Modelling of the Proposed Salmon Farm at Little Colonsay

Part 2. Nutrients

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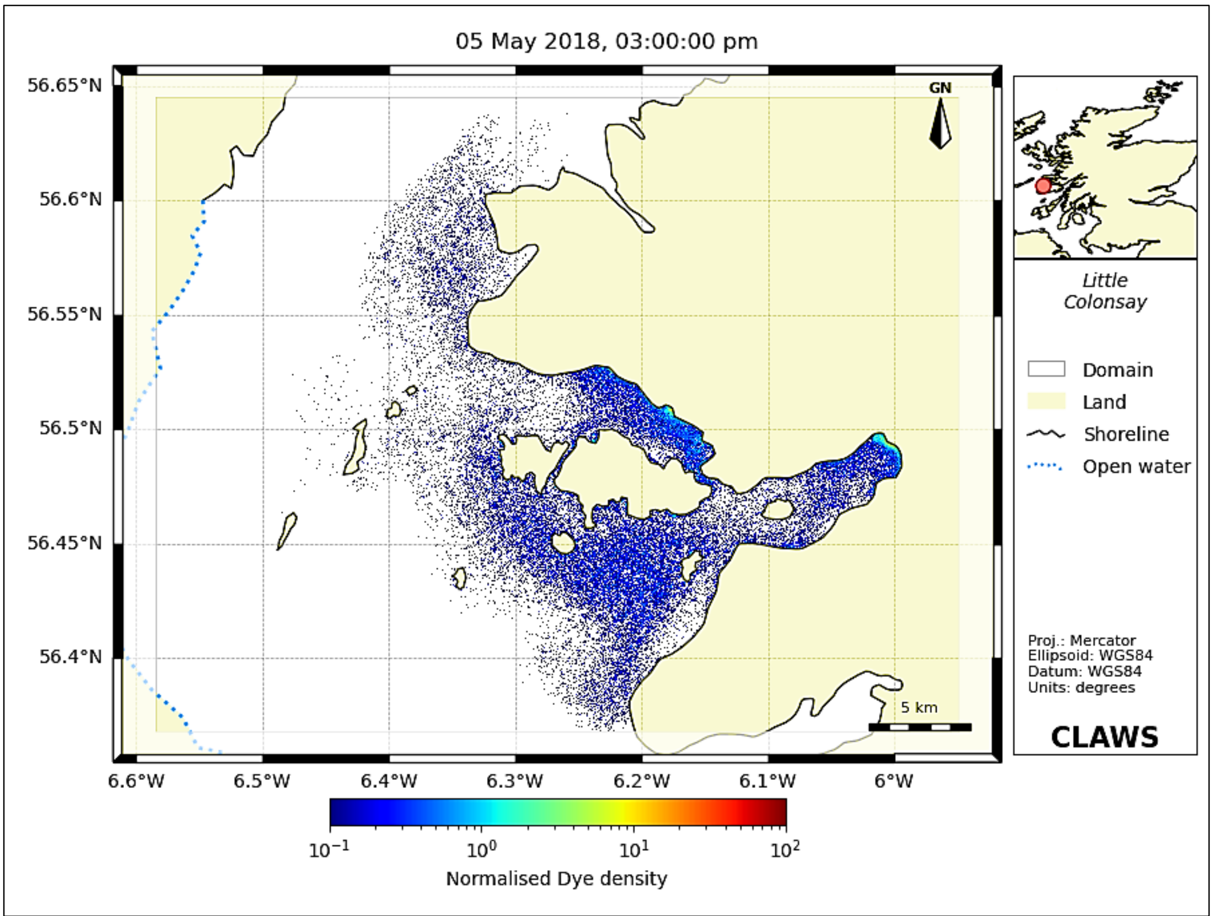

Executive Summary

A particle-based nutrients model has been developed and applied at the proposed Bakkafrost salmon farm near Little Colonsay. The nutrients model is part of a suite of particle-based, open-source modules known as CLAWS – Chemicals, Lice and Waste from Salmon Farms [CLAWS, 2023]. Other particle modules in the CLAWS repository include those to describe sea lice bath treatments and particulate waste deposition from finfish farms. The nutrients model calculates the sea area, mean height, volume and flushing time prior to deriving an equilibrium concentration enhancement (ECE) index for soluble nitrogen. A 3D hydrodynamics model based on the TELEMAC code is used to drive the particle-based flushing time calculation. The hydrodynamics model contains the influence meteorological forcing and of stratification brought about by freshwater inflows and air-water heat transfer. For the Lagrangian particle-tracking the open-source code OpenDrift [OpenDrift, 2023] has been used. Results show that the estimated flushing time is in broad agreement with previously published data.

About the Report Authors

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Tom is a chartered professional engineer with over 25 years' experience in applied computational mechanics. After a first degree in Environmental Engineering at the University of Strathclyde, Tom undertook a Ph.D in Vortex Shedding Flowmeter Pulsating Flow Computational Fluid Dynamics (CFD) Studies at the same university. Subsequently, he was awarded a JM Lessels scholarship from the Royal Society of Edinburgh for a one-year post-doctoral position at the Institute de Mécanique des Fluides de Toulouse, France in the field of numerical oceanography. The IMechE presented Tom with the Alfred Rosling Bennett Premium and Charles S Lake Award in 2003 for CFD in applied aerodynamics. In 2013 Tom returned from an EPSRC-funded sabbatical in the USA, where he carried out fundamental research in rarefied gas dynamics at the University of Michigan and the Lawrence Berkeley Laboratory in California. From 1994-2017 he was a Senior Lecturer in the Department of Mechanical and Aerospace Engineering at the University of Strathclyde specialising in heat transfer, fluid mechanics and applied CFD. His work is reported in over 50 refereed journal and conference publications. He is currently a director at the engineering consultancy firm MTS-CFD.

Dr Vincent Casseau *MSc PhD, Engineering Consultant*

Vincent is an engineering consultant with background experience in fluid dynamics and computer science. He obtained his Masters engineering degree in Aeronautics and Aerospace at ISAE-ENSMA, Poitiers, France. Following an internship at the European Space Agency, Vincent undertook a Ph.D in high-speed re-entry physics at the University of Strathclyde under the supervision of Dr Tom Scanlon, where he developed an open-source platform to solve hypersonic continuum and rarefied flows that has since been used in 15+ countries. Vincent was a Postdoctoral Fellow at McGill University in Montreal, Canada from

2019-2021, where he co-led the development of a monolithic software system to simulate hypervelocity civilian craft, partnering with Ansys and Lockheed Martin.

Dr Matt Stickland *BSc PhD CEng FIMechE, Engineering Consultant, MTS-CFD.com*

After a first degree in Aeronautical Engineering at the University of Manchester, Matt worked for BAE Systems (Military Aircraft) at Warton in Lancashire in the Wind Tunnel Department working on projects which included EAP, EFA (Typhoon), Tornado and HOTOL. After leaving BAE in 1990 Matt worked for YARD Consulting Engineers in Glasgow modelling the heat and fluid flows in Advanced Gas Cooled reactors during on-load refuelling. In 1991 Matt accepted a senior lectureship in the Department of Mechanical Engineering at the University of Strathclyde where his research interest covered both experimental and computational heat transfer and fluid dynamics. He was awarded a PhD for his research into 3D imaging and its application to fluid flow visualisation. For his research in the field of experimental and computational fluid dynamics he was awarded the 2003 AR Bennett Premium/CS Lake Award and the 2004 T A Stewart-Dyer Prize/Frederick Harvey Trevithick Prize from the Institute of Mechanical Engineers. In 2022 Matt left the University of Strathclyde to take a directorship with the Engineering consultancy firm MTS-CFD. Matt is a Chartered Engineer and a Fellow of the Institute of Mechanical Engineers. He has published his research in over 100 papers in refereed journal and conference proceedings.

1 Introduction and motivation

This report has been prepared for Simon Cowell, by engineering consultants MTS-CFD, as part of hydrodynamic modelling services to consider the impact of nutrients emanating from existing and proposed fish farms on the West Coast of Scotland.

Operational fish farms have the potential to affect the marine environment in several ways, via the release of waste in the form of dissolved nutrients, particulate organic matter, pesticides and live parasitic salmon lice.

