Appendix K Water column assessment

Ngāi Tahu Seafood Resources Limited

Hananui Aquaculture Project

Water Column Assessment

Evidence of Pete Wilson regarding the Water Column Assessment and Proposed Conditions

Dr Pete Wilson
5/11/2025

Introduction

My name is Pete Wilson.

My role in relation to the Hananui Aquaculture Project (“**HAP**”) has been to provide expert evidence in relation to the effects of the proposed activity on the water column. I was the lead author of the Water Column Assessment, which is provided within **Appendix K** of the application.

This evidence has been prepared to accompany the application by Ngāi Tahu Seafood Resources Limited (“**NTS**”) for approvals required for the HAP under the Fast-track Approvals Act 2024 (“**FTAA**”). It has been prepared on the understanding that the process for determining applications under the FTAA does not require a hearing to be held, and accordingly the purpose of this evidence is to confirm that, relative to my area of expertise, the Water Column Assessment provides an appropriate description of the relevant environment, the proposed activities comprising the effects of the HAP on that environment, and the way those effects are proposed to be managed.

My findings are set out in full in the Water Column Assessment included within **Appendix K** of the application.

While this application is not being considered by the Environment Court, I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court of New Zealand Practice Note 2023 and that I have complied with it when preparing this evidence. Other than when I state I am relying on the advice of another person, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Qualifications and Experience

I am a Principal Water Quality Scientist at SLR Consulting New Zealand Limited (SLR).

I graduated from Auckland University of Technology with a PhD in marine biogeochemistry and the University of Waikato with a BSc and MSc(Hons) in chemistry.

I have over 12 years of experience in local government, consulting, and academia. I am experienced in resource management, ecological impact assessments, and designing, implementing, and reporting on monitoring programmes, including regional state of the environment programmes.

I conduct technical peer reviews and prepare ecology and water quality reports supporting resource consent applications including wastewater and stormwater discharges into freshwater and marine environments, coastal developments, and aquaculture (mussel and fish farms). I routinely assess ecological effects against national policies and standards and regional and district plans. I have also prepared and presented expert evidence at Council hearings and the Environment Court.

I have been involved in other consent applications for new finfish farms in New Zealand. My roles in these projects have been:

- Water quality expert on behalf of the Applicant, conducting water quality analyses to support an application for the Pare Hauraki Kaimoana farm in the Coromandel Marine Farming Zone, Hauraki Gulf; and
- Lead water quality expert on behalf of Marlborough District Council for the New Zealand King Salmon Blue Endeavour marine farm. This included expert conferencing with water quality experts for the Applicant and the Department of Conservation to inform the consent conditions.

I am currently the President of Mātai Moana a Aotearoa (New Zealand Marine Sciences Society) and a General Certified Environmental Practitioner (CEnvP) under the Environment Institute of Australia and New Zealand programme.

In providing this evidence in relation to water column effects, I have considered the following matters as relevant to that topic:

- The project description provided by NTS as set out in section 6 of the substantive application document;
- The description of the existing environment, the effects of the HAP on that environment and their significance, and the proposed management and mitigation measures to manage those effects all as set out in the assessment of environmental effects accompanying the application;
- The Hydrodynamic Modelling and Water Quality Modelling reports, both of which were prepared by R. Zyngfogel, P. McComb, and S. Weppe for Oceanum on behalf of NTS and are attached as appendices to the Water Column Assessment; and
- A wide range of published literature, which describe the water column characteristics in the study area, and effects of finfish farming on the environment. These sources are all referenced in the Water Column Assessment.

Confirmation of Contents of Report and Proposed Conditions

I confirm that in my opinion the Water Column Assessment contain an accurate and appropriate description of the environment, the actual and potential effects of the HAP, and the recommended actions to manage those effects within my area of expertise.

I confirm that in my opinion the contents of the Water Column Assessment may be relied on in making a decision on the approvals sought for the HAP and confirm that provided effects within my area of expertise are managed as proposed in the application those effects will not be unacceptable and will be managed to a standard that I consider meets good practice.

I confirm that I have reviewed the conditions that NTS proposes for the approvals being sought as they relate to my area of expertise. I confirm that in my opinion, those proposed conditions are appropriate.

[redacted]

Dr Pete Wilson
5/11/2025

Ngāi Tahu Seafood Resources Limited

Hananui Aquaculture Project

Water Column Effects Assessment

Evidence of Reid Forrest regarding Water Column Assessment and Proposed Conditions

Reid Forrest
11-6-2025

Introduction

My name is Reid Forrest.

