where a relationship between sediment flux and IQI is used as a proxy for environmental impact. 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.

Table 5. Benthic EQS parameters

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

3.2 In-feed treatments – SEPA default model

In-feed chemical compliance determines the maximum quantity of Emamectin Benzoate to be used on site. The methods and NewDepomod particle dispersion parameters used for the SEPA default chemical model are outlined in (SEPA 2019a) and (SEPA 2019b). Model settings are identical to the benthic model. Input feed parameters are defined in Table 3, and dispersion parameters are defined in Table 4. For the treatment of Emamectin Benzoate, 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 hrs leading up to the 118th day, sampled at a 3hr interval.

3.2.1 Emamectin Benzoate EQS

In-feed chemical EQS values are defined using the most recent guidelines from the UK Technical Advisory Group (2019). These values and descriptions are shown in Table 6. This uses the 100m mixing zone principal, with a chemical contour value of 23.5 ng/kg of dry sediment. This is equivalent to 0.01175 µg/kg of wet sediment.

Table 6. In-feed chemical EQS parameters

In-Feed (Emamectin Benzoate)		
Mixing zone	Area	Total area which exceeds the pertinent EQS (0.01175 µg/kg) should not exceed the 100 m mixing zone area.

3. Input data

Hydrographic Data and Marine Modelling

Hydrographic data was collected from 10/09/2020 to 14/01/2021, where a 90-day subset was taken between 14/09/2020 and 13/12/2020. This is in accordance with the regulatory guidance stated in SEPA (2019a). Three depth cells are provided, this represents flow characteristics from the near surface, pen bottom and near bed layers. Flow directional data has been corrected to Grid North using a reference deviation of 04° 14' W in 2005 with an annual rate of change of 12". The hydrographic inputs are shown in Table 7 below:

Table 7. Hydrographic input information.

	Near Surface (46.62m, cell 46)	Cage Bottom (33.62m, cell 33)	Near Bed (1.62m, cell 0)
Mean Speed (m/s)	0.167	0.165	0.117
Ranked Percentage at 0.03 m/s (%)	2.2	2	4.7
Ranked Percentage at 0.045 m/s (%)	5	4.7	10.3
Ranked Percentage at 0.095 m/s (%)	22.4	22.1	40.5
Maximum Speed (m/s)	0.478	0.456	0.346
Residual Speed (m/s)	0.078	0.078	0.046
Residual direction (degrees)	306.9	305	304.4

Current velocities near the seabed of the 90-day deployment record a residual speed of 0.046 m/s, with a mean bed speed of 0.117 m/s. This provides a residual flow speed of 39.3% of the mean bed speed. As this exceeds the 35% threshold stated in SEPA's modelling guidance, the mean residual current must be subtracted from the bed cell.

The vertical (z) resuspension dispersion coefficient used in the default model is calculated based on the mean bed velocity ($\bar{u}_z$). For the raw data this is 0.00154, and 0.00163 when residual currents are removed.

UK Hydrographic Office (UKHO) (UKHO 2014) bathymetry data has been used. For the SEPA default model, a uniform bathymetry is applied based on values under the proposed farm location. This produces a uniform depth value of 54m. The model domain is shown in Figure 2. A regular structured grid with a 25m resolution is used to represent bathymetry and coastlines. As the site is located over 2km away from the nearest shoreline, no coastline is used within the model domain.

