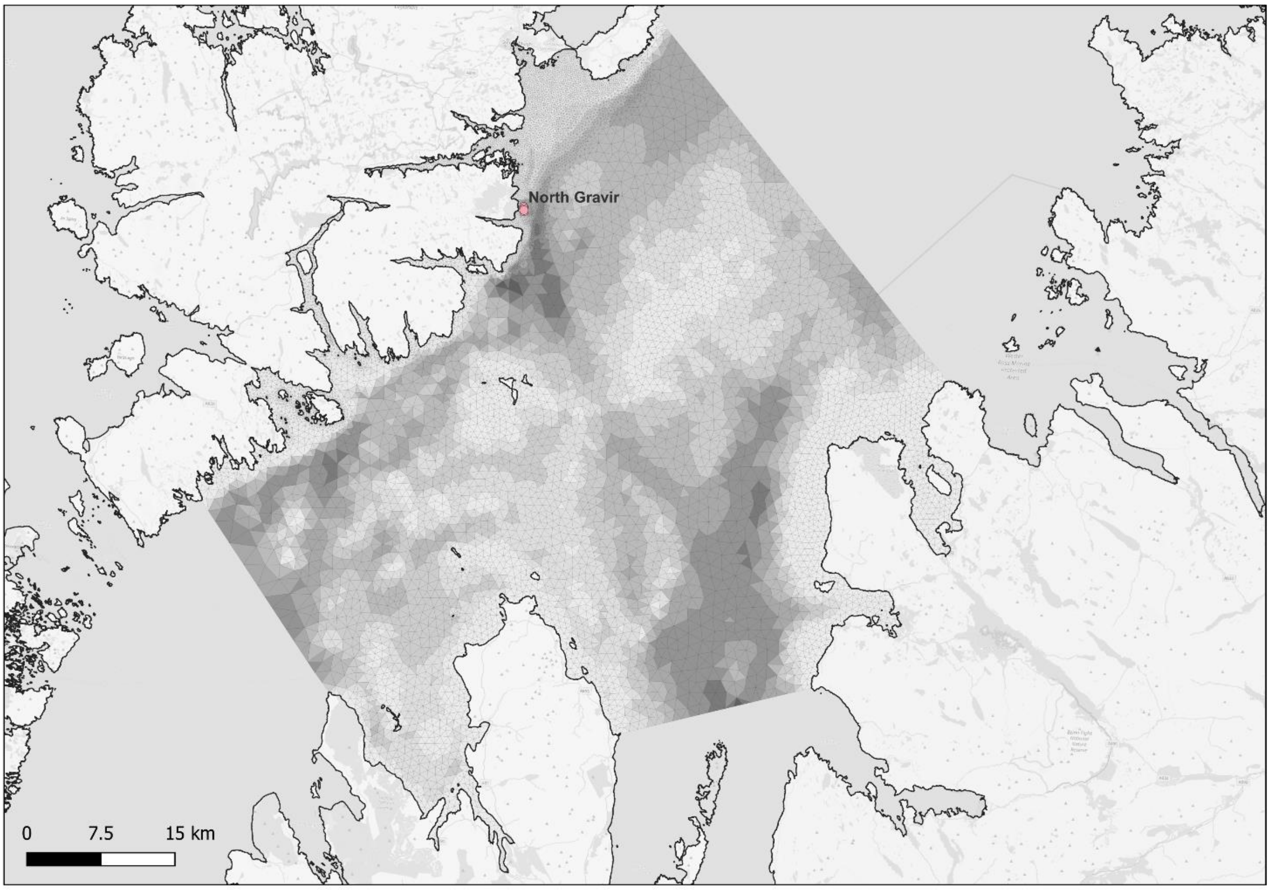
North Gravir Aquaculture Modelling

Depositional and Bath Treatment Assessment Report

Project No 26802148

5th March 2024

Prepared for Bakkafrost Scotland Ltd



Hydrodynamic modelling for North Gravir and Lewis Island Finfish Farm development

Depositional and Bath Treatment Assessment Report

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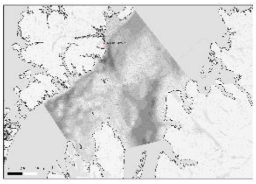
Prepared for:	Bakkafrost Scotland Ltd
Represented by	Penny Hawdon (Site Development Manager)



Area of interest and computational mesh of Outer Hebrides North Gravir hydrodynamic model

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1 Introduction

This report has been prepared for **Bakkafrost Scotland Ltd.** (BFS) by **DHI Water Environments UK Ltd.** (DHI) in relation to dispersion modelling for the aquaculture site at North Gravir, Outer Hebrides. The report will provide a description of the dispersion modelling undertaken for both waste solids and bath treatments around the vicinity of North Gravir (NG).

This document and its accompanying appendices constitute an addition to the **hydrodynamic database climatology model** [1] report.

1.1 Background to the Study

The Outer Hebrides, also known as the Western Isles, is an archipelago located off the west coast of mainland Scotland. It consists of a chain of islands, the largest of which are Lewis and Harris, North Uist, South Uist, Benbecula and Barra.

Aquaculture activities play a significant role in the Outer Hebrides' economy and food production. The region's coastal waters offer ideal conditions for aquaculture due to their clean, nutrient-rich environment. Salmon farming is one of the primary aquaculture activities in the area, with several farms located around the islands. These farms rear Atlantic salmon, providing a sustainable source of high-quality protein.

Aquaculture activities in the Outer Hebrides adhere to strict regulations and sustainability practices to protect the natural environment and maintain the long-term viability of the industry. The industry provides employment opportunities for local communities and contributes to the region's economy while promoting the production of healthy and sustainable seafood. With a focus on increasing production, it is understood that the companies are seeking opportunities for new prospective sites and/or the re-opening of inactive sites.

Operational fish farms have the potential to affect the marine environment in several ways via the release of waste materials in the form of dissolved nutrients, medicines, and particulate organic matter. The management of the risks surrounding salmon lice are also of fundamental importance to producers. Consequently, the aquaculture sector is highly regulated by the Scottish Government. There is a requirement for fish farm operators to use modelling tools to demonstrate compliance with the environmental standards relating to the spatial extent and the intensity of impacts, both in the local area around fish pens and in the wider environment.

Increasingly, operators are required to use marine hydrodynamic modelling approaches to support license applications. Hydrodynamic modelling refers to a class of numerical models that simulate the flow of water within a specified geographic area in a physically realistic way. This includes flow due to a range of forcing conditions including tidal variations, density gradients, and meteorological factors (air pressure and wind). Hydrodynamic models provide the physical basis for many other types of numerical environmental modelling such as the transport, dispersion, and decay of dissolved or suspended substances.

1.2 Aims and Objectives

The overall aim of the project is to use the 3-dimensional climatological hydrodynamic model developed for this study (see [1]) to inform a risk-based approach to management and development of aquaculture sites in the waters around Outer Hebrides with specific focus to North Gravir developments and activities.

To achieve this aim, the objectives of this dispersion modelling document are to report on the analysis results of the following:

- Depositional model of the waste solids over a 1-year simulation
  - 2-dimensional
  - 3-dimensional
- Dispersion model of the bath treatment over spring and neap tides
  - 2-dimensional

Climatology Model

The fundamental principle of a climatology model is the assumption that the conditions for a particular day (or month) and at a particular location do not change significantly from one year to the next; hence, the long-term average conditions on a certain day (or month) should be a good approximation to the expected conditions for that day (or month). This offers a simple technique for predicting the mean status of the atmospheric and oceanographic conditions within a region (i.e., to understand the seasonal variability, but not to the interannual variability).

The hydrodynamic climatology model thus provides a useful reference for how the expected flow patterns, tidal and/or baroclinically driven, temperature, and salinity vary over seasonal cycles, the wind climate, and gradients in water density. However, the climatology model output does not reflect episodic weather events as for example winter storms which occur at relatively high frequency at these latitudes.

1.3 Report Layout

The remaining sections of this report are organised as follows:

- Section 2 summarises information on the geographic and environmental setting of the Little Minch and Outer Hebrides.
- Section 3 describes the setup of the Particle Tracking model of North Gravir. This includes the mesh, model setups for depositional modelling (waste feed and faeces), bath treatment dispersion modelling (for azamethiphos and deltamethrin) and outputs.
- Section 4 describes the Modelling results for both Depositional modelling and bath treatment modelling.
- Section 5 provides a conclusion of the impact assessments undertaken for North Gravir.

2 Study Data Basis

North Gravir is found in the Outer Hebrides, an archipelago located off the west coast of mainland Scotland (Figure 2.1). A detailed description of the geographical setting of the Area of Interest (AOI) can be found in [1]. The model mesh, boundaries and bathymetry domain of the Hydrodynamic Climatological model are shown Figure 2.3 and Figure 2.4. The database and setup utilized for the HD model development is detailed in [1]; no further description is provided herein.

The basis of this report is to detail the cumulative depositional modelling of waste solids and bath treatment modelling. North Gravir Fish Farm layout consists of 5 pens of circumference of 200 m and width of 63.7 m, Gravir West consists of 2 pens and Gravir Outer consists of 10 pens: the bathymetry and geographic details are summarised in Figure 2.2 and Table 2.1. The bathymetry shown in Figure 2.2 is from the Hydrodynamic Climatological model mesh. The GVRN1 site centre is located at pen GVRN1_02.

Of particular interest is the potential impact on Priority Marine Features (PMFs) in the polygon area for Burrowed Mud and point location for European Spiny Lobster shown in Figure 2.2, as provided by BFS. Note: Statistical analysis of the PMF polygon area for Burrowed Mud was conducted based the statistical results of all mesh elements within the PMF polygon and was conducted for Solid Waste Modelling only. Statistical analysis of the European Spiny Lobster point location was analysed for both Solid Waste Modelling and Bath Treatment Modelling.

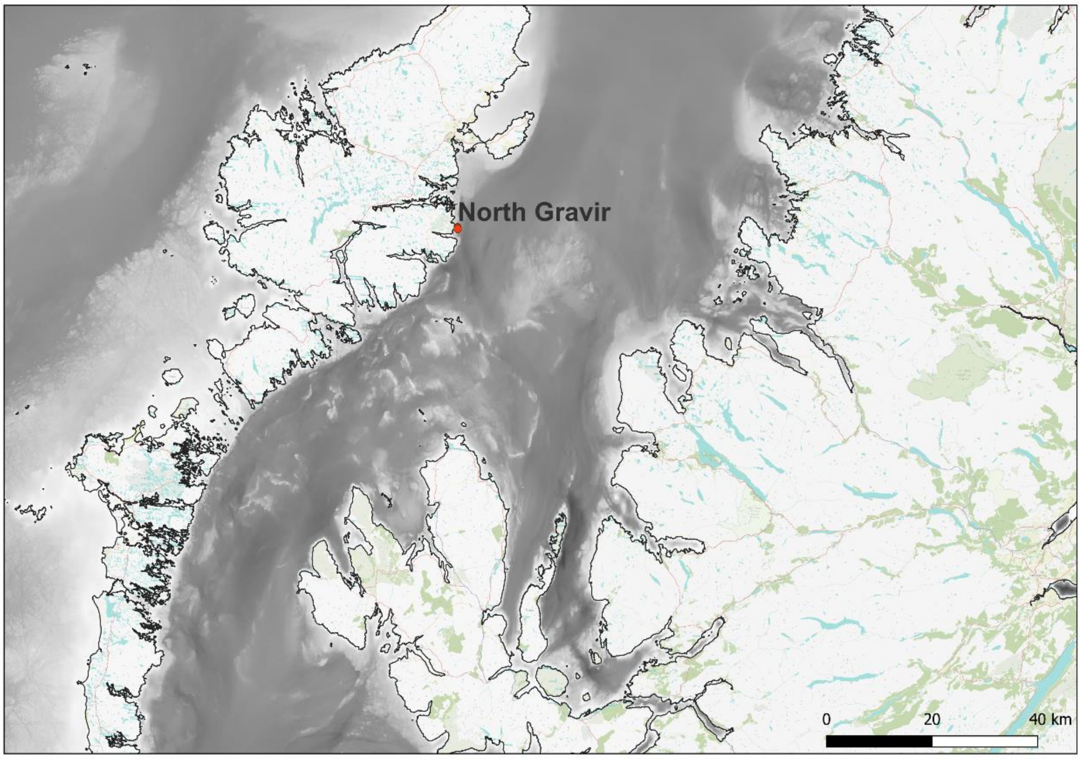

Figure 2.1 Map showing the geographic position of North Gravir area of interest. In relation to the Outer Hebrides main islands (west land boundaries) and the Isle of Skye, northwest mainland Scotland (east land boundary). North Gravir site is depicted in red.

