Modelling of the Proposed Salmon Farm at Little Colonsay

Part 1. Hydrodynamics

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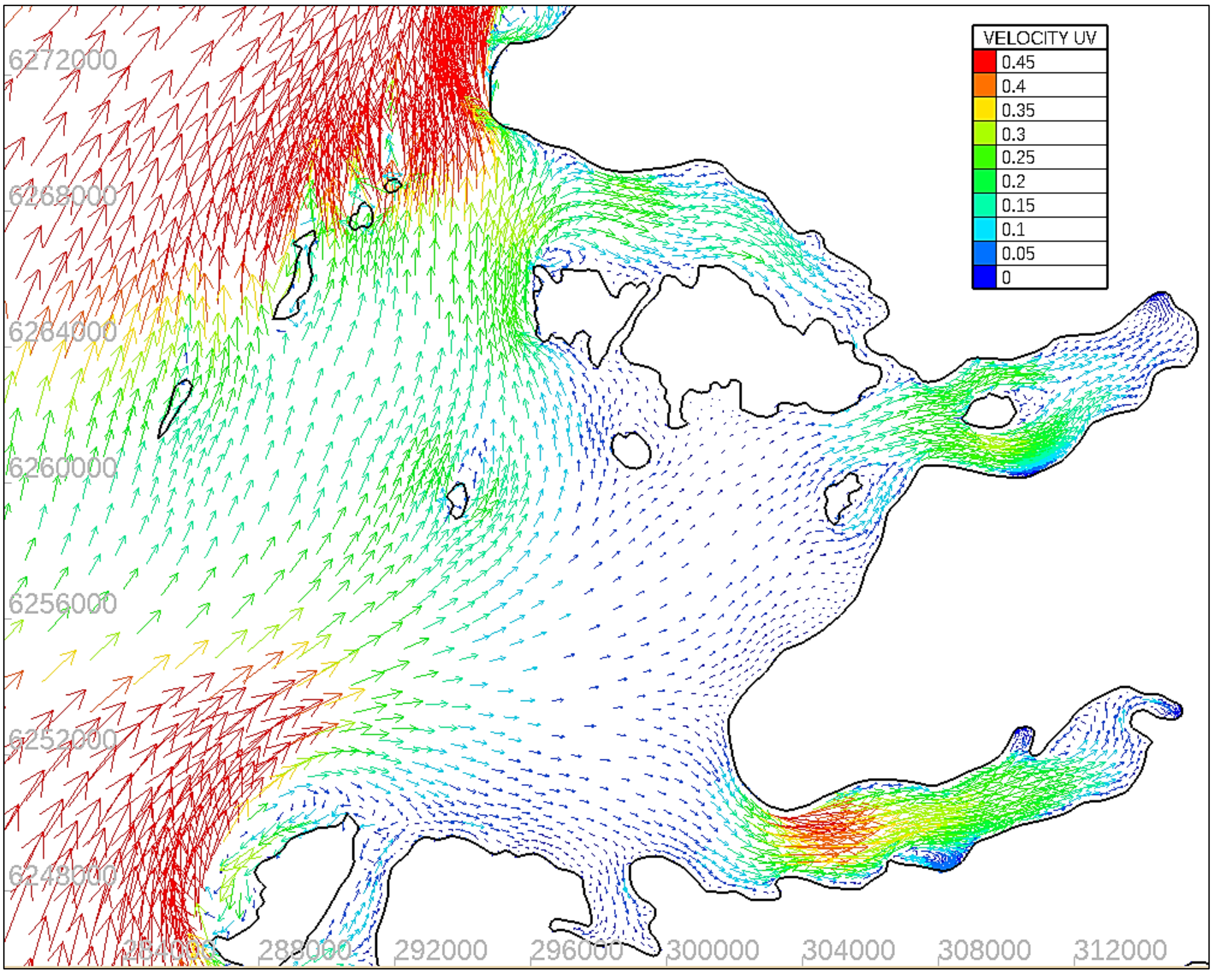

Executive Summary

Two- and three-dimensional hydrodynamic (HD) models of the West Coast of Scotland have been constructed using the Telemac code [TELEMAC, 2023]. The 3D model domain extends from the Mull of Kintyre in the South to Cape Wrath in the North and includes all main islands of the West Coast. The 2D model in this report is a smaller subset of the larger 3D case. Model validation for both 2D and 3D has been reported elsewhere [SCANLON_A, 2023], [SCANLON_B, 2023] and this report focuses on further validation of the 2D model against physical observations at Little Colonsay.

The influence of meteorological wind forcing on the modelled current speeds was included for the time of year of the study. Coriolis force for Earth spin and sea-bed friction were also included in the model. In the 2D case, sea-bed friction and TELEMAC-specific calibration parameters were varied in order to calibrate the model against physical observations.

The 2D model has been validated against published observed hydrographic data (water current speed and direction) at Little Colonsay. These data were lifted from the current surveys performed by the salmon farm operator Bakkafrost (formerly known as The Scottish Salmon Company (SSC)).

The models correctly simulate the propagation of the tide over the West Coast and provide a reasonable description of the flow currents at Little Colonsay in terms of current magnitude and direction. In general, the model data compares favourably against the SEPA calibration/validation requirements for hydrodynamic and discharge modelling [SEPA, 2019]. Python scripts have been written to allow the direct comparison of observed and modelled data as part of the open source platform CLAWS – Chemicals, Lice and Waste from Salmon Farms [CLAWS, 2023]. Other modules in the CLAWS toolbox include those for pesticide treatments, dissolved nutrients and solid particle feed waste.

With this report and other validation studies [SCANLON_A, 2023], [SCANLON_B, 2023] it is concluded that the TELEMAC hydrodynamic models can capture the general dynamics of the water levels and current circulation around the West Coast of Scotland with a specific focus in this report on model validation at Little Colonsay.

The models offer general insight into the spatial and temporal variation in the flow environment around the West Coast of Scotland. They also provide a suitable basis for modelling sea lice impact on wild salmon and sea trout and an assessment of both the near-field and far-field dispersion effects of lice treatment pesticides, feed waste and dissolved nutrients.

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 sea lice, pesticides, nutrients and waste 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, bath treatment pesticides and live parasitic salmon lice.

The report describes the development of a 2D hydrodynamics model to capture adequately the current patterns around Scotland's West coast and islands with a focus on Little Colonsay. The hydrodynamics model contains the influence of wind and tidal forcing.

As part of the hydrodynamics development work, new Python scripts have been written to allow the user to compare directly modelled and observed data. These data are output in a format that quickly allows the user to assess how the model data compares against the SEPA calibration/validation requirements for hydrodynamic and discharge modelling [SEPA, 2019]. The Python scripts form part of the open source toolbox CLAWS – Chemicals, Lice and Waste from Salmon Farms [CLAWS, 2023]. Other modules in the CLAWS software suite include those for pesticide treatments, dissolved nutrients and solid particle feed waste.