The report describes the application of a particle-based nutrients model to determine sea area, mean height, volume and flushing time prior to deriving an equilibrium concentration enhancement (ECE) index for soluble nitrogen [GILL, 2002]. The nutrients model is part of a suite of particle-based, open-source modules known as CLAWS – Chemicals, Lice and Waste from Salmon Farms [CLAWS, 2023]. Other particle modules in the CLAWS repository include those to describe sea lice bath treatments and particulate waste deposition from finfish farms.

A 3D hydrodynamics model based on the TELEMAC code [Scanlon_A, 2023], [Scanlon_B, 2023] is used to drive the particle-based flushing time calculation. The hydrodynamics model contains the influence of weather forcing and stratification through the salinity and temperature fields.

Previous work on flushing times has been based on yearly estimates of sea loch volumes derived from Admiralty chart data and a maximum tidal range that is assumed to exist continually throughout the year [Edwards, 1986]. This yearly-based approach will produce general guidance on flushing times but it cannot adequately take into account the local effects of complex bathymetry (sills), littoral topography, weather forcing, stratification, cumulative effects of nutrients emanating from different water body types such as sea lochs/open sea zones and variations in the tidal range due to the spring/neap tidal cycles throughout the year. The authors [Edwards, 1986] also state that possible errors may exist where bathymetry data is sparse, as in and around many of the sea loch sills.

The work proposed in our new model represents a more physically realistic approach. We take account of the fact that flushing times, and hence ECE values, will vary according to the time of year due to variations in the spring/neap tide cycles. We propose that an average value of the tidal range during the period of the study should be used as opposed to the maximum and minimum values. Using maximum and minimum values for the tidal range will lead to shorter flushing times and a non-conservative estimate of the ECE index.

2 Background data

2.1 *Site location*

The proposed site location of the Bakkafrost salmon farm is off the West coast of Mull, adjacent to the island of Little Colonsay as shown in Figure 1.

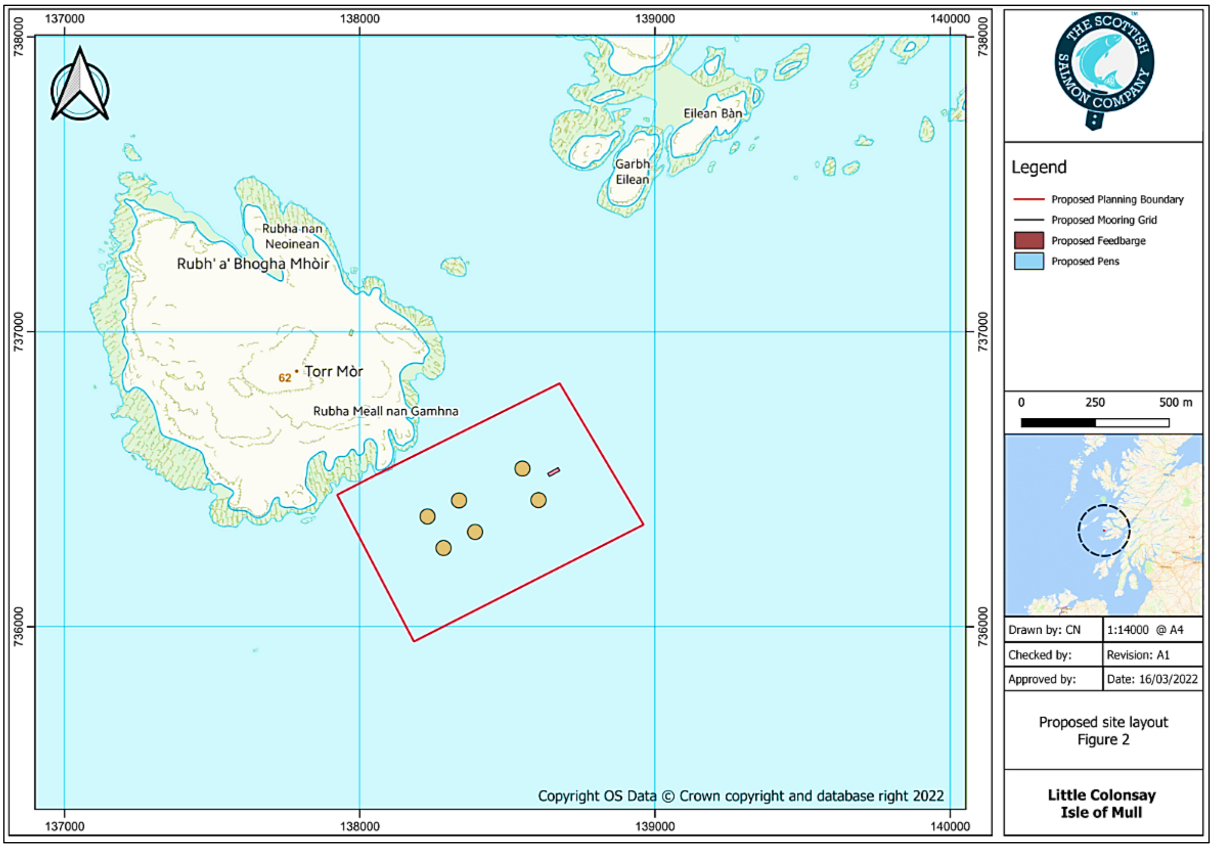


Figure 1 *Geographic location of the proposed Bakkafrost salmon farm at Little Colonsay (inset on lower right shows the general location).*

2.2 *Hydrodynamic model*

The hydrodynamic data used to determine the flushing times is based on a 3D, non-hydrostatic Telemac model of the West Coast of Scotland, the extent of which is shown in Figure 2. 10 terrain-following vertical sigma layers are applied in the model and it also includes the influence of meteorological forcing and stratification due to freshwater inflows and atmosphere-water heat exchange. Extensive validation and verification tests have been undertaken against physical data and inter-model comparisons with the Scottish Shelf Model (SSM) results [Scanlon_A, 2023], [Scanlon_B, 2023] and at Little Colonsay itself [MTS_CFD_hydro_LC, 2023]. Particle number and time-step sensitivity analyses were carried out until there was an insignificant change in the predicted flushing time (< 1%). The final particle number employed was 200,000 and a time-step of 300 s was used. Details of the nutrient modelling process can be found at [CLAWS_NUTRIENTS, 2023] and a summarised version of the methodology is provided in this report.

2.3 *Bathymetry data*

The bathymetry data for the present study have been collected from a range of different sources including publicly available data sets provided by Marine Scotland for the Scottish Shelf Model [SSM, 2023], digitised Admiralty charts and bathymetry information from the UK's Digimap Ordnance Survey Collection [DOSC, 2023]. The bathymetry used in the model is shown in Figure 3.

2.4 *Particle-tracking*

For the Lagrangian particle-tracking the open-source software OpenDrift has been used [OpenDrift, 2023].