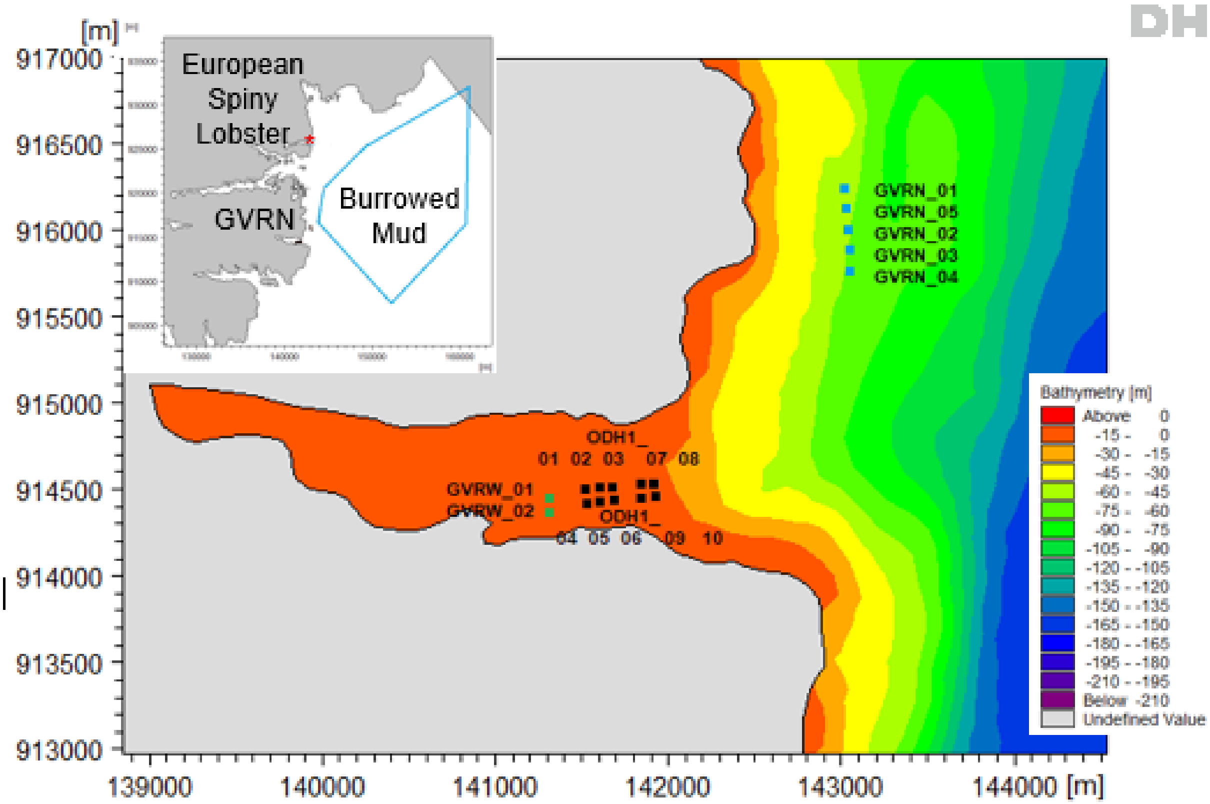

Figure 2.2 **Map of the bathymetry showing the position of the three project fish farms, (inset panel) overview map, including PMF locations.**
Pens in blue are North Gravir (GVRN1), green are Gravir West (GVRW1) and black are Gravir Outer (ODH1). Inset: PMF location as red point and blue polygon.

Table 2.1 **Geographic location data for North Gravir pens.**

Site ID	Pen ID	Location		Pen circumference [m]*	HD Mesh Depth [m]
		Easting BNG]	Northing [BNG]		
North Gravir (GVRN1)	01	143020.0	916238.0	200	55.45
	02**	143036.0	915999.0	200	55.01
	03	143043.0	915879.0	200	60.37
	04	143051.0	915759.0	200	65.10
	05	143028.0	916118.0	200	55.86
Gravir West (GVRW1)	01	141309.0	914446.0	120	2.82
	02	141316.0	914366.3	120	2.13
Gravir Outer (ODH1)	01	141520.0	914500.0	120	2.93
	02	141599.7	914507.0	120	2.82
	03	141679.4	914513.9	120	3.34
	04	141527.0	914420.3	120	1.78
	05	141606.7	914427.3	120	2.82
	06	141686.4	914434.2	120	3.34
	07	141839.0	914528.0	120	7.92
	08	141918.7	914535.0	120	7.92
	09	141846.0	914448.3	120	5.68
	10	141925.7	914455.3	120	7.24

** Site centre - used for bath treatment compliance testing

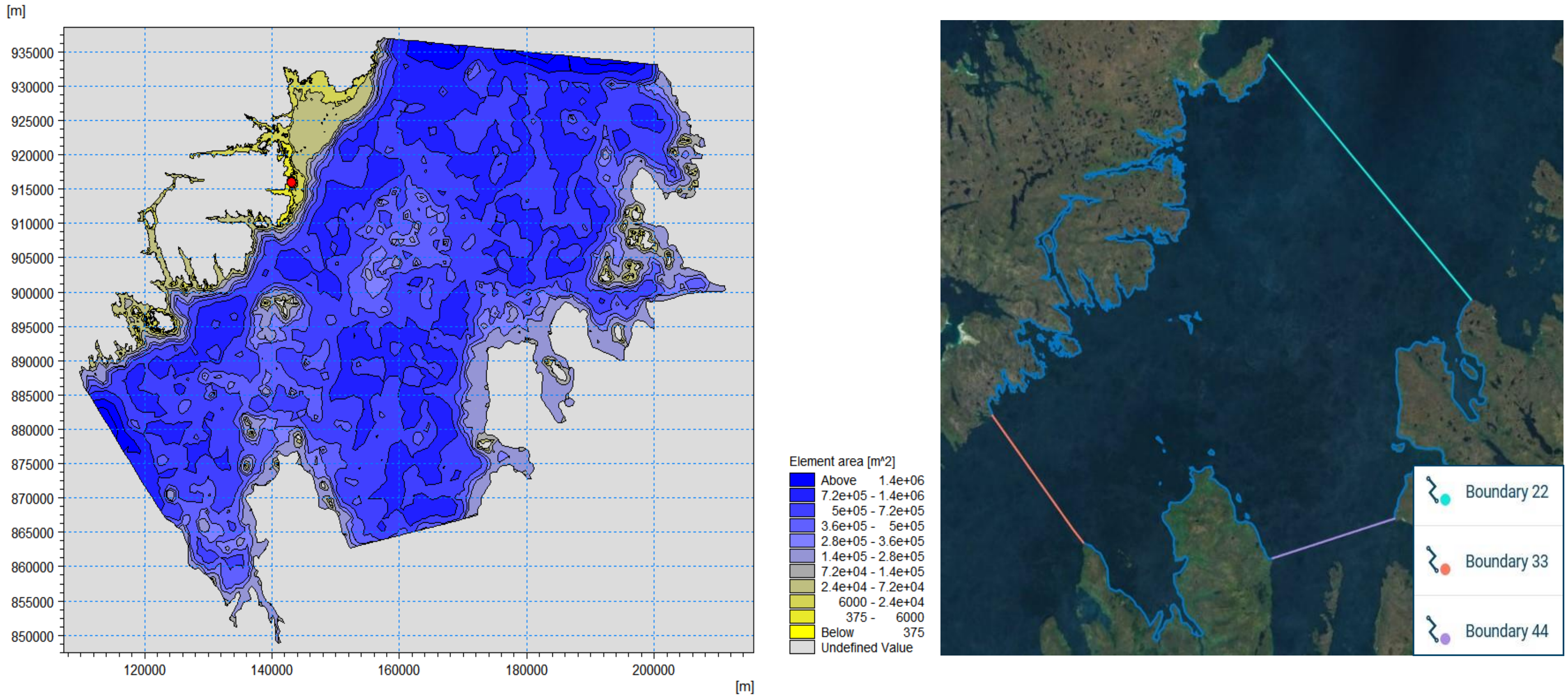

Figure 2.3 Mesh resolution [m] across the $HD_{NG\_hindcast}$ computational domain of BFS (left panel) and defined open sea boundaries (right panel).

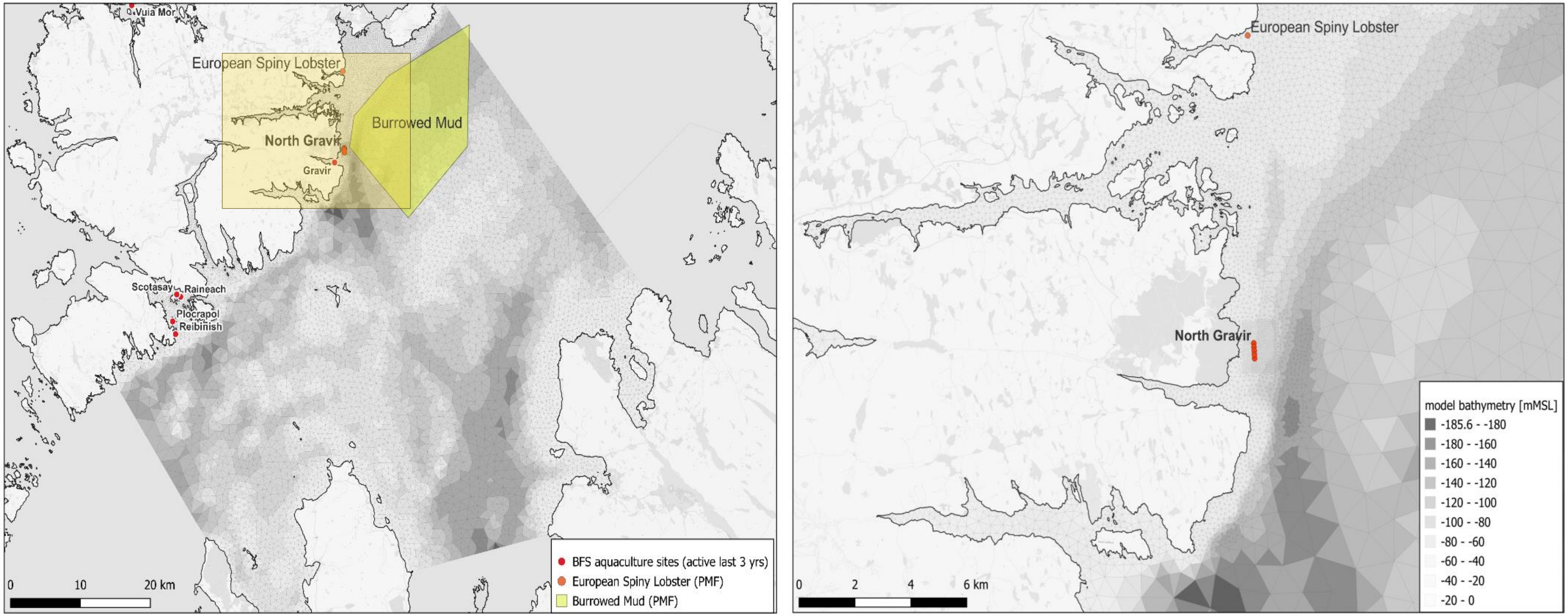

Figure 2.4 **Computational domain of the regional North Gravir hydrodynamic model with the Burrowed Mud PMF polygon and Spiny Lobster PMF overlain (left panel) and zoomed in perspective of the main areas of interest (right panel).**
Mesh resolution is significantly improved in the area of interest versus ECLH, as seen in Figure 4.3 and Figure 4.8 of [1], allowing for a better representation of coastal and bathymetric features.

3 Modelling Methodology

This section describes the modelling methodology for the assessment of the cumulative depositional modelling of waste solids (Section 3.2), and bath treatment medicine (Section 3.3).

The modelling methodologies for all impact assessments in this report were based on the application of the MIKE 21 Particle Tracking Module, which is briefly described below. More detail can be found in [2].

3.1 MIKE 21 Particle Tracking Module

The modelling was performed using the Particle Tracking module within the MIKE21/3 Coupled Model FM [3] with hydrodynamic conditions provided by the 3-dimensional HD model described in [1], Section 4.

The particle tracking (PT) module is a component of the MIKE 21/3 modelling system and has been used to model the transport and fate of suspended and sedimented substances discharged from fin fish aquaculture sites under the influence of the fluid transport and associated dispersion processes. The discharged substances are considered as particles being advected with the surrounding water body and dispersed because of random processes in two dimensions. The particles may settle with a constant settling velocity and settled particles may be resuspended if the bed shear stress exceeds a critical threshold. A corresponding mass is attached to each particle, which may be reduced during the simulation due to decay.

The following processes may be attached to individual particle classes:

- Settling
- Erosion/Resuspension
- Decay
- Dispersion

The model calculates the path of each particle and outputs the instantaneous concentrations of individual particle 'classes' based on the hydrodynamic model input. Particle tracking techniques can be an efficient way to study the fate of matter in the water environment. This technique uses a Lagrangian discretisation, splitting all mass in the system into several particles with specific coordinates and masses.

All impact assessment models in this study were performed using the PT module, with hydrodynamic conditions provided by the 3-dimensional HD model. A description of the model inputs, settings and outputs are described in the Solid Waste Modelling and Bath Treatment Modelling sections individually.