2 Background data

2.1 *Site location at Little Colonsay*

The focus of the hydrodynamics modelling study is the proposed Bakkafrost salmon farm at Little Colonsay. Figure 1 shows the location of the proposed farm including the position of the 6 salmon pens at the site.

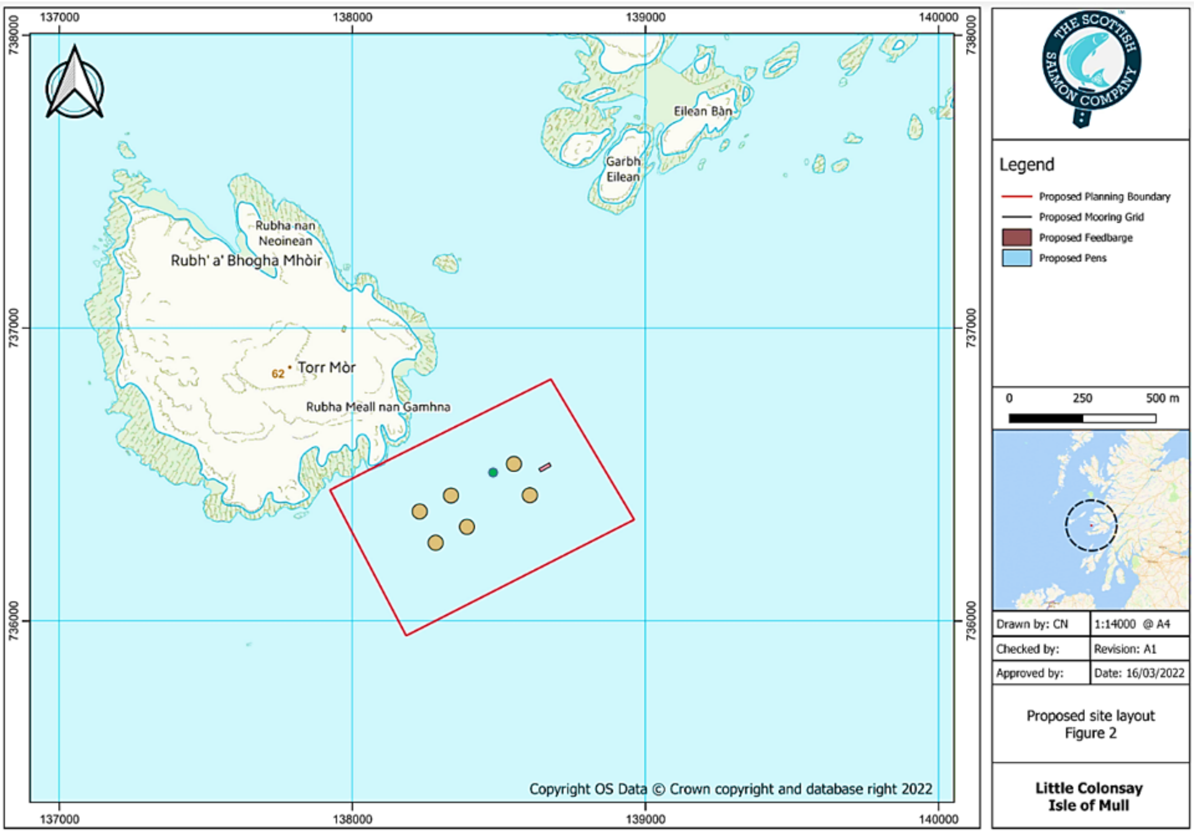

Figure 1 *Little Colonsay and location of the proposed Bakkafrost salmon farm (inset shows general location). Observed data are gathered at the flowmetry point indicated by the green dot.*

2.2 *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 is applied. The shorelines were then constructed using the freely-available BlueKenue software [BLUEKENUE, 2011].

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 for the general West Coast model is shown in Figure 2.

2.4 *Hydrodynamic mesh and validation at Little Colonsay*

A 2D, depth-averaged hydrodynamics model based on the TELEMAC code [Scanlon_B, 2023] has been developed. The extent of the full West Coast model is shown in Figure 3. Wind forcing is included in the hydrodynamics model based on weather data at 6-hourly intervals [ERA, 2023]. The hydrodynamic modelling approach along with validation studies is described in full elsewhere, [Scanlon_A, 2023], [Scanlon_B, 2023] and is only summarised here.