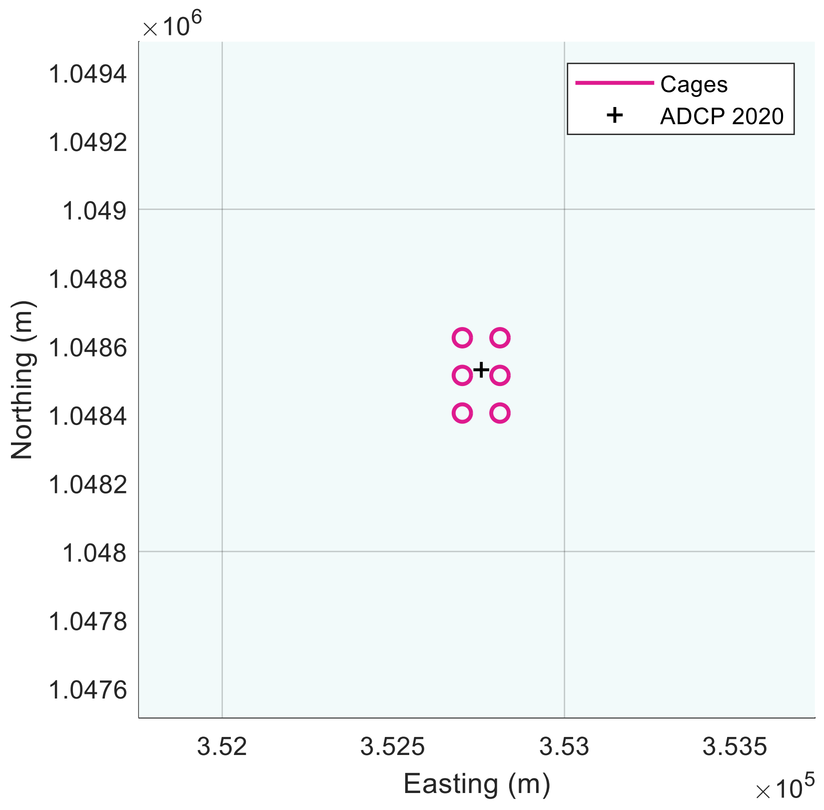


Figure 2 NewDepomod model domain. Pen layout and ADCP deployment location are shown within the domain.

4. Results

4.1 Benthic - Maximum biomass

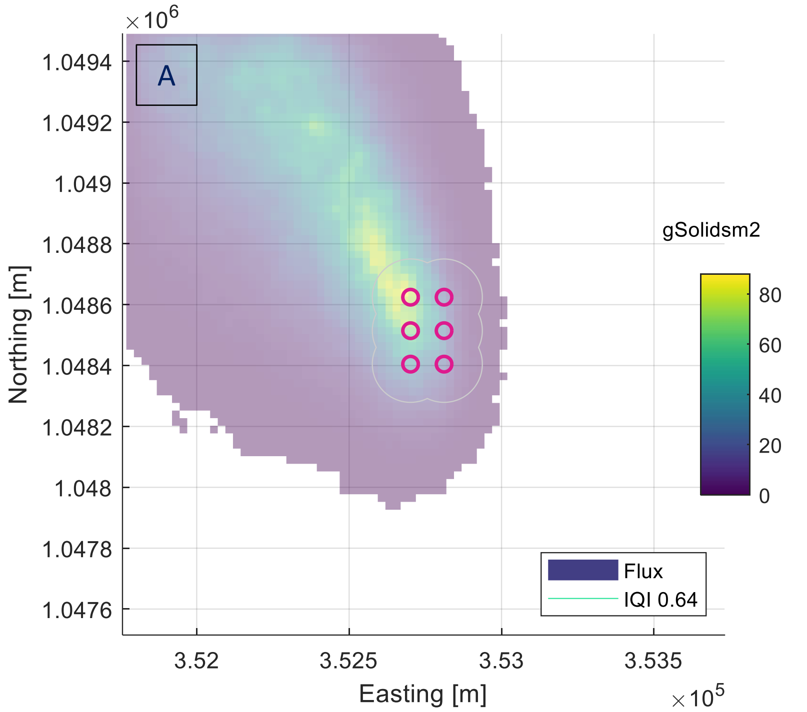
The SEPA default model was run to indicate the maximum biomass at the site. Previous modelling (see NewDepomodModellingReportEastMoclett_V1.pdf) and discussion with the modelling team at SEPA have concluded a consented biomass of 3,850T. As minor discrepancies in the default model settings were present in the initial modelling, the key model runs have been re-run with up-to-date model parameters to quantify predicted impact.