The position of particles during the model simulations were used to calculate the mass of the modelled substance in each model mesh element. This was based on a higher resolution flexible mesh covering the North Gravir area model with a resolution of 1,250 m^2 (which equates to approximate length scales on average of 28 m, minimums of 11 m and maximums of 48 m), see also [1]. The mesh used in all impact assessments was the same mesh used in the Hydrodynamic modelling setup (see [1], Section 4).

3.2 Solid Waste Modelling

This section describes the modelling methodology for assessing the deposition of waste solids (feed and faeces) from the North Gravir (GVRN1) site, as well as the cumulative deposition from the North Gravir (GVRN1), Gravir West (GVRW1) and Gravir Outer (ODH1) sites.

The PT depositional model calculates both 2D and 3D output results, with 3D HD climatological input forcing. Section 4.1 describes the results of the Depositional PT modelling. Only 2D model outputs were reported; models were run individually for all source locations and then later combined in post-processing. The results discussed are for $PT3D_{Depo2D\_GVRN1}$ and $PT3D_{Depo2D\_COMB}$.

3.2.1 Environmental Quality Standards

The current Environmental Quality Standards (EQS) applied by SEPA quantifies the impact of deposited solids on the environment with respect to the Infaunal Quality Index (IQI). The IQI is a multimetric index that expresses the ecological health of benthic macro-invertebrate (infauna) assemblages, reflecting how the structure and functioning of benthic macro-invertebrate assemblage changes over anthropogenic pressure gradients, for example from organic enrichment of sediments [4]. IQI is expected to decrease as organic enrichment increases as the proportion of species tolerant to organic enrichment increase, while evenness and species richness decreases.

An IQI score of 0.64 represents the ecological moderate/good status boundary for benthic macro-invertebrate (infauna) assemblages.

Table 3.1 Ecological status boundaries for IQI.

Status	IQI
High / Good	0.75
Good / Moderate	**0.64**
Moderate / Poor	0.44
Poor / Bad	0.24

The particle Tracking module within the MIKE21/3 Coupled Model FM does not explicitly model IQI conditions, as shown in Table 3.1. Therefore, the following criteria in Table 3.2 should be used to identify a scenario which is likely to comply with local scale "mixing zone" standards.

Table 3.2 Criteria for compliance with local scale 'mixing zone' standards (from [5]).

Standard	Type	Definition	Model Requirement
Pen-edge	Intensity	>1 species of enrichment polychaete at densities > $100m^{-2}$ at pen edge locations	Mean deposited mass withing the 250 gm^{-2} impact area should not exceed 2000 gm^{-2} where wave exposure is less than 2.8, or 4000 gm^{-2} where wave exposure is 2.8 or greater.
Mixing Zone	Extent	Total area (m^2) impacted to worse the 0.64 IQI should not exceed the 100 m composite mixing zone area (m^2)	Total area (m^2) with a mean deposited mass more than $250gm^{-2}$ should not exceed the 100m mixing zone area (m^2) where wave exposure is less than 2.8, or 120% of the mixing zone area (m^2), where wave exposure is 2.8 or greater.

3.2.2 Model Configuration

The information below summarises the configuration of the MIKE 21 PT model for the simulation of waste solids.

Table 3.3 Particle source locations and waste solid input rates as specified in the solid waste depositional model setup.

All pens	Peak Biomass [tonnes]	Waste Solids	
		Waste Feed [kg/day]	Faeces [kg/day]
GVRN1	4680.00	894.52	4337.80
GVRW1	515.70	98.57	477.99
ODH1	2285.20	436.78	2118.11
Single pen	**Peak Biomass [tonnes]**	**Waste Feed [kg/pen/day]**	**Faeces [kg/pen/day]**
GVRN1	936.00	178.90	867.56
GVRW1	257.85	49.28	239.00
ODH1	228,52	43.69	211.81

Particle Classes

A range of solid particles with varying properties are released from the Marine Pen Fish Farm's (MPFF). For practical reasons, it is not feasible to model such a large range of feed types all with different input rates, settling velocities, decay rates, and resuspension thresholds. Instead, we choose to model the behaviour of groups of particles. These groups (or particle "classes") share common characteristics which will behave in a broadly similar way.

There are two particle classes that represent waste solids in the Solid Waste Modelling:

- Wasted feed (uneaten)
- Faeces

Particle Properties

The properties of each of the particle classes are summarised in Table 3.3 and are based on the default particle parameters as specified in [6].

Source Locations

There are multiple sources for three fish farm location in the model setup representing the North Gravir, Gravir West and Gravir Outer site. The source locations are summarised in Table 3.3. The sources were specified at a depth of 8m below the still water level, with release from the centre of each of the proposed pens.

Input Rates

The mass associated with each particle class was specified as a constant flux released from the source location over the one-year model simulation. The input rates were proportional to the “on farm” biomass and were calculated following the method as outlined in Appendix B of [7] (also described in [6]).

The biomass for North Gravir, Gravir West and Gravir Outer was set as 4,680 tonnes, 515.7 tonnes and 2285.2 tonnes respectively as provided by BFS. The wasted feed and faeces were provided by BFS and the total input rate [kg/day] for each source location [kg/pen/day] in the model setup is summarised in Table 3.4.

Settling Velocities

Settling characteristics of fish feed and faeces are likely to change depending on fish size, feed composition, and the physical properties of the seawater [8].

The mean value of the settling velocity recommended by SEPA in NewDEPOMOD was used for feed pellets (0.095 m/s) and salmon faeces (0.032 m/s) based on [6] respectively.

Dispersion

The horizontal and vertical dispersion coefficient are often used as a calibration parameter for the Particle Tracking model.

The dispersion coefficients from NewDEPOMOD were applied with horizontal dispersion of 0.1 m^2/s and vertical dispersion of 0.001 m^2/s.

Decay

The existing assessment methods (e.g., NewDEPOMOD) contain no allowances for decay of solids in the model. This is due to the benthic module being validated using total particulate material and associated benthic effects (i.e., solids not carbon), [9]. Consequently, no decay was specified for waste solids in the depositional model.

Resuspension/Erosion

As noted in Table 3.4 the SEPA interim guidance values [6] have been used as the basis for the Erosion Threshold.

It should be noted that no consideration of geotechnical stability of sedimented material (i.e., due to the variation in the seabed steepness) is included in the depositional model. For resuspension/erosion it is assumed that the seabed represents a level surface.

Table 3.4 General settings for solid waste model.

Solid Waste Depositional Model settings		
Model period	365 (summer to summer)	
Hydrodynamic Conditions	3-dimensional hydrodynamic model • Tidal conditions for one year • Climatological averaged wind forcing	
Model input time step [seconds]	900	
Model output time step [seconds]	10800	
Sources	Representing MPFF sites per scenario • GVRN1: 5 source locations • GVRW1: 2 source locations • ODH1: 10 source locations (see Table 2.1)	
Particle Classes	Class 1: Waste feed	Class 2: Faeces
Number of particles per source and per time step	50	50
Total number of particles	1752050	1752050
Decay [/s]	0	0
Settling velocity [m/s]	0.095	0.032
Erosion Threshold [N/m^2]	0.02	0.02
Horizontal dispersion [m^2/s]	0.1	0.1
Vertical Dispersion [m^2/s]	0.001	0.001

3.2.3 Model Outputs

The output from the depositional model simulations included:

- 2D model output at 3 hourly intervals of the total, suspended and sedimented solids for each particle class in every cell of the model domain.
- 3D model output at 3 hourly intervals of the total, suspended and sedimented solids for each particle class in every cell of the model domain.

These 2D and 3D depositional model outputs were run for individual source locations GVRN1, GVRW1 and ODH1, with 3D HD climatological database as input forcing, which were then combined in post-processing. The processed 2D model outputs were then labelled $PT3D_{Depo2D\_GVRN1}$ and $PT3D_{Depo2D\_COMB}$.

3.3 Bath Treatment Dispersion Modelling

This section describes the methodology for the assessment of bath treatment medicine dispersion at the North Gravir site.

First, an overview of bath treatment medicines and Environmental Quality Standards (EQS) is presented (Section 3.3.1). The configuration of the MIKE 21 PT module and scenarios is then described (Section 3.3.2). Finally, the model outputs are specified (Section 3.3.3).

The Bath Treatment model calculates the 2D output results, with 3D HD climatological input forcing. Section 4.2 describes the results of the Bath Treatment PT modelling. Only North Gravir is modelled for the Bath treatment (no cumulative modelling is undertaken). Only these 2D model outputs are reported for $PT3D_{Bath\_GVRN1}$.

For the assessment of the Bath treatments on the PMF locations, only the European Spiny Lobster location is analysed.

3.3.1 Overview of Bath Treatment Medicines and Environmental Quality Standards

According to Section 6 of [6], there are several bath medicines licensed by SEPA for use in Scotland. These medicines contain three different active ingredients: Azamethiphos, Deltamethrin and hydrogen peroxide. Hydrogen peroxide is considered to pose a relatively low environmental risk and is not dealt with in this document.

The following summary of bath treatment chemicals and their EQS is an abridged version of the information in section G.2 of [10].

- Azamethiphos: remains in aqueous phase until it is broken down into non-toxic derivatives with a determined decay rate. Historically a decay half-life of 8.9-days has been determined (see Section G.2 of [10]). Recently SEPA have confirmed an updated decay rate of 5.6-days [11][1]. As a result of the Azamethiphos decaying over time, two standards are applied, one at 3-hours after any discharge and the other 72-hours after the final discharge in any treatment period, after which periods the quantity of chemical is predicted to have reduced by 1% and 21% respectively.

- Deltamethrin: readily binds to particles and is hence removed from the aqueous phase under the biologically active conditions prevalent in Scotland's coastal waters. Thereafter, it is incorporated into the sea-bed sediment where is it considered of negligible risk to the environment. Consequently, the EQS is applied 6-hours after discharge, setting the maximum concentration whilst in the aqueous phase.

When testing for compliance it has been recommended in [6] to follow the values as given in Table 3.5 (adapted from Table G-1 of [10]).

The longest-term EQS defined for Azamethiphos (72-hours) is applicable only in relation to the completion of the whole treatment programme. The EQS of 40 ng/l applies within an allowable zone of effect (AZE) which has a maximum area of 0.5 km^2. The EQS may be exceeded within the AZE, providing that the peak concentration is not larger than a Maximum Allowable Concentration (MAC) of 100 ng/l.

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[1] In October 2020 the UK Government Department for Environment Food & Rural Affairs (DEFRA) updated the estimated half-life of Azamethiphos to 5.6 days. This has been confirmed by SEPA in December 2023 [11]. In this modelling study, a sensitivity test of this value found no discernible difference in results.

The short-term EQS for Azamethiphos (3-hours) and Deltamethrin (6-hours) are applicable for a single release only. An EQS applies within an AZE that is determined from the mixing zone ellipse calculated from the BathAuto model (see Section 3.2.5 of [7]). Based on a mean surface current speed, and following the mixing zone ellipse calculation as detailed in Table G-5 within Appendix C of [7], the following EQS values were provided by BFS and are used in this study:

- Azamethiphos: the area with concentration above 250 ng/l should not exceed 0.238 km^2 3-hours after a single release.
- Deltamethrin: the area with concentration above 6 ng/l should not exceed 0.673 km^2 6-hours after a single release.

Table 3.5 Environmental Quality Standard for Bath treatment (see [6]).

Timescale	Standard	Type	Medicine
72-hours	100 ng/l	MAC	**Azamethiphos**
72-hours	40 ng/l	EQS	
3-hours	250 ng/l	EQS	
6-hours	6 ng/l	EQS	**Deltamethrin**

3.3.2 Model and Scenario Configuration

Modelling the discharge from bath treatment is subject to a wide range of variables including the farm size and layout, pen dimensions, treatment sequence, treatment dose (initial concentration), the environmental conditions (i.e., tidal state, wind conditions, and dispersion characteristics).

SEPA (in Section 6.4.2 of [7]) require that the following considerations are made regarding the scenarios to be modelled:

- The most representative scenario
- The most precautionary scenario

The following outlines the setting for the bath treatment modelling performed.

Farm Layout and Pen Size

During the bath treatment it is assumed that the net is raised to a treatment depth of 3 m: hence, giving a treatment volume of approximately 9548.7 m^3 per 200 m pen. Width of the pens is ~63.7m.

Treatment Dosage

The required treatment dosage (along with the pen dimensions) will determine the initial mass of medicine introduced into the marine environment. The treatment concentration of Azamethiphos and Deltamethrin were taken to be, respectively 100 mg/l (0.1 g/m^3) and 2 mg/l (0.002 g/m^3). This gives a standard treatment mass (per pen) of:

- Azamethiphos: 900 g
- Deltamethrin: 17 g

This methodology assumes that the full treatment dose is released to the environment following treatment. This is a conservative assumption as there is evidence to suggest that medicines readily bind to fish such that the concentration is reduced by up to a quarter during the treatment [8].