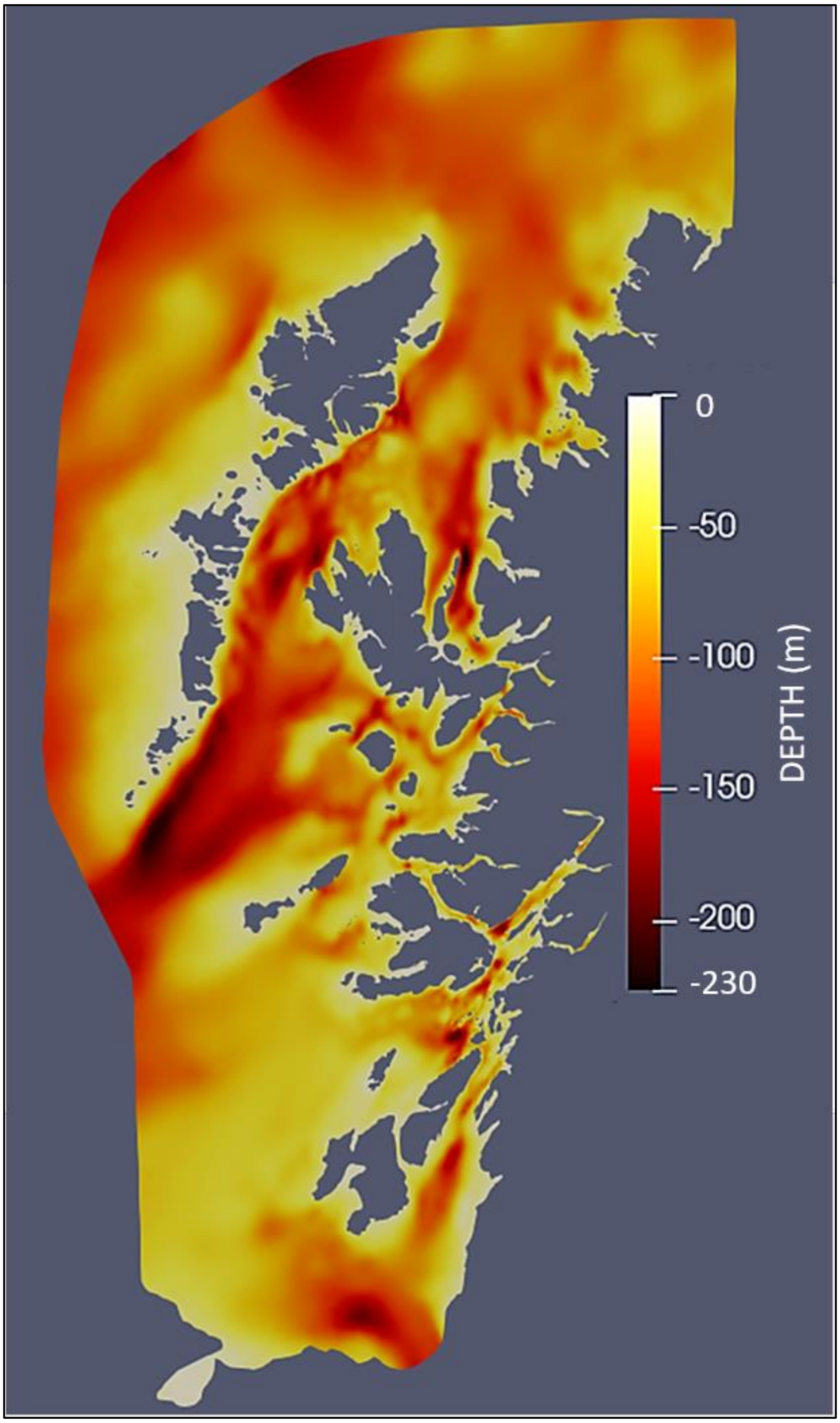

Figure 2 *West Coast model bathymetry (m).*

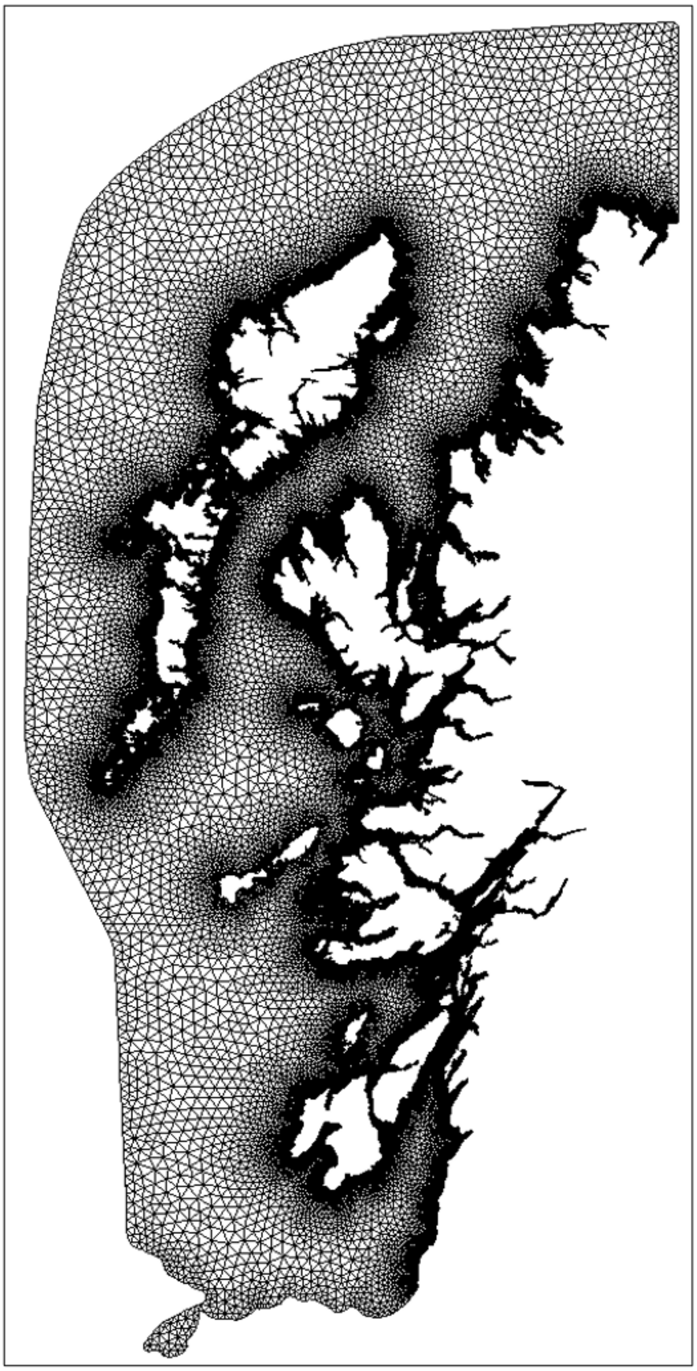

Figure 3 *TELEMAC hydrodynamic mesh and West Coast model extent.*

2.5 *Reducing the size of the hydrodynamics data set*

The 2D Telemac hydrodynamics model for the full West Coast consists of a large data set of flow variables in a mesh with ~1.42 million elements and a file size of 4.1 Gb. It would be beneficial in terms of disk storage and computational expenditure if the data set could be reduced in size to one focusing on the area surrounding Little Colonsay. A Python script has been created to achieve this reduction and the file size for the hydrodynamics is reduced substantially from 4.1 Gb to 0.3 Gb. Figures 4-6 show the original full scale model mesh (4.1

Gb, blue) and the cropped model (0.3 Gb, red) that is used for the hydrodynamics simulation. The time-step size employed in the hydrodynamics simulation was 60 s.

