Socio-Economic Impact Assessment of Aquaculture Development in the Falklands – Environmental Carrying Capacity Report

REPORT FOR THE FALKLANDS ISLAND GOVERNMENT

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Abbreviations and Acronyms

AC	Assimilative Capacity
ADCP	Acoustic doppler current profiler
AS	Adventure Sound
AZE	Allowable Zone of Effect
CS	Choiseul Sound
ECE	Equilibrium Concentration Enhancement
FIG	Falkland Islands Government
$g/m^2/yr$	grams per square metre per year
GS	Grantham Sound
m	Metre(s)
MEP	MacAlister Elliott and Partners
MP	Main Passage
N	Nitrogen
NEI	Nutrient Enhancement Index
NOAA	National Oceanic and Atmospheric Administration
N:P	Nitrogen-to-phosphorus
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
P	Phosphorous
RB	Ruggles Bay
SEPA	Scottish Environment Protection Agency
t	Tonne(s) (i.e., 1,000 kilograms)
UKTAG	United Kingdom Technical Advisory Group
WFD	Water Framework Directive

Preface

This report is for the purposes of demonstrating how carrying capacity is calculated using computer modelling. The initial project plan submitted by Unity Marine was used purely for demonstrating how the modelling process would be applied to a potential project and this report is not intended as a critique of Unity Marine's proposal.

Carrying capacities are dependent upon site locations and farm configuration. The modelling process can be used to identify how best to locate and space sites and pens to maximise carrying capacities. The capacities cited in this report therefore only relate to the proposed layouts and could be higher if different configurations were proposed.

This modelling has been based on the assumption of using an all-in, all-out model as recommended by MEP in the Legislative Review of Salmon Farming in the Falkland Islands report. Carrying capacity could be higher if a different approach were to be taken.

Executive Summary

Aquaculture, an increasingly important component of global food production, must balance increased fish production with environmental sustainability. In the case of the Falkland Islands, there are many pristine marine ecosystems which are sensitive to nutrient inputs and would as such require careful management should an aquaculture sector be developed (in this case, salmon farming). To protect such environments, models can be used to evaluate the potential impacts of aquaculture and ensure that developments fall within sustainable limits.

It is important to distinguish between localised (particulate solid depositional) impacts—such as those directly beneath individual farms—and broader zonal (water quality environmental) impacts, which affect water quality across the wider aquaculture zone. Both types of impacts were considered in this study using DEPOMOD and Equilibrium Concentration Enhancement (ECE) models, respectively, and must be jointly evaluated to avoid misinterpretation of carrying capacity figures.

Carrying capacity refers to the maximum level of aquaculture activity, —such as fish biomass or feed input, that a specific site or wider zone can support without causing unacceptable environmental harm. It is not a fixed number, but rather a dynamic threshold influenced by local conditions like water currents, seabed type, and farm layout, as well as broader environmental factors such as nutrient levels in the water column. In this study, carrying capacity is assessed using two complementary models: one focused on the seabed (DEPOMOD) and the other on water quality (ECE). These models help determine how much farming can occur in a given area while still protecting the surrounding ecosystem.

This report utilises the ECE model to predict the impacts of nutrients and provide guidance on sustainable levels of salmon cage production. In total, five sites of potential interest, identified in an earlier study by Unity Marine (Grantham Sound, Main Passage, Ruggles Bay, Adventure Sound and Choiseul Sound), were assessed to quantify the maximum potential biomass of a farm in each zone, as defined by regulatory limits on sustainability from Scotland. This was completed through the use of DEPOMOD screening model predictions of the deposition of particulate waste feed and faecal material arising from an individual farm location. In addition, a pre-screening modelling assessment that did not require use of models was undertaken by the following methods:

(i) following some of the advice in the Scottish Environment Protection Agency (SEPA) regulatory framework regarding characteristics looked for in large sites (>2,500 t maximum biomass); and
(ii) examining some current velocity data from existing farms in Scotland to see how they compared with currents at some of the proposed Falkland Island sites.

Together, this allowed for the determination of potential maximum biomass for a site, which was then converted into an annual production. It should be noted that individual site characteristics—such as bathymetry, cage layout, hydrodynamic dispersiveness, and the number of cages—can significantly influence the derived figures. These factors introduce variability in carrying capacity estimates and should be considered when interpreting the results. As well as determining maximum biomass for the sites, the feed ration used was also presented in the screening modelling to obtain the predictions. This aligns with international regulatory thinking (i.e., that farms could be consented on maximum or total feed use rather than a maximum limit on biomass or production). However, it should again be noted that operational practices, including feeding strategies and harvesting strategies (e.g., partial vs. full harvest), also influence nutrient outputs and model predictions. These practices are determined by individual operators and may vary across sites and over time.

Ultimately, the goal of this study is to determine a series of maximum production values which will be used to inform the wider socio-economic impact assessment currently being undertaken by Hatch and MacAlister Elliott and Partners Ltd (MEP). As such, the study emphasises the importance of using

predictive models to guide informed decision-making and in striking a balance between economic aquaculture goals and environmental stewardship in sensitive ecosystems like the Falkland Islands.

Elaborating on a previous report completed by MEP in 2021 (and updated in 2025), the predicted production volumes were considered within the context of the following development scenarios:

- **Option 1:** No salmon farming in the Falkland Islands
- **Option 2:** Commercial salmon farming takes place and is limited only by the carrying capacity of the environment
- **Option 3:** Commercial salmon farming takes place but is limited well below the carrying capacity of the environment
- **Option 4:** Commercial salmon farming is allowed but through niche methods such as 'organic production'

The assessments utilised recently measured and up-to-date bathymetry readings, as well as current velocity data from a range of sources, including useful and lengthy datasets of current velocity measured by ADCP. These findings were summarised in a report for Choiseul Sound and Grantham Sound and made available by contacts at Unity Marine. While Unity Marine contributed to earlier site identification, it is important to note that future development of the sector may involve multiple operators. Therefore, the findings of this report are not limited to a single entity and should be interpreted as sector-wide guidance.

Given the lack of Falklands-specific information and datasets, the data provided by Unity Marine represents the best available information on the zones, although processed ADCP data was not available at the time of this assessment. From the remaining three zones (Main Passage, Ruggles Bay and Adventure Sound), modelled current data reports were available. Digitised versions of current speed time series graphs were used in the assessments, as the processing of the raw ADCP data was not within the scope of this study. Despite differences in current velocity data sources between zones, a rank of dispersiveness for the different zones was arrived at and used throughout the assessments.

In the context of SEPA guidelines, Main Passage and Ruggles Bay would likely be considered dispersive sites, while Adventure Sound has current speeds indicative of a depositional area. Choiseul Bay and Grantham Sound represent areas in-between dispersive and depositional, tending towards depositional. Resultingly, a rank of dispersiveness was found as follows ((i) most and (iv) least):

(i) Main Passage = Ruggles Bay
(ii) Choiseul Sound
(iii) Grantham Sound
(iv) Adventure Sound.

The ADCP measured current reports for Choiseul Sound and Grantham Sound confirmed that there is a wind-driven current regularly observed and not just as a result of a single extreme wind event. Given the persistent winds in the Falkland Islands, this means that although these two zones are at the depositional end of the dispersive scale, they will have reliable wind driven current in addition to the tidal component.

Based on this range of dispersiveness across the zones, dispersive zones such as Main Passage and Ruggles Bay would be expected to have larger individual farms, compared to less dispersive zones such as Adventure Sound which would have smaller individual farms. The assessments confirmed a difference between the zones in terms of farm size.

The results of the ECE model also highlight varying nutrient enhancement levels across the five proposed aquaculture zones. ECE values ranged from 1.32 µg/L (moderate impact) to 4.10 µg/L (high impact), remaining within acceptable thresholds established by OSPAR and UK Technical Advisory Group (UKTAG) frameworks. Grantham Sound, Main Passage, Ruggles Bay and Adventure Sound demonstrate moderate nutrient enhancements, indicating potential for sustainable aquaculture with appropriate management. However, Choiseul Sound exhibited higher impacts, necessitating stricter controls to maintain ecological balance.

In the pre-screening modelling assessment (which did not involve any modelling), it was found that Main Passage and Ruggles Bay are zones that could support large sites (i.e., >2,500 tonnes (t) maximum biomass). Using the average consented maximum biomass of 'large sites' in Scotland as a comparative value, a figure of 3,405 t per site was calculated for these zones. At the other end of the dispersive scale, Adventure Sound is depositional, so individual farm maximum biomass is likely to be <2,500 t and perhaps about half that of a typical farm in the dispersive zones. Choiseul Bay and Grantham Sound were found to be in-between, around 2,500 t maximum biomass per farm. For this assessment and using a total of 20 sites across the Falkland Islands, two annual production figures for the whole Falkland Islands were arrived at under two types of production scenario: (A) sites with a 15-month production period followed by 3 months of fallowing – 32,200 t/yr, and (B) a longer 21 month production period followed by 3 months of fallowing – 24,100 t/yr.

The screening modelling assessment was independent of the previous assessment and undertaken by modelling the deposition footprints of the farms at a certain feed ration. The feed ration used was a three-month average of the time around peak feed input in the production models A and B. Feed ration is dependent on the maximum farm biomass in a production cycle, so in the screening model, feed input was adjusted until the screening model predictions approximately met the regulatory standards. In this assessment, model predictions were allowed to exceed regulatory standards because the resuspension modelling undertaken in the Scottish framework would reduce some of the severity and result in sites passing the assessment. Maximum biomass at an individual farm varied between 3,500 t for Main Passage and Ruggles Bay, to 1,700 t for Adventure Sound. Total annual production figures for the Falkland Islands using the screening model were therefore reported as (A) 31,200 t/yr and (B) 27,300 t/yr. A further scenario added to this assessment was to allow the dispersive zones, Main Passage and Ruggles Bay, to have individual farms that were the same as the largest site currently consented in Scotland (i.e., ~4,700 t maximum biomass per site). Accordingly, the total annual production figures for the Falkland Islands with these very large sites were (A) 35,200 t/yr and (B) 30,300 t/yr.

Based on the above findings,

- For individual farms, the maximum production values in each of the aquaculture zones are as follows
    - **Grantham Sound:** 1,100-1,460 t/year
    - **Main Passage:** 1,700-3,125 t/year
    - **Ruggles:** 1,700-3,100 t/year
    - **Adventure Sound:** 850-1,133 t/year
    - **Choiseul Sound:** 1,250-1,675 t/year
- for 20 cage farms, the maximum production values for each of the four potential development scenarios are as follows:

    - **Option 1:** nil
    - **Option 2:** 27,300-35,200 t/year
    - **Option 3:** 24,100-27,300 t/year
    - **Option 4:** 24,100 t/year

To note that the estimated sustainable carrying capacity is calculated using 2 different models with Depomod based on the level that arises from limiting particulate matter deposition below a single farm and the ECE model based on the water quality of the aquaculture zone. These two figures often differ, sometimes significantly.

The difference originates from the two different principles on which calculations are made. The particle deposition model sets a limit to production so that anoxia does not occur on the bottom which would significantly decrease benthic biodiversity. The cumulative estimated production in an aquaculture zone for Depomod is calculated by multiplying the maximum carrying capacity of a single farm by the number of farms within an aquaculture zone. There is a possibility to install more farms in an aquaculture zone if there are suitable sites available and the buffer (minimum distance) between farms is respected.

The ECE model of water quality in the water column limits cumulative production within an aquaculture zone to reduce the risk of intensive phytoplankton bloom whose subsequent decomposition would cause hypoxia in the water column and possibly cause a fish kill in the cages.

Since both limits must be observed, the smaller of the two computed values should be taken during the planning and consenting of fish farm development in the five zones. This dual-model approach underscores the importance of considering both localised benthic impacts and broader water column effects. Public understanding should reflect that carrying capacity is not a fixed number but a function of multiple, interacting environmental and operational variables.

1. Introduction

The Falkland Islands Government (FIG) is exploring the potential for commercial salmon farming in the waters surrounding the Falkland Islands, a British Overseas Territory located in the South Atlantic, approximately 300 miles from the coast of South America. To support FIG in their evaluation, Hatch and MacAlister Elliott & Partners (MEP) have been commissioned to undertake a comprehensive study focusing on the socio-economic and environmental aspects of aquaculture development.

While Unity Marine have contributed to earlier site identification, the future development of salmon farming in the Falkland Islands may involve multiple operators. This report is therefore intended to provide guidance applicable across the sector, rather than being specific to any one company.

This environmental carrying capacity report, a precursor to the ongoing Socio-Economic Impact Assessment (SEIA) being led by Hatch, aims to evaluate the potential environmental impacts of salmon farming in the Falkland Islands by exploring four development scenarios:

- **Option 1:** No salmon farming in the Falkland Islands
- **Option 2:** Commercial salmon farming takes place and is limited only by the carrying capacity of the environment
- **Option 3:** Commercial salmon farming takes place but is limited well below the carrying capacity of the environment
- **Option 4:** Commercial salmon farming is allowed but through niche methods such as 'organic production'

The approach taken uses predictive models to assess the depositional impact of salmon farms and the potential impacts on nutrient levels. Based on these findings, maximum production volumes for each of the four scenarios were determined. These values provide critical data for the SEIA which quantifies the number of possible employment opportunities that may arise as a result of sectoral development in the Falklands, based on an anticipated number of jobs per tonne of production. Together, the findings aim to support FIG's decision-making process and ensure that any future aquaculture activities fall within sustainable and environmentally responsible limits.

A significant component of this study involves modelling the environmental impact of nutrient loas using the DEPOMOD the Equilibrium Concentration Enhancement (ECE) models. DEPOMOD predicts the deposition footprint of waste feed and faeces on the seabed, assessing the severity and extent of the impact on the benthic community. It uses particle tracking and resuspension processes to simulate the accumulation and redistribution of waste particles. The ECE model estimates the impact of nutrient discharges on water quality by calculating the enhancement of dissolved nitrogen (N) levels above background concentrations. It considers factors such as the rate of nutrient discharge, the total biomass of the farms, and the flushing rate of the water body. Together, these models provide a comprehensive assessment of the environmental impacts of salmon farming. DEPOMOD helps determine the deposition footprint and benthic impacts, while the ECE model evaluates the water quality effects of nutrient discharges. By integrating these modelling efforts, the study aims to determine the maximum sustainable biomass for each site, identify critical environmental challenges and guide FIG in their decision-making process and in developing regulatory standards for the sector should developments proceed. This integrated approach ensures a thorough and informed assessment of the environmental implications of large-scale salmon farming in the Falkland Islands.

1.1. Potential impacts arising from fish cage culture

Aquaculture has become an important component of global food production, providing a significant source of animal protein. However, its environmental sustainability is contingent on the responsible management of nutrient emissions, especially in sensitive ecosystems like those of the Falkland Islands' waters. For example, significant enrichment (eutrophication) of sounds and bays as a result of nutrient-loading from salmon farms could lead to enhanced growth of phytoplankton, and undesirable disturbances to the balance of organisms and water quality.

The introduction of salmon farming to the Falkland Islands' waters would lead to increased nutrient input. Without mitigation, this could result in a greater risk of eutrophication or other undesirable change, especially when coupled with the effects of other pressures. The greatest risk lies in those waterbodies where the nutrient Assimilative Capacity (AC) of the environment becomes overloaded during peak summer temperatures. Increased (but not harmful) concentrations of ammonium (NH_4^+) and phosphate (PO_4^{3-}) can be observed within tens of metres (m) from salmon farms. Models predict, and limited observations confirm, increased nutrients in Scottish lochs where salmon farming occurs; the increase can be substantial during summer. Calculations suggest that this could also be happening in coastal waters such as the Minch. There is, however, no evidence of increased phytoplankton growth or production due to these nutrients.