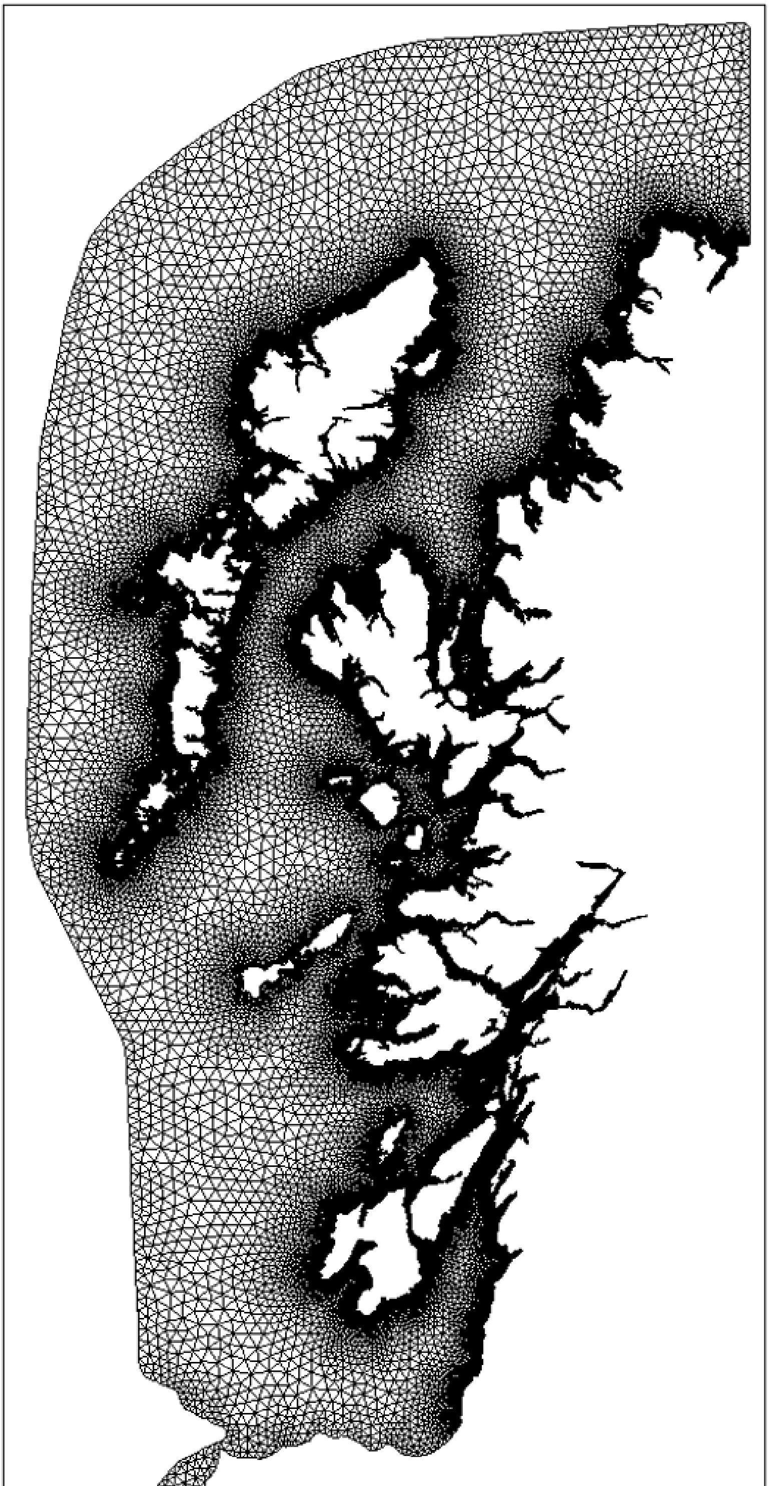


Figure 2 *Telemac 3D hydrodynamic mesh and model extent.*

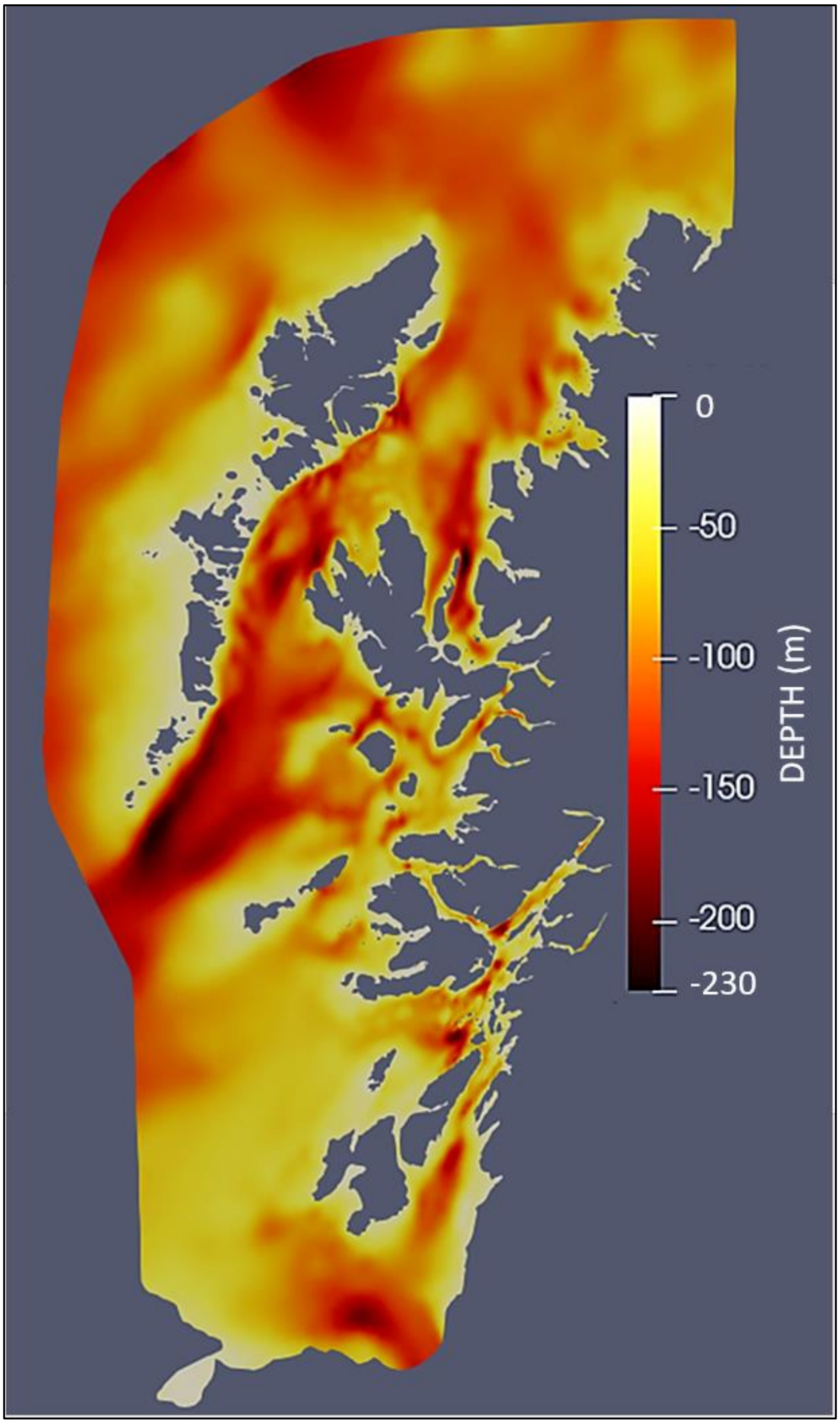


Figure 3 *West Coast model bathymetry (m).*

3 Methodology

3.1 *Shoreline database*

The shorelines delineating land and water areas are obtained from the GSHHG (Global Self-consistent, Hierarchical, High-resolution Geography) database [WESSEL, 1996]

[DAGESTAD, 2018] and the highest possible resolution has been applied. This allowed the shorelines and computational mesh to be constructed using the freely-available BlueKenue software [BLUEKENUE, 2011] with results shown in Figure 4. The mesh employed in the nutrients study is a sub-set of the larger hydrodynamics model shown Figure 2. For details of the sub-set modelling approach see [CLAWS, 2023] and [MTS_CFD_hydro_LC, 2023].