My role in relation to the Hananui Aquaculture Project ("**HAP**") has been to provide expert evidence in relation to [the effects of the proposed operation on water column characteristics. I was a contributor to the SLR Water Column Assessment which is provided within **Appendix K** of the application.

This evidence has been prepared to accompany the application by Ngāi Tahu Seafood Resources Limited ("**NTS**") for approvals required for the HAP under the Fast-track Approvals Act 2024 ("**FTAA**"). It has been prepared on the understanding that the process for determining applications under the FTAA does not require a hearing to be held, and accordingly the purpose of this evidence is to confirm that, relative to my area of expertise, the SLR Water Column Assessment provides an appropriate description of the relevant environment, the proposed activities comprising the effects of the HAP on that environment, and the way those effects are proposed to be managed.

My findings are included within the SLR Water Column Assessment included within **Appendix K** of the application.

While this application is not being considered by the Environment Court, I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court of New Zealand Practice Note 2023 and that I have complied with it when preparing this evidence. Other than when I state I am relying on the advice of another person, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Qualifications and Experience

I am currently a Principal Consultant in the Ecology and Marine Science team at SLR Consulting NZ Limited, where I have been employed since 2014. Prior to this I was also held the role of Coastal Ecologist at the Cawthron Institute between 2007 and 2014.

I graduated from Otago University with a BSc in Zoology, a Postgraduate Diploma in Marine Science and an MSc in Marine Chemistry.

I have been involved in baseline assessments, pre-and post-impact monitoring and ongoing consent condition monitoring for marine farms and other coastal developments since 2007 across both New Zealand and Australia in freshwater, estuarine, coastal and offshore environments. I am also experienced in the development and implementation of monitoring programmes for benthic and water column environments, I have also prepared and presented expert evidence at Council and EPA hearings.

I have been involved in other consent applications for new marine farms in New Zealand including;

- initial assessments of potential locations;

- baseline assessments of water column and benthic characteristics;
- development of environmental monitoring plans;
- assessment of environmental effects through staged development processes; and
- collation of monitoring reports for regulators.

In providing this evidence in relation to the potential effects of the proposed marine farming development on the surrounding water column environment, I have considered the following matters as relevant to that topic:

- The project description provided by NTS as set out in section 6 of the application;
- The description of the existing environment, the effects of the HAP on that environment and their significance, and the proposed management and mitigation measures to manage those effects all as set out in the assessment of environmental effects accompanying the application;
- The technical assessments of Oceanum an Calypso Science on the Hydrodynamic Model development and its application to water column characteristics modelling]; and
- The Hydrodynamic Modelling and Water Quality Modelling reports, both of which were prepared by R. Zyngfogel, P. McComb, and S. Weppe for Oceanum on behalf of NTS and are attached as appendices to the Water Column Assessment; and
- A wide range of published literature, which describe the water column characteristics in the study area, and effects of finfish farming on the environment. These sources are all referenced in the Water Column Assessment.

Confirmation of Contents of Report and Proposed Conditions

I confirm that in my opinion the water column assessment contains an accurate and appropriate description of the environment, the actual and potential effects of the HAP, and the recommended actions to manage those effects within my area of expertise.

I confirm that in my opinion the contents of the water column effects assessment may be relied on in making a decision on the approvals sought for the HAP and confirm that provided effects within my area of expertise are managed as proposed in the application those effects will not be unacceptable and will be managed to a standard that I consider meets good practice.

I confirm that I have reviewed the conditions that NTS proposes for the approvals being sought as they relate to my area of expertise. I confirm that in my opinion, those proposed conditions are appropriate.

[redacted]

Reid Forrest

11.6.25

Ngāi Tahu Seafood Resources Limited

Hananui Aquaculture Project

Oceanographic modelling

Evidence of Rémy Zyngfogel regarding Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling.

Rémy Zyngfogel
10/11/2025

Introduction

My name is Rémy Zyngfogel.

My role in relation to the Hananui Aquaculture Project ("**HAP**") has been to provide expert evidence in relation to hydrodynamical model and water quality modelling. I wrote the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling which is provided within **Appendix K** of the application.

This evidence has been prepared to accompany the application by Ngāi Tahu Seafood Resources Limited ("**NTS**") for approvals required for the HAP under the Fast-track Approvals Act 2024 ("**FTAA**"). It has been prepared on the understanding that the process for determining applications under the FTAA does not require a hearing to be held, and accordingly the purpose of this evidence is to confirm that, relative to my area of expertise, the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling provides an appropriate description of the relevant environment, the proposed activities comprising the effects of the HAP on that environment, and the way those effects are proposed to be managed.