The 'balance of organisms' in the phytoplankton has reportedly changed in at least one Scottish loch used for farming, but this is likely due to causes other than nutrients from salmon. In most cases, data allowing an assessment of the changes in plankton communities over time are not available. However, models suggest that organic waste from farms could add to the risk of deoxygenation in waterbodies with a poorly flushed basin water (i.e. water that is trapped behind sills).

1.1.1. Nutrient levels in marine waterbodies

As described above, fish cage culture introduces dissolved nutrients, primarily N and phosphorus (P), into marine systems. These inputs influence nutrient levels, nutrient budgets, and, potentially, the ecological balance of marine ecosystems. Farmed fish excrete dissolved N (as ammonia (NH_3) or NH_4^+) and P compounds through their gills and metabolic processes, with additional nutrient inputs from the decay of organic waste, such as uneaten feed and fish faeces. These nutrients are introduced into the water column, where they may:

(i) Stimulate phytoplankton and macroalgae growth during periods of adequate sunlight, especially in N-limited marine environments like the Falkland Islands; and
(ii) Increase local concentrations of dissolved inorganic N and P, altering nutrient balances.

However, the fate of these nutrients is influenced by several factors, including:

- **Dilution and dispersion**: Nutrients are dispersed by tidal flows, currents, and mixing processes. In regions with high water exchange rates, such as those in the Falkland Islands, nutrient concentrations may remain within acceptable limits.
- **Nitrification**: NH_4^+ released by fish is often rapidly converted to nitrate by chemo-autotrophic microorganisms. This process can reduce localised NH_4^+ concentrations but may still contribute to overall nutrient enhancement.
- **Assimilation by primary producers**: Phytoplankton and macroalgae readily assimilate available nutrients, incorporating them into the food web.

While localised increases in NH_3 may occur near fish cages, studies have shown that on a broader scale, most of the observed N is not directly traceable to fish farms but rather to secondary processes, such as the excretion of nutrients by planktonic or benthic organisms that consumed farm-related organic matter.

1.1.2. Nutrient budgets

The contribution of fish farming to the overall nutrient budget of a marine water body depends on:

- **Proportion of farm-derived nutrients**. The extent to which fish farms contribute to the total nutrient load compared to other sources, such as river inflows or oceanic inputs. For example, in other marine systems, fish farming has contributed between 2% and 35% of N inputs, depending on the intensity of farming and local hydrodynamics.

- **Retention and cycling**. Farm-derived nutrients may enter the sediment, where they can be recycled back into the water column or stored, affecting long-term nutrient availability.

In the Falkland Islands, where natural nutrient levels are low, even small contributions from fish farming could significantly alter nutrient budgets. Enhanced N levels could shift the N-to-P ratio (N:P), potentially exacerbating N limitation and favouring certain phytoplankton species.

1.1.3. Eutrophication and algal blooms

Eutrophication occurs when excessive nutrient enrichment leads to enhanced growth of phytoplankton and algae, potentially causing undesirable ecological effects. The likelihood and severity of eutrophication depend on.

- **Nutrient limitation**. In coastal marine systems, N is typically the limiting nutrient for algal growth. Anthropogenic N inputs, such as those from fish farming, can stimulate primary production, especially during the growing season when light availability is high.
- **Water exchange and flushing**. High water exchange rates reduce the residence time of nutrients, mitigating the risk of eutrophication. The Falkland Islands' marine systems likely have moderate to high flushing rates, reducing the likelihood of sustained nutrient buildup.
- **Ecological consequences**. Symptoms of eutrophication include:
    - Increased chlorophyll concentrations and algal biomass.
    - Changes in phytoplankton community composition, favouring opportunistic species over diatoms or other balanced taxa.
    - Reduced oxygen levels (hypoxia) in the water column and sediments, potentially impacting benthic organisms.

While studies have demonstrated localised nutrient enrichment near fish farms, broad-scale impacts, such as significant algal blooms or ecosystem imbalances, are less commonly observed. This is often due to the rapid dispersion and cycling of nutrients and their assimilation into the food web.

1.2. Ensuring sustainable production through modelling

As a region characterised by relatively pristine waters with low nutrient levels, the Falkland Islands are sensitive to potential nutrient inputs that would arise from the development of a salmon farming industry. However, the potential impacts of nutrient loading can be evaluated through the modelling of farm sites. Models are commonly used to guide sustainable development in the sector, and address several key areas (as evaluated in more detail in MEP's 'best practices and recommendations' report):

- **Determining cumulative carrying capacity:** Models can calculate the maximum biomass of salmon that can be sustainably farmed within a given water body. By estimating nutrient production rates and flushing capacities, this can provide regulators with information that can be used to set limits on the scale of aquaculture developments and thus ensure nutrient enhancements remain within safe thresholds.
- **Site selection**: The ECE model enables the identification of sites with high flushing rates, which are more resilient to nutrient inputs. This aids in minimising localised impacts and helps maintain ecological balance in the surrounding environment.
- **Mitigating environmental risks**: Nutrient enrichment brings risks, such as eutrophication, harmful algal blooms, and imbalances in marine ecosystems. The ECE model predicts the likelihood of these outcomes by assessing the scale of nutrient enhancement relative to natural dispersion mechanisms. For example, if the predicted ECE suggests a significant risk, mitigation measures such as adjusting feeding practices or reducing stocking densities can be implemented.
- **Compliance with regulatory standards**: Should a decision be made that allows for the development of salmon farming in the Falkland Islands, there is potential for the local government to adopt regulatory frameworks similar to those used in Scotland, where ECE values are compared

to nutrient thresholds. Ensuring compliance with these standards helps to maintain water quality and supports the long-term viability of aquaculture.

1.2.1. Understanding carrying capacity

Carrying capacity in aquaculture refers to the maximum amount of fish biomass or feed input that a marine environment can support without causing unacceptable environmental degradation. It is a critical concept for ensuring that aquaculture operations remain sustainable over the long term.

There are two main types of carrying capacity considered in this study:

- **Local (depositional) carrying capacity**: This refers to the ability of the seabed directly beneath and around a fish farm to absorb particulate organic waste (such as uneaten feed and faeces) without leading to harmful conditions like anoxia (oxygen depletion) or loss of benthic biodiversity. This is assessed using the DEPOMOD model.
- **Zonal (environmental) carrying capacity**: This refers to the broader ability of a water body (e.g., a bay or sound) to assimilate dissolved nutrients (mainly nitrogen and phosphorus) without triggering negative effects such as eutrophication or harmful algal blooms. This is assessed using the ECE model.

These two types of carrying capacity are not interchangeable. A site may be able to handle waste on the seabed but still be at risk of water quality issues, or vice versa. Therefore, both must be considered together. In practice, the lower of the two limits—either from DEPOMOD or ECE—should be used when determining the sustainable scale of a farm.

Carrying capacity is influenced by many factors, including:

- Hydrodynamics (e.g., current speed, tidal flushing)
- Farm layout and cage density
- Feeding practices and fish growth rates
- Background nutrient levels and ecological sensitivity

By modelling these factors, this study aims to provide realistic estimates of how much salmon farming can occur in each proposed zone without exceeding environmental thresholds.

1.2.2. Predicting the impact of salmon cage production

In the Falkland Islands, salmon cage production would introduce dissolved nutrients, particularly N (in the form of NH_3) into the surrounding waters. The ECE model offers a method to estimate the extent of nutrient enhancement above natural levels. The model incorporates site-specific parameters, such as:

- **Tidal dynamics**. The semi-diurnal tide prevalent in Falkland waters plays a key role in determining the flushing rate.
- **Water volume and surface area**. These parameters define the capacity of the system to dilute and disperse nutrient inputs.
- **Background nutrient levels**. Establishing baseline nutrient concentrations is critical for assessing the incremental impact of farming.

By calculating the ECE for different farming scenarios, the model can predict whether nutrient levels will exceed acceptable thresholds, such as the OSPAR and UKTAG standards, which limit nutrient increases to 50% above background values.

1.2.3. The Equilibrium Concentration Enhancement (ECE) model

The ECE model offers a powerful tool for understanding and managing the potential impact of nutrient discharges from salmon cage production. The ECE model was developed to quantify the concentration of nutrients added to a body of water as a result of fish farming activities. It is particularly effective in environments where aquaculture contributes to nutrient loading, such as nitrogenous compounds from fish excretion and feed waste.

The model works by balancing nutrient inputs against natural dispersion and losses, such as denitrification. It calculates the steady-state enhancement of nutrient levels within a marine system, and provides a practical, scientifically grounded approach to managing nutrient inputs from aquaculture. Its simplicity and reliance on measurable parameters make it accessible for regulatory and operational use. However, the model has limitations. It assumes that tidal flushing is the primary mechanism for water exchange, potentially underestimating the influence of wind and river inputs. Additionally, it does not fully account for nutrient removal processes like nitrification and sedimentation, which could reduce the actual impact of nutrient emissions.

In simpler terms, the ECE model helps predict how much nutrient levels might rise in a bay or sound due to the cumulative fish farming undertaken, and whether those increases stay within safe environmental limits.

1.2.4. Depositional models

In Scotland, the regulatory modelling framework for aquaculture includes assessments which model the deposition of waste feed and faecal material from a proposed or existing fish farm. The severity and extent of this deposition on the seabed is limited by regulatory standards to minimise benthic impact underneath the cages and within a mixing zone which extends a certain distance from the cage edge. Prior to 2019, the AutoDEPOMOD model was used in the framework, but individual site size had been increasing as the industry sought more dispersive sites. In response, a new framework was adopted, which was based on a larger validation data set, including larger sites and sites at the dispersive end of the scale. Since 2019, the NewDEPOMOD model has been used in Scotland for the purpose of screening and in detailed model assessments.

Prior to AutoDEPOMOD, the extent of the deposition footprint was limited to a fixed distance from the cages – 100 metres (m) from the cage edge. But as fish farm models were developed and validated in the late 1990s, and were being considered for the regulatory framework, a better method for the deposition extent was developed, which used an ‘equivalent area’ method. This meant that instead of distance being fixed, the area of depositional footprint became the focus, allowing footprints to be extended >100 m at sites where current in a particular direction was strong. The area of this footprint, however, was limited to being less than the equivalent area of 100 m around the cage groups (i.e., in basic terms, a 100 m boundary was drawn around the cage groups, the area inside this boundary calculated, and the extent of the footprint of the proposed site had to be less than this). In NewDEPOMOD, this ‘100 m mixing zone’ is defined by the predicted solids deposition of 250 grams of waste feed and faeces per square metres of seabed per year (250 g/m^2/yr). The term for this mixing zone is the Allowable Zone of Effect (AZE).

Within this mixing zone, there has to be some limit on the severity of the deposition footprint, otherwise at depositional sites in particular there would be high levels of deposition resulting in severe impact underneath the cages, possibly leading to reduced fish health. The severity underneath cages is therefore limited in the Scottish regulatory framework by calculating the average solids deposition of the footprint out as far as the 250 g/m^2/yr contour. A further regulatory standard is applied here to limit severity – 2,000 g/m^2/yr for the majority of sites with a value of 4,000 g/m^2/yr being used for sites exposed to waves. In this Falkland Islands study, the lower 2,000 g/m^2/yr for low to average wave exposure was used, as high wave exposure sites have already been filtered out in the revised proposal. This aspect is discussed later.

Ultimately, DEPOMOD helps estimate how much waste will settle on the seabed beneath an individual farm and whether it could harm the marine life living there.

1.2.5. Screening models

Screening modelling assessments were introduced into the regulatory framework in Scotland in 2019 to allow initial assessment of the potential size of a fish farm site. Although these assessments are not as extensive as the detailed modelling assessments, the screening assessments do provide useful information regarding potential maximum farm biomass. These assessments use site-specific data, both observed (e.g. current velocity and depth) and proposed (e.g. cage layouts and feed input). The expectation of these screening assessments is thus that dispersive sites (i.e., caused by high current speed and/or depth) will be larger than sites in depositional areas where current speeds are low.

Prior to any modelling of a site, a simple assessment using current speed and depth can provide a reasonable first estimate of the potential scale of a site. For example, the SEPA regulatory guidelines offer some guidance on characteristics of large sites relative to current velocity. In Scotland as a ballpark figure, 'large sites' are loosely defined as sites >2,500 t maximum biomass, with the largest consented site in Scotland currently set at 4,680 t. For a while in Scotland, salmon sites were limited to 2500 t maximum biomass, but since the regulatory modelling framework was overhauled and improved, sites are now larger than this. The Scottish data shows 15 sites >2,500 t maximum standing biomass, 33 sites at 2,500 t, and 399 sites <2,500 t. These are standing maximum biomass figures that require a conversion factor to get to an annual production figure, which is dependent on the length of production cycle plus the fallow period.

1.3. Approach taken in this study

In this study, the objectives are to undertake assessments of one proposed site per zone in the Falkland Islands and provide maximum biomass and annual production figures for each zone based on the number of sites proposed per zone. Reasonable confidence in these findings is expected because:

(i) detailed modelled current velocity data undertaken to a high standard were available for each zone,
(ii) observed current velocity data summaries were available for two of the zones,
(iii) the observed and modelled current show significant differences between the zones in terms of dispersiveness – this is helpful because it means the assessments are also tested for dispersive sites as well as depositional sites,
(iv) an established model (DEPOMOD) was used, with SEPA regulatory modelling framework established default model parameters and regulatory standards that were limiting,
(v) the SEPA regulatory framework was overhauled in 2019 (therefore reasonably up-to-date) and currently reflects the trend in the salmon farming industry for larger and more dispersive individual sites, and
(vi) the pre-modelling assessment and screening model predictions of maximum sustainable biomass were in broad agreement.

Pre-screening model assessments were undertaken for each selected site in each of the five proposed zones of Main Passage, Ruggles Bay, Choiseul Sound, Grantham Sound and Adventure Sound. Current speed, bathymetry, guidance from SEPA regulatory modelling framework and published data on consented maximum biomass for Scottish salmon marine fish farms. This assessment resulted in ballpark figures for maximum individual farm biomass. Pre-screening modelling was then undertaken using more detailed information on current velocity and bathymetry, and information on proposed cage layouts and production data. Screening model predictions of maximum individual farm biomass were also obtained.

As the proposal presented annual production figures for a typical farm, each proposed zone and for the Falkland Islands as a whole, the maximum biomass calculated in the assessments for each farm were converted to annual production using both (A) a proposed production cycle of 15 months + 3 months fallow and (B) a longer cycle of 21 months production + 3 months fallow.

In addition to environmental factors, operational practices such as feeding regimes, stocking densities, and harvesting strategies (e.g., partial vs. full harvest) can also influence nutrient outputs and model predictions. These practices are determined by individual operators and may vary across sites, further contributing to variability in environmental impact.

Pre-screening and screening model assessments were undertaken using regulatory standards aligned with Scenario 2, as previously described. Scenario 3 represented a more conservative 'Gold' standard, while Scenario 4 reflected only 'organic farming' practices.

In both of these types of assessments, the site analysed in the assessment was assumed to be typical of the zone itself, so that production for the zone could be calculated depending on the number of sites proposed for that zone (i.e., it was assumed all sites in the same zone would have the same maximum biomass and hence annual production). However, it is important to note that individual farm sites within the same zone may differ in terms of bathymetry, current speed, and cage layout. These differences can influence the actual carrying capacity and environmental impact of each site. While this variability is not captured at the screening stage, it would be addressed in more detailed site-specific assessments during future planning phases.

In reality, proposed farms within the same zone would be expected to have different bathymetry and hydrography and so in detailed assessments would have slightly different maximum biomass. However, assuming all farms in the same zone have the same maximum biomass is not considered to be a limitation at the screening stage.