In the case of the default model, where the raw current data is used (EastMoclett001_1), benthic impact does not exceed 250g/m^2, therefore no impact is observed. When residual currents are removed (EastMoclett002_1), a large area of deposition is shown. This is equivalent to 251.3% of the 100m mixing zone area. Due to the large extent of the predicted area of impact, cage edge values are shown to be low, with a value of 779.7 g/m^2. In this case, it is believed that the model over predicts dispersion, resulting in a high compliant biomass. When the residual currents are removed the model shows an underprediction in dispersion, providing a large benthic footprint and an overly cautious approach.

The 90-day average spatial coverage of the deposited solids is shown in Figure 3 for both cases presented in table 8. This suggests the majority of sediment flux deposition is around the north-northwest of the pen group.

Table 8. EQS results from the benthic SEPA default model.

Model type	Default settings	Default settings
Residual currents	Included	Removed
Project name	EastMoclett001_1	EastMoclett002_1
Biomass (tonnes)	3,850	3,850
Stocking density (kg/m^3)	14.99	14.99
100m mixing zone (m^2)	153,708	153,708
Predicted impact area (m^2)	0	386,250
Area of 100m mixing (%)	0	251.3
Mean deposited mass (g m^{-2} yr^{-1})	0	779.7



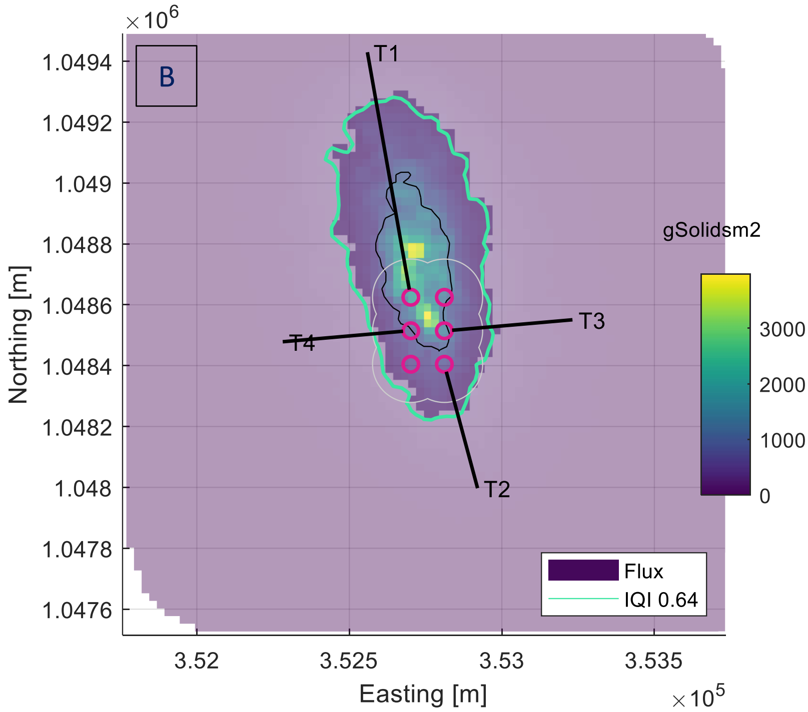


Figure 3. Solid flux distribution around the farm for cases A (Default model, inc. residual currents biomass = 3,850t) and B (Default model, residual bed currents removed, biomass = 3,850t), Transects locations 1-4 are also shown.

Four transects are taken from the pen edges and extend beyond the impact area. The location of these are shown in Figure 3 (B) with individual transect results plotted in Figure 4. Transect information is displayed in Table 9. All transects record flux values of more than

250 g/m^2. For transects 2,3, and 4 the amount of deposition quickly reduces. Transect 1 shows a higher initial flux that extends to 800m.