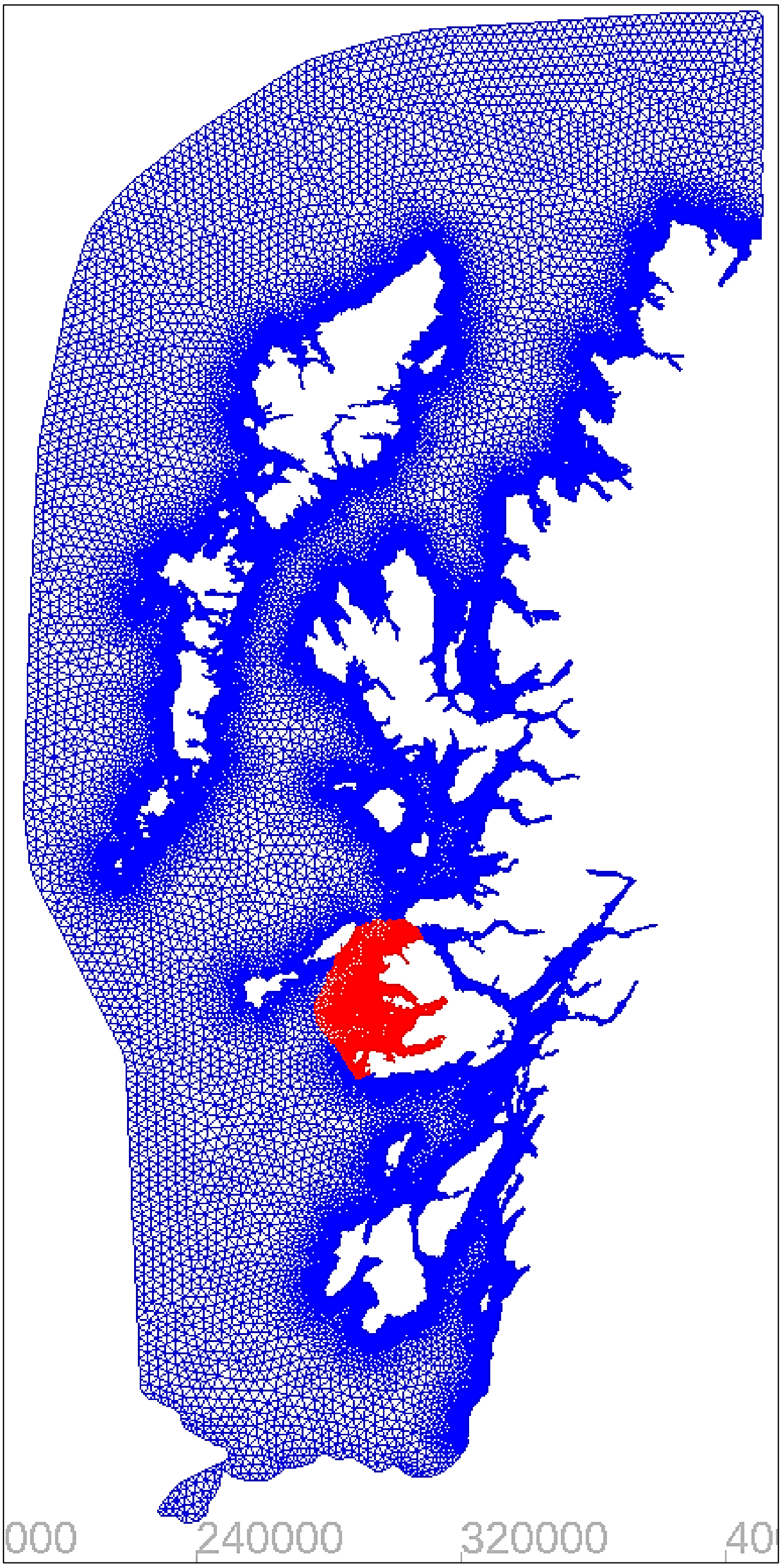

Figure 4 *Original Telemac 2D hydrodynamics mesh (4.1 Gb, blue) and reduced size model (0.3 Gb, red).*

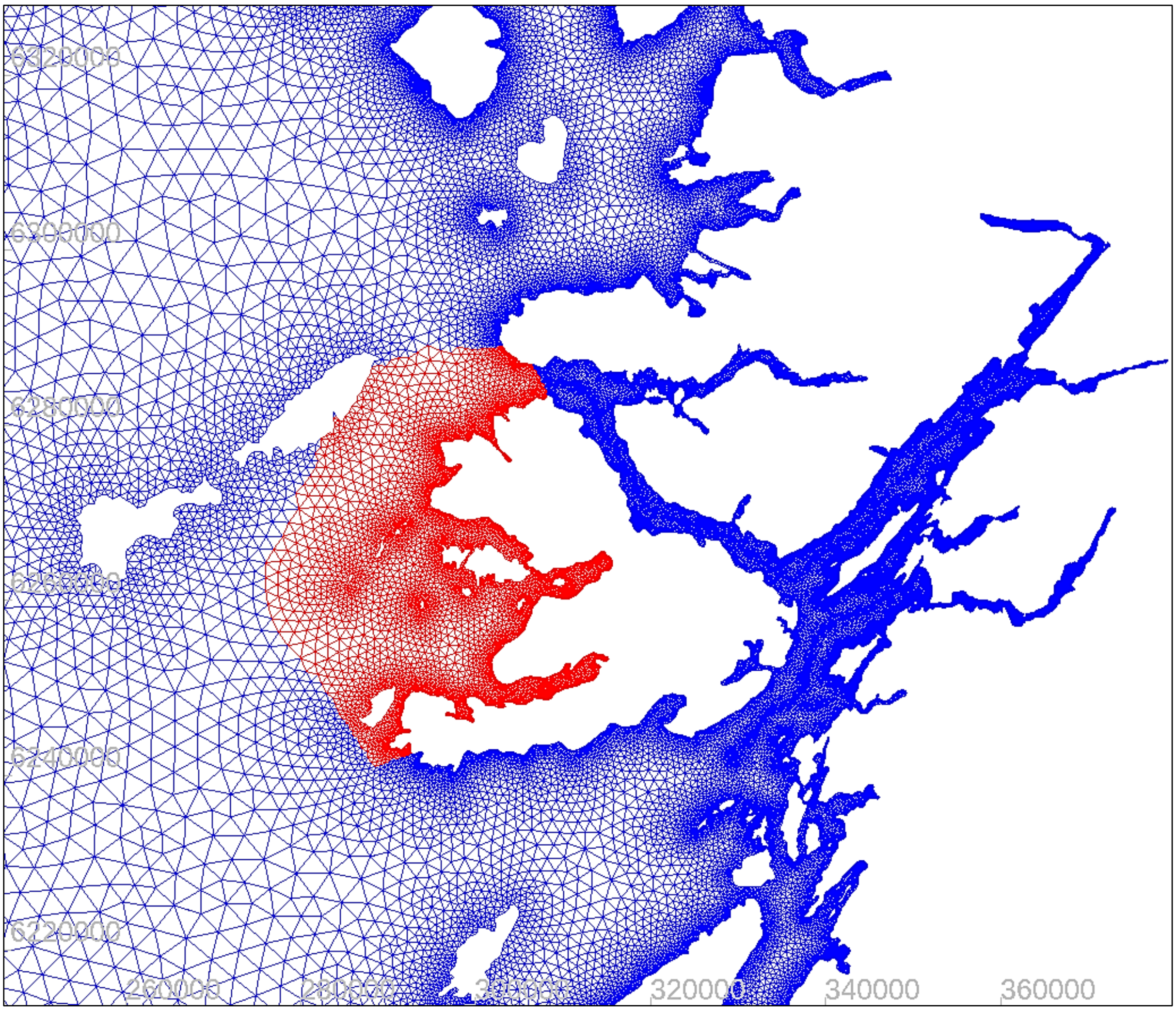

Figure 5 *Zoomed view of original Telemac 2D hydrodynamics mesh (4.1 Gb, blue) and reduced size model (0.3 Gb, red).*