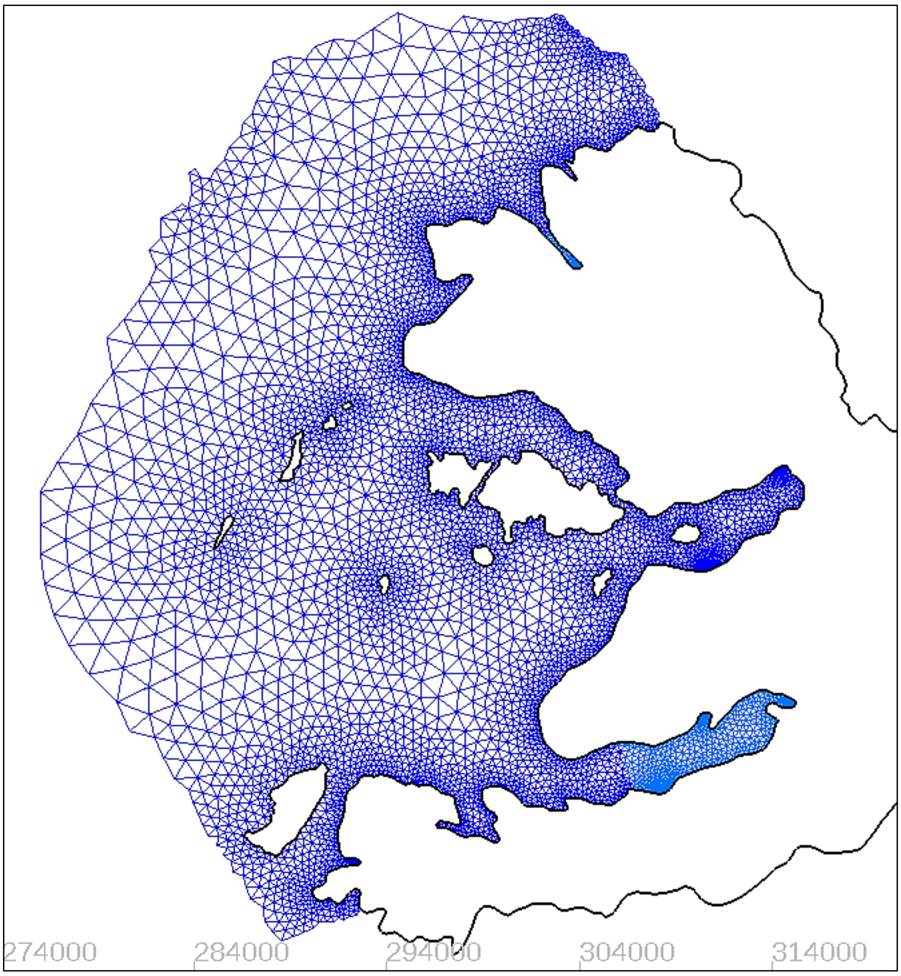


Figure 4 *Shorelines and reduced size 3D computational mesh in the Little Colonsay area.*

3.2 *Particle seeding in CLAWS*

The format JSON (JavaScript Object Notation) [JSON, 2023] is used to select the control and seeding areas for the flushing time calculation. JSON is a lightweight file format storing text as a series of keywords – value pairs and its extension GeoJSON conveniently encodes geographic data structures. The website http://geojson.io/ allows the user to draw a polygon around the geographic area of interest. The example of Little Colonsay is shown in Figure 5 and the polygon is saved in GeoJSON format.

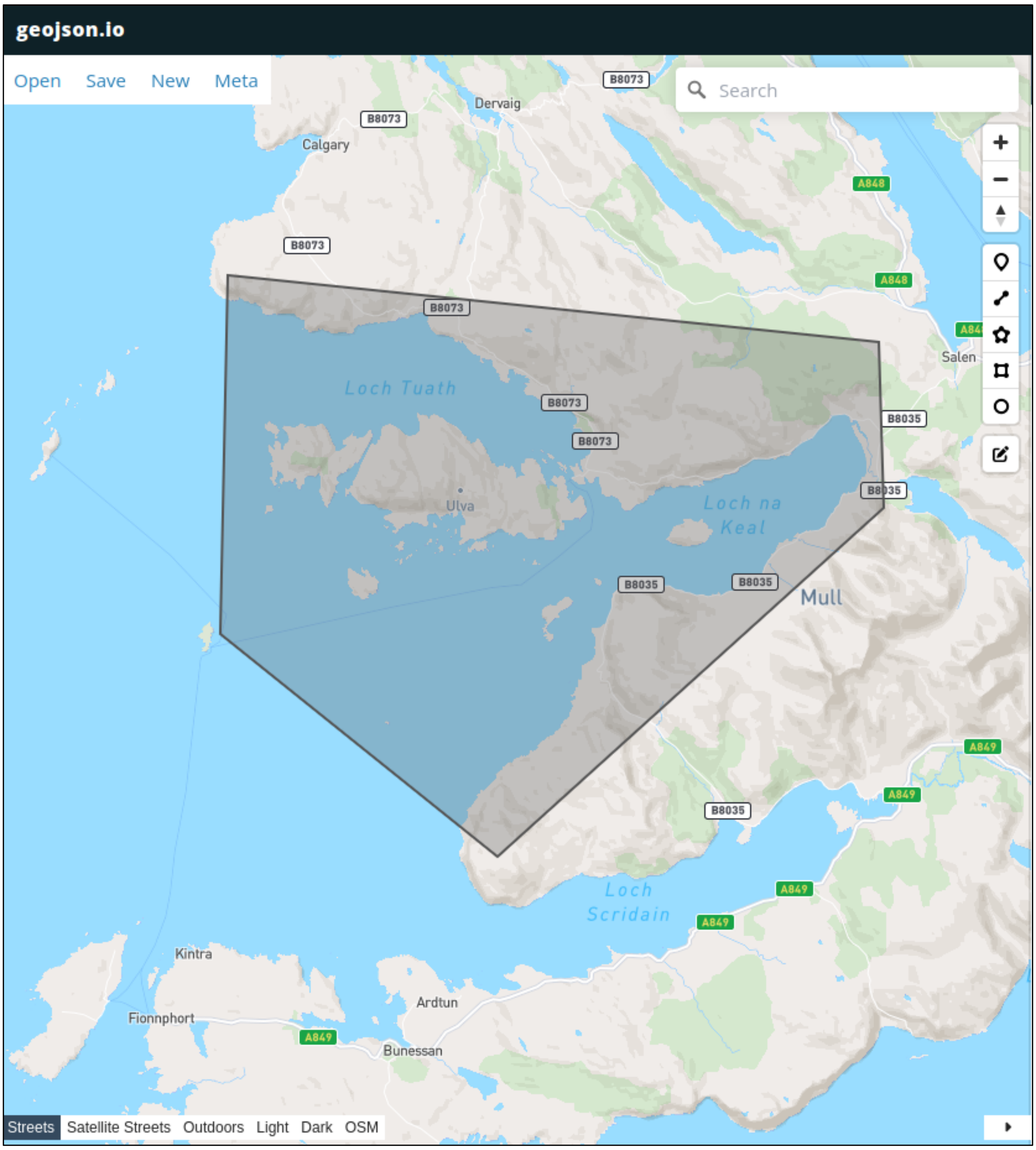


Figure 5 *Control area polygon drawn around Little Colonsay using* http://geojson.io/.

The area was selected in order to incorporate the 4 salmon farms currently in operation in the area in addition to the proposed farm at Little Colonsay. The farm locations are shown in Figure 6 and the biomasses, taken from the SEPA screening document [SEPA_SCRN, 2023], are shown in Table 1. The total biomass in the system for all 5 farms was 8,337 tonnes.