2. Methodology

This section explains how scientific models have been used to estimate the environmental impact of salmon farming in the Falkland Islands. Two main models were used:

- **Pre-modelling assessment** (Screening). A preliminary, non-modelling method that evaluated site suitability by comparing current speeds and depths at proposed sites with those at established salmon farms in Scotland, based on Scottish regulatory guidelines. This provided a rough, comparative estimate of potential site capacity.
- The **DEPOMOD model**, which predicts how much solid waste (like uneaten feed and fish faeces) would settle on the seabed.
- The **ECE model**, which estimates how much nitrogen (a key nutrient) would build up in the water from fish farming.

These models help in understanding how much farming each area can support without harming the environment—this is known as the carrying capacity.

2.1. ECE Model

2.1.1. Data requirements

For this modelling approach, there are a number of key data requirements, as follows:

1. **Physical characteristics of the marine system**

- Volume of the water body (V): The total volume of the marine system (e.g., bay, sound) in cubic m (m^3), which can be calculated using bathymetric data that provides depth and area measurements.
- Surface area (A): The area of the marine system in square m (m^2), crucial for estimating tidal exchange.
- Tidal range (R): The average spring tidal range in m (m), which determines the volume of water exchanged per tidal cycle (tidal prism).

2. **Tidal exchange parameters**

- Flushing time (T_F): The time it takes for the water body to exchange its volume, typically calculated using the tidal prism method.
- Flushing Rate (Q): The annual volume of water exchanged in the system (m^3/yr)

3. **Nutrient loading**

- Nutrient output per unit biomass (S): The amount of dissolved nutrients (e.g., in kg N/year) produced by each ton of farmed biomass. This depends on.

  - Feed composition. Nutrient content of feed and feed conversion ratio.
  - Fish size and age. Older, larger fish excrete more nutrients.
  - Temperature and metabolism. Higher temperatures may increase metabolic waste.

- Total biomass (M): The total fish biomass (in tonnes) in the farming operation.

4. **Background nutrient levels**

- Baseline concentrations of nutrients (e.g., N) in the water column, typically derived from historical monitoring data or site-specific studies.

2.1.2. Calculating the ECE index

The methodology for calculating nutrient enhancement in the five aquaculture zones followed the approach developed by Marine Scotland Science in their Locational Guidelines. The key focus was to quantify the enhancement of dissolved N levels, primarily NH_3, resulting from salmon farming.

Farmed salmon excrete N as a metabolic by-product, primarily in the form of NH_3, into the surrounding water column. The quantity of N released varies depending on factors such as feed composition, fish age, size, and water temperature. Older and larger fish excrete greater quantities of N, while warmer water temperatures can accelerate metabolic processes, further increasing nutrient output. The total emissions of NH_3 from a farming operation are directly proportional to the biomass of fish being farmed and the specific stage of their production cycle.

To estimate the effects of these nutrient emissions on the marine ecosystem, the ECE box model was used—a tool that calculates how much nitrogen builds up in the water compared to natural levels. This model predicts the increase in dissolved N concentrations above natural background levels, accounting for the production rate of nutrients, water volume, and flushing characteristics of the aquaculture zones. The ECE model provides a quantitative framework for assessing the local and broad-scale impacts of nutrient emissions on water quality.

2.1.3. Estimating the area and volume of sounds in the Falklands

The physical dimensions of the aquaculture zones, including their surface area and volume, were calculated using a combination of high-resolution bathymetric data and geographic mapping tools. Accurate estimation of these parameters is critical for applying the ECE model and understanding the dilution and dispersion potential of each zone.

Bathymetric data were sourced from the i-Boating app, which integrates official hydrographic charts from sources such as NOAA (United States), UKHO (United Kingdom and Ireland), and CHS (Canada). These charts provided reliable and up-to-date marine navigation data. The nautical charts were imported into Google Earth, where the coastlines of the aquaculture zones were mapped with precision. Using the polygon tool in Google Earth, bathymetric contour lines were drawn at 10 m intervals, and the area of each contour was calculated in km^2.

Figure 1: High water tidal predictions for the Falkland Islands

To estimate the volume of each aquaculture zone, the area of each contour zone was multiplied by its average depth. For example, the area between the 20-30 m contours was assigned an average depth of 25 m. The total volume of the zone was then calculated by summing the volumes of all contour zones. This provided the necessary data to determine the flushing capacity and nutrient dispersion characteristics of each aquaculture zone. Following the provision of measured bathymetry by Unity Marine, the average depths were adjusted for the actual bathymetry. High tide was also estimated using the tidal predictions using high water full and change calculations and then plotted into Google Earth.

2.1.4. Predicted ECE for maximum biomass

The proposed production levels for each aquaculture zone were evaluated using the ECE model to estimate the nutrient enhancement resulting from the maximum allowable biomass. The model incorporated key parameters, including the daily nutrient production rates of farmed fish, the volume of the water body, and its flushing characteristics. Flushing time, which represents the rate at which nutrients are exchanged and dispersed, was a critical input for these calculations.

2.1.5. Formulae used

1. **Calculating the ECE**

$$ECE = \frac{S \times M}{Q}$$

Where:

- ***S*** represents the nutrient output per biomass unit
- ***M*** is the total biomass of farmed fish
- ***Q*** is the flushing rate of the system, quantified through the following two equations:

$$Q = \frac{365 \times V}{TF}$$

Where:

TF is the time (no. days) it takes for the water body to exchange its volume i, typically calculated using the tidal prism method (below):

$$TF = \frac{0.52 \times V}{0.7 \times A \times R}$$

Where:

- ***V*** is the volume of the marine system basin (m^3) – can be calculated using bathymetric data that provides depth and area measurements
- ***A*** is the surface area of the marine system (m^2) – crucial for estimating tidal exchange
- ***R*** is the spring tidal range (m) – determines the volume of water exchanged per tidal cycle (tidal prism)

The factor 0.52 is the number of days per tidal cycle (1 tidal cycle = 12.4 hours = 0.52 days), and the factor 0.7 approximates the mean tidal range from the spring tidal range (see Gillibrand *et al*, 2002).

The flushing rate, which is critical to determining how quickly a water body exchanges its volume, is influenced by tidal dynamics, water volume, and the tidal range.

2. **Determining nutrient loading**

To obtain the nutrient output per biomass (***S***), data on feed, fish excretion rates, and environmental factors is required. Once values are known, ***S*** can be multiplied by the total biomass (***M***) of fish in the system to calculate total nutrient emissions. The total nutrient load is therefore defined as:

$$Total\ nutrient\ load = S\ x\ M$$

The ECE result is then converted into a concentration (e.g., micrograms/litre) for easier comparison with background levels and regulatory thresholds.

3. **Evaluating against thresholds**

Scotland has developed the Nutrient Enhancement Index (NEI) to assess and classify the potential nutrient impact of fish farms on water bodies. This tool provides a systematic way to evaluate nutrient enhancement and its ecological consequences. The NEI quantifies nutrient enhancement as a result of fish farming activities. It considers the volume of the water body, nutrient inputs from farms, and flushing rates. The index is categorised into classes, with higher values indicating greater nutrient enrichment. For example:

- **NEI = 1**. Low nutrient enhancement (e.g., <0.3 µmol N/L increase).
- **NEI = 2**. Moderate enhancement (e.g., 0.3–1 µmol N/L).
- **NEI = 3 or 4**. High nutrient enhancement (>1 µmol N/L), requiring regulatory intervention.

In the context of regulation (for Scotland), the NEI is applied in conjunction with models like the ECE to predict nutrient levels under different production scenarios. Farms with NEI values exceeding thresholds must implement mitigation measures, such as reducing stocking density or improving feed efficiency.

The ECE model predicted the concentration of nitrogenous nutrients in the water column under proposed farming conditions. These predictions were then classified using the NEI, which categorises nutrient enhancement into levels based on its potential environmental impact. For instance, low enhancement corresponds to minimal increases in nutrient levels (e.g., <0.3 µmol N/L), moderate enhancement represents modest increases (e.g., 0.3–1 µmol N/L), and high enhancement signifies significant nutrient enrichment. NEI classifications provide a clear framework for assessing the sustainability of aquaculture operations and identifying zones where nutrient impacts may require mitigation.

Table 1: Index of nutrient enhancement.

Predicted ECE for nitrogenous nutrients arising from finfish farming (µmol l^{-1})	Nutrient enhancement index	Impact enhancement category
> 10	5	Very high
3 – 10	4	High
1 – 3	3	Moderate
0.3 – 1	2	Low
<0.3	1	Minimal
0	0	None

The NEI helps classify how much nutrient enrichment is expected from fish farming. This makes it easier to understand whether a site is likely to have minimal, moderate, or high environmental impact—and whether action is needed to reduce that impact.

Other threshold standards

Three key frameworks guiding nutrient management are the OSPAR Commission, the UKTAG on the Water Framework Directive (WFD) and the NEI in Scotland.

These organisations provide thresholds for nutrient enrichment, ensuring that human activities such as aquaculture remain within sustainable limits. These thresholds are important because they help governments and regulators decide how much fish farming can happen in a given area without damaging the environment. If nutrient levels go above these thresholds, it could lead to problems like algal blooms or low oxygen levels in the water.

Explored below are the thresholds established by OSPAR and UKTAG, their scientific basis, and their application to sustainable aquaculture practices, particularly in the Falkland Islands.

The OSPAR Commission Framework

The OSPAR Commission is an international agreement aimed at protecting the marine environment of the North-East Atlantic. Its eutrophication strategy is a cornerstone for regulating nutrient pollution, especially in sensitive coastal and marine ecosystems.

OSPAR employs the Common Procedure for Eutrophication Assessment, which evaluates water bodies based on nutrient levels, primary production (such as phytoplankton biomass), and oxygen depletion. The framework's goal is to identify whether a water body is eutrophic and to implement measures to prevent or mitigate nutrient enrichment.

A defining aspect of the OSPAR guidelines is the 50% threshold rule, which states that nutrient concentrations in a water body should not exceed 50% above natural background levels. This threshold ensures that nutrient enhancements from anthropogenic sources, such as agriculture or aquaculture, do not push ecosystems beyond their capacity to absorb and process these inputs sustainably. For marine systems, N is often the primary focus because it is the limiting nutrient for algal growth in coastal environments. By limiting N enrichment, the OSPAR guidelines help prevent harmful algal blooms, oxygen depletion, and disruptions to marine biodiversity.

The UKTAG and WFD

The UKTAG operates as a technical advisory body, providing scientific guidance for implementing the European Union's WFD. The WFD seeks to achieve "good ecological status" for all water bodies, with specific nutrient thresholds forming a key part of its framework.

Similar to OSPAR, the UKTAG applies the 50% increase rule, setting nutrient concentration thresholds relative to background levels. These thresholds are adjusted for the ecological sensitivity and natural characteristics of each water body. Exceeding these limits can downgrade the ecological status of a water body, signalling the need for remedial action to restore water quality.

The UKTAG framework also classifies water bodies into categories such as "high," "good," "moderate," "poor," and "bad" ecological status. This classification provides a clear benchmark for assessing water quality and ensures that nutrient management aligns with ecological health goals. In marine environments, N thresholds are prioritized due to its critical role in controlling primary productivity, whereas P thresholds are more relevant in freshwater systems.

2.2. Depositional modelling

Depositional modelling is used to estimate how much particulate solid waste—such as uneaten feed and fish faeces—settles on the seabed beneath fish farms. This helps determine whether a site can support salmon farming without harming the marine environment. In this study, a simplified version of the DEPOMOD model was used to predict the extent and severity of seabed impacts at proposed farm sites in the Falkland Islands.

2.2.1. Pre-screening model assessment

In the ADCP current velocity data report for Choiseul Sound and Grantham Sound (DHI, 2020), several Scottish fish farms are mentioned in the discussion. Current speeds measured at the Scottish sites were compared with the measurements at these two zones. Publicly available information on the maximum consented biomass for these Scottish sites was compiled (Scotland Aquaculture, 2025), including information on current speed and maximum consented biomass together.

Another component of this assessment was to examine regulatory guidance in the screening model guidance note published by SEPA (SEPA, 2019, 2024b). This gave specific recommendations on average current speeds and near-bed current speeds expected to be measured at large fish farm sites (>2,500 t maximum biomass). This guidance note allows users of the screening model to consider whether the measured current velocity data they have measured at the site under examination, is indicative of a dispersive site and may therefore support large sites.

It was also noted that the proposed zones in the Falkland Islands have quite different average current velocity, representing dispersive to depositional. In turn, this means the average maximum biomass at a dispersive site would be expected to be quite a bit higher than a depositional site.

This pre-screening step helps identify whether a site is likely to be suitable for large-scale farming based on current speeds and comparisons with similar sites in Scotland.

2.2.2. Screening model assessment

Screening modelling provides a more detailed estimate of how much fish biomass a site can support, based on predicted waste deposition and regulatory thresholds.

Each of the five proposed aquaculture zones was assessed using model predictions of the deposition of particulate waste feed and faecal material arising from an individual farm location. In the model for each site, a three-month average around the highest feed input was used to predict severity and extent of the deposition ‘footprint’ on the seabed underneath and in the near vicinity of the farm. This highest feed input month and the 2 or 3 months preceding it, is usually around the time of highest seawater temperatures (late summer/early autumn).

Some standard regulatory limits that are used in the model NewDEPOMOD, which is part of the Scottish Environment Protection Agency (SEPA) regulatory modelling framework, assisted in determining estimates of maximum sustainable biomass for the proposed sites. Whilst NewDEPOMOD was not used, a variant of the original DEPOMOD model was used and directly compared predictions of ‘severity’ and ‘extent’ of the deposition footprint against SEPA regulatory standards. For this approach, the term ‘screening modelling’ was adopted, as this is undertaken in the SEPA regulatory framework to indicate at an early stage in the process what level of sustainable production might be attainable for a site. The SEPA standards for sites that are not in high wave exposed areas were used because the proposed sites had already been assessed in the proposal for wave exposure and the wave exposed sites had not been included in the map of proposed sites.

It is important to note that in particulate modelling, maximum standing biomass is usually reported (in tonnes). This is the maximum biomass that could be held at any one time on the farm in the production cycle. In much of the background information and studies undertaken to date on the potential for the aquaculture industry in the Falkland Islands, 'production' or 'annual production' figures (t/yr) are quoted. The maximum biomass for one site was converted to two different production cycles. Production cycle A was 15 months production + 3 months fallow. Production cycle B was 21 months + 3 months fallow. Annual production figures for one site were multiplied by the number of proposed sites for that zone to determine estimated zone annual production (t/yr).

A proposed site location from each zone was set up in DEPOMOD using measured depth, admiralty charts and proposed cage layouts of 2 by 5 cages (50 m cage diameter with 19 m net depth; 50 m spacing between each cage).

Main Passage, Ruggles Bay and Adventure Sound modelled current were used from data in DHI (2019). Modelled current for Choiseul Sound and Grantham Sound were also used and then improved by calibrating with measurements of average current speeds at different depths (DHI, 2020). This meant that a higher confidence was obtained in the predictions for Choiseul Sound and Grantham Sound because measured current information was available from the survey report.

An adjustment was also made by decreasing current speed with depth using measured average current speeds with depth if available.

In DEPOMOD, standard model parameters for salmon used in the SEPA regulatory framework were used (i.e., salmon feed (9.5 cm/s) and faecal (3.2 cm/s) particle settling rates, 85% pellet digestibility, 9% water content). The project proposal specifies uneaten feed wastage as 1.5 %; the regulatory modelling framework uses 3 % wasted feed. In the DEPOMOD modelling a figure of 2 % uneaten feed was used.

DEPOMOD was then run with the resuspension model switched off for a particular biomass in all 10 cages to see if SEPA regulatory severity and extent thresholds were exceeded. Some minor adjustments were then made to biomass and the model was adjusted to find the highest biomass that still met environmental standards. As this was a screening exercise, detailed modelling was not required at this stage (though some 'what if' scenarios are explored in Appendix B).