Treatment Sequence and Frequency

The frequency with which individual pens within a farm are treated will determine the overall timeframe for the modelling exercise and, ultimately, the concentration of medicines in the marine environment. This report has conducted analysis for both single release treatment scenarios as well as full release treatment scenarios.

Firstly, for compliance testing, a single fish pen is treated in isolation (i.e., a single pen for the full model run). It is released at a single location, the site centre, at the normal pen release depth. SEPA require single release scenarios for both a single 3hr treatment mass for both Azamethiphos and Deltamethrin, as well as an additional scenario for Deltamethrin of a combined 3 x 3hr treatment mass. This is summarised in Table 3.6 and Table 3.7.

Secondly, for a full representative treatment scenario, it is required that fish pens are treated individually (i.e., one pen at a time), considering the practical considerations that will determine how many fish pens it is possible to treat in a single day. SEPA recommend in [6] that a realistic treatment regime of 4 treatments in a 24-hour period, with 3-hour intervals between each treatment.

For Azamethiphos and Deltamethrin, as requested by BFS we have adopted a more conservative realistic treatment schedule of 3 treatments in a 24-hour period, with 3-hour intervals between each treatment, and is summarised in Table 3.6.

Environmental Conditions

The specific environmental conditions during which treatment will take place will determine the dispersion and dilution of the bath treatment medicines in the marine environment. Consideration should be given to:

- Spring or neap tidal conditions
- Flood and ebb flow conditions
- Non-tidal flow (i.e., meteorological conditions)

It is likely that neap tidal conditions with no meteorological forcing will provide the most precautionary estimate of dispersion regrading achieving the required EQS. This also makes sense from a practical and safety point of view, as it will make manoeuvring of tarpaulin into place for the treatment process easier. On the other hand, it may be only during stronger flow conditions (e.g., spring tidal forcing and more windy conditions) that represent the most precautionary scenario with regards to the MAC.

Scenarios were performed to test the sensitivity of results to different environmental conditions as summarised in Table 3.7. This included both a neap and a spring period, modelled as tidal only conditions with no wind forcing, as well as testing the different decay rate as recommended by SEPA and DEFRA.

In numerical models the dispersion usually describes transport due to non-resolved processes. In coastal areas it can be transport due to non-resolved turbulence or eddies. Especially in the horizontal directions the effects of non-resolved processes can be significant, in which case the dispersion coefficient should depend on the resolution. Simulations were performed using a constant horizontal eddy viscosity of 0.1 m^2/s. This value is the default value as recommended for dispersion modelling by SEPA.

Half-Life

As mentioned above, Azamethiphos remains in the aqueous phase until it is broken down into non-toxic derivatives for which historically a decay half-life of 8.9 days had been determined. SEPA have updated the decay half-life to 5.6 days. Both these decay rates were tested in different bath treatment model scenarios (specified as an equivalent to a decay rate of 9.01x10-7 s^{-1} and 1.43x10-06 s^{-1} respectively). This is summarised on Table 3.7.

Deltamethrin readily binds to particles and is rapidly removed from the aqueous phase and was therefore modelled without decay.

Simulation Period

The bath treatment simulations were run for a total of 156 hours. This included the 27-hour treatment period, 72-hour post treatment period, plus additional hours as a check for additional concentration peaks.

Table 3.6 Summary of bath treatment sequence at North Gravir.

Pen ID	Pen Width [m]	Pen Depth [m]	Release Time [hours]	
			Azamethiphos	Deltamethrin
GVRN1 01	63.7	3	+00	+00
GVRN1 02*	63.7	3	+03	+03
GVRN1 03	63.7	3	+06	+06
GVRN1 04	63.7	3	+24	+24
GVRN1 05	63.7	3	+27	+27

* Single pen testing released from this location (equivalent site centre) at timestep +00.

Table 3.7 Summary of $PT3D_{Bath}$ scenarios at North Gravir.

Scenario ID*	Treatment Sequence	Forcing Scenario Tides	Half-life [days]	Treatment mass per pen [kg]	
				Azamethiphos	Deltamethrin
BT101	Full	Tidal forcing only: s = springs n = neaps	8.9	0.900	0.017
BT102			5.6	"	"
BT001	Single*		"	"	"
BT003			"	"	0.051

* Single pen compliance testing used the ID 000, with the last digit identifying the treatment mass used.

3.3.3 Model Outputs

The output from the bath treatment model simulations included:

- 2D model output only
  - Hourly values of the total concentration of bath medicines in every cell of the model domain throughout the simulations.
  - Hourly values of the concentration of bath medicines in the top 5 m of the water column (from still water level) in every cell of the model domain throughout the simulations.

These PT3D bath treatment models were run for a single fish farm source location GVRN1, using the depth-averaged u- and v-velocity components and surface elevation from the 3D HD climatological database as input forcing; these model outputs are reported as $PT3D_{Bath\_GVRN1}$.

4 Modelling Results

This section describes the 2D modelling results, with input forcing form the 3D HD climatological database, for the assessment of the individual and cumulative depositional modelling of waste solids (Section 4.1), and bath treatment medicine (Section 4.2).

4.1 Solid Waste Modelling

A one-year model simulation (summer to summer) of the dispersion of solid waste was performed as described in Section 3.2. From the model results the total sedimented solids on the seabed (waste feed + faeces) were calculated for each model grid cell for the total water column, suspended sediments, and deposited sediments. During result processing, all elements with a water depth less than 0.4 m were excluded, as well as all elements touching a land boundary.

Depositional modelling was undertaken for two scenarios; North Gravir GVRN1 pens only ($PT3D_{Depo\_GVRN1}$), as well as cumulative modelling for the combined North Gravir GVRN1, Gravir West GVRW1 and Gravir Outer ODH1 pens ($PT3D_{Depo\_COMB}$).

Additional analysis of the impact on the PMF point for European Spiny Lobster and PMF area for Burrowed Mud was undertaken for both $PT3D_{Depo\_GVRN1}$ and $PT3D_{Depo\_COMB}$.

4.1.1 Individual Deposition Results

The individual contributions of the three source locations are shown briefly, to provide an overview of each site's impact to the GVRN1 and cumulative results which are presented in more detail.

Figure 4.1 provides a brief overview of the contributions of waste solids from each of the three sites, GVRN1, GRVW1 and ODH1; images show the average suspended waste solids over the last 90 days of the 1-year individual model simulations. No PMF locations are shown.

Both ODH1 (10 pens) and GVRW1 (2 pens) have a similar mass contribution for each timestep, which is visibly different to GVRN1(5 pens), and as such display similar waste solid distributions.

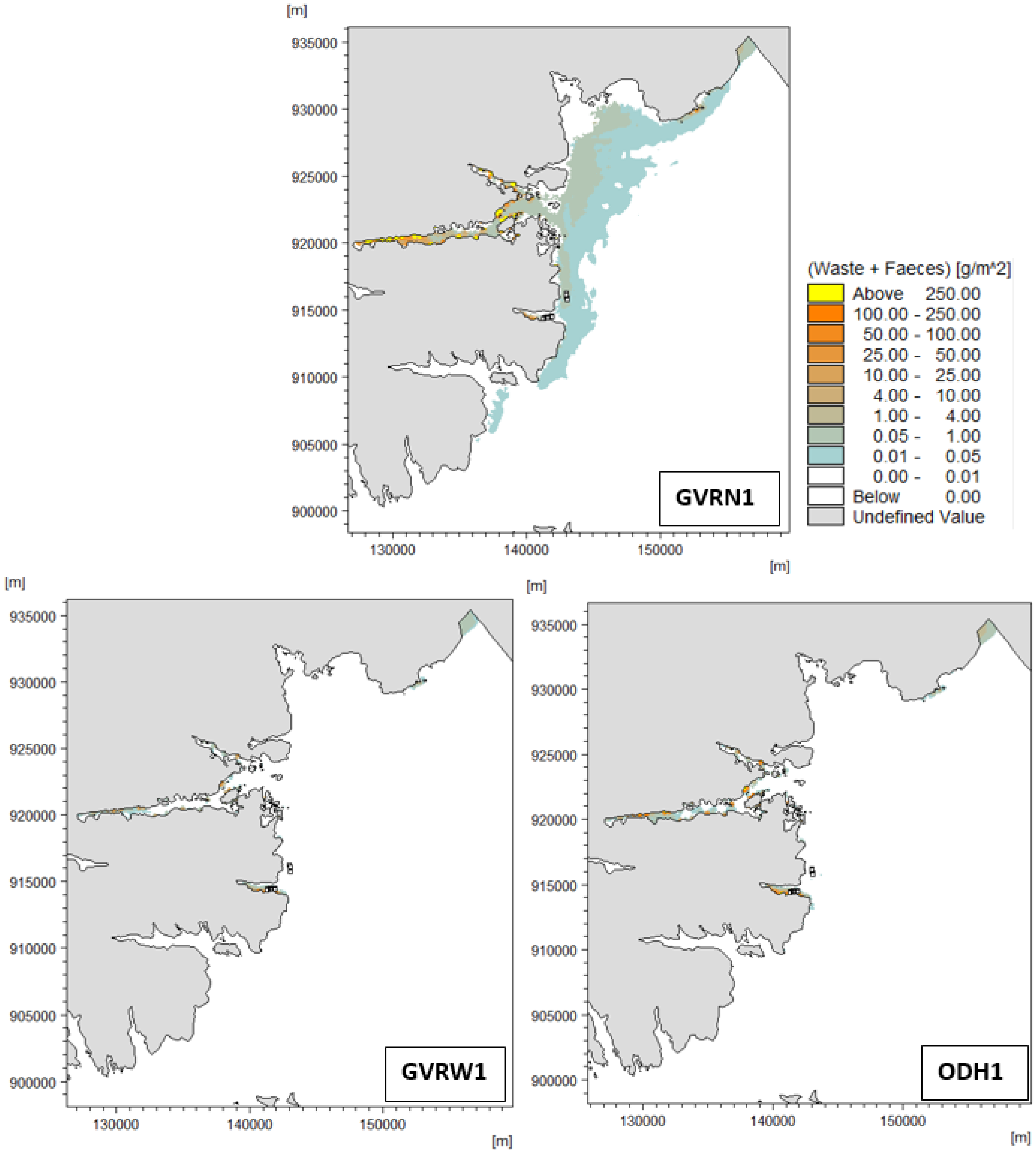

Figure 4.1 Overview maps of the individual site contributions of the average suspended waste solids (g/m^2) of the last 90 days of the 1-year PT3D$_{Depo}$ model simulations.
(Top panel) North Gravir, GVRN1 (Bottom left panel) Gravir West, GVRW1 and (Bottom right panel) Gravir Outer ODH1. The site locations shown by the unlabelled black dots.

4.1.2 GVRN1 Deposition Results

Figure 4.2 shows the depositional timeseries of the maximum and average concentrations for total solids, and the average concentrations for total suspended and total sedimented for the entire PT3D$_{Depo_GVRN1}$ model run, focussed in on the last 90 days. The term ‘total’ denotes the combined waste feed and faeces results for each modelled item. Data has been smoothed over 3x three-hourly timesteps for display purposes.

Figure 4.3 shows the extent and average concentration of impact from GVRN1, taken over the last 90 days of the model run for both suspended and sedimented solids respectively. The contour of the 250g/m^2 for average suspended and sedimented concentrations is shown in yellow.

Whilst the spread of waste solids in the suspended water column from the site is relatively extensive, the spatial extent exceeding the 250g/m^2 contour is limited to areas around the coast and inlets. Waste solids have limited sedimentation over the last 90 days of the 1-year simulation due to the tidal currents being highly erosive leading to extensive transport or resuspension of waste solids in the study domain. Deposition occurs mostly along the coastline and in isolated hotspots in the narrow inlets, including the shallow waters directly north of the MPFF.

In addition to the conservative nature of the modelled assessment (the assumption of the constant peak tonne biomass as stated in Table 3.3, and associated waste loss in the entire model period), a fixed critical threshold was used for resuspension. It is noted that work within SEPA and the industry relating to the use of NewDEPOMOD has found use of a simple criterion for resuspension in faster flow regimes can result in too much resuspension, potentially overestimating spreading around and outside of the study domain. Additionally, once waste particles reach outside of the domain boundaries to the north, they are excluded from the model calculations.