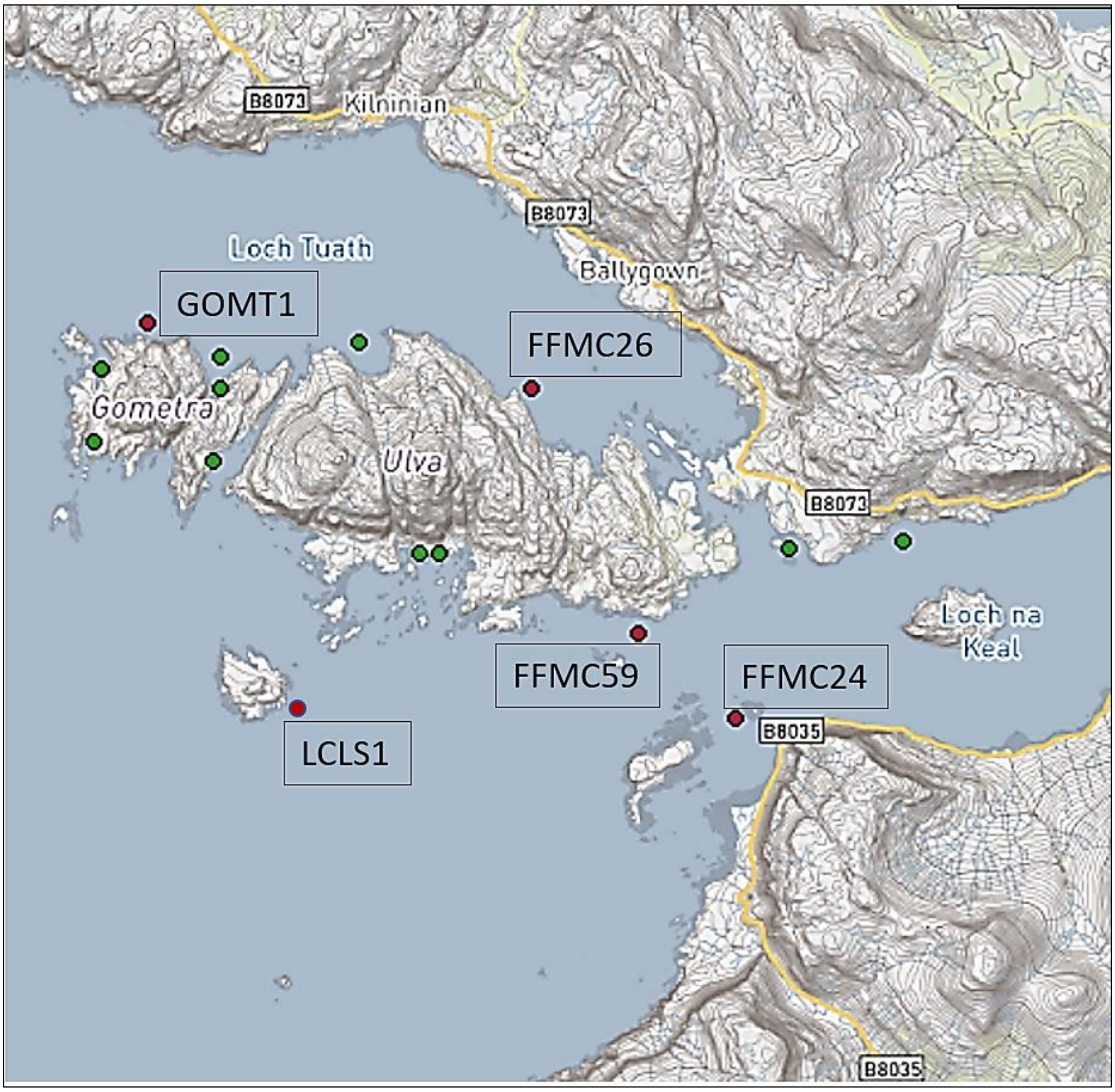


Figure 6 *Location of the 5 salmon farms in the nutrient control area highlighted by red dots. Green dots are active shellfish farms. Farm locations taken from [AQUA_SCOT, 2023].*

Table 1 *Salmon farm biomasses in the nutrient calculation [SEPA_SCRN, 2023].*

Site ID	Name	Biomass (tonnes)
LCLS1	Little Colonsay	2773
GOMT1	Gometra	1944
FFMC26	Tuath	850
FFMC24	Inch Kenneth	270
FFMC59	Geasgill	2500

The polygon coordinates are decoded using Python's *json* package and the control area is computed by interrogating the mesh in OpenDrift. Particles are seeded randomly in each of the mesh elements that are fully inside the seeding areas, which in this example is set to be the control area, and the target number of particles per element is a function of the total number of particles to insert and the element to seeding area ratio. The initial locations of the 200,000 randomly seeded particles are shown in blue in Figure 7, although they can't be individually distinguished.

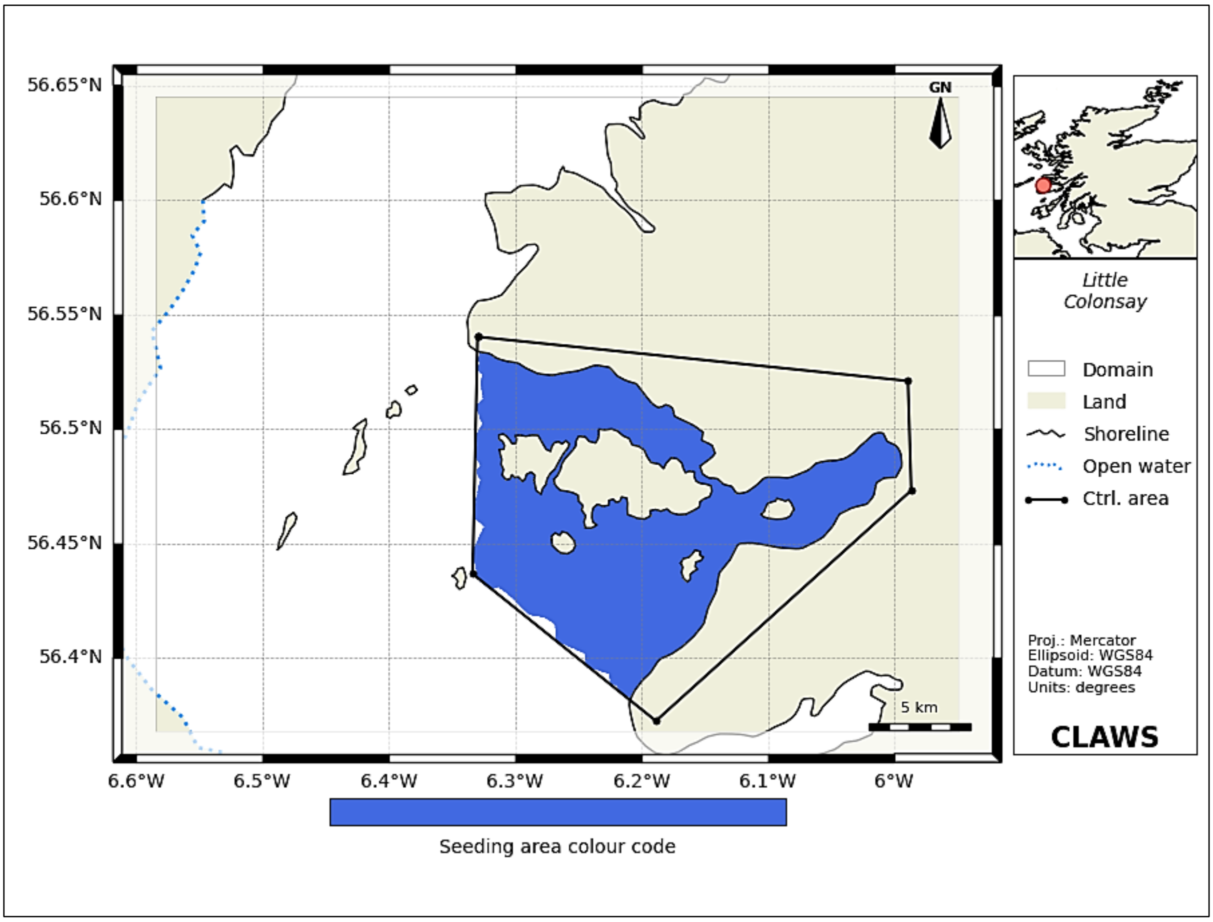


Figure 7 *Random initial particle generation within the bounds of the json control area (see Fig. 5) in CLAWS.*

The flushing time is defined as the time taken for 63% of the particles to leave the original polygon zone [PARTRAC, 2020], [MONS, 2002].

4.3 *Setting up and running the case*

4.3.1 *Using the pre-processing script to calculate the sea area, mean depth, volume and tidal range*

As discussed in section 1, using the maximum and minimum values for the tidal range over a year will lead to an under-estimation of the flushing time, i.e., a shorter flushing time. It is more appropriate to use the average tidal range over the period of the study concerned. In this instance the study period is from the 2nd-19th May 2018 and covers the neap tide cycle.

The CLAWS pre-processing Python script calculates the system area, mean depth and tidal range with the results shown in Figures 8 and 9. The area, mean depth and tidal range were calculated as 141.84 km^2, 19.39 m and 2.286 m, respectively. For further details on the calculation methodology see [CLAWS, 2023]. The user then includes these values in the Python run script to calculate the flushing time for the system.