My findings are set out in full in the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling included within **Appendix K** of the application.

While this application is not being considered by the Environment Court, I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court of New Zealand Practice Note 2023 and that I have complied with it when preparing this evidence. Other than when I state I am relying on the advice of another person, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Qualifications and Experience

I am a physical oceanographer and numerical modeller.

I graduated from National Oceanography Centre, Southampton (United Kingdom) with a Master's degree in Physical Oceanography.

My professional background includes more than a decade of experience in marine environmental consultancy, specialising in coastal hydrodynamic modelling, pollutant and sediment dispersion, and environmental impact assessments for aquaculture, dredging, and coastal infrastructure developments.

In providing this evidence in relation to the hydrodynamic and water quality modelling for the proposed Hananui Aquaculture Project, I have considered the following matters as relevant to that topic:

- The project description provided by NTS as set out in section 6 of the substantive application document;
- The description of the existing environment, the effects of the HAP on that environment and their significance, and the proposed management and mitigation measures to manage those effects all as set out in the assessment of environmental effects accompanying the application;
- The configuration, calibration, and validation of the numerical model (SCHISM) used to simulate hydrodynamics and dispersion processes;
- The assessment of potential water quality effects using the validated hydrodynamical model, with an Eulerian approach applied to simulate total nitrogen, dissolved oxygen, and benthic detritus processes; and
- The reliability and uncertainty of the model predictions in the context of assessing potential environmental effects.

Confirmation of Contents of Report

I confirm that in my opinion the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling contain an accurate and appropriate description of the environment, the actual and potential effects of the HAP, and the recommended actions to manage those effects within my area of expertise.

I confirm that in my opinion the contents of the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling may be relied on in making a decision on the approvals sought for the HAP and confirm that provided effects within my area of expertise are managed as proposed in the application those effects will not be unacceptable and will be managed to a standard that I consider meets good practice.

[redacted]

Rémy Zyngfogel

10/11/2025

Ngāi Tahu Seafood Resources Limited

Hananui Aquaculture Project

Oceanographic modelling

Evidence of Peter McComb regarding Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling.

Peter McComb
10/11/2025

Introduction

My name is Peter McComb .

My role in relation to the Hananui Aquaculture Project ("**HAP**") has been to provide expert evidence in relation to hydrodynamical model and water quality modelling. I was the lead author of the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling which is provided within **Appendix K** of the application.

This evidence has been prepared to accompany the application by Ngāi Tahu Seafood Resources Limited ("**NTS**") for approvals required for the HAP under the Fast-track Approvals Act 2024 ("**FTAA**"). It has been prepared on the understanding that the process for determining applications under the FTAA does not require a hearing to be held, and accordingly the purpose of this evidence is to confirm that, relative to my area of expertise, the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling provides an appropriate description of the relevant environment, the proposed activities comprising the effects of the HAP on that environment, and the way those effects are proposed to be managed.

My findings are set out in full in the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling included within **Appendix K** of the application.

While this application is not being considered by the Environment Court, I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court of New Zealand Practice Note 2023 and that I have complied with it when preparing this evidence. Other than when I state I am relying on the advice of another person, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Qualifications and Experience

I am an ocean scientist specialising in physical oceanography.

I graduated from the University of Waikato with a Doctor of Philosophy and a Bachelor of Science and Post-Graduate Diploma in Marine Science from the University of Otago.

My professional experience spans oceanographic and geophysical surveys, metocean data collection, metocean design studies for oil and gas developments, subsea ocean cables, scour and pipeline stability studies, port development and dredging studies, coastal process investigations, and the analysis and interpretation of environmental data and numerical modelling outcomes.

In providing this evidence in relation to the hydrodynamic and water quality modelling, I have considered the following matters as relevant to that topic:

- The project description provided by NTS as set out in section 6 of the substantive application document;
- The description of the existing environment, the effects of the HAP on that environment and their significance, and the proposed management and mitigation measures to manage those effects all as set out in the assessment of environmental effects accompanying the application;
- The configuration, calibration, and validation of the numerical model (SCHISM) used to simulate hydrodynamics and dispersion processes;
- The assessment of potential water quality effects using the validated hydrodynamical model, with an Eulerian approach applied to simulate total nitrogen, dissolved oxygen, and benthic detritus processes; and
- The reliability and uncertainty of the model predictions in the context of assessing potential environmental effects.