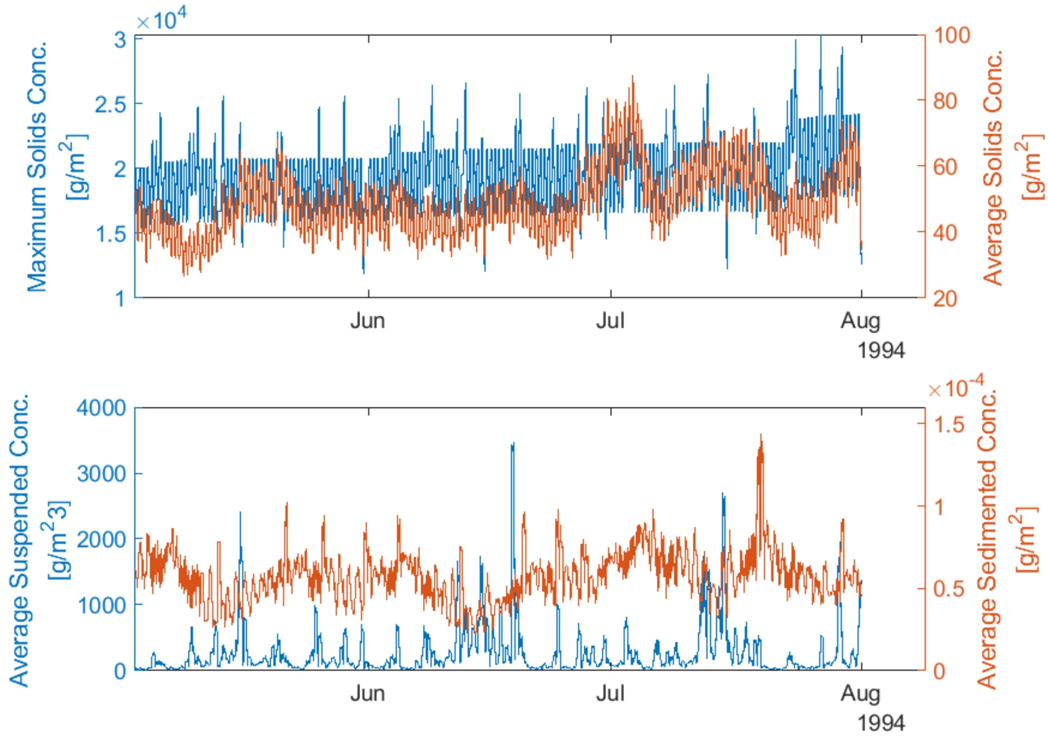

Figure 4.2 Timeseries of depositional concentrations over the entire PT3D$_{Depo_GVRN1}$ model run.

Concentrations for maximum and average solids (top panel) and average suspended and sedimented solids (bottom panel). Only the last 90 days of this entire timeseries is displayed.

4.1.3 COMB Deposition Results

The individual contributions of the three sites have been shown previously in Section 4.1.1, to provide an overview of each site's impact to the cumulative results which are presented in more detail here.

Cumulative Impact of All Sites

Figure 4.4 shows the extent and concentration of impact from the combined three sites as an average, taken over the last 90 days of the $PT3D_{Depo\_COMB}$ model run for both suspended and sedimented solids, respectively.

These figures also show the contour of the 250g/m^2 of cumulative deposited material for average sedimented and average suspended concentrations.

Whilst the spread of waste solids from the site is relatively extensive, the spatial extent extending the 250g/m^2 contour is limited to areas around the coast and inlets. The average suspended and sedimented waste solids of the cumulative results are dispersed in similar locations as the $PT3D_{Depo\_GVRN1}$. There are some additional hotspots around the inlet where the GVRW1 and ODH1 sites are located. The spread of the cumulative maximum results (for both suspended and sedimented) reaches further south, corresponding to the input from the GVRW1 and ODH1 sites.

It is important to note the conservative nature of the model in combination with the high current velocities could provide an overestimation of the waste solid spreading around and beyond the study domain.

4.1.4 PMF Deposition Results

Figure 4.3 and Figure 4.4 also shows an overview of the two PMF locations overlaid the average concentration of the $PT3D_{Depo\_GVRN1}$ and $PT3D_{Depo\_COMB}$ model run for both suspended and sedimented solids, respectively. In these overview images there are no PMF mesh elements exceeding the EQS 250 g/m2 limit for Burrowed Mud and no waste solids are suspended or deposited at the European Spiny Lobster location at all.

Table 4.1 summarises the average and maximum sedimented deposition concentrations at the PMF locations, taken over the last 90 days of the $PT3D_{Depo\_GVRN}$ and $PT3D_{Depo\_COMB}$ model run.

Table 4.1 Summary of average and maximum suspended and sedimented deposition in the PMF locations, over the last 90 days of the 1-year simulation for $PT3D_{Depo\_GVRN1}$ and $PT3D_{Depo\_COMB}$.

PMF/ Sensitive features	Suspended Concentrations [g/m^2/last90days]			
	Average		Maximum	
	Burrowed Mud	European Spiny Lobster	Burrowed Mud	European Spiny Lobster
$PT3D_{Depo\_GVRN1}$	0.01	-	2.59	-
$PT3D_{Depo\_COMB}$	0.01	-	18.46	-
PMF/ Sensitive features	**Sedimented Concentrations [g/m^2/last90days]**			
	Average		Maximum	
	Burrowed Mud	European Spiny Lobster	Burrowed Mud	European Spiny Lobster
$PT3D_{Depo\_GVRN1}$	0.79	-	129.84	-
$PT3D_{Depo\_COMB}$	0.84	-	138.35	-

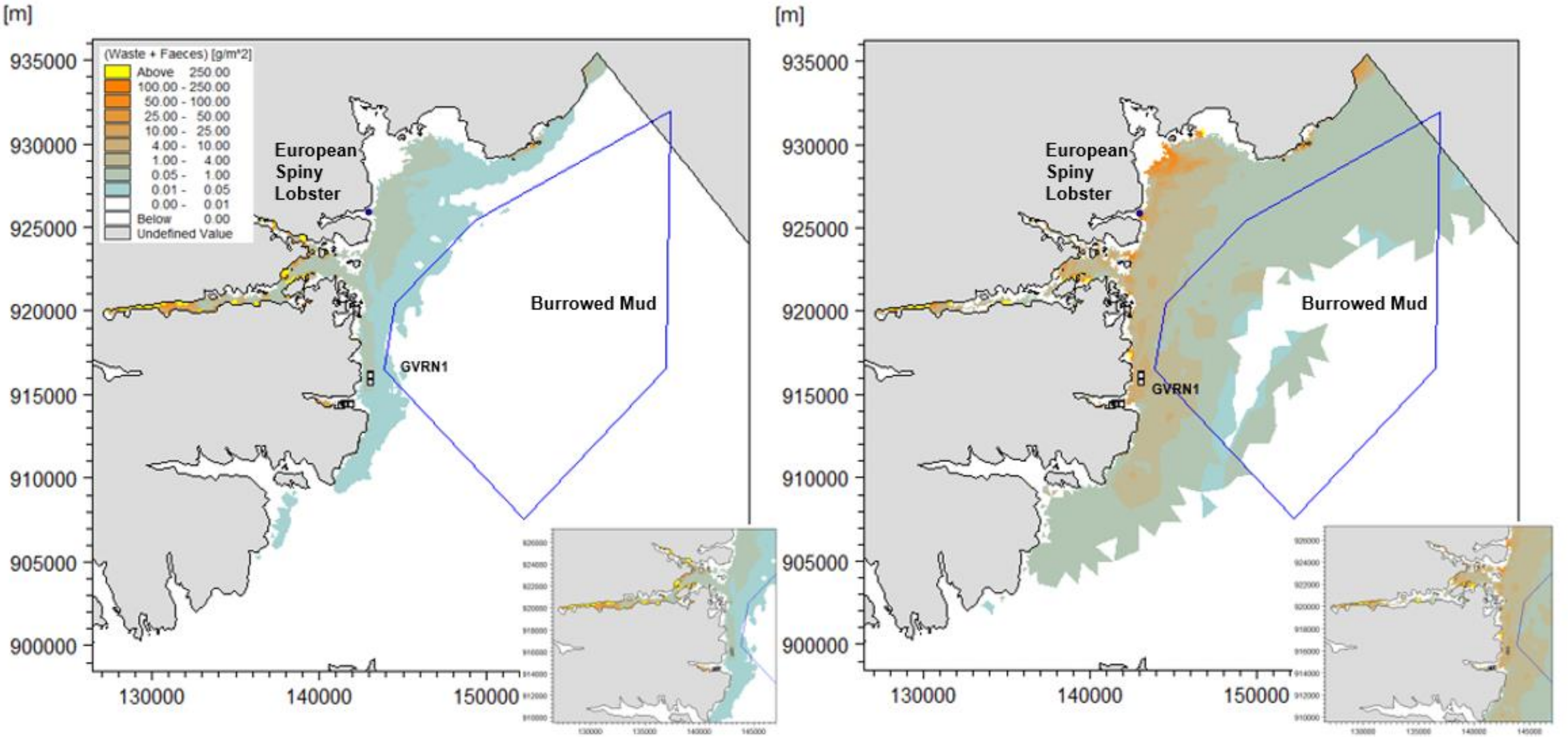

Figure 4.3 **Maps of the average concentration of waste solids (g/m^2) from individual PT3D$_{Depo_GVRN1}$ with the PMF locations overlain; (inset panels) closeup overview map.**

The suspended waste solids (left panel) and sedimented waste solids (right panel) of the last 90 days of the 1-year model simulation. The site locations shown by the unlabelled black dots. The exceedance of the 250 g/m^2 value of average/maximum concentration is shown in yellow.

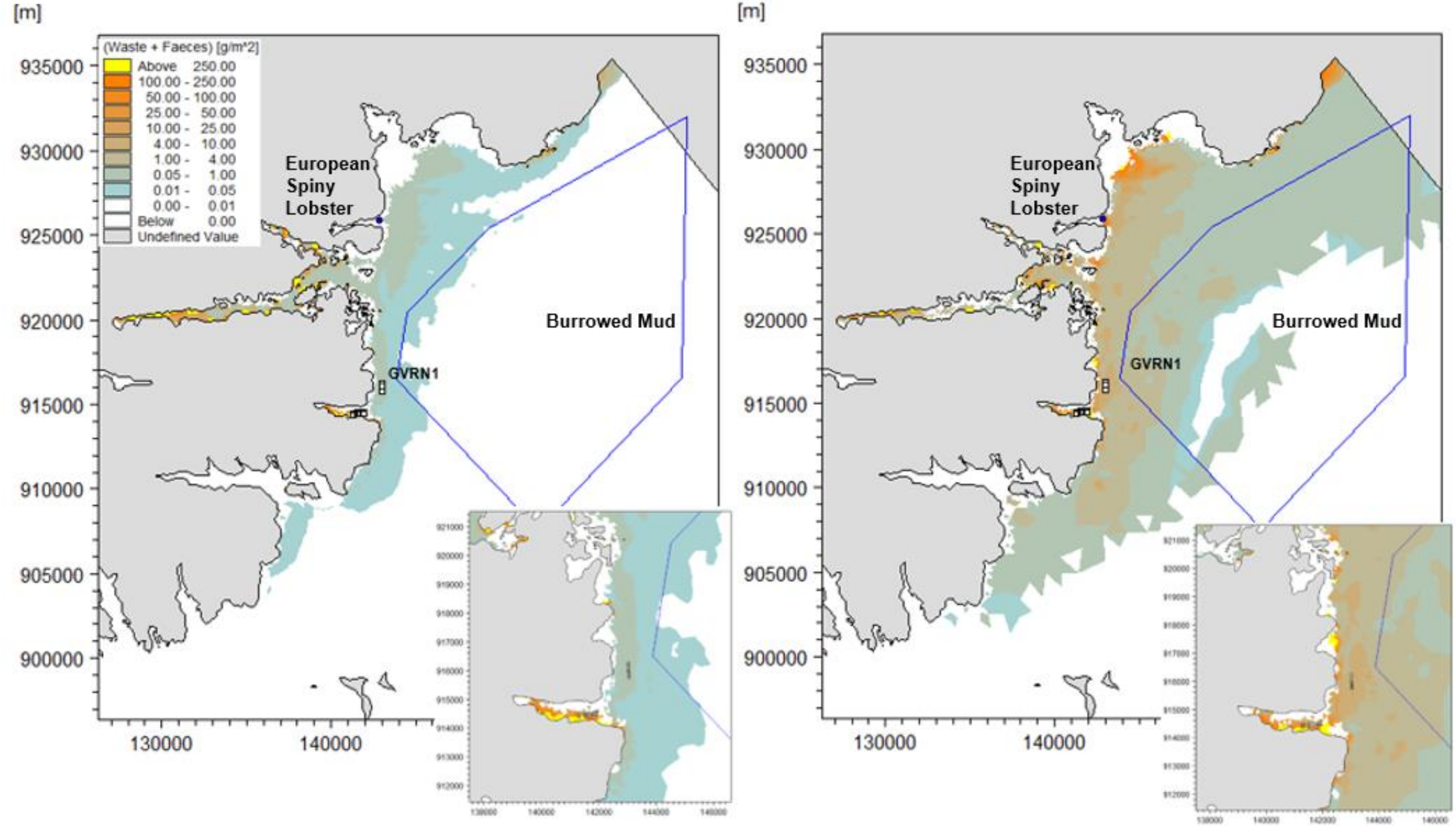

Figure 4.4 **Maps of the average concentration of waste solids (g/m²) from cumulative PT3D$_{Depo_COMB}$ with the PMF locations overlain; (inset panels) closeup overview map.**

The suspended waste solids (left panel) and sedimented waste solids (right panel) of the last 90 days of the 1-year model simulation. GVRN1 pens and additional GVRW1 and ODH1 site locations shown by white squares, PMF polygon outlined in dark blue.