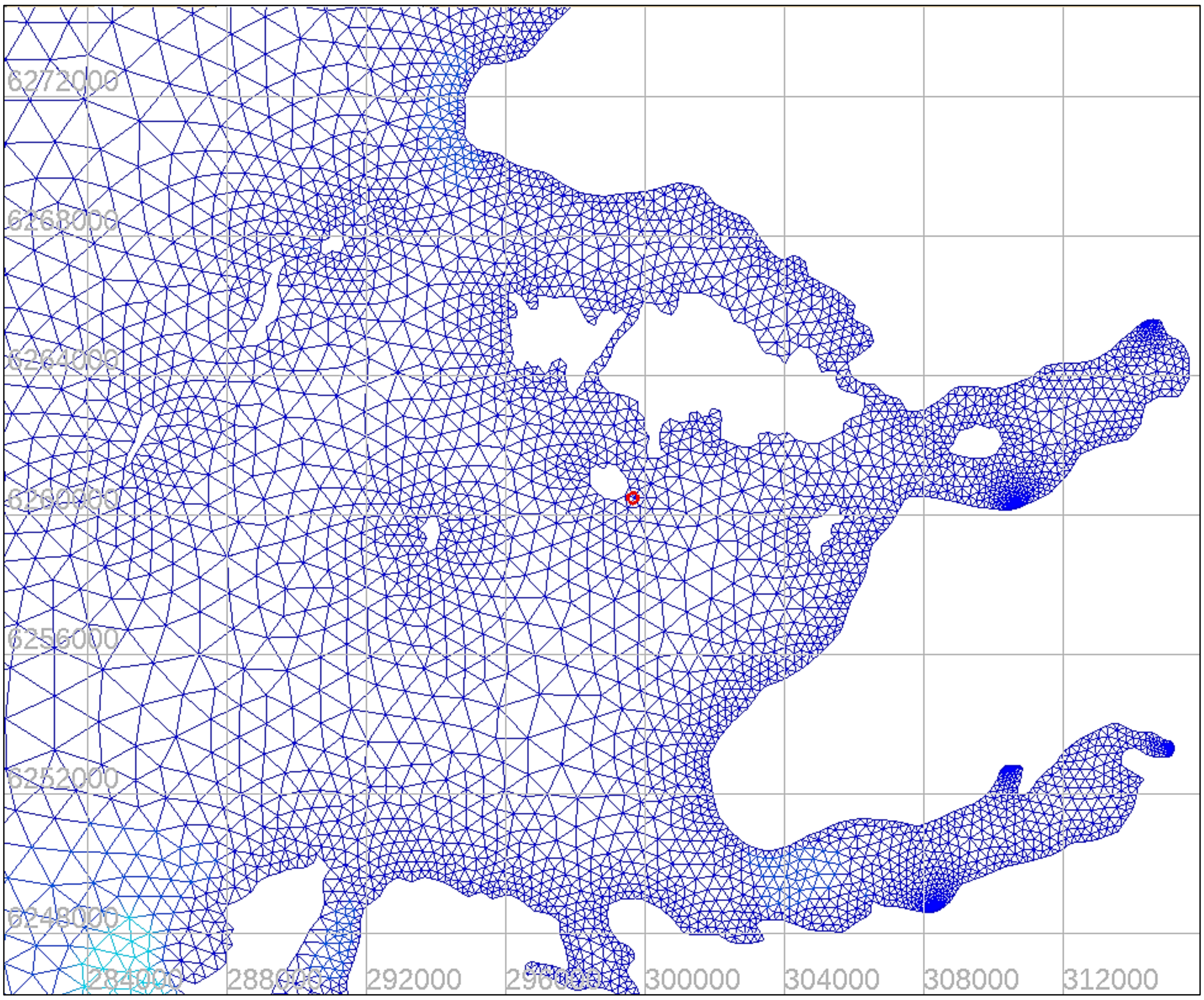

Figure 6 *Hydrodynamic mesh near Little Colonsay*. *Model data are extracted at the flowmetry point indicated by the red circle.*

3 Results

3.1 *Hydrodynamics simulation*

The model was run for a period of 80 days from the 4th July to the 20th September 2021. This period covered the data range captured by SSC/Bakkafrost at the site [SSC, 2023].

Figures 7-10 show various representations of the predicted model data including current speed, current direction and sea elevation. Figures 11 and 12 show snapshots of the flow patterns in the Little Colonsay area during flood and ebb tides.

Comparison is made between a 3-month observed data set at the flowmetry location [SSC, 2023] and the Telemac 2D model results and these are shown in Table 1. In general, results show a satisfactory agreement between the modelled and observed data for the depth-averaged velocity magnitude and direction. For the direction, the modelled value of the major axis (see Fig.6) is 225^o which, when compared to the observed value of 201^o, falls within the +/- 30^o range of the SEPA standards for hydrodynamic modelling [SEPA, 2019].

For the current magnitude, the predicted depth-averaged velocity at the flowmetry location was 0.053 m/s compared with 0.056 m/s for the measured value. The predicted mean current speed is within 5.4% of the physical observation.

Similarly, for the mean residual current, a value of 0.011 m/s was calculated by the TELEMAC 2D simulation, while the observed value was 0.0103 m/s. The simulated value was thus within 6.4% of the observed residual current speed.

Table 1 *Comparison between observed [SSC, 2023] and modelled data for the flowmetry location (see Fig. 6).*

Data	Depth-averaged velocity (m/s)	Major axis direction (deg)	Depth-averaged residual current magnitude (m/s)
Observed	0.056	201	0.0103
Modelled	0.053	225	0.011