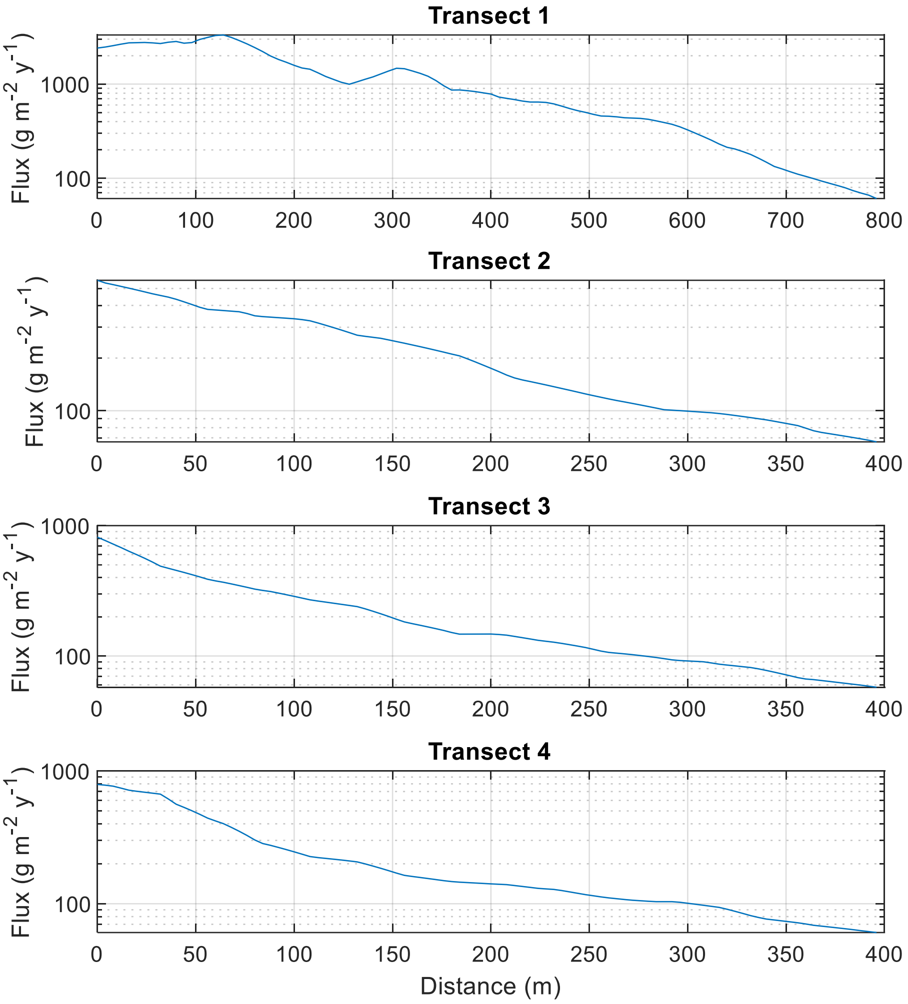


Figure 4. Transects (T1-T4) of organic solids with distance from cage edge.

Table 9. Transect information

	Origin		Length (m)	Bearing (°)	Distance of IQI 0.64 (m)
	East	North			
Transect 1 (T1)	352696.7	1048649.6	792	350	625.4
Transect 2 (T2)	352817.8	1048379.9	396	165	151.0
Transect 3 (T3)	352836.9	1048516.2	396	85	123.2
Transect 4 (T4)	352676.1	1048513.0	396	265	98.3

The adjusted model parameters used in the revised benthic modelling have produced very similar impacts to the previous modelling work. Due to the large proportion of the residual current components in the flow data, resuspension within the bed model is either over or underpredicted. Due to the dispersive and exposed nature of the site a proposed biomass of

3,850t provides a suitable compromise. This offers a precautionary biomass given the limitations of default modelling parameters, and yet is still commercially viable.

4.2 NewDepomod - In-feed treatment (SLICE)

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 reduce adverse environmental effects from chemotherapeutants, the in-feed chemical default model is applied. Peak biomass was modelled using a biomass of 3,850 t. Compliance with in-feed chemical EQS parameters was achieved with 1.5 g of EmBZ. The chemical distribution is shown in Figure 5, with EQS performance values shown in Table 10. This indicates an impact area of 88.6% of the 100m mixing zone. This passes all EQS when a treatment quantity of 1.5 g is used.