4.2 Bath Treatment Dispersion Modelling

The dispersion of bath medicines was modelled for North Gravir only ($PT3D_{Bath\_GVRN1}$, 5 pens), as described in Section 3.3. See * Single pen testing released from this location (equivalent site centre) at timestep +00.
Table 3.7 for an overview of the model simulations performed.

The single treatment baseline results are discussed in Section 4.2.1. The results for the full Bath Treatments sequences are discussed in Section 4.2.2. The results for the assessment of the bath treatments on the PMF sensitive features are discussed in Section 4.2.3, for $PT3D_{Bath\_GVRN1}$ only.

The bath treatment model seasons for compliance and testing are as follows:

- Spring tide – Summer (early July)
- Neap tide – Summer (early July)

Scenario BT101 Azamethiphos has the older decay half-life of 8.9 days, while BT102 Azamethiphos has the updated decay half-life of 5.6 days. Both scenarios have no decay on the Deltamethrin. Aside from a sensitivity comparison of the different decay rates, a decay half-life of 5.6 days (BT102) is used in all other modelling.

In all bath treatment plots, the relevant +3hr, +6hr and +72hr EQS time limits are shown in dashed vertical lines. The dashed horizontal lines defining the 72-hour AZE of 0.5 km^2 and the Bath-Auto AZE of 0.238 km^2 for Azamethiphos, and 0.673 km^2 for Deltamethrin.

For the PMF Bath Treatment results, only the location for the European Spiny Lobster is analysed.

4.2.1 Short-term EQS Compliance

The top row of Figure 4.5 shows the results of single pen compliance testing for Azamethiphos and Deltamethrin, modelling the results of a single pen release (3hr treatment mass). For Azamethiphos the scenario for a single treatment mass of 1 pen is shown (BT001, using a decay half-life of 5.6 days), while for Deltamethrin the scenarios for a single treatment mass of 1 pen (BT001) and 3 pens (BT003) is shown (with no decay). Additionally, Figure 4.10 compares the maximum concentration and areal extent of the single release BT003 scenario over the long-term.

For both Azamethiphos and Deltamethrin the total area of the single treatment release does not exceed the 250 ng/l and 6 ng/l EQS limits respectively, either during the initial time-limits or throughout the model simulations. The neap scenario takes longer to disperse than the spring scenario for all scenario types.

The area with concentration of Azamethiphos above 250 ng/l does not exceed 0.238 km^2 3-hours after a single release, although the maximum concentration at that timestep is above 250 ng/l.

The area with concentration of Deltamethrin above 6 ng/l does not exceed 0.673 km^2 6-hours after a single release for both treatment mass scenarios. The values of the single pen treatment sequences at the timesteps of both short and long term EQS limits is summarised and compared to the full treatment sequence in Table 4.2.

The bottom row of Figure 4.5 shows the results of full treatment sequence with the short-term compliance limits for Azamethiphos of above 250 ng/l and

Deltamethrin of above 6ng/l. Both do not exceed these limits for the full treatment sequence.

The short term Azamethiphos EQS value of the single pen and full treatment sequence at the +3hr and +72hr after final treatment timestep is compared and summarised to the long-term EQS for the full treatment in Table 4.2. Long term Deltamethrin EQS value at +6hr is also summarised in this table.

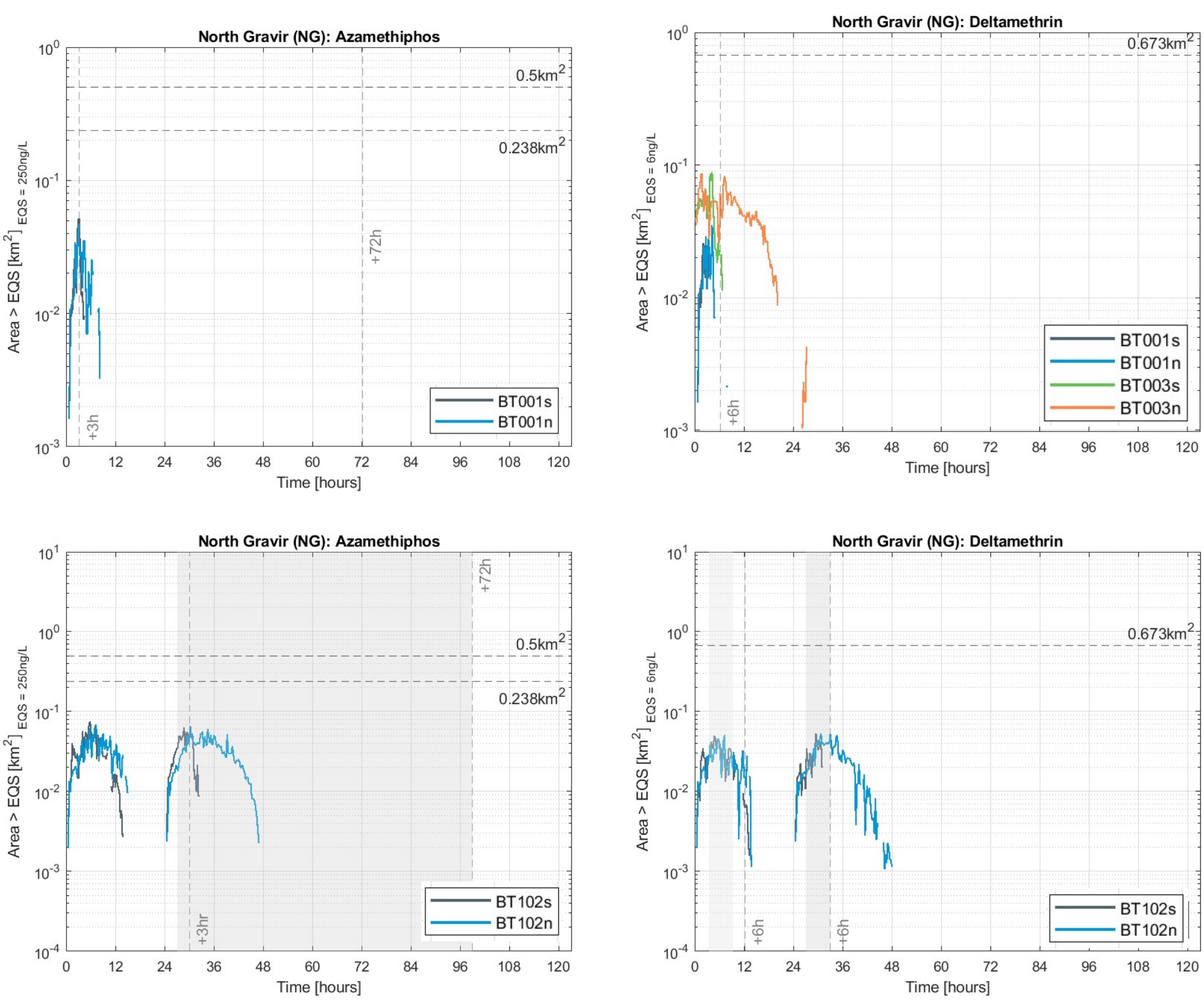

Figure 4.5 **Short-term EQS compliance testing of $PT3D_{Bath\_GVRN1}$ model results.** Single treatment release of a 1 x 3hr-treatment mass and a combined 3 x 3hr-treatment mass (top panel) and full treatment sequence (bottom panel) in relation to Azamethiphos (left panel) and Deltamethrin (right panel) in top 5 m of surface (Zrange). Time-series of the modelled area with medicine concentration greater than EQS of 250 ng/l for Azamethiphos and 6 ng/l for Deltamethrin.

4.2.2 GVRN1 Bath Treatment Results

Figure 4.7 provides an illustration of the dispersion of Azamethiphos at +3hr on Day 1 and Day 2 of the GVRN1 MPFF (based on PT3D$_{Bath_GVRN1}$ model BT102, neap tides). Figure 4.7 shows the dispersion of Azamethiphos at +72hr after final treatment of the GVRN1 MPFF.

At +3hr after the third and final treatment during day 1 (left panel of Figure 4.6), one small patch of high concentration is evident in the vicinity of the pens at GVRN1. There are also two distinct areas of higher concentrations to the north of the site. These are the medicine released from the three previous pen treatments during day 1, which have been advected and dispersed along the north-south current.

After +3hr time of the second and final treatment during day 2 (right panel of Figure 4.6), the remnant concentration patches from day 1 and the treatments from day 2 have combined and dispersed along a north-south axis.

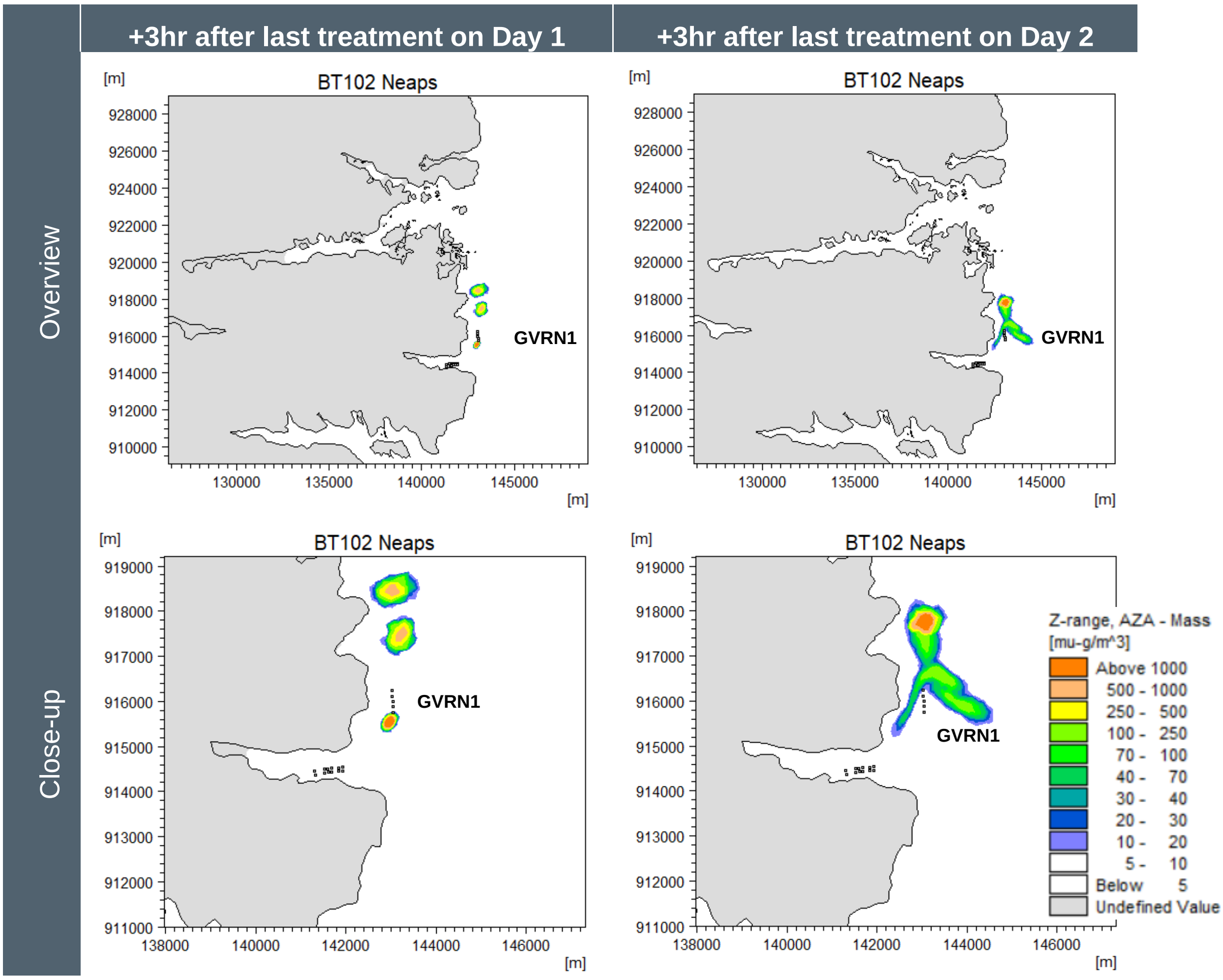

Figure 4.6 Snapshot of the +3hr concentration of Azamethiphos in µg/m^3 (equivalent to ng/l) in the upper 5m of the water column for PT3D$_{Bath_GVRN1}$ BT102 neap tide scenario.
(Top panels) overview of the wider domain (Bottom panels) closeup of the immediate vicinity of the MORR1 MPFF. The +3hr snapshots shown are for the time of the last treated pen on day 1 (left panels), and day 2 (right panels) of the treatment sequence. The 5 pens of the GVRN1 MPFF, and the pens for the GVRW1 and ODH1 MPFF are shown by the unlabelled black dots.