Approximate predictions of maximum sustainable biomass/production have been provided for each zone according to the following: (i) Scenario 2 where limits were determined using regulatory standards (production cycles A and B), (ii) Scenario 3 where limits were 'well under' or a 'gold' standard and (iii) Scenario 4 – organic production (approx. 10 kg/m^3 stocking density).

An additional scenario was undertaken within scenario 2, where the dispersive sites Main Passage and Ruggles Bay were given a maximum biomass of the largest site in Scotland, approximately 4700 tonnes.

No salmon farms exist in the Falkland Islands to validate model predictions against site-specific monitoring data, so due to this uncertainty predictions of maximum sustainable biomass and annual production were not presented to a precise degree.

2.2.3. Gold standard and organic farming scenarios

In practice, it would not be necessary to rerun screening model runs with stricter regulatory limits to obtain annual production figures for the Gold standard (Scenario 3). This is because Scenario 3 would most likely lie between Scenario 2 (regulatory) and Scenario 4 (organic). Similarly, for Scenario 4, it is not necessary to rerun the screening model because stocking densities could be examined from the Scenario 2 runs to determine if the organic stocking density of 10 kg/m^3 had been exceeded. Using the Scenario 2 results for maximum biomass per farm, if stocking densities exceeded 10 kg/m^3, then biomass can be scaled down and annual production figures recalculated to obtain results for Scenario 4. Thus, Scenario 3 production figures were between these two.

Table 2: Scenarios used to determine annual production figures for the Falkland Islands.

Scenario	Limit	Approach taken	Production cycle
2.1A	Regulatory	Pre-screening model assessment	A
2.1B	Regulatory	Pre-screening model assessment	B
2.2A	Regulatory	Screening model	A
2.2B	Regulatory	Screening model	B
2.3A	Regulatory	Screening model + dispersive sites go to max. biomass	A
2.3B	Regulatory	Screening model + dispersive sites go to max. biomass	B
3	'Gold'	'Gold' standard or 'well under' – stricter regulatory limits	Detail not modelled
4	Organic	Organic	Detail not modelled

Note: A – 15 months production + 3 months fallow, B – 21 months + 3 months fallow.

In other words, because Scenario 3 (Gold standard) and Scenario 4 (Organic) are more conservative than Scenario 2, it was not necessary to re-run the models. Instead, results from Scenario 2 were adjusted to reflect lower stocking densities or stricter environmental limits.

3. Predicting the impact of salmon production on dissolved nutrient levels and estimating sustainable cumulative production using the ECE model

3.1. Grantham Sound

The coastal contour was drawn, and the area was calculated for Grantham Sound, in addition to the bathymetry contour lines and the volume (Figure 2 and Table 3). The total water surface area of the proposed aquaculture area in Grantham Sound is 589 km^2, with a volume of 16,209,200,000 m^3. The model parameters of the ECE are presented in Table 4, finding the calculated cumulative sustainable carrying capacity within the NEI low threshold, at a maximum of 36,500 t of standing biomass.

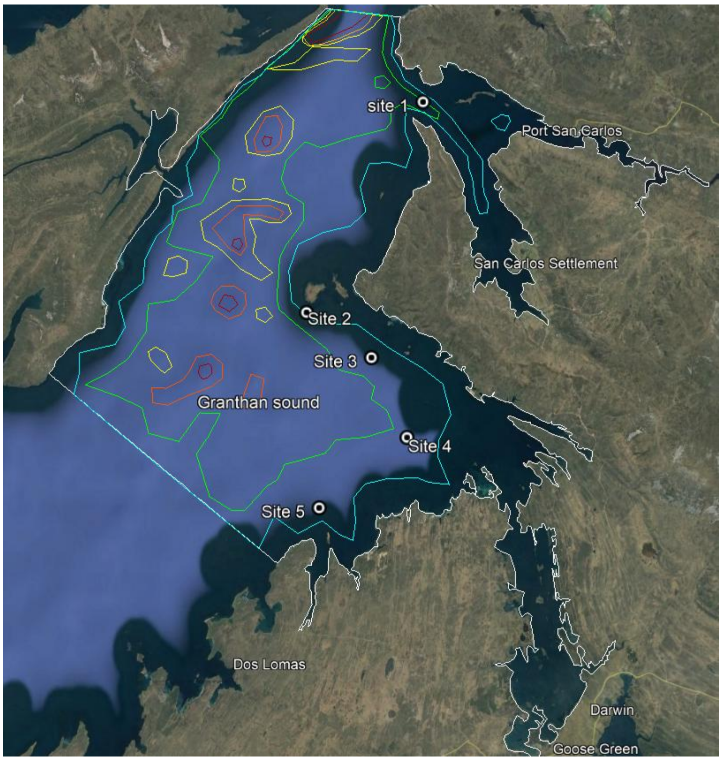

Figure 2: Area and bathymetry for Grantham sound

Table 3: Calculations for Grantham Sound

Water depths (m)	Area (km^2)	Volume (m^3)	%
>60	4.32	299,808,000	1.8%
50 to 60	14.69	872,586,000	5.4%
40 to 50	12.35	610,090,000	3.8%
30 to 40	192.64	7,590,016,000	46.8%
20 to 30	148.65	4,370,310,000	27.0%
0 to 20	216.35	2,466,390,000	15.2%
Total	589	16,209,200,000	100.0%

Table 4: ECE for Grantham Sound

Parameter	Value	Unit
Volume of water body (***V***)	16,209,200,000	m^3
Surface area (***A***)	589,000,000	m^2
Tidal range (***R***)	1.8	m
Nutrient output per biomass (***S***)	60	kgN/t/yr
Total biomass (***M***)	36,500	t
Flushing time (***TF***)	11.36	days
Flushing rate (***Q***)	520,925,192,308	m^3/yr

Total nutrient load (***S*** x ***M***)	2,190,000	kgN/yr
ECE	4.20	µg/L

3.2. Main Passage

The coastal contour was drawn, and the area was calculated for Main Passage, in addition to the bathymetry contour lines and the volume (Figure 3 and Table 5). The total water surface area of the proposed aquaculture area in Main Passage is 650.96 km^2, with a volume of 23,210,300,000 m^2. The model parameters of the ECE are presented in Table 6, finding the calculated cumulative sustainable carrying capacity within the NEI low threshold, at a maximum of 40,000 t of standing biomass.

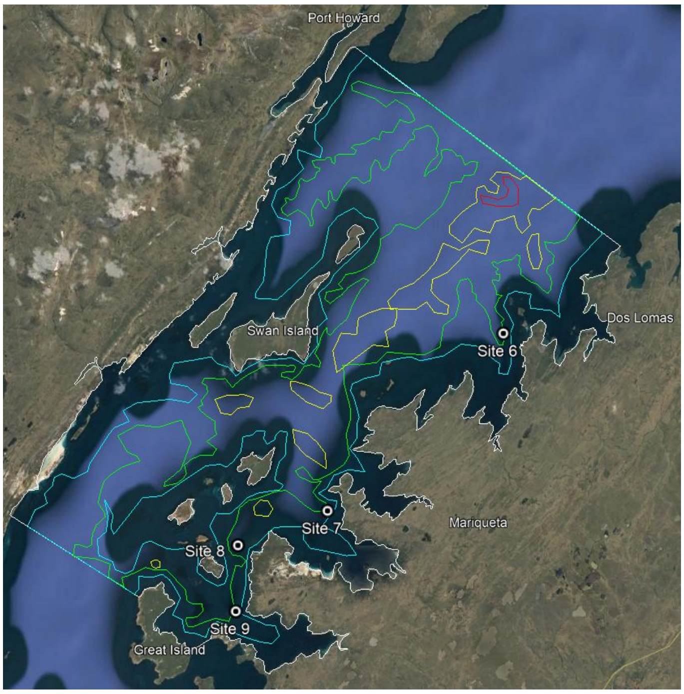

Figure 3: Area and bathymetry for Main Passage

Table 5: Calculations for Main Passage

Water depths (m)	**Area (km^2)**	**Volume (m^3)**	**%**
>60	0	-	0.0%
50 to 60	2	128,000,000	0.6%
40 to 50	37.47	2,023,380,000	8.7%
30 to 40	234.53	10,319,320,000	44.5%
20 to 30	232.2	7,894,800,000	34.0%
0 to 20	144.76	2,844,800,000	12.3%
Total	650.96	23,210,300,000	100.0%
Islands	33.04	0	

Table 6: ECE for Main Passage

Parameter	**Value**	**Unit**
Volume of water body (***V***)	23,210,300,000	m^3
Surface area (***A***)	650,960,000	m^2
Tidal range (***R***)	1.5	m
Nutrient output per biomass (***S***)	50	kgN/t/yr
Total biomass (***M***)	40,000	t
Flushing time (***TF***)	17.66	days
Flushing rate (***Q***)	479,770,038,462	m^3/yr
Total nutrient load (***S*** x ***M***)	2,000,000	kgN/yr

ECE	23,210,300,000	µg/L

3.3. Ruggles Bay

The coastal contour was drawn, and the area was calculated for Ruggles Bay, in addition to the bathymetry contour lines and the volume (Figure 4 and Table 7). The total water surface area of the proposed aquaculture area in Ruggles Bay is 284 km^2, with a volume of 6,729,600,000 m^3. The model parameters are presented in Table 8, finding the calculated cumulative sustainable carrying capacity within the NEI low threshold, at a maximum of 17,000 t of standing biomass.

Figure 4: Area and bathymetry for Ruggles Bay

Table 7: Calculations for Ruggles Bay

Water depths (m)	Area (km^2)	Avg. depth (m)	Volume (m^3)	%
>60	0	69.5	-	0.0%
50 to 60m	0	59.5	-	0.0%
40 to 50m	6.94	49.5	343,530,000	5.1%
30 to 40m	84.36	39.5	3,332,220,000	49.5%
20 to 30m	61.16	29.5	1,804,220,000	26.8%
0 to 20m	131.54	9.5	1,249,630,000	18.6%
Total	284		6,729,600,000	100.0%
Islands	7.32	0	0	

Table 8: ECE for Ruggles Bay

Parameter	Value	Unit
Volume of water body (***V***)	6,729,600,000	m^3
Surface area (***A***)	284,000,000	m^2
Tidal range (***R***)	1.5	m
Nutrient output per biomass (***S***)	50	kgN/t/yr
Total biomass (***M***)	17,000	t
Flushing time (***TF***)	11.74	days
Flushing rate (***Q***)	209,313,461,538	m^3/yr

Total nutrient load (***S*** x ***M***)	850,000	kgN/yr
ECE	4.06	µg/L

3.4. Adventure Sound

The coastal contour was drawn and the area was calculated for Adventure Sound, in addition to the bathymetry contour lines and the volume (Figure 5 and Table 9). The water surface area of the proposed aquaculture area in Adventure Sound is 373.4 km^2, with a volume 6,687,900,000 m^3. The model parameters of the ECE are presented in Table 10, finding the calculated cumulative sustainable carrying capacity within the NEI low threshold, at a maximum of 27,500 t of standing biomass.

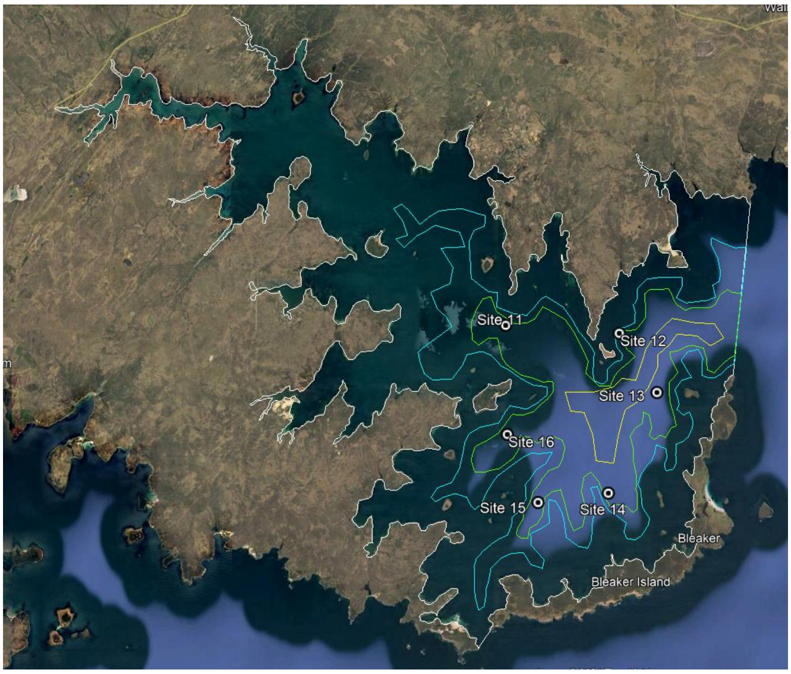

Figure 5: Area and bathymetry for Adventure Sound

Table 9: Calculations for Adventure Sound

Water depths (m)	Area (km^2)	Volume (m^3)	%
>60	0	-	0.0%
50 to 60m	0	-	0.0%
40 to 50m	12	570,000,000	8.5%
30 to 40m	56.9	2,190,650,000	32.8%
20 to 30m	56.1	1,542,750,000	23.1%
0 to 20m	251	2,384,500,000	35.7%
Total	376	6,687,900,000	100.0%
Islands	2.6	0	

Table 10: ECE for Adventure Sound

Parameter	Value	Unit
Volume of water body (***V***)	6,687,900,000	m^3
Surface area (***A***)	373,400,000	m^2
Tidal range (***R***)	1.8	m
Nutrient output per biomass (***S***)	50	kgN/t/yr
Total biomass (***M***)	27,500	t
Flushing time (***TF***)	7.39	days
Flushing rate (***Q***)	330,243,576,923	m^3/yr
Total nutrient load (***S*** x ***M***)	1,375,000	kgN/yr
ECE	4.16	µg/L

3.5. Choiseul Sound

The coastal contour was drawn, and the area was calculated for Choiseul Sound, in addition to the bathymetry contour lines and the volume (Figure 6 and Table 12). The water surface area of the proposed aquaculture area in Choiseul Sound is 198.5 km^2, with a volume of 3,495,200,000 m^3. The model parameters of the ECE are presented in Table 10, finding the calculated cumulative sustainable carrying capacity within the NEI low threshold, at a maximum of 12,000 t of standing biomass.