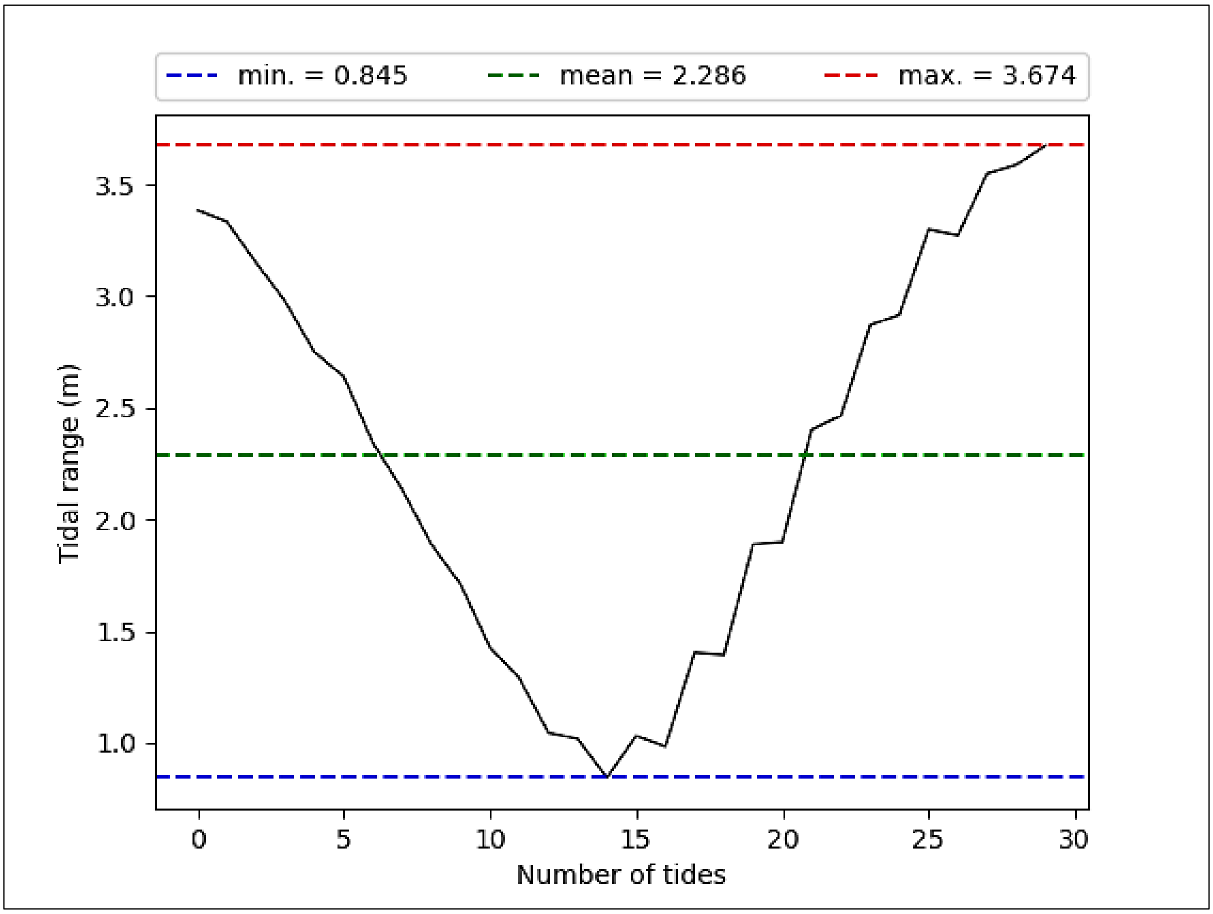


Figure 8 *Tidal range (m) graph at the proposed farm location for the period 2nd-19th May 2018.*

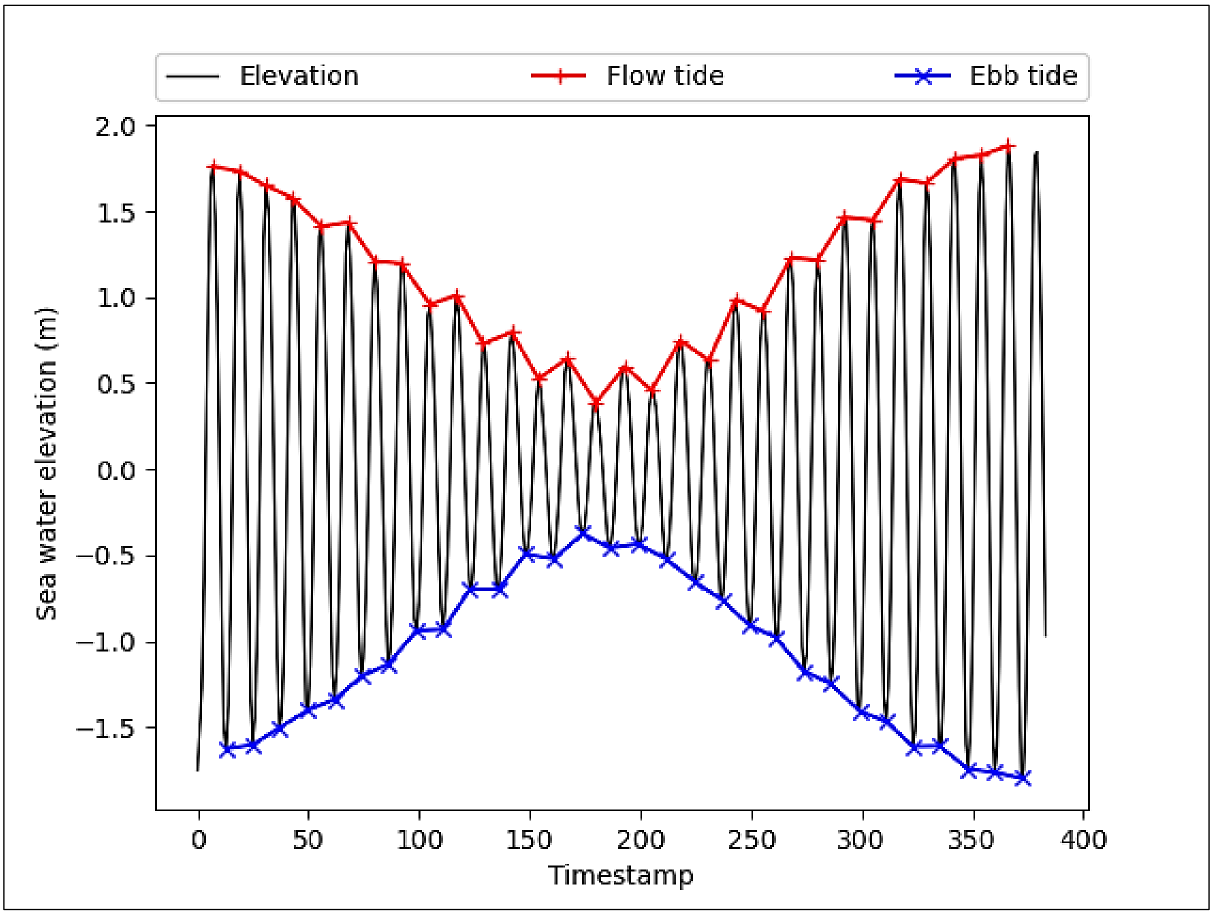
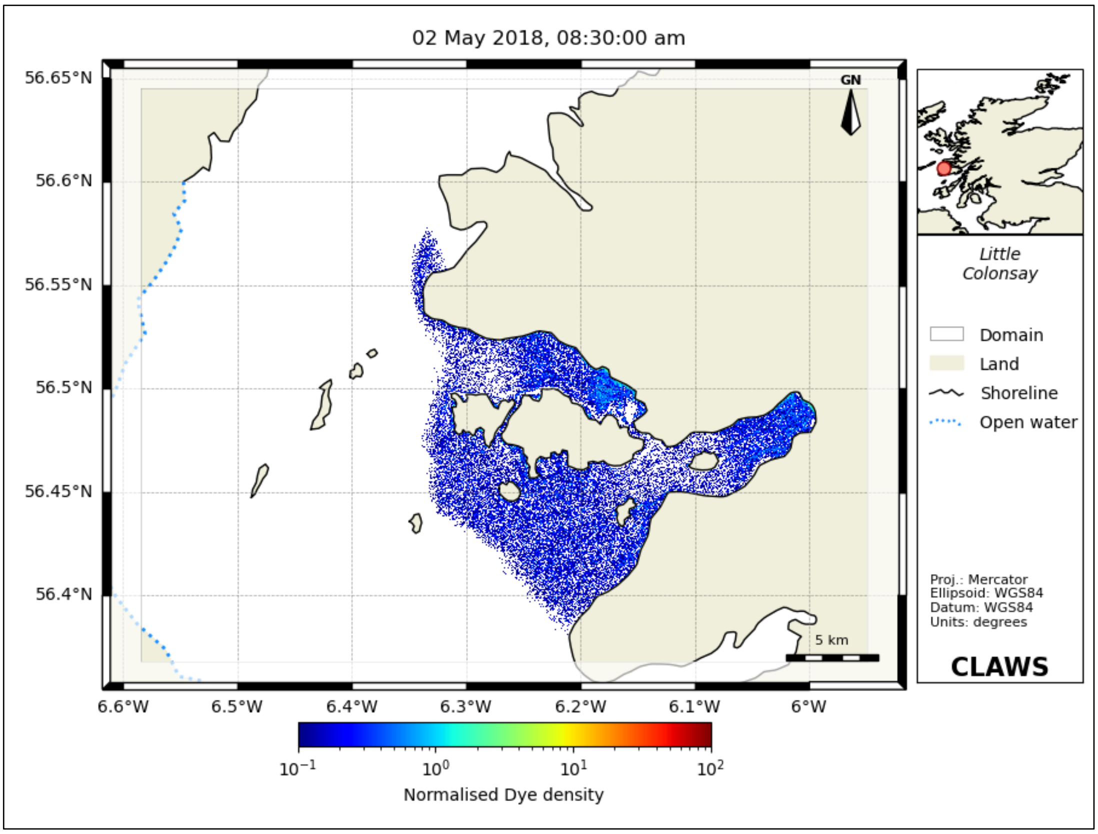