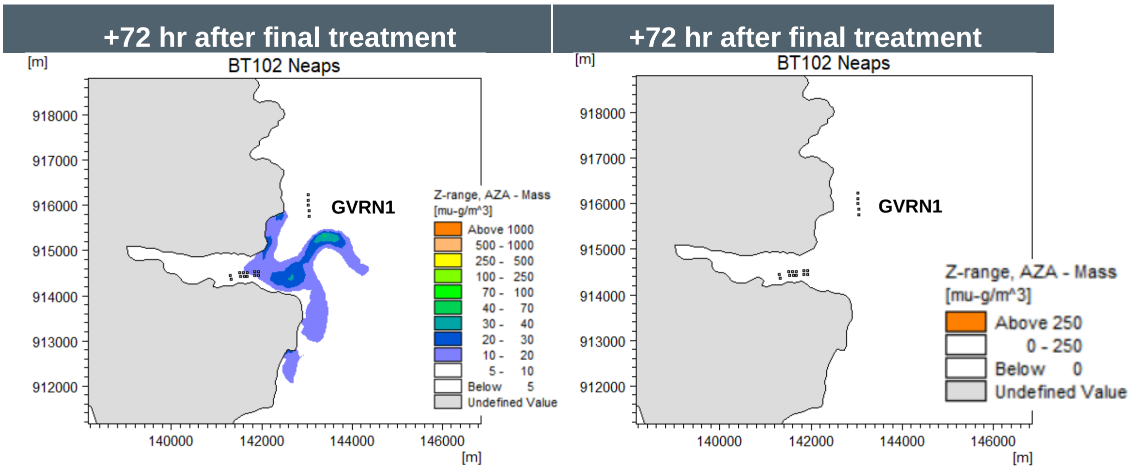

Figure 4.7 Snapshot of the +72hr concentration of Azamethiphos in µg/m³ (equivalent to ng/l) in the upper 5m of the water column for $PT3D_{Bath\_GVRN1}$ BT102 neap tide scenario. The +72hr snapshots from the time of the last treated pen on day 2 (left panel), showing the concentration over the 250 µg/m³ EQS limit (right panel). The 5 pens of the GVRN1 MPFF, and the pens for the GVRW1 and ODH1 MPFF are shown by the unlabelled black dots.

The panels in Figure 4.7 shows the map of the concentration of Azamethiphos 72-hours after the final pen has been treated, including the contour of any area over the 250 ng/l (µg/m³) EQS limit. While the patch of Azamethiphos is dispersed along the coast and caught in local eddies, the maximum concentrations in the model domain are extremely low due to dispersion and decay processes.

Comparing Decay Rates and Tidal Variation

Table 4.2 summarises the actual values at the various 3hr, 6hr and 72hr timesteps for the single treatment and full treatment sequences for both Azamethiphos and Deltamethrin.

The following describe the Azamethiphos results for $PT3D_{Bath\_GVRN1}$.

The left panel of Figure 4.8 shows a time-series of the maximum concentration of Azamethiphos for four model simulations with differing environmental conditions and decay rates (spring and neap tidal simulations for BT101 with half-life of 8.9 days; BT102 with half-life of 5.6 days). There are 5 peaks in the time-series that correspond to the treatment of each pen. In all simulations the maximum concentration decreases in the hours following the last treatment. Within a period of 72-hours following the final treatment the maximum concentration in all runs was less than the MAC of 100 ng/l. The impact of the decay rate on Azamethiphos is minimal.

The right panel of Figure 4.8 shows a time-series of the modelled areal extent where the concentration of Azamethiphos exceeds the 72-hour EQS of 40 ng/l (see Table 3.5). The impact of the decay rate on Azamethiphos is minimal. In the spring simulations the maximal area was between 1 and 10 km², with this area rapidly decreasing below the AZE limit of 0.238 km² 24 to 36 hours after the final treatment, well before the required window of 72-hours after the final treatment. In the neap simulations the maximal area was between 1 and 10km² again, taking a longer time to disperse below the AZE limit of 0.238 km². The areal extent of the Azamethiphos did fall below the AZE at the required window of 72-hours after final treatment; and then briefly redistribute over a larger area again after the +72-hour limit.

The following describe the Deltamethrin results for $PT3D_{Bath\_GVRN1}$.

There is no decay on Deltamethrin, and these figures only show the tidal forcing. At no time during any of the spring and neap model scenarios was the areal extent of Deltamethrin above the AZE of 0.673 km^2 for all models tested.

Figure 4.9 shows the Deltamethrin results for BT102. The left panel shows a time-series of the maximum concentration of Deltamethrin for the spring and neap model simulation, while the right panel shows a time-series of the areal extent of Deltamethrin with concentration above the 6-hour EQS of 6 ng/l.

The maximum concentration shows multiple short-lasting low peaks and resurgence of concentration over time. The spring-tide scenarios are below the maximum EQS limit of 6ng/l at 6hr after the final treatment. The neap-tide scenarios are just above the maximum EQS limit, with a small resurgence right at and around the +6hr after final treatment timestep, as well as a slow dispersal rate for the next 12 hours.

The maximum concentration for the neap run of BT102 at +6hr is a near miss and slowly disperses over the following 12 hours. It does not exceed the 6ng/l value again after the final treatment. The maximum concentration for the spring model for BT102 is below the EQS limit at the +6hr after final treatment timestep.

At no time is the total areal extent above the 6ng/l EQS limit exceeded for either tidal scenario.

Comparing Short Term and Long Term EQS

The compliance testing results of the single pen treatment and full treatment sequence of the short- and long-term EQS limits for Azamethiphos and Deltamethrin, as stated in Table 3.5 and Figure 4.5, are summarised in Table 4.2.

These values represent the value over entire $PT3D_{Bath\_GVRN1}$ model domain at the stated timestep after final treatment release, and do not represent maximum values across the entire timeseries itself.

For Azamethiphos compliance, it is important to clarify that the timestep for the single pen +3hr is not the same timestep for the full treatment +3hr, which is 30hrs after the initial release. This therefore allows the treatment concentration time to disperse over a larger area in the model domain and accounts for any lower or higher maximum values between the two.

Figure 4.10 shows the Deltamethrin results for single treatment scenario BT003. The left panel shows a time-series of the maximum concentration of Deltamethrin for the spring and neap model simulation, while the right panel shows a time-series of the areal extent of Deltamethrin with concentration above the 6-hour EQS of 6 ng/l. The maximum concentrations where just above the 6 ng/l EQS at +6hr limit for the spring tidal cycle scenario, falling below the limit within a few timesteps. The maximum concentration for the neap tidal cycle is above the 6 ng/l EQS at +6hr limit. It is important to note that at no time is the total areal extent above the 6ng/l EQS limit exceeded for either spring or neap tidal cycle scenario.

The AZE max area limit for Azamethiphos above 250 ng/l of 0.238km^2 is not breached for any model scenario. The AZE max area limit for Deltamethrin above 6ng/l of 0.673km^2 is not breached for any model scenario.

Table 4.2 Compliance after single and full treatment for short and long term EQS of $PT3D_{Bath\_GVRN1}$ models.

Treatment Type	Treatment Sequence	Timestep after last release*	Scenario ID	Scenario Tide	Area EQS (km^2)	Max Conc. (ng/l)
Azamethiphos	**Short Term Compliance: EQS > 250 ng/l**					
	Single Release**	T_0 + 3hr	BT001	Spring	0.05	326.35
				Neap	0.03	533.64
		T_0 + 72hr	BT001	Spring	-	9.13
				Neap	-	4.53
	Full Treatment***	T_{27} + 3hr^{++}	BT102	Spring	0.05	991.25
				Neap	0.07	701.04
		T_{27} + 72hr	BT102	Spring	-	10.81
				Neap	-	26.54
	Long Term Compliance: EQS > 40 ng/l					
	Full Treatment	T_6 + 24hr^{++}	BT102	Spring	0.16	991.25
				Neap	0.28	701.04
		T_{27} + 24hr	BT102	Spring	-	23.51
				Neap	0.28	179.41
		T_{27} + 72hr	BT102	Spring	-	10.81
				Neap	-	26.54
Deltamethrin	**Long Term Compliance: EQS > 6 ng/l**					
	Single Release	T_0 + 6hr	BT003	Spring	0.02	8.69
				Neap	0.06	10.89
		T_6 + 24hr^{++}	BT003	Spring	-	1.90
				Neap	-	4.19
	Full Treatment	T_6 + 6hr	BT102	Spring	0.01	9.71
				Neap	0.02	10.00
		T_{27} + 6hr	BT102	Spring	-	2.46
				Neap	0.04	10.85

* T_0, T_6 and T_{27}: Timestep in hours of the final treatment release.
** Single release treatment: single treatment being released from single location (treatment mass designated by last digit in Scenario ID).
*** Full treatment: 5 pens being released in sequence over 2 days.
$^{++}$ Identical timestep: monitoring different EQS limits results in different notation.

4.2.3 PMF Bath Treatment Results

The concentrations for Azamethiphos and Deltamethrin for $PT3D_{Bath\_GVRN1}$ BT102 in the top 5m of the water column at only the European Spiny Lobster PMF location (as shown in Figure 2.4) was analysed.

Results indicated this location experienced no occurrence of either treatment chemicals for either springs or neap tidal scenarios at any time during the model scenarios. This is due to the distance from the GVRN1 fish farm as well as the sheltered nature of the location with regards to the prevailing currents. No timeseries plots or statistics will therefore be provided.

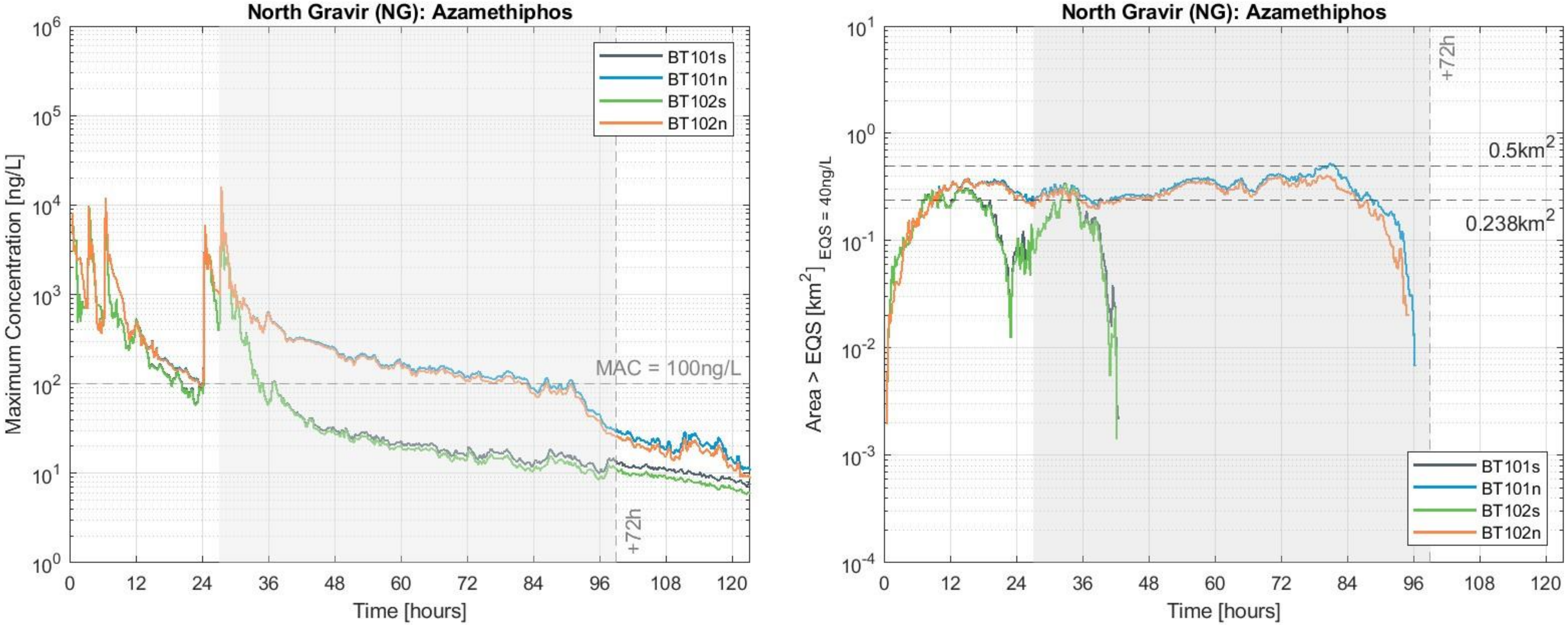

Figure 4.8 **$PT3D_{Bath\_GVRN1}$ BT101 and BT102 model results for Azamethiphos in top 5m of surface (Zrange).**
Bath treatment (900 kg per pen) in relation to 72-hours EQS and MAC from simulations BT101 (neap and spring tide with half-life 8.9 days), and BT102 (neap and spring tide with half-life 5.6 days). (Left panel) maximum concentration of Azamethiphos (ng/l) within the model domain at each time step, with the 72-hour MAC value of 100 ng/l. (Right panel) time-series of the modelled area with Azamethiphos concentration greater than 40 ng/l, with the 72-hour AZE of 0.5 km^2 area and the calculated AZE from BathAuto of 0.238 km^2 is defined by dashed horizontal lines. For both panels the time from the last pen release to the +72-hours is shaded in grey block.