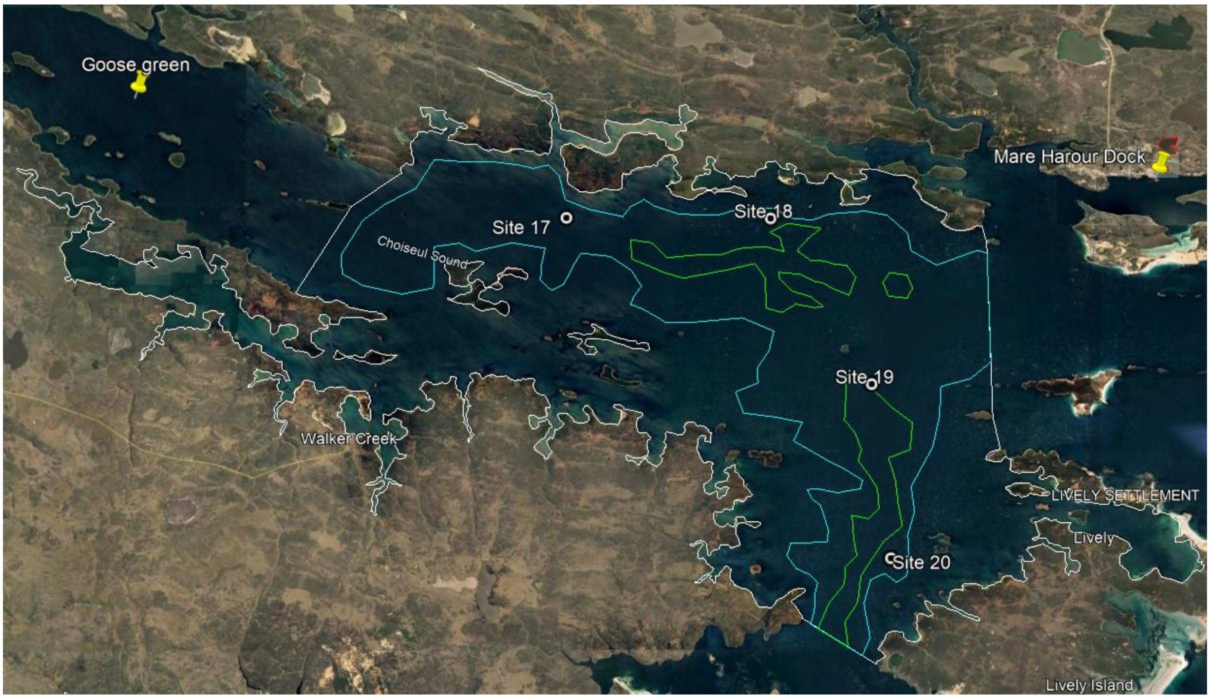

Figure 6: Area and bathymetry for Choiseul Sound

Table 11: Calculations for Choiseul Sound

Water depths (m)	Area (km^2)	Avg. depth (m)	Volume (m^3)	%
>60	0	65	-	0.0%
50 to 60m	0	55	-	0.0%
40 to 50m	0	45	-	0.0%
30 to 40m	12.41	35	465,375,000	13.3%
20 to 30m	68.79	25	1,891,725,000	54.1%
0 to 20m	119.8	7	1,138,100,000	32.6%
Total	201		3,495,200,000	100.0%
Islands	2.52	0	0	

Table 12: ECE for Choiseul Sound

Parameter	Value	Unit
Volume of water body (***V***)	3,495,200,000	m^3
Surface area (***A***)	198,480,000	m^2
Tidal range (***R***)	1.5	m
Nutrient output per biomass (***S***)	50	kgN/t/yr
Total biomass (***M***)	12,000	t
Flushing time (***TF***)	8.72	days
Flushing rate (***Q***)	146,283,576,923	m^3/yr
Total nutrient load (***S*** x ***M***)	600,000	kgN/yr
ECE	4.10	µg/L

4. Assessment of particulate discharges from proposed farms in FI

This section explains the amount of particulate solid waste (like uneaten feed and fish faeces) that would settle on the seabed beneath salmon farms in different parts of the Falkland Islands was estimated. The DEPOMOD model was used to predict how far and how severely this waste would spread. These predictions help determine how large each farm can be without harming the seabed environment.

4.1. Pre-screening model assessment

The pre-screening assessment uses basic information like water depth and current speed to estimate whether a site is likely to be suitable for large-scale farming. In the pre-modelling assessment, modelled current average speed (DHI, 2019) and measured average current speeds (DHI, 2020) were used, as well as recently measured depths for each site location. The depth range at the proposed sites across all zones varies approximately between 30 to 41 metres – these would not be considered particularly deep sites.

A simple model shows that an uneaten salmon feed pellet settling at a rate of 9.5 cm/s in a 25 m water column, takes 263 seconds to settle from sea surface to seabed and would be transported 26 m by a 0.10 m/s current. For a 50 m water column, the time to settle is doubled and so the distance transported from the cages is doubled to 52 m if the same current is applied (i.e., in this example the particle is dispersed more widely in the deeper site). For comparison, a waste faecal particle settling at 0.032 cm/s would be transported 78 m when settling from sea surface to bed in a 25 m water column, and 156 m distance in a 50 m water column. In low currents of less than 0.1 m/s, which are typical for Choiseul Sound and Granthan Sound, both waste feed and faecal particles are settling out close to the cages.

Table 13: Current velocity data for the proposed Falkland Island aquaculture zones and measurements from operational Scottish fish farms

Country	Zone/area	Current velocity (m/s				Data source	Depth (m)
		Surface	Net depth	Near-bed	Average		
Falkland Islands	*Main Passage*	*N/A*	*N/A*	*N/A*	*0.270*	*Modelled depth average[1]*	*41*
Falkland Islands	*Ruggles Bay*	*N/A*	*N/A*	*N/A*	*0.240*	*Modelled depth average[1]*	*30*
0.12 m/s - approximate threshold used in Scotland[4] – large sites (>2,500 t biomass) tending to have average current speeds > 0.12 m/s							
Scotland	Copister	0.071	N/A	N/A	0.071	Measured surface[2]	29
Scotland	Poll na Gille	0.068	0.061	0.081	0.070	Measured average[2]	26
Falkland Islands	*Choiseul Sound*	*0.064*	*0.054*	*0.069*	*0.062*	*Measured average[3]*	*31*
Scotland	Loch Linnhe	0.084	0.048	0.051	0.061	Measured average[2]	-
Falkland Islands	*Grantham Sound*	*0.066*	*0.054*	*0.050*	*0.057*	*Measured average[3]*	*36*
Scotland	Gob na Hoe	0.057	0.050	0.049	0.052	Measured average[2]	24
Falkland Islands	*Adventure Sound*	*N/A*	*N/A*	*N/A*	*0.020*	*Modelled depth average[1]*	*35*

Notes. 1. DHI (2019), 2. In: DHI (2020) – data sourced from public register of fish farm information in Scotland. 3. DHI (2020). 4. SEPA (2019).

Table 13 examines the mean modelled current speeds for each zone (without storm conditions) presented in DHI (2019). This data shows Ruggles Bay and Main Passage have mean current speeds around 0.25 m/s, and the other three zones, Choiseul Sound, Adventure Sound and Grantham Sound have mean speeds of around 0.05 m/s. The measured current velocity data for Choiseul Sound and

Granthan Sound showed a slightly higher average around 0.06 m/s. As the proposed sites in all zones are of similar depth, this indicates that the dispersive capability of Ruggles Bay and Main Passage is likely to be much more than the other zones. Thus, they are likely to support larger individual farms as the average current speeds are five times higher in some comparisons. Comparison of Falkland Island zones current speeds with Scottish sites quoted in DHI (2020), found that the Scottish sites quoted had similar current speeds to Choiseul Sound, Grantham Sound and Adventure Sound.

The ability of a site to disperse waste depends largely on its current speed. Sites with stronger, more consistent water movement are considered dispersive, meaning they can spread waste over a wider area and reduce its accumulation on the seabed. These sites are generally more suitable for larger farms. In contrast, depositional sites have weaker currents, so waste tends to settle directly beneath the cages. These areas require smaller farms to avoid environmental harm. The ranking below reflects this gradient from most dispersive to most depositional:

1. Main Passage
2. Ruggles Bay
3. Choiseul Sound
4. Grantham Sound
5. Adventure Sound

Further in this assessment, a brief examination of the maximum biomass consent data for Scottish marine was taken, primarily for salmon farms (Scotland's aquaculture, 2025). Historically, the potential size of individual farms in Scotland in many cases was limited to 2,500 t biomass. Around 2019, the SEPA regulatory framework was overhauled and so it is quite likely that since then, the average site size being proposed and under assessment, has been increasing.

The Scottish fish farm data shows:

- 15 sites > 2500 t maximum consented biomass,
- 33 sites at 2500 t, and
- 399 sites < 2500 t

In the Scottish regulatory framework, 'large sites' have been typically referred to as 2,500 t consented maximum biomass. This is for an individual farm. Of these 33 sites that have a 2,500 t consented biomass, these may have been limited to the 2,500 t threshold prior to 2019. It is therefore quite likely some sites may expand in future applications.

The largest farm in Scotland is 4680 t biomass, and the average size of the 15 'large sites' in Scotland is 3405 t. The project proposes most individual farms in each zone to have a size of more than 5000 t, larger than the largest site in Scotland.

Some specific guidance was sought in the SEPA regulatory guidelines regarding what information would indicate that a site could potentially be a 'large site' (i.e. >2,500 t consented biomass). The following is quoted from SEPA (2019):

"Marine finfish aquaculture farms using open-net pens will benefits from operating in locations where there are strong, repeating, water currents to erode and disperse waste. For the purposes of screening, we consider locations which meet the following water flow criteria to be generally suitable for larger farms:

- *Locations with average water flow speeds of greater than, or equal to, 0.12 m/s (0.23 knots)*
- *Locations where water flow speeds are often above the threshold of 0.095 m/s (0.18 knots)*

Locations with these properties are likely to disperse discharged material rapidly, and regularly erode sediment discharged to the seabed. In general, we would look for these properties to be maintained over a large area around the proposed site. The thresholds stated above are indicative."

The SEPA guidelines help to identify whether a site has strong enough water currents to disperse waste effectively. Sites that meet these criteria are more likely to support larger farms without harming the environment.

The near-bed current velocity of 0.095 cm/s is used by SEPA as an indicative threshold and is also used in regulatory modelling in Scotland. Above this indicative threshold, erosion of waste particles in the deposition footprint is expected to begin, dispersing the particles more widely. Prior to regulatory modelling be established in Scotland, this threshold of 0.095 cm/s was used in validation of the DEPOMOD fish farm model (Cromey et al. 2002). Therefore, sites that often have current speeds above this threshold are tending towards the dispersive end of the scale.

Using the above guideline criteria, the zones were assessed to determine if they met these criteria for large sites (Table 14).

Table 14: How the Falkland Island proposed zones meet the SEPA guideline criteria which are indicative of dispersive sites.

Zone	Average current velocity > 0.12 m/s?	Near-bed current velocity "often above" 0.095 cm/s?	Likely to support large sites? (>2,500 t maximum biomass)
Main Passage	Yes	Yes	Yes
Ruggles Bay	Yes	Yes	Yes
Choiseul Sound	No	(Yes) – 22 %	(Yes)
Grantham Sound	No	No – 4 %	(No)
Adventure Sound	No	No	No

Note. (Yes) and (No) means some uncertainty

For the Falkland Island zones, Main Passage and Ruggles Bay meet both of these criteria and so could potentially support large sites (i.e., farm size >2,500 t biomass). Each site in these dispersive zones was assigned a maximum biomass of an average large site in Scotland – 3,405 t maximum biomass.

Choiseul Sound has 22 % of near-bed current speeds above 0.095 m/s and so is likely to meet the criteria of 'flow speeds are often above the threshold of 0.095 m/s'. However, Choiseul Sound has an average current speed of 0.062 m/s and does not meet the average current speed of 0.12 m/s. This means that Choiseul Sound may meet one of the criteria for supporting large sites (i.e. farm size >2,500 t biomass). As one criteria is not met and the other criteria may be met, it seems appropriate to assess that the farm biomass in a typical farm in Choiseul Sound would be around 2,500 t (i.e., different to Main Passage and Ruggles Bay which meet both criteria and so those zones are likely to support sites > 2,500 t).

Adventure Sound and Grantham Sound do not meet either of these criteria, meaning that these zones would not be expected to support large sites (i.e., individual farm biomass would be expected to be <2,500 t). On the scale of dispersiveness, Adventure Sound is depositional and has much lower average current speeds than Main Passage and Ruggles Bay. Adventure Sound was therefore assigned a maximum site biomass of approximately half of the site maximum biomass for the dispersive zones, Main Passage and Ruggles Bay. Grantham Sound lies somewhere on the dispersive scale between Choiseul Sound and Adventure Sound, so a site biomass somewhere in-between was assigned accordingly.

4.2. Screening model assessment

The screening model provides a more detailed prediction of how much waste would settle on the seabed and whether it would exceed environmental limits. Main Passage and Ruggles Bay have similar average and maximum current speeds, so it was only necessary to screen model Main Passage to get an indication for both zones.

In the screening modelling predicted waste levels (in terms of severity and extent) were allowed to exceed regulatory thresholds in some zones. This is because the model did not include resuspension (i.e., the natural process whereby water currents lift and redistribute waste particles, reducing their accumulation on the seabed). For Main Passage and Ruggles Bay, resuspension is more likely to occur as modelled current speeds often exceeded the 0.095 m/s threshold in these two zones. Including resuspension in the model here would therefore likely reduce the predicted severity and extent of depositional impacts, meaning that the estimated maximum biomass for these zones would still meet environmental standards. As such, the results for these zones are considered conservative and realistic, even though resuspension was not explicitly modelled.

Choiseul Sound had some observed current speeds that were above the resuspension threshold, so the standards were allowed to be exceeded here. Grantham Sound and Adventure Sound had minimal or no current speeds above the resuspension threshold, so the standards were applied more rigidly. With these three zones, the extent of deposition footprint was similar to or less than the 100 m mixing zone equivalent area, but severity was over the standard for the 'pass'.

The predicted deposition footprints are shown in Appendix A.

Table 15 summarises the results of the pre-screening and screening model assessments under Scenario 2. It shows the estimated maximum sustainable biomass for a typical farm in each zone, and the corresponding annual production per farm, per zone, and for the entire Falkland Islands. Two production cycles were considered:

- A: 15 months production + 3 months fallow
- B: 21 months production + 3 months fallow

Table 15: Screening model assessment results for Scenario 2.1 and 2.2

The maximum biomass for a typical farm in each of the 5 zones, with annual production per farm, zone and for the whole of the Falkland Islands. MP – 4 farms, RB – 1 farm, CS – 4 farms, GS – 5 farms, AS – 6 farms. Total = 20 farms. Production cycle abbreviations: A – 15 months + 3 months fallow, B – 21 months + 3 months fallow.

Scenario	Site	Maximum sustainable biomass per farm (t)	Annual production per farm (t/yr)	Annual production per zone (t/yr) (to nearest 100 t/yr)	Total annual production (t/yr)
2.1A – pre-screening assessment	MP	3,405	2,270	9,100	**32,200**
	RB	3,405	2,270	2,300	
	CS	2,500	1,667	6,700	
	GS	2,200	1,467	7,300	
	AS	1,700	1,133	6,800	
2.1B - pre-screening assessment	MP	3,405	1,703	6,800	**24,100**
	RB	3,405	1,703	1,700	
	CS	2,500	1,250	5,000	
	GS	2,200	1,100	5,500	
	AS	1,700	8,50	5,100	
2.2A - screening model	MP	3,500	2,333	9,300	**31,200**
	RB	3,500	2,333	2,300	
	CS	2,300	1,533	6,100	
	GS	2,000	1,333	6,700	
	AS	1,700	1,133	6,800	
2.2B - screening model	MP	3,500	1,750	7,000	**27,300**
	RB	3,500	1,750	1,800	
	CS	2,875	1,438	5,800	
	GS	2,500	1,250	6,300	
	AS	2,125	1,063	6,400	

Table 16 presents the results of Scenario 2.3, where the most dispersive zones (Main Passage and Ruggles Bay) were allowed to reach the maximum biomass currently consented in Scotland (4,700 tonnes). This scenario explores the upper limit of production potential in the Falklands under favourable dispersive conditions.

Table 16: Screening model assessment results for Scenario 2.3

Which allows dispersive sites to be maximum consented in Scotland – maximum biomass for a typical farm in each of the 5 zones, with annual production per farm, zone and for the whole of the Falkland Islands. MP – 4 farms, RB – 1 farm, CS – 4 farms, GS – 5 farms, AS – 6 farms. Total = 20 farms. Production cycle abbreviations: A – 15 months + 3 months fallow, B – 21 months + 3 months fallow.