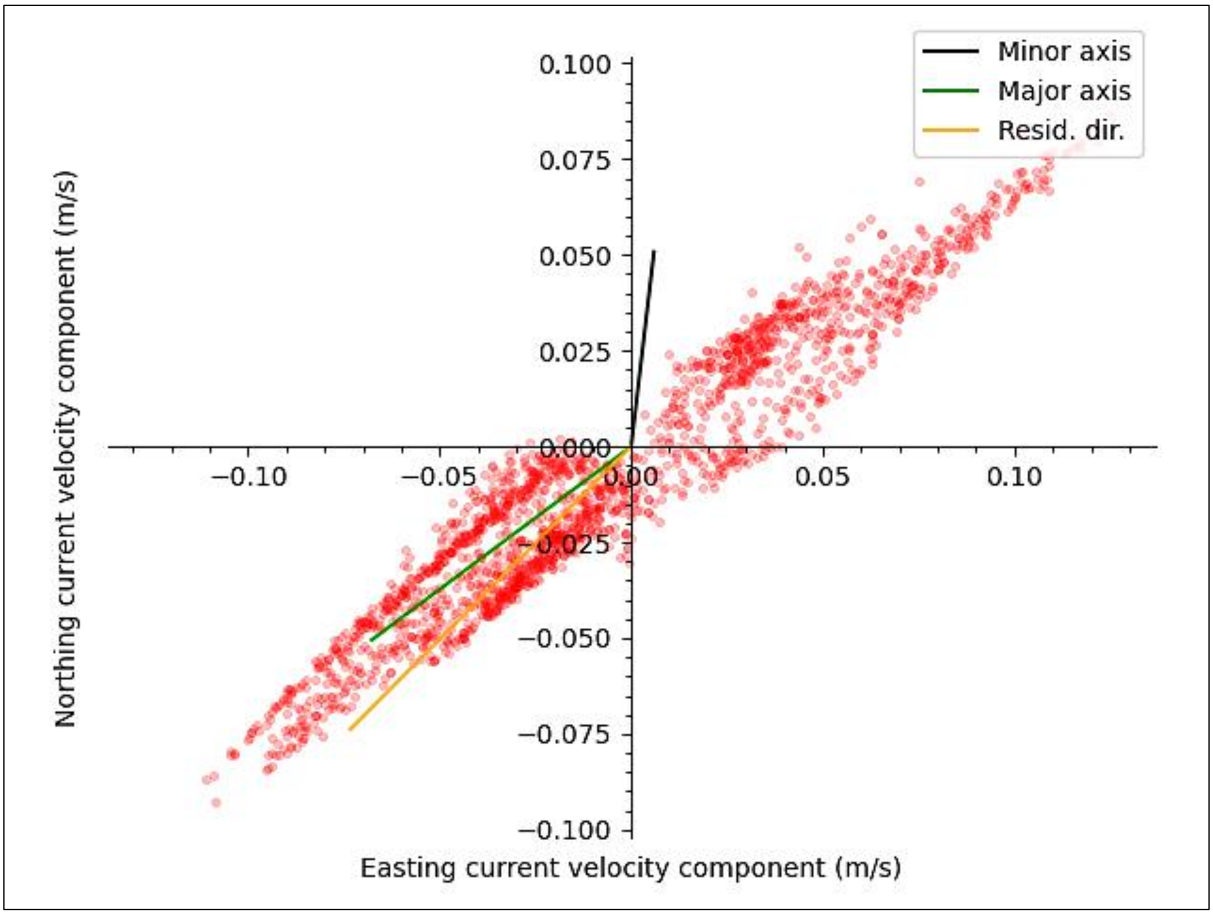

Figure 8 *Northing versus Easting components of velocity predicted by the hydrodynamic model at the flowmetry location (see Fig. 6). Data is for the period of 80 days from the 4th July - 20th September 2021.*

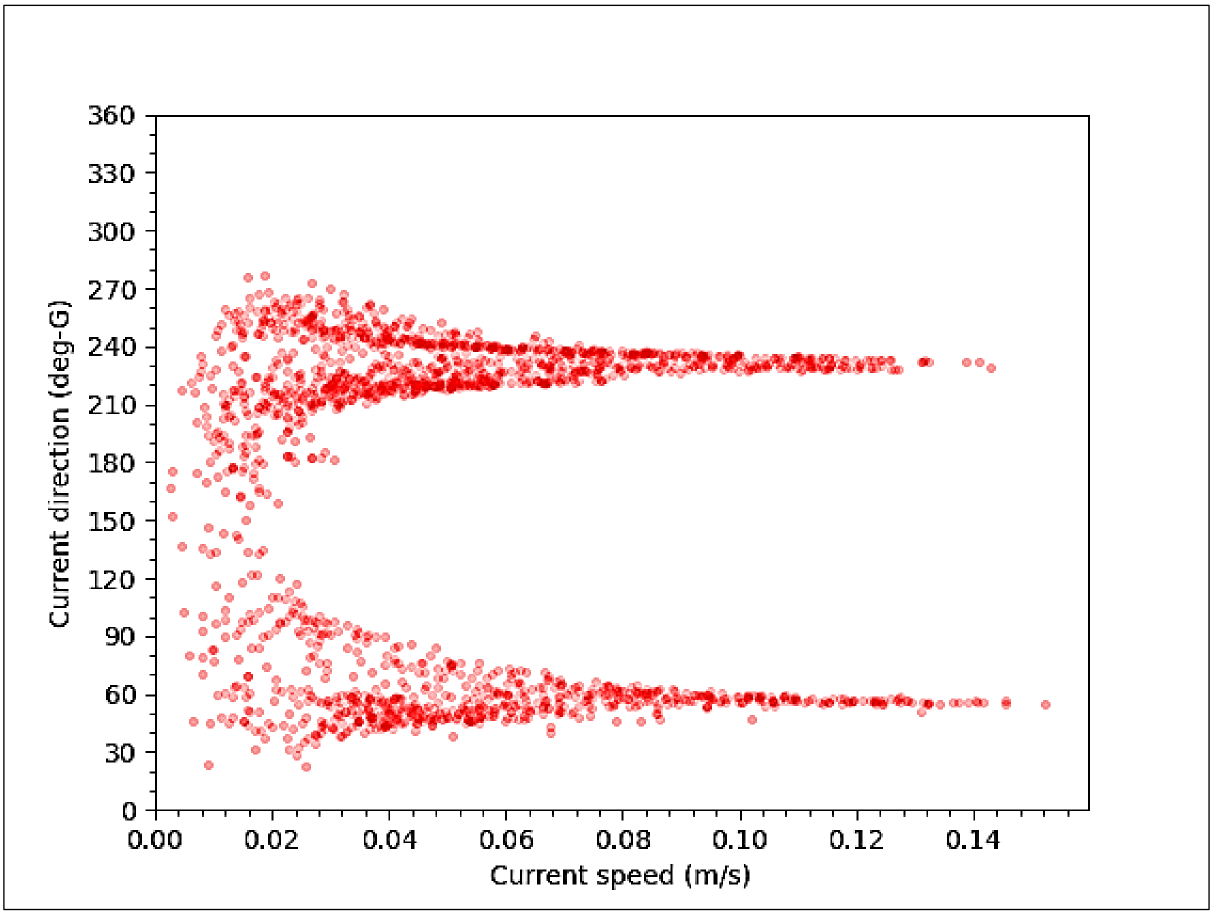

Figure 9 *Current speed (m/s) versus direction (deg) for the hydrodynamic model at the flowmetry location (see Fig. 6). Data is for the period of 80 days from the 4th July - 20th September 2021.*