Table 10. EQS results from the EmBZ SEPA default model.

Model type	Default model - residual current speed removed
Project name	EastMoclett002_1
Biomass (tonnes)	3,850
Stocking density (kg/m^3)	15.0
Chemical quantity (g)	1.5
100m mixing zone (m^2)	153,708
Predicted impact area (m^2)	136,250
Area of 100m mixing (%)	88.6

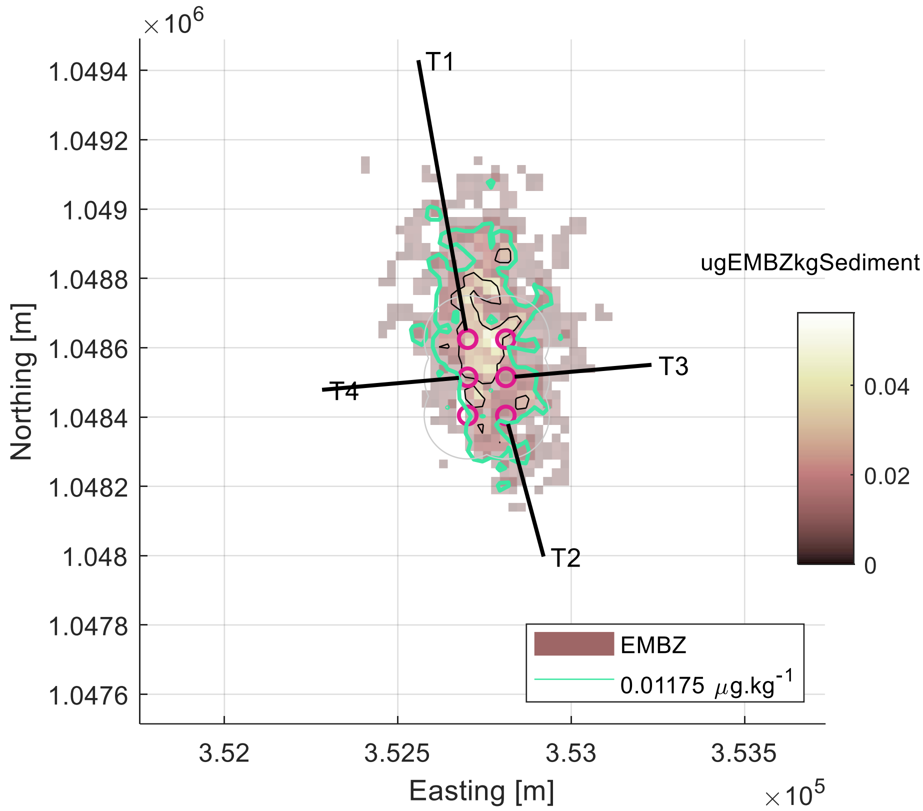


Figure 5. Chemical distribution around the farm using SEPA default modelling parameters, with EmBZ transect locations 1-4.

4.2.2 Transects

Four transects were taken from the pen edge to measure chemical quantity within the model domain (Figure 5). These indicate increased chemical concentration beneath the pens. The chemical footprint is shown to be relatively centralised, with a slight elongation towards the north.