Scenario	Site	Maximum sustainable biomass per farm (t)	Annual production per farm (t/yr)	Annual production per zone (t/yr) (rounded nearest 100 t/yr)	Total annual production (t/yr)
2.3A - screening model plus dispersive sites max. biomass	MP	4,700	3,133	12,500	**35,200**
	RB	4,700	3,133	3,100	
	CS	2,300	1,533	6,100	
	GS	2,000	1,333	6,700	
	AS	1,700	1,133	6,800	
2.3B - screening model plus dispersive sites max. biomass	MP	4,700	2,350	9,400	**30,300**
	RB	4,700	2,350	2,400	
	CS	2,875	1,438	5,800	
	GS	2,500	1,250	6,300	
	AS	2,125	1,063	6,400	

Table 17 shows the average feed input used in the screening model for each zone. To avoid overestimating impacts, the model used the average feed input over the three peak months of the production cycle, rather than a single maximum value.

Table 17: Feed input for a typical farm used in the screening model for each zone.

To avoid using unrepresentative maximum values of feed input, the average of the three months at the time of maximum feed input was used. The maximum biomass of the farm depends on the details of the production cycle used.

Zone	Typical farm - Maximum feed input as an average of 3 months (t/month/farm)	Typical farm - maximum feed input as an average of 3 months (kg/cage/day)
Main Passage	457	1,473
Ruggles Bay	457	1,473
Choiseul Sound	300	968
Grantham Sound	261	842
Adventure Sound	222	715

5. Discussion and interpretation

5.1. Zone and farm buffers

Buffers between zones and farms—and between broader aquaculture zones—are important for environmental and biosecurity. One of the primary motivations for regulating the minimum distance between aquaculture farms is to reduce the risk of disease transmission. Aquaculture operations are susceptible to various diseases, which can spread rapidly between closely situated sites, particularly in regions with strong water currents that facilitate the movement of pathogens. If farms are located too close to each other, an outbreak at one site can easily spread to neighbouring farms, leading to widespread losses.

Effective biosecurity is an essential component of a sustainable aquaculture industry. As such, adequate spacing between farms supports stronger biosecurity protocols by reducing the likelihood of cross-contamination. Waterborne pathogens, contaminated equipment, and human activity are common vectors for disease spread in aquaculture. Greater distances between farms act as a buffer, minimising the risk of these vectors transmitting diseases from one farm to another.

The environmental impacts of aquaculture can be significant, particularly when farms are located close together. Concentrated farming activities can lead to excessive nutrient loading, increased organic waste accumulation, and localised degradation of water quality and benthic habitats. These cumulative impacts can harm the surrounding marine environment, leading to issues such as eutrophication and the loss of biodiversity.

Marine habitats, including seagrass beds, coral reefs, and spawning grounds, are essential for the health and productivity of marine ecosystems. These habitats are often vulnerable to the impacts of aquaculture, particularly when farms are densely clustered. Ensuring adequate spacing between farms helps to protect these sensitive areas by allowing for the natural regeneration of habitats and preventing their degradation from concentrated farming activities.

While spacing between individual farms is important, spacing between entire aquaculture zones is equally critical. Larger buffers between zones help prevent cumulative impacts across broader ecosystems and reduce the risk of regional disease spread. International best practice often recommends a minimum of 5 km between aquaculture zones to ensure that nutrient and disease impacts from one zone do not overlap with those of another, especially in interconnected marine environments. Table 18 summarises international regulations and practices regarding minimum distances between farms.

Table 18: Country regulations on the minimum distance between farms

Norway: The location and distance between farms would be managed through regional planning and environmental assessments to avoid negative environmental impacts and ensure sustainable practices. Based on satellite image analysis, the distance between cages is approximately 2.5 km.
Scotland: Scottish regulations on this can vary depending on local ecological assessments. Based on satellite image analysis, the distance between cages is approximately 5 km.
Ireland: Farm spacing and site selection are regulated under regional planning guidelines and environmental assessments to prevent overcrowding and ensure environmental sustainability. Based on maps the distance between cages is approximately 2 km.
Faroe Islands: There is a statutory distance of 2.5 km between farms to prevent the spread of disease and to minimise the risk from sea lice (Independent Aquaculture Licensing Review Group, 2019).

In the Falkland Islands, the average distance between farm locations proposed by Unity Marine is 6.26 km (range 3.4-13.7, Table 19), exceeding the minimum standards seen in other countries and therefore representing good practice (regulators typically enforcing a minimum distance of 2.5 km between farms).

Table 19: Distance between farm sites

Distances between sites	km
Site 1 to site 2	13.7
Site 2 to site 3	4.40
Site 3 to site 4	5.00
Site 4 to site 5	6.50
Site 6 to site 7	15.6
Site 7 to site 8	6.30
Site 8 to site 9	4.15
Site 11 to site 12	5.70
Site 12 to site 13	3.40
Site 13 to site 14	5.50
Site 14 to site 15	3.50
Site 15 to site 16	3.70
Site 17 to site 18	5.80
Site 18 to site 19	5.50
Site 19 to site 20	5.10
Average	**6.26**

However, the average distance between the proposed zones is 6.45 km (range 2.3-26.3 km), which is contrary to good practice whereby recommended regulations would enforce a minimum distance of 5 km between aquaculture zones. Table 20 presents these inter-zone distances.

Table 20: Distance between zones

Distance between zones	km
Zone 1 and 2	2.3
Zone 2 and 3	6.7
Zone 4 and 5	26.3
Average	**6.45**

5.2. Production scenarios

5.2.1. According to nutrient thresholds (the ECE model)

The ECE model estimates nutrient enhancement in the water column and helps determine sustainable production limits. Under Scottish regulations (

Table 21) a concentration of <0.3 µmol of total dissolved N/litre in the environment is considered low and sustainable in the long term.

Table 21: Regulatory thresholds

Thresholds	Concentration	Concentration	Comments
NEI = 1.	<0.3 µmol N/L	<4.2 µg N/L	Low nutrient enhancement
NEI = 2.	0.3–1 µmol N/L	4.2 – 14 µg N/L	Moderate enhancement
NEI = 3 or 4.	>1 µmol N/L	>14 µg N/L	High nutrient enhancement requires regulatory intervention.

Using these thresholds, the maximum sustainable production across all zones is estimated at 133,000 t/year (Table 22). However, this figure only accounts for production limits within nutrient thresholds and not seabed impacts.

Table 22: Estimated maximum sustainable yield for each zone

Estimated Maximum sustainable yield (t/yr)			Regulatory		Gold
Aquaculture zones	NEI index (µg/L)	Proposed prod (t/yr)	Max sustainable (t/yr)	% of max	50% of NEI (t/yr)
Grantham Sound	4.20	12,500	36,500	34%	18,250
Main Passage	4.17	10,000	40,000	25%	20,000

Ruggles	4.06	5,000	17,000	29%	8,500
Adventure Sound	4.16	12,500	27,500	45%	13,750
Choiseul Sound	4.10	10,000	12,000	83%	6,000
Average	4.14	-	-	38%	-
Total		50,000	133,000		66,500

The 'gold standard' scenario could use be considered to be 50% of the low NEI threshold (<0.15 µmol N/L or 2.1 µg N/L), resulting in a reduced maximum sustainable production limit of 66,500 t/year from the zones. This is a more precautionary approach, using only half of the allowable nutrient threshold. Adopting a conservative benchmark helps account for uncertainty in model predictions and provides an added layer of environmental protection. In this scenario, the production of 10,000 t in Choiseul Sound would fall above gold standard thresholds (i.e., 6,000 t), suggesting that fewer farms or reduced production may be necessary. That said, the sites proposed in other zones (e.g., Main Passage) could be larger (depending on depositional modelling results) or more sites could be added within the zone (depending on site availability and minimum distance between farms).

5.2.2. According to depositional thresholds (DEPOMOD)

While the ECE model focuses on nutrient levels in the water column, the DEPOMOD model assesses the impact of solid waste on the seabed. Both models provide complementary insights and must be considered together to ensure environmentally sustainable aquaculture. Accounting for the depositional models, using the screening modelling results with the production cycle B for Scenario 2, and adjusted figures to limit stocking density to 10 kg/m^3, Scenario 3 and 4 could be calculated as per Table 23.

Table 23: Annual production figures for the Falkland Islands for each scenario

Scenario	Total annual production for 20 farms in the Falkland Islands (t/yr)	Notes
2 - Regulatory	27,300 – 30,300	2.2B and 2.3B (longer production cycle)
3 - 'Gold'	24,100 – 27,300	-
4 - Organic	24,100	-

5.3. Confidence in model prediction and annual production figures

An index (Table 24) was devised to demonstrate where the Falkland Island screening model predictions compared to completely undeveloped models, and locally validated models. In summary, an index of 8 to 10 is given to a model that is locally validated, and an index of 4 to 7 is for models that are unvalidated locally. Many applications of aquaculture impact models have an index of greater than 4 – i.e. they are using models that have been validated elsewhere and then applying them to the local situation. Despite an index of 4 appearing low, model predictions at this level give a useful first assessment of a site, often helping to stimulate discussion with stakeholders at the early stage of a project. In practice, many modelling applications seek to have an index of 7, meaning that an established model from another area is being used with detailed local information. The regulatory modelling framework in Scotland has an index of higher than 7, because significant local validation of the framework and models has taken place.

Table 24: Index describing the level of confidence in model predictions

Confidence rating	Description
10	Validated model – works satisfactory for numerous sites across the whole range
9	Partly validated model – refined and tested with additional sites (e.g., predictions compared with monitoring data)
8	Attempt to validate model for a small number of sites – modelled versus observed, compared in detailed validation experiments

7	Unvalidated model, but with detailed, recently measured, site-specific input data (e.g., measured current data, proposed production data, cage layouts, bathymetry, etc.)
6	More site-specific data added (e.g., more detail on feed rations, bathymetry, cage layouts, current speeds, stakeholder inputs, etc.)
5	Some site-specific data (e.g., some modelled or measured current speed, estimates of feed rations, bathymetry, cage layouts, etc.)
4	Model taken to a new region or farmed species, with minimal stakeholder input and an unvalidated model
3	Model developed for a new region with no local stakeholders
2	Model developed and validated elsewhere
1	New model

<table>
<tr><th colspan="7">Confidence rating</th></tr>
<tr><td>10</td><td></td><td rowspan="3">Validated locally</td><td></td><td rowspan="5">Detailed modelling</td><td rowspan="6">‘What if’ scenarios useful</td><td rowspan="4">Regulatory modelling framework (e.g., SEPA)</td></tr>
<tr><td>9</td><td></td><td></td></tr>
<tr><td>8</td><td></td><td></td></tr>
<tr><td>7</td><td>Refined FI modelling with ADCP data, production data, revised plans etc.</td><td rowspan="7">Unvalidated locally</td><td rowspan="3">Screening modelling</td></tr>
<tr><td>6</td><td>Choiseul Sound, Grantham Sound</td><td></td></tr>
<tr><td>5</td><td>Adventure Sound, Ruggles Bay, Main Passage</td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td></tr>
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Figure 7: Index of confidence showing the Falkland Islands zones

DHI (2020) provided measured current velocity summaries for Choiseul Sound and Grantham Sound which were useful for the assessments, but the actual measurements in the model could not be used directly. Thus, this was allocated a score of 6 (Figure 7). With ADCP measurements used directly in the model, Choiseul Sound and Grantham Sound would have an index of 7 which would be the maximum value the index could attain without local validation of predictions for operational farms. The other three zones – Adventure Sound, Ruggles Bay and Main Passage – had an index of 5 as measured current data were not yet available, either as processed data or summary reports. With measured ADCP data used in modelling, these three zones would also increase from 5 to a maximum of 7. As more site-specific data—particularly processed ADCP measurements—becomes available, the confidence in model predictions will improve. This will allow for more precise planning, better-informed regulatory decisions, and adaptive management as the sector develops.

A specific guideline relating to this index is based upon availability of measured current velocity data for the modelling. To attain an index of 7, detailed measured current velocity data would be used in the modelling. This measured information is available for all of the zones but not yet processed into a usable form.

6. Conclusions

The application of the ECE model to assess the sustainability of salmon cage production in the Falkland Islands reveals key insights into nutrient enhancement dynamics and site-specific carrying capacities:

1. **Grantham Sound:** The regulatory standard for cumulative production would be 36,500 t/year and the gold standard would be 18,250 t/year.
2. **Main Passage:** The regulatory standard for cumulative production would be 40,000 t/year and the gold standard would be 20,000 t/year.
3. **Ruggles Bay:** The regulatory standard for cumulative production would be 17,000 t/year and the gold standard would be 8,500 t/year.
4. **Adventure Sound**: The regulatory standard for cumulative production would be 27,500 t/year and the gold standard would be 13,750 t/year.
5. **Choiseul Sound:** The regulatory standard for cumulative production would be 12,000 t/year and the gold standard would be 6,000 t/year.

Whilst insightful, any given site would need to adhere to strict limits of maximum sustainable biomass, which for the purposes of this study were adopted from SEPA guidelines. The assessments showed that the five proposed aquaculture zones lie across the range – dispersive to depositional. Main Passage and Ruggles Bay are dispersive and so could support large sites (> 2,500 t), whereas Adventure Sound is depositional and so would be expected to have smaller sites (< 2,500 t). Choiseul Sound and Grantham Sound are in-between these, and so perhaps could be described as the middle of the range. However, from the measured ADCP data, Choiseul Sound does have higher current and dispersive qualities than Grantham. The rank of dispersiveness and maximum biomass of individual sites in the zones is therefore as follows:

1=. Main Passage = Ruggles Bay

3. Choiseul Sound
4. Grantham Sound
5. Adventure Sound.

The ADCP data summary reports provided (DHI, 2020) were helpful as the measurements showed that Choiseul Sound and Grantham Sound have wind driven currents as well as tidal currents. This means that although these sites are not dispersive sites, they will have reliable currents because of the persistent local winds.

Through various assessment methods, differences between the zones in terms of the maximum biomass of individual farms were found (as expected). This is believed to be a useful finding as it indicates what size of farm could be sustainable depending on the dispersive qualities of each zone. Even if the maximum biomass predictions were scaled up or down, there should still be some relative difference between the zones given the dispersive range that the zones occupy. Therefore, upon application of the DEPOMOD model, the range of production volumes for 20 farms in the five zones (i.e., accounting for all possible scenarios described in the report) are revealed as:

1. **Grantham Sound** – 5 farms**:** 5,500-7,300 t/year
2. **Main Passage** – 4 farms: 6,800-12,500 t/year
3. **Ruggles Bay** - 1 farm: 1,700-3,100 t/year
4. **Adventure Sound** – 6 farms: 5,100-6,800 t/year
5. **Choiseul Sound** – 4 farms**:** 5,000-6,700 t/year

Taken together but excluding scenario 2.1 the pre-screening model assessment, this provides context for the potential development scenarios of the proposed aquaculture sector for 20 farms:

- **Option 2:** 27-300-35,200 t/year (i.e., where commercial salmon farming takes place and is limited only by the carrying capacity of the environment)
- **Option 3:** 24,100-27,300 t/year (i.e., where commercial salmon farming takes place but is limited well below the carrying capacity of the environment)
- **Option 4:** 24,100 t/year (i.e., where commercial salmon farming is allowed but through niche methods such as organic production)

The findings underscore the necessity of strategic aquaculture zoning and strict regulatory frameworks with strong monitoring protocols to develop industry growth and at the same time sustain both ecological integrity and industry growth. The adoption of site-specific management strategies informed by modelling would enable the Falkland Islands to maximise aquaculture productivity while safeguarding its marine ecosystems. Such strategies are not within the scope of this current exercise but are discussed in detail in MEP's 'best practices and recommendation' report. Moving forward, adaptive management—where decisions are updated as new data and insights emerge—will be essential. This approach will help ensure that aquaculture development in the Falkland Islands remains both economically viable and environmentally responsible.