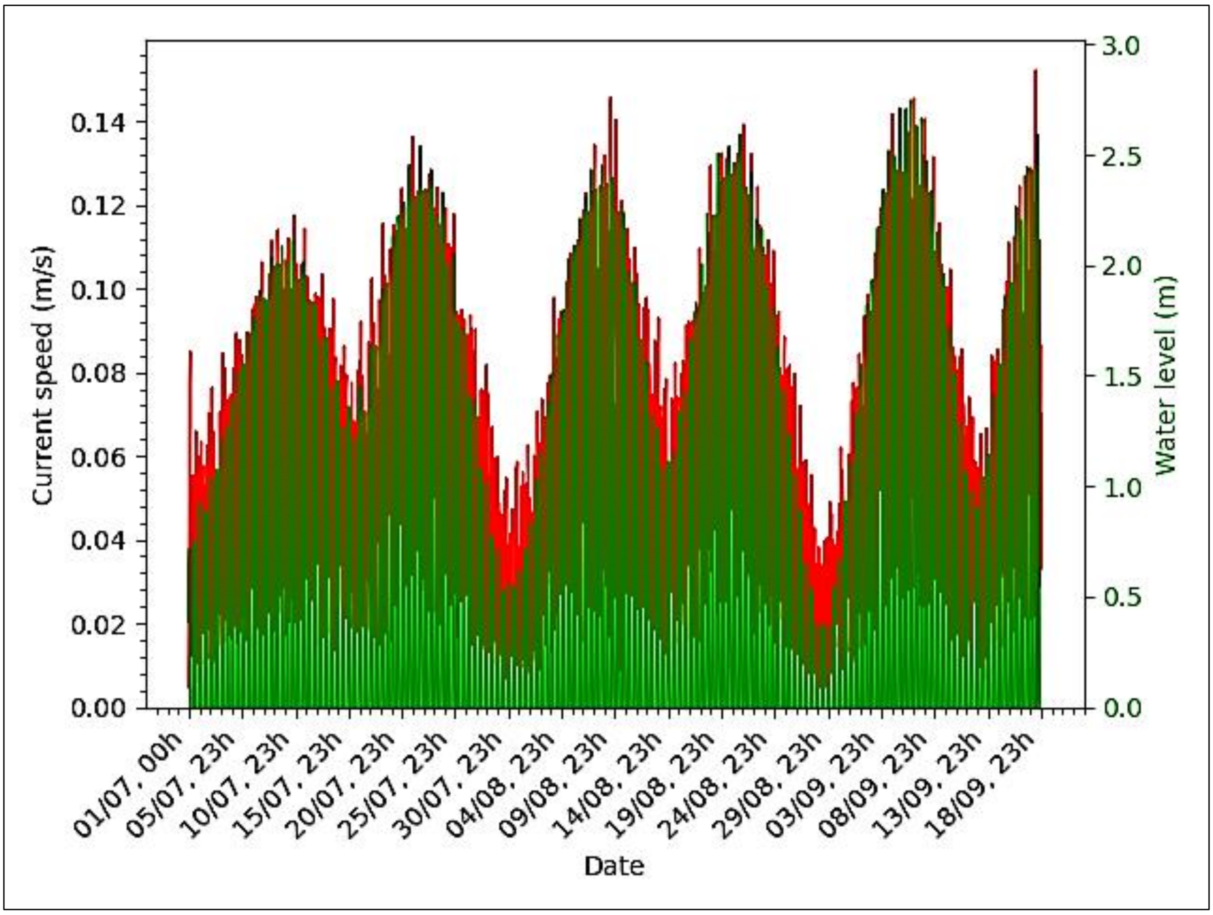

Figure 10 *Current speed (m/s)(red) and sea level (m)(green) predictions from the hydrodynamic model at the flowmetry location (see Fig. 6). Data is for the period of 80 days from the 4th July - 20th September 2021.*

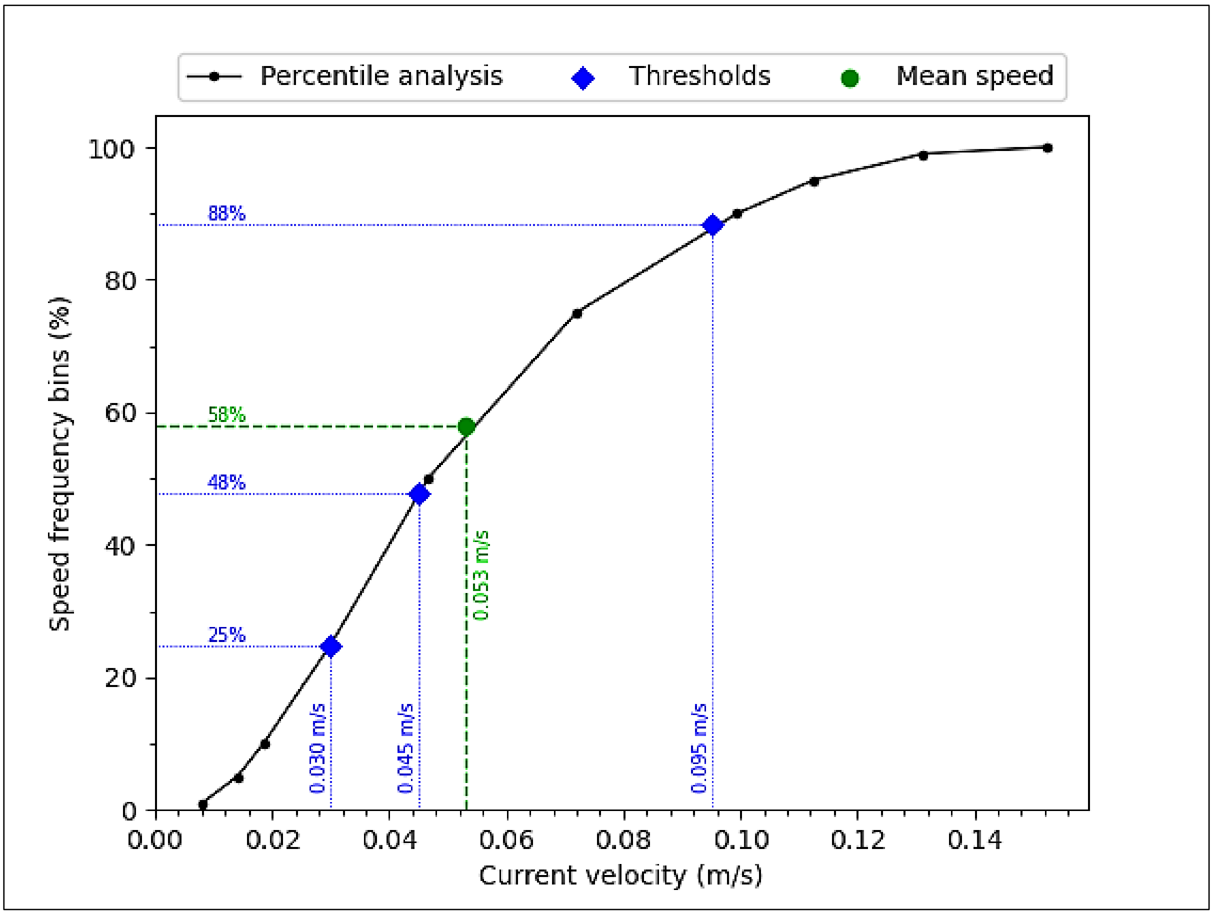

Figure 11 *Current speed (m/s) percentile data for the hydrodynamic model showing an average velocity of 0.053 m/s. Data is for the flowmetry location (see Fig. 6) for the period of 80 days from the 4th July - 20th September 2021.*