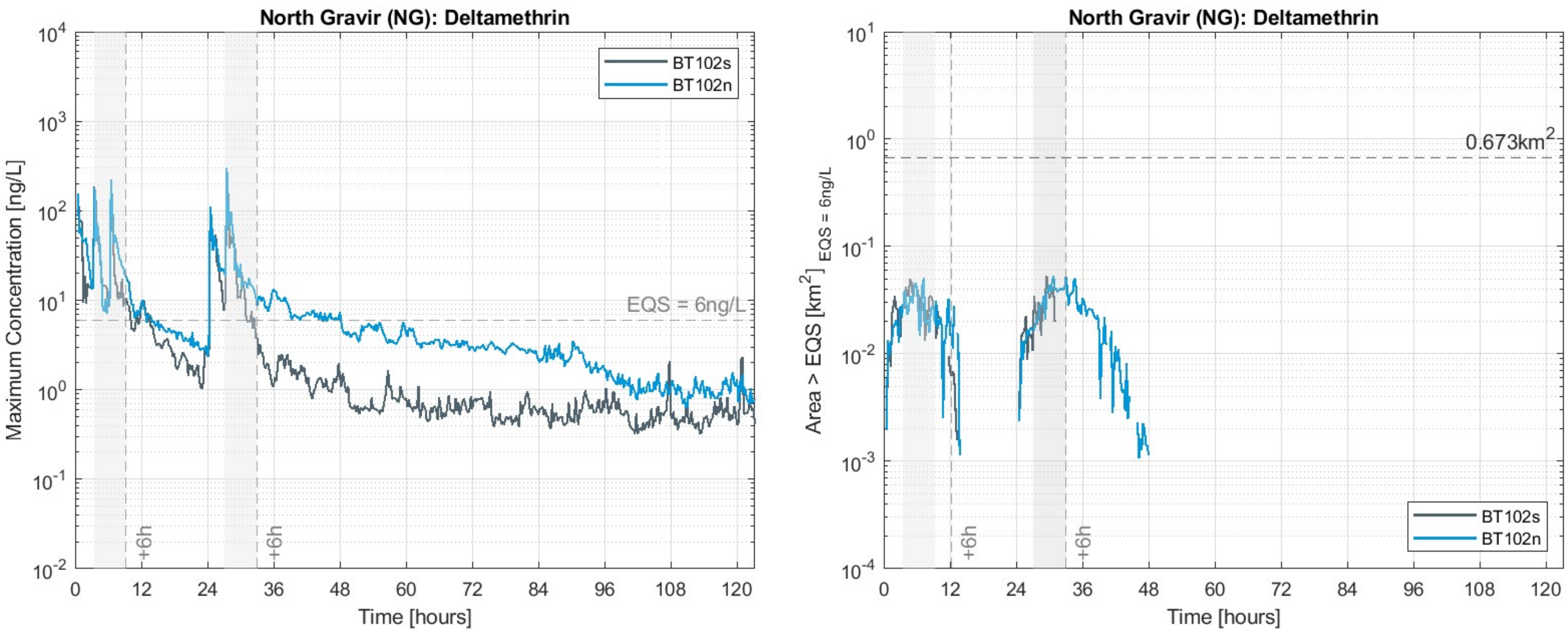

Figure 4.9 **$PT3D_{Bath\_GVRN1}$ BT102 model results for Deltamethrin in top 5m of surface (Zrange).**
Bath treatment above 6 ng/l (6-hour EQS) from simulations BT102 (17 g per pen) (neap tide and spring tide with no decay). (Left panel) maximum concentration of Deltamethrin (ng/l) within the model domain at each time step, with the 6-hour EQS value of 6 ng/l. (Right panel) time-series of the modelled area with Deltamethrin concentration greater than 6 ng/l, with the 6-hour AZE of 0.5 km^2 area defined in dashed horizontal line The calculated AZE from BathAuto is shown by the dashed horizontal line at 0.673 km^2. For both panels the time from the last pen release to the +6-hours is shaded in grey block.

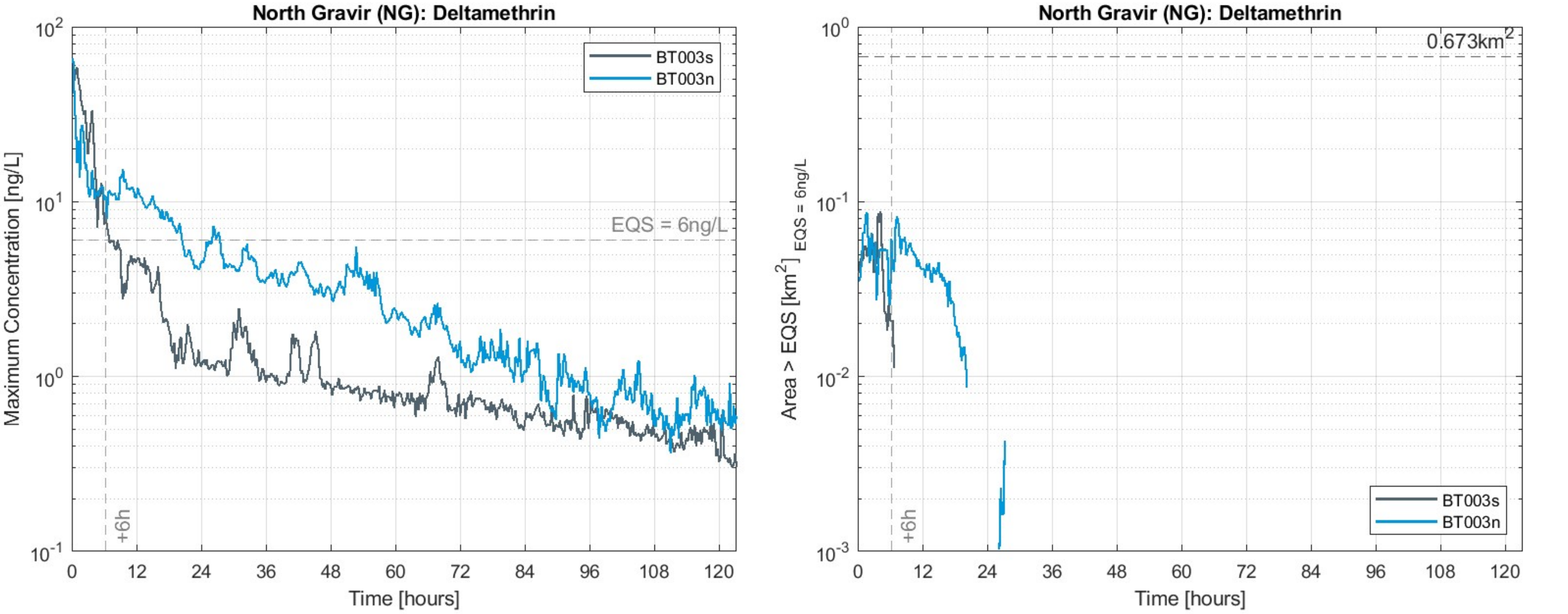

Figure 4.10 **PT3D$_{Bath_GVRN1}$ BT003 model results for Deltamethrin from a single release in top 5 m of surface (Zrange).**
Bath treatment (51 g for single pen, site centre) above 6 ng/l (6-hour EQS) from simulations BT003: (neap tide and spring tide with no decay). (Left panel) maximum concentration of Deltamethrin (ng/l) within the model domain at each time step, with the 6-hour EQS value of 6 ng/l. (Right panel) time-series of the modelled area with Deltamethrin concentration greater than 6 ng/l, with the 6-hour calculated AZE from BathAuto of 0.673 km^2 is shown by the dashed horizontal line. For both panels the time from the last pen release to the +6-hours is shown by a dashed line.

5 Conclusions

BFS are proposing the North Gravir MPFF at a biomass at the site of 4,680 tonnes with a site infrastructure of large 200m circumference pens. This report has presented a detailed marine modelling study to simulate the dispersion of waste solids and of veterinary medicines to understand the risk to the environment from the proposal.

A 3-dimensional climatological hydrodynamic database [1] and particle tracking model of the study area was developed. The hydrodynamic model was calibrated and then independently verified against in situ measurements [1]. Only the 2D model outputs for both Depositional and Bath treatment models (with input forcing from the 3D HD climatological database) are analysed in detail.

5.1 Waste Solids Conclusion

Assessment of the impact from the proposed MPFF's on the distribution of waste solids has been undertaken using the numerical models run for a one-year period. Only $PT3D_{Depo\_GVRN1}$ model outputs for the North Gravir site, as well as the cumulative effects of $PT3D_{Depo\_COMB}$ (North Gravir, Gravir West and Gravir Outer), is being assessed in this study. These models were forced with the 3D HD climatologic model as input forcing.

North Gravir

For North Gravir, the higher current speeds lead to a greater distribution of waste solids away from the site. There is a large dispersion of waste solids to the north of the site domain, however deposition can be seen to be limited to areas along the coast and in the narrow inlets. It is important to note that the conservative nature of the modelled assessment. Faster flow regimes can result in the models overestimating the resuspension and transport of particles beyond the open domain boundaries.

Very low concentrations of total and suspended waste solids are dispersed throughout the site domain. It is apparent that the isolated hotspots around the coastline of the inlets and islands are more prone to higher concentrations of total and sedimented waste solids, due to the current speeds being significantly lower in these areas. The waste solids get trapped in the narrow inlets and are dependent on tidal and seasonal current dynamics to flush the inlets clear.

There is limited to no impact on the PMF Burrowed Mud area due to waste solids released from North Gravir GVRN1 alone. There is no impact on the PMF European Spiny Lobster from North Gravir GVRN1 alone.

Cumulative North Gravir, Gravir West and Gravir Outer

The inclusion of Gravir West and Gravir outer to the North Gravir results shows minor variation to the sedimented waste solids in the north of the study domain, with most of the difference in the cumulative plots located in the immediate vicinity of the cumulative sites, GRVW1 and ODH1 MPFFs, in Loch Odhairn.

There is no discernible difference in the impact on the PMF Burrowed Mud form the COMB waste solid sites compared to GVRN1 only. There is no occurrence of waste solids in suspension or deposited at the PMF European Spiny Lobster location.

5.2 Bath Treatment Conclusion

Simulations of the dispersion of bath medicines from the pens at the North Gravir site were performed representing realistic bath treatment sequences, for different environmental conditions.

Dispersion at the surface, where bath medicines are released, are considered a realistic representation of hydrodynamic conditions; especially when one considers the effect of applied wind stress on the water column. Only $PT3D_{Bath\_GVRN1}$ model outputs were analysed for the report. These models used the depth-averaged u- and v-velocity components and surface elevation from the 3D HD climatological database as input forcing.

These results are considered conservative. The methodology assumes that full treatment dose is released to the environment following treatment.

While the historical value for the half-life of Azamethiphos (8.9 days) is a conservatively high value, it was shown that there is relatively little difference in the dispersion of Azamethiphos based on using the decay rate of 8.9 days (BT101) or 5.6 days (BT102). A decay rate of 5.6 days was adopted for all further Azamethiphos testing, including assessing the impact on PMF locations.

It was shown that the EQS for Azamethiphos (based on maximum 3 pens per day at 900 g per pen), can be achieved during both spring and neap tidal conditions with a 24-hour treatment mass of up to 2700 g on the first day and up to 1800 g on the second day.

It was shown that the EQS for the Deltamethrin areal extent, based on the initial request of 3 pens per day at 17 g of Deltamethrin per pen (BT102), can be achieved during both spring and neap tidal conditions with a 24-hour treatment mass of 51 g on the first day and 34 g on the second day. It should be noted that the maximum concentration at the +6hr timestep after last release is above the EQS value of 6ng/l for the BT102 neap scenario.

It was shown that the EQS for the Deltamethrin areal extent, based on the additional request of 3 treatment masses being released from single location at a total of 51 g of Deltamethrin (BT003), can be achieved during both spring and neap tidal conditions. It should be noted however that the maximum concentration at the +6hr timestep after last release is above the EQS value of 6ng/l for the neap tidal cycle while the spring tidal cycle showed to be well within the limits.

It was shown that at no time did the areal extent of Deltamethrin exceed the AZE areal limit of 0.673 $km^{2,}$ at the requested treatment mass of 17 g per pen.

From both the Azamethiphos and Deltamethrin simulations it has been shown that overall spring tidal cycles are preferable to the neap tidal cycles.

There is no impact on the PMF European Spiny Lobster due to bath treatment releases from North Gravir GVRN1.

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