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Appendices

Appendix A – Screening model predictions of waste deposition footprints for each zone

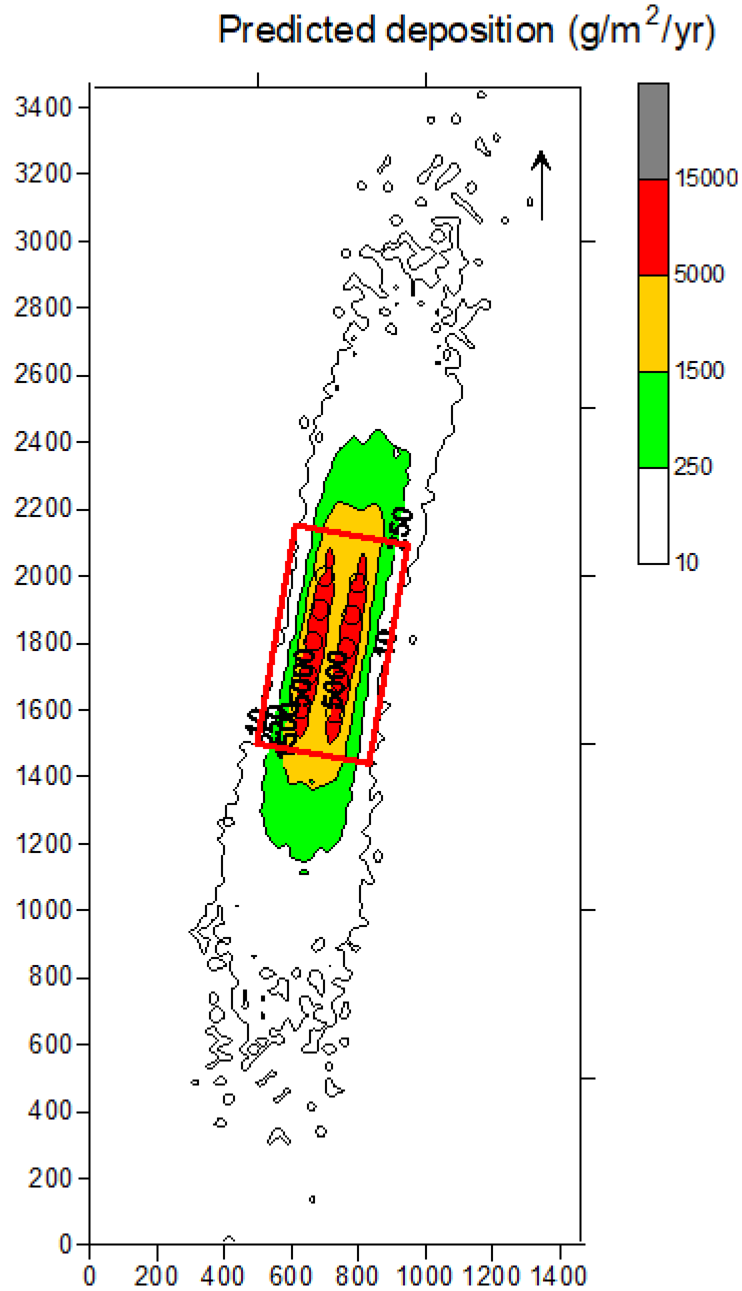

Figure 8: Depositional model for Main Passage/Ruggles Bay

Screening model predicted deposition using a feed input of 1,473 kg feed/cage/d (approx. 3,500 t maximum biomass) (resuspension model switched off). In detailed modelling with a resuspension model, the severity and extent of this deposition footprint is likely to be reduced significantly.

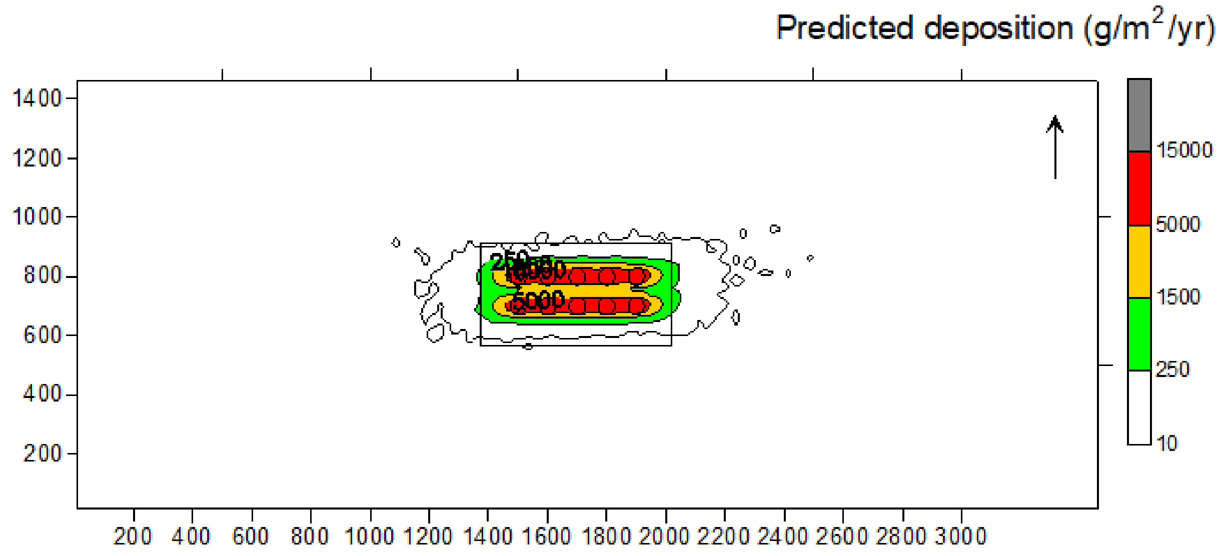

Figure 9: Depositional model for Choiseul Sound

Screening model predicted deposition using a feed input of 968 kg feed/cage/d (2,875 t maximum biomass) (resuspension model switched off). In detailed modelling with a resuspension model, the severity of this deposition footprint is likely to be moderately reduced.

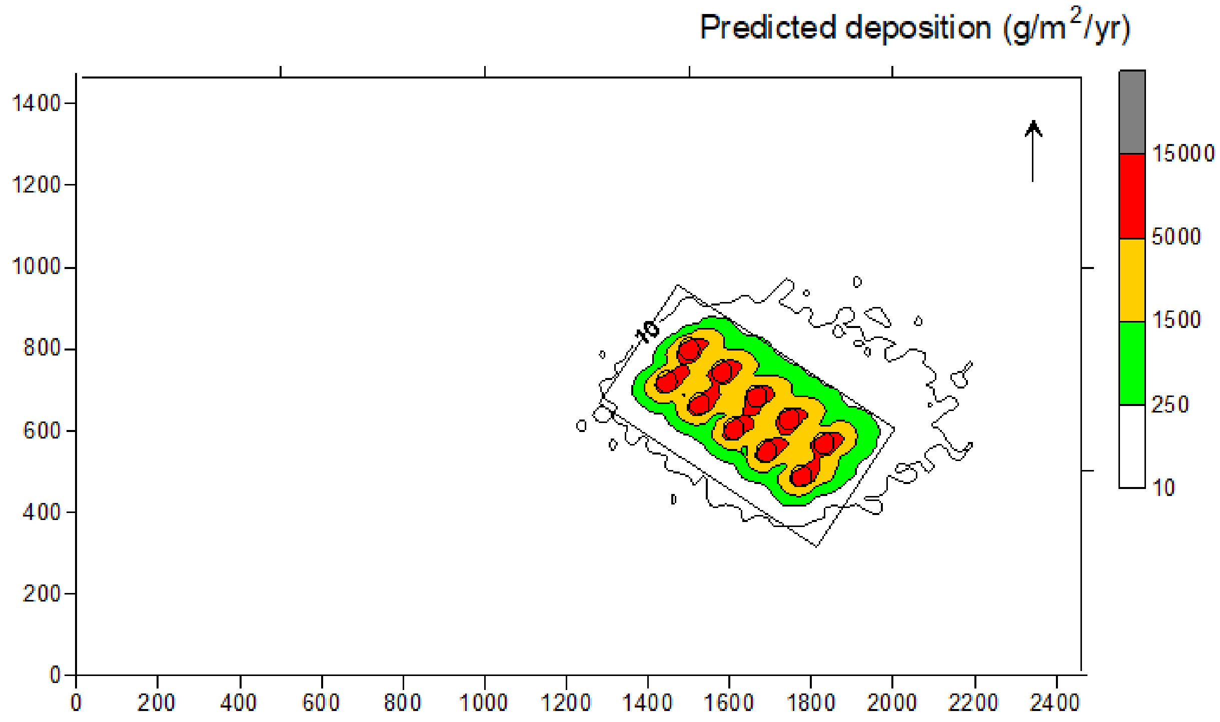

Figure 10: Depositional model for Grantham Sound

Screening model predicted deposition using a feed input of 842 (2,500 t maximum biomass) (resuspension model switched off). No or very minimal change would be expected with a resuspension model applied.

Appendix B – 'What if' management scenarios for Choiseul Sound and the effect on deposition footprint 'severity' and 'extent'

The following series 'what if' scenarios show screening model predictions of waste feed and faecal deposition footprints (g/m^2/yr), with the resuspension model switched off.

- Deposition footprint extent is defined by the 250 g/ m^2/yr contour – the outer limit of the green colour. The 100 m mixing zone is approximately shown by the rectangular box and is a 100 m distance from the cage edge. For the 2 by 5 cage layout (cages show as circles), the 100 m mixing zone has an area 227,500 m^2. For a site to pass the footprint extent criteria, the area enclosed in the 250 g/m^2/yr contour has to be less than the 100 mixing zone area. In all of the scenarios that follow for Choiseul Sound the extent criteria are passed.
- Deposition footprint severity is calculated from the average deposition contained within the 250 g/m^2/yr (i.e., what is the average deposition across the farm deposition footprint area). This has to be less than 2,000 g/m^2/yr for a sheltered to moderately exposed site. The red colour of 5,000 g/m^2/yr underneath the cages shows deposition that is tending towards causing moderate to high benthic impact. The 15,000 g/m^2/yr contour (grey colour) is undesirable and usually not seen in model predictions.

Farm biomass for these scenarios was kept constant at 2,300 t – a variable was then changed and the screening model re-run to show the effect on severity and extent. For this particular zone, severity is of interest because average current speeds are relatively low and so model predictions tended to show deposition close to cages.

The changes in severity and extent between scenarios are not that obvious from the contour plots in some scenarios. To quantify the differences between scenarios, we calculated the average severity and the extent. A short description was also given in the scenario caption to describe how severity and extent were affected. Maximum deposition was also calculated for comparison – this is not used in the Scottish regulatory modelling framework but is a useful indicator of predicted impact. The maximum deposition would be for one model grid cell – 25 m by 25 m which is about one third of a single cage surface area.

In the contour plots the scale along the *x* and *y* axis is in metres.

The 10 g/m^2/yr contour is shown to indicate the predicted outer limit that the smallest and slowest settling particles could reach from the cages (without resuspension). This very low level of deposition is much less than the expected natural sedimentation for Choiseul Sound. This contour, however, is sometimes useful for planning purposes.

Depth of water column is 31 m for the standard scenario in Choiseul Sound and surface, mid-water and near-bed average current speeds are 0.064, 0.054 and 0.069 m/s respectively. Net depth means the size of the net in the vertical dimension. So a net depth of 19 m means the net extends from surface to the bottom of the net at 19 m. No account of cone shape is necessary for screening modelling or these 'What If' scenarios. In most cases just one variable is changed between scenarios in the sequence.

An additional contour of 7,500 g/m^2/yr has been added to help distinguish between scenarios.

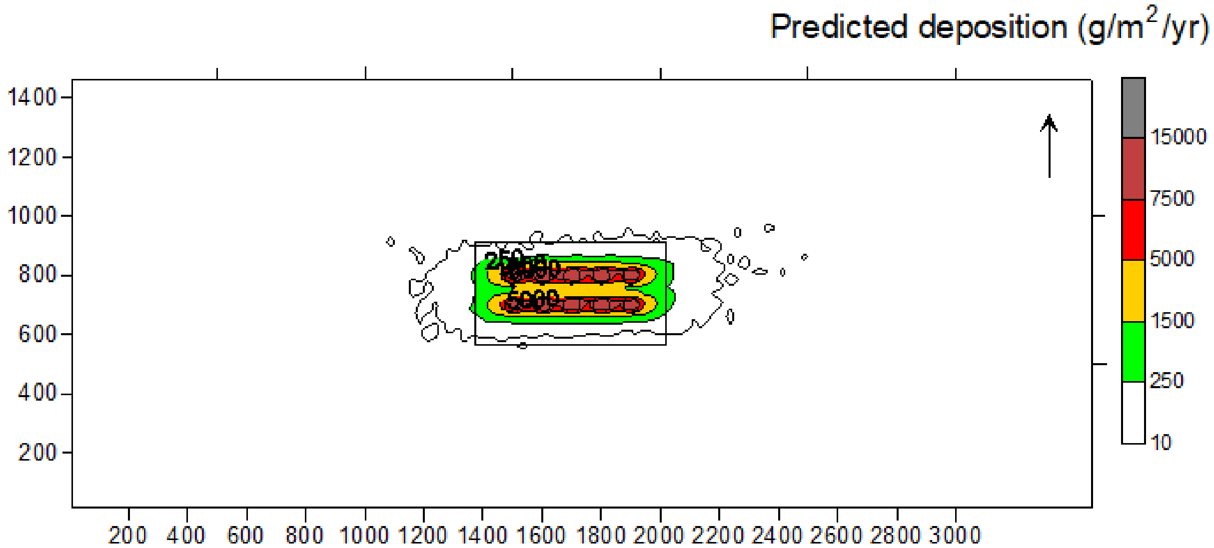

Figure 11: Predicted deposition footprint of deep nets (19 m)

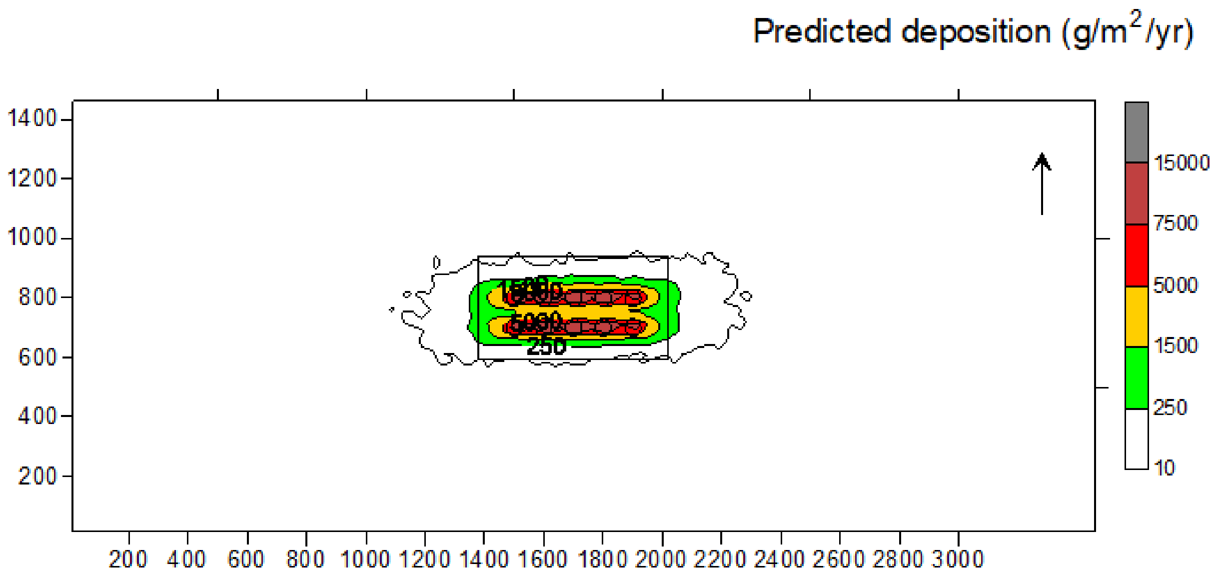

Figure 12: Predicted depositional footprint of shallow nets (12 m)

The extent is slightly more and severity slightly less because particles in the shallow nets are closer to the surface - the particles spend longer in the water column during settling. Shallow nets are used in this example as the standard scenario because of the recommendation that cage net depth should be one third of water column depth. 2% feed wasted was used as the standard scenario, which is the same used in the screening modelling assessments.