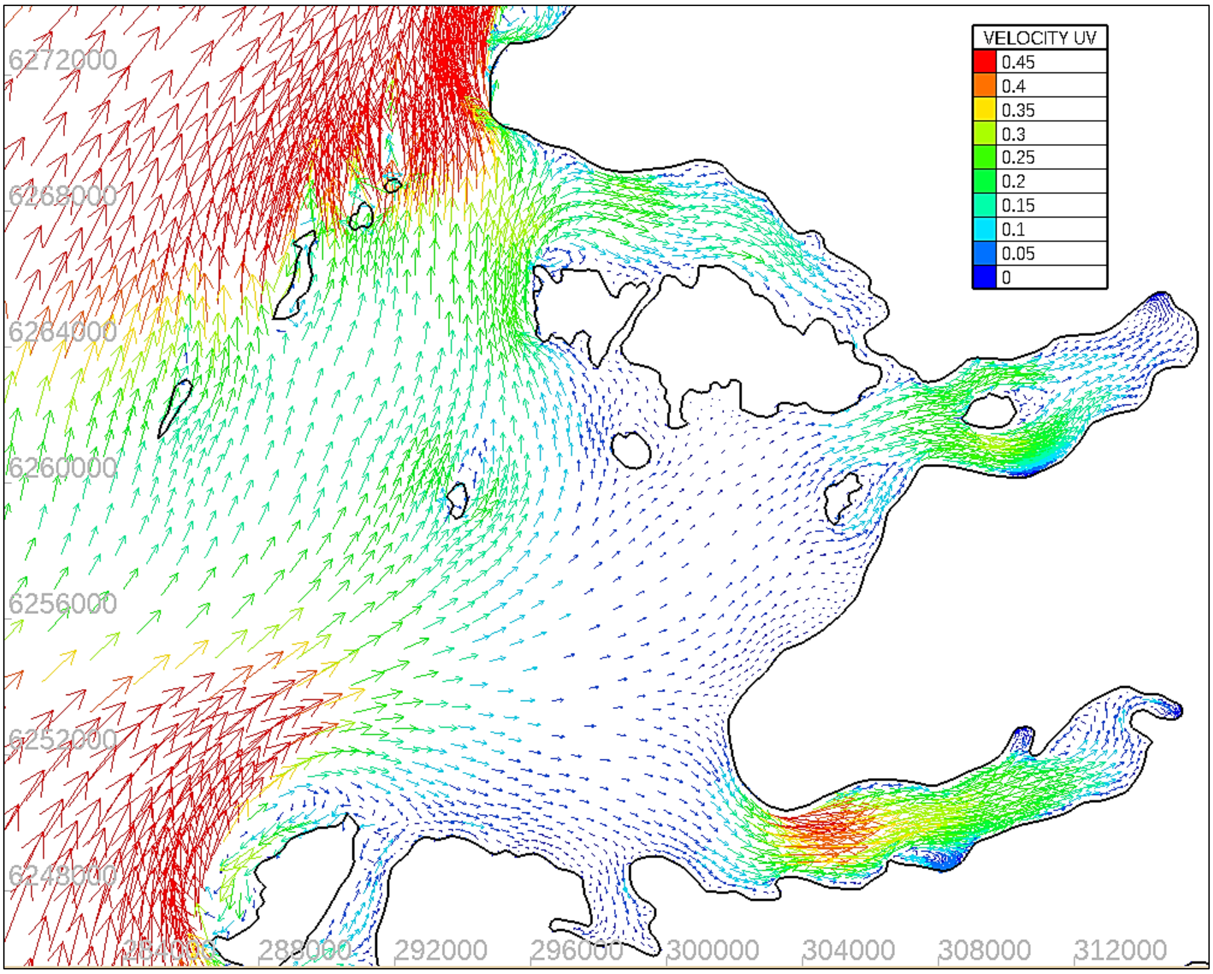

Figure 12 *Snapshot example of current velocity (m/s) during a flood tide.*

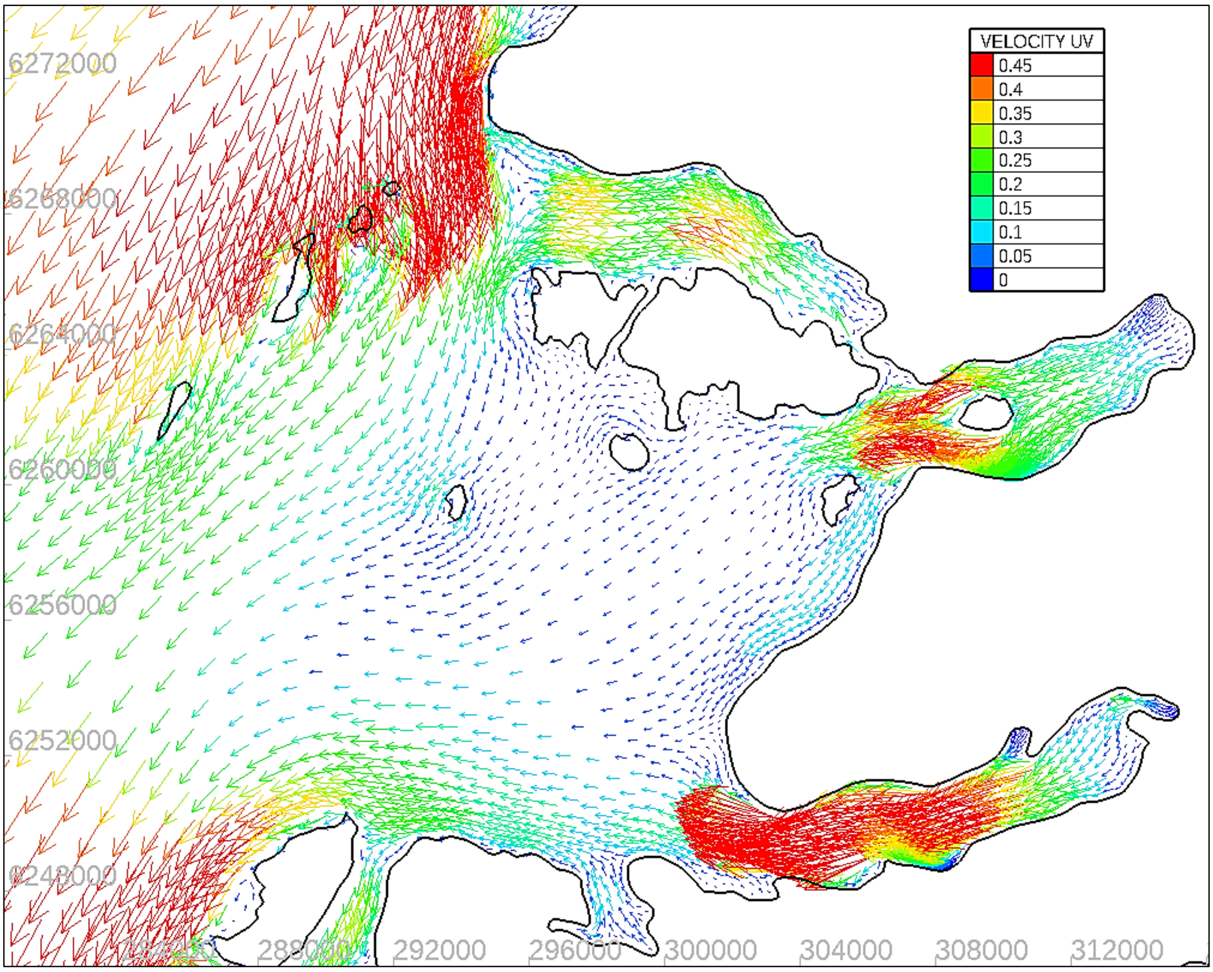

Figure 13 *Snapshot example of current velocity (m/s) during an ebb tide.*

6. Conclusions

The hydrodynamic models, generated using the 2D Telemac software, provide a satisfactory description of the flow currents in the vicinity of Little Colonsay in terms of current magnitude and direction. In general, the model data compares favourably against the SEPA calibration/validation requirements for hydrodynamic and discharge modelling [SEPA, 2019] and physical observation at the site. Python scripts have been used to allow the direct comparison of observed and modelled hydrodynamic data as part of the open source platform CLAWS – Chemicals, Lice and Waste from Salmon Farms [CLAWS, 2023].

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