Figure 9 *Sea water elevation (m) graph at the proposed farm location for the period 2nd-19th May 2018.*

4.4 *Results*

Figure 10 shows snapshots of the dispersion patterns of the 200,000 particles used in the flushing time study. The Loch/open sea system is seen to flush mainly to the west, with exiting particles then heading northwards in tidal pulses. Note that the units in these plots are arbitrary for this flushing time study and they represent the concentration of particles in a sampling box of surface area 20 m × 20 m and depth extending down to the sea bed. The concentration plots are also normalised using the maximum initial concentration.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56.65°N
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5 km
Little Colonsay
Domain
Land
Shoreline
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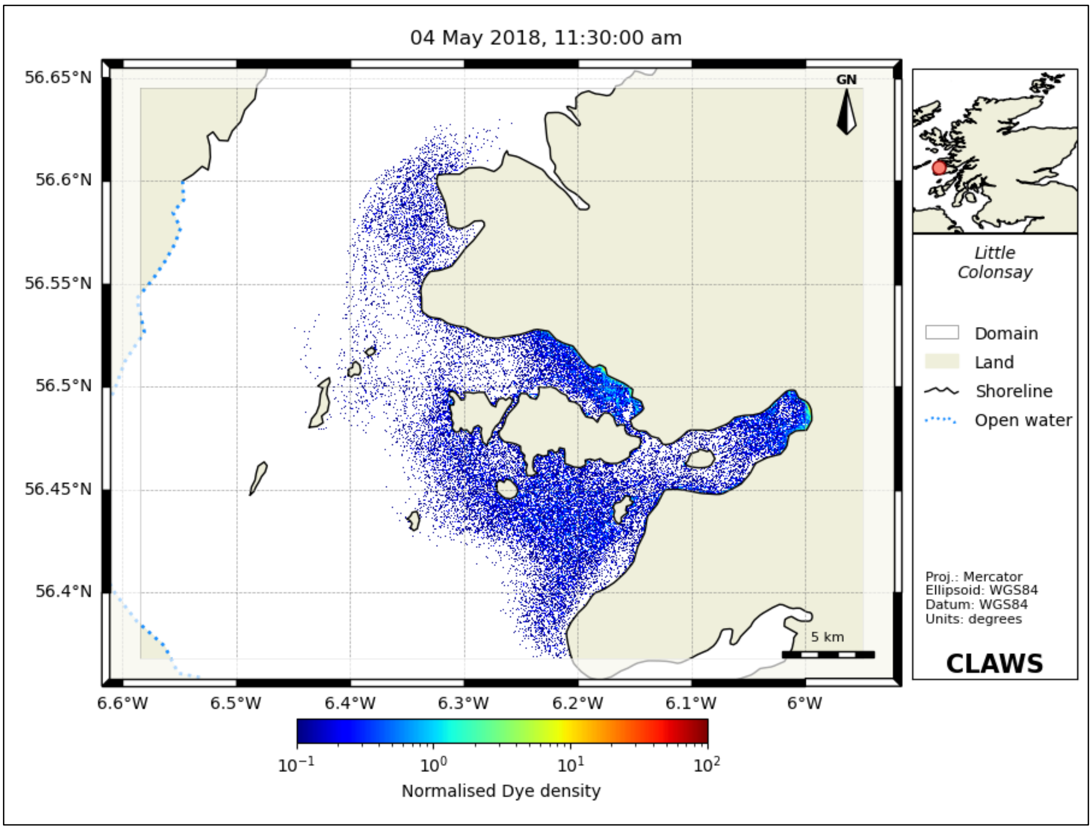
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Open water
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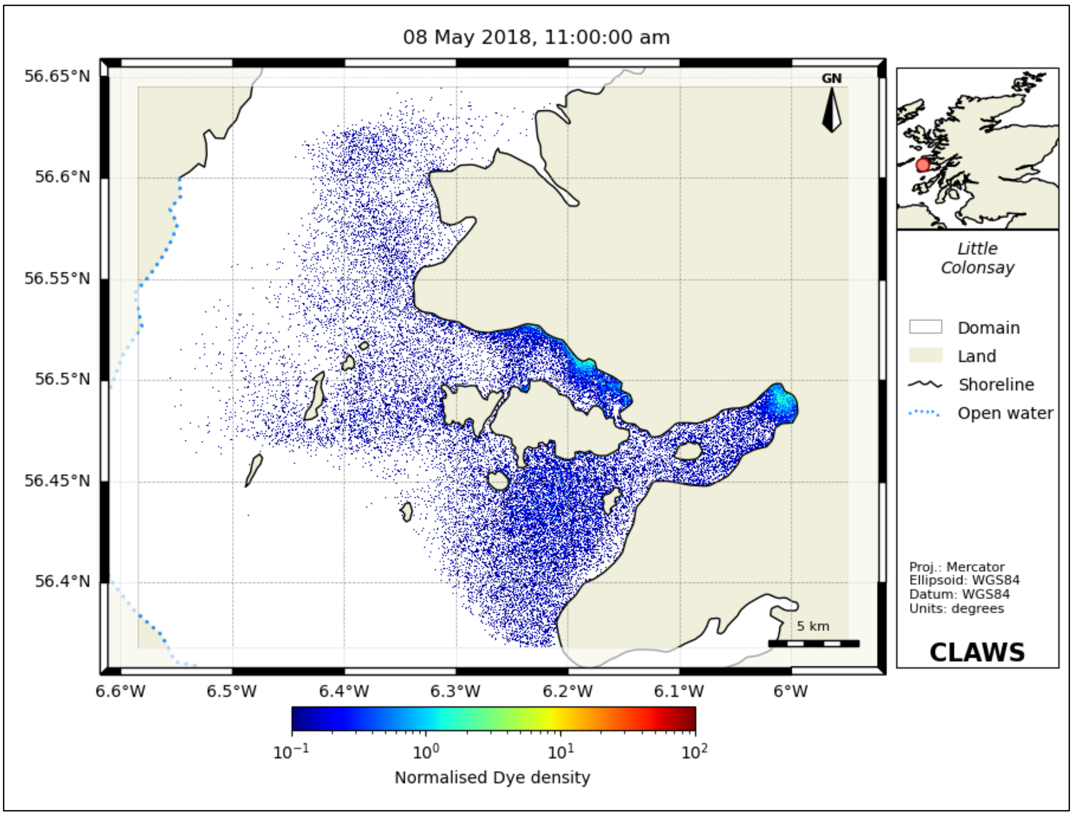