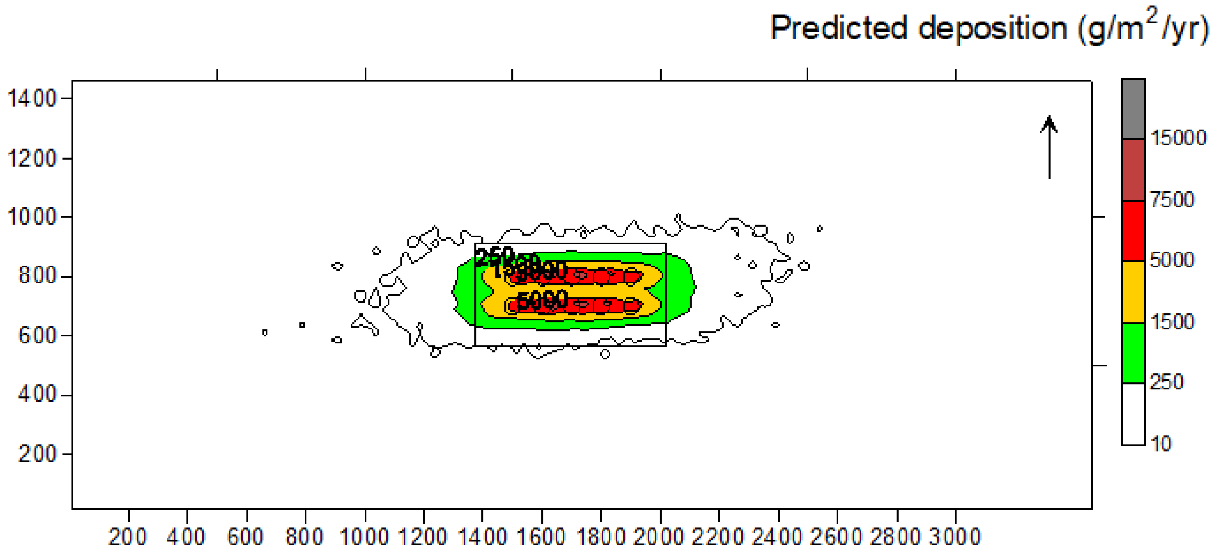

Figure 13: Water column depth 41 m

The extent of the footprint is increased in the above scenario, as shown by the green area extending to approximately 200 m. Severity is reduced shown by the almost complete absence of the purple colour (7,500 g/m^2/yr contour)

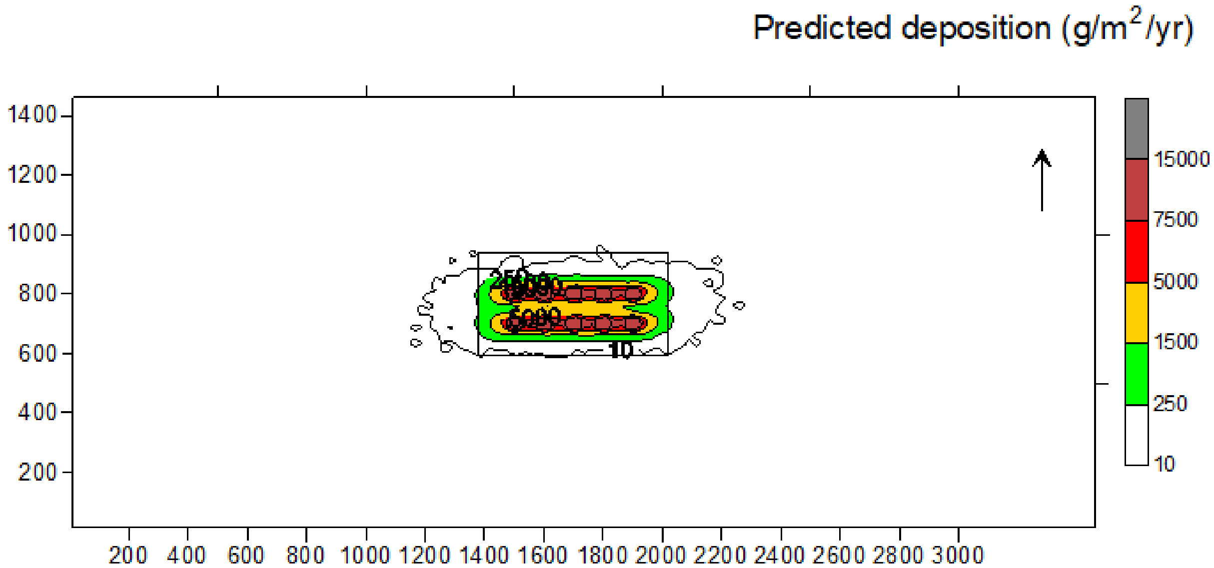

Figure 14: Water column depth 25 m

The extent of the footprint is decreased in the above scenario, and so therefore severity must be higher because biomass (and so feed input) is the same. The purple colour of the 7,500 g/m^2/yr contour has reappeared.

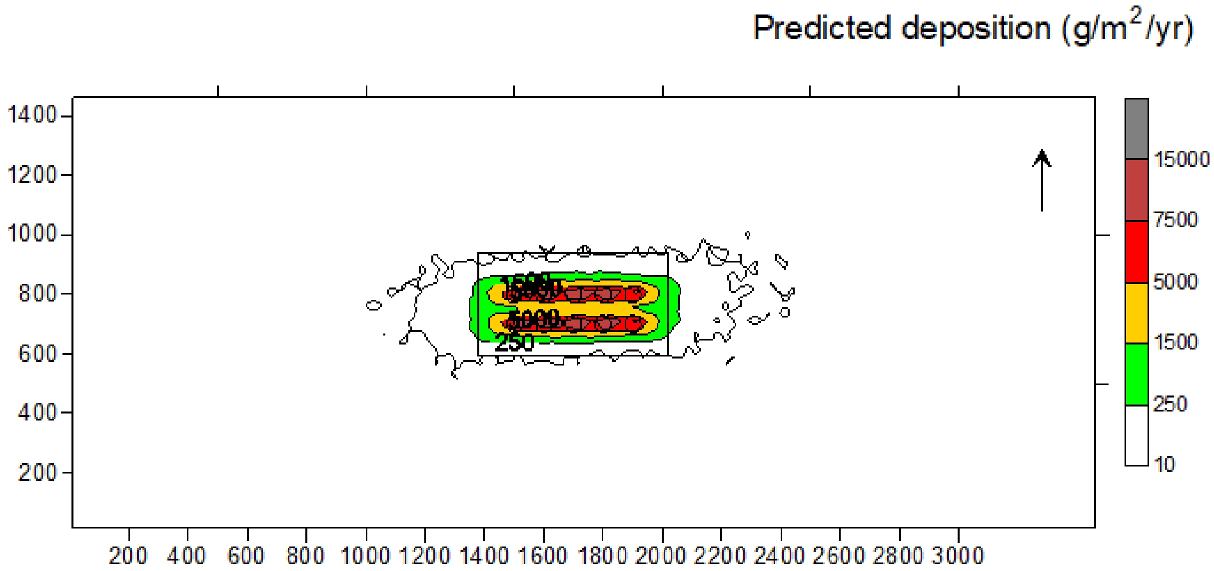

Figure 15: Feed wastage of 1.5%

With slightly less feed wasted, more feed is consumed and so slightly more faeces produced. So a slightly larger extent is shown in the scenario. Severity is reduced directly underneath the cages shown by the purple colour, which is only just joined up between 4 cages in each row, with the last cage in each row having no/minimal purple colour. In particular, maximum severity is reduced in this scenario.

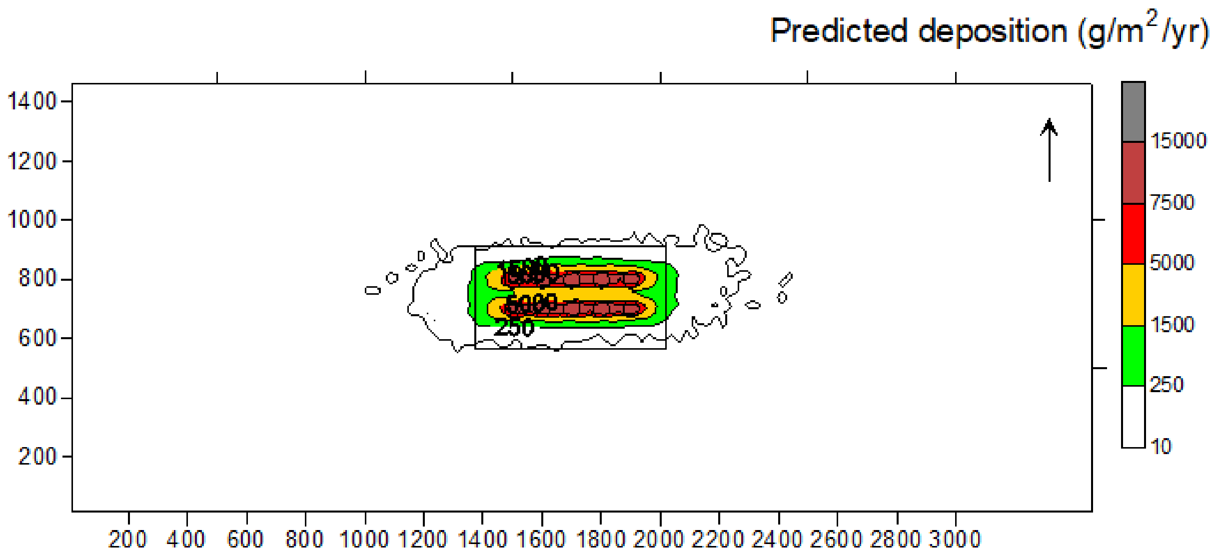

Figure 16: Feed wastage of 3%

There is a higher severity underneath the cages shown in this scenario with more purple coloured area (7,500 $g/m^2/yr$), joined up between cages.

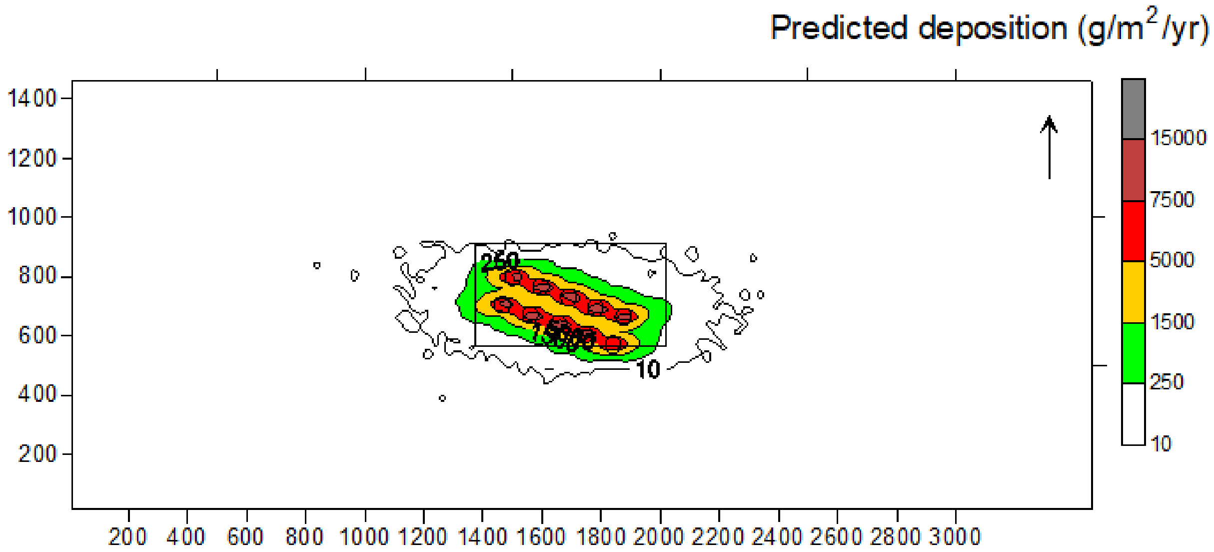

Figure 17: Cage group orientation changed by 20º

The cage group orientation has been changed in the above scenario, but current direction remains the same. This shows less severity underneath the cages as the current is passing through the group at an oblique angle (i.e., group orientation is not aligned with the current direction). This scenario shows that using both locally measured currents and site-specific group orientation in detailed modelling will give the most accurate predictions (i.e., there is some sensitivity in model predictions to cage orientation). In the screening modelling, we appropriately assumed that all sites within the same zone were orientated the same. Orientations were different between zones.

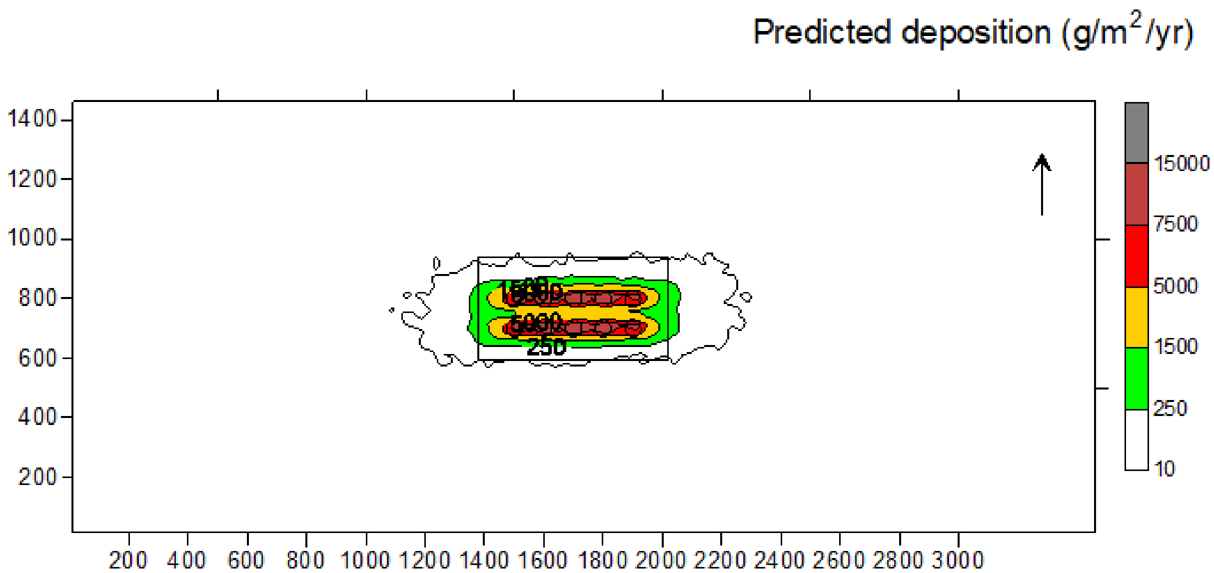

Figure 18: East-west cage group orientation

The same scenario as 'Shallow nets (12 m)' shown above, for comparison.