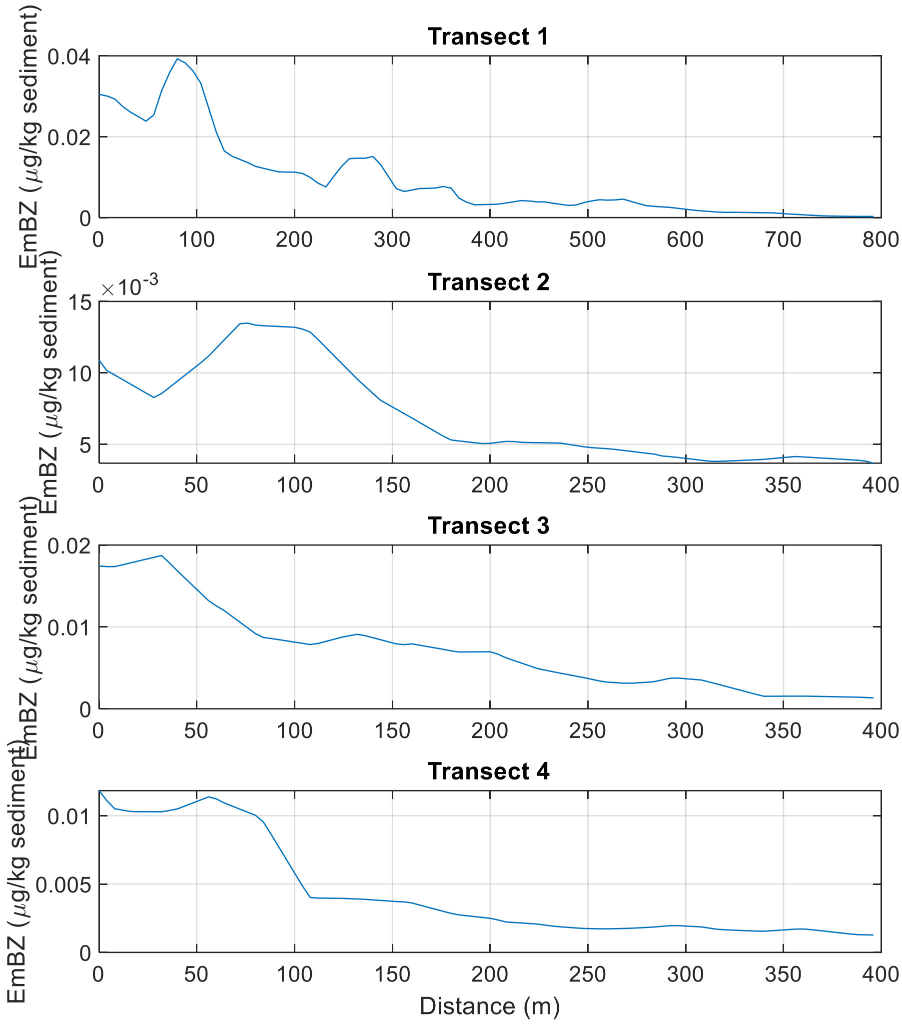


Figure 6 Transects (T1-T4) of chemical (EmBZ) concentration with distance from pen edge.

4.2.3 Treatable biomass

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 4.57 t, requiring 0.8 Kg of SLICE.

5. Conclusion

The benthic modelling highlights the dispersive nature of the proposed East Moclett site. The results of the SEPA default model show difficulties when modelling particle dispersion in regions with large mean and residual currents. This results in very dispersive condition when residual currents are included and large accumulation when residuals are removed. A compromise in biomass of 3,850T has been agreed. This results in a benthic footprint occupying 251.3% of the 100m mixing area and a mean deposited mass of 779.7g/m^2.

However, the scale of this modelled impact area is deemed unrealistic, due to the magnitude of the wave and current exposure at the site.

In-feed chemical modelling provides a total allowable quantity of 1.5 g of EmBZ. The majority of the chemical deposition is distributed beneath the north pens of the farm. A predicted impact area of 88.6% of the 100m mixing area was calculated.

The results from the benthic and chemical modelling suggest the proposed East Moclett site will result in minimal benthic impact through the deposition of solid waste with a biomass of 3,850t. In-feed chemical modelling permits very low quantities of Emamectin Benzoate to be used at the site. This consented mass is not considered an effective treatment option. In the event of infection, other treatment methods would be used, this may consider bath or non-chemical treatments such as Hydrolicer or Thermolicer.

6. References

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 11/12/19).

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UK Hydrographic Office (UKHO) (2014) “Admiralty Marine Data” Available at: https://www.gov.uk/guidance/inspire-portal-and-medin-bathymetry-data-archive-centre (Accessed 11/12/19).

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