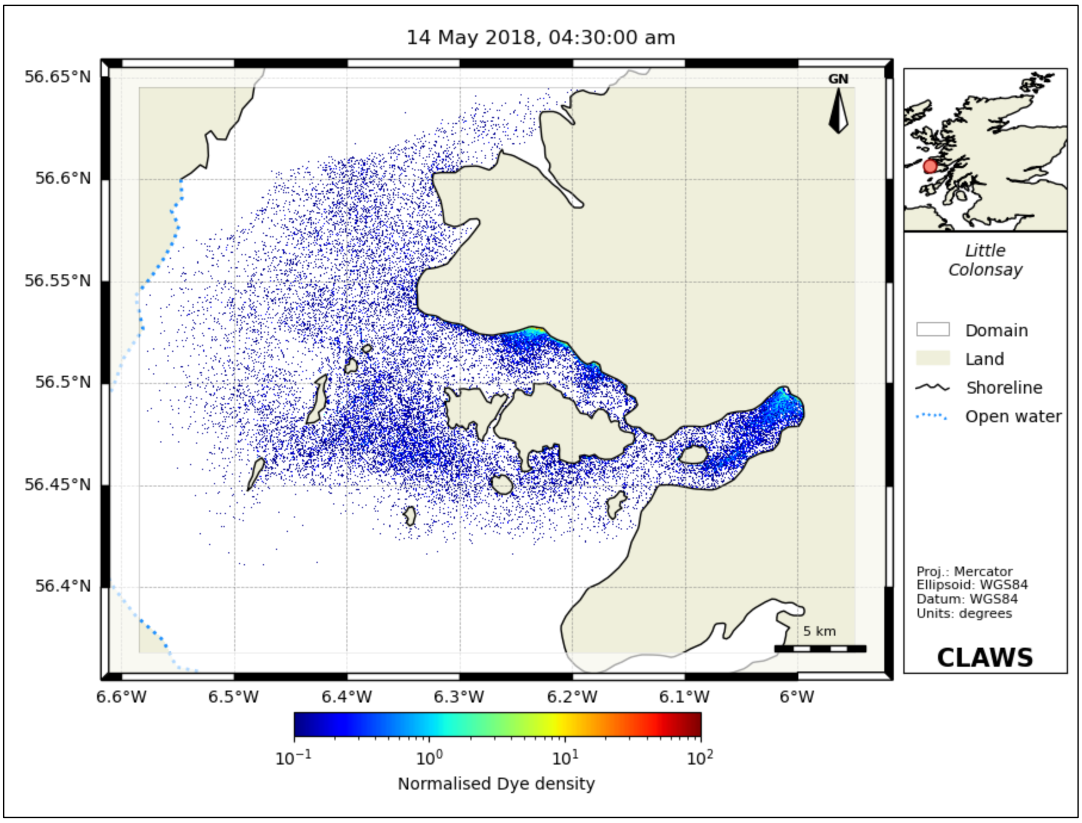

Figure 10 *Snapshots of particle dispersion in the Little Colonsay system.*

The flushing time, defined previously as the time taken for 63% of the particles to leave the original polygon zone [PARTRAC, 2020], [MONS, 2002], was calculated to be 16.46 days as shown in Figure 11.

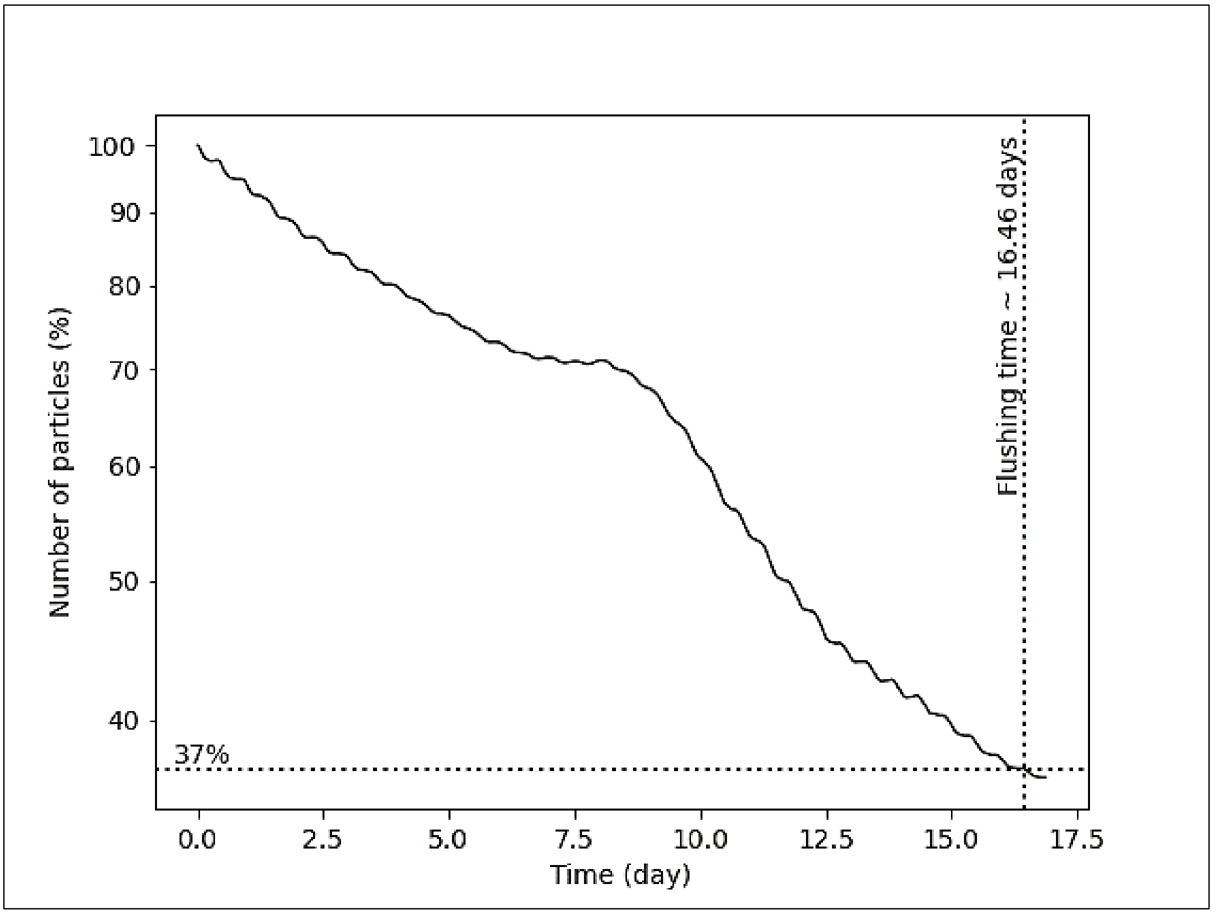

Figure 11 *Graph showing flushing time calculation of 16.46 days.*

The ECE index has been calculated as follows, based on *[GILL, 2002]*:

System area = 141.84 km^2

System mean depth = 19.39 m

System Volume = 2,750 Mm^3

Mean tidal range = 2.286 m

Flushing time = 16.46 days

Yearly flushing rate = (365/16.46) × 2,750 × 10^6 = 60,981 Mm^3/yr

Q = 60,981 flushing rate Mm^3/yr

S = 48.2 kgN/biomass tonnage per year

M = 8,337 Biomass tonnage per year (total for all farms in the Little Colonsay system)

ECE = S × M/Q = (48.2 × 8,337)/60,981 = 6.59 µg/L

ECE = 0.47 µmol/L

ECE index = 2, as defined in Table 2 [GILL, 2002]

Table 2 – *Equilibrium Concentration Enhancement (ECE) Index [GILL, 2002]*

Nutrient Concentration Level (µmol/L)	ECE Index
>10	5
3-10	4
1-3	3
0.3-1	2
<0.3	1
0	0

6. Conclusions

A particle-based nutrients model has been developed for application in salmon farms in semi-enclosed sea lochs and open sea areas. The nutrients model is part of a suite of particle-based, open-source modules known as CLAWS – Chemicals, Lice and Waste from Salmon Farms [CLAWS, 2023]. Other particle-based modules in the CLAWS repository include those to describe sea lice bath treatments and particulate waste deposition from finfish farms. The nutrients model calculates the sea area, mean height, volume and flushing time prior to deriving an equilibrium concentration enhancement (ECE) index for soluble nitrogen. The model is capable of handling multiple zones of interconnected sea areas in a combined ECE calculation. A 3D hydrodynamics model based on the TELEMAC code [CLAWS, 2023] has been used to drive the particle-based flushing time calculation. The hydrodynamics model contains the influence of meteorological forcing and stratification brought about by freshwater inflows and atmosphere-water heat exchange. For the Lagrangian particle-tracking the open-source code OpenDrift [OpenDrift, 2023] has been used. Results show that the calculated flushing time in the Little Colonsay system was 16.46 days. This led to the determination of a soluble nitrogen ECE index value of 2 for the salmon farm biomass of 8,337 tonnes in the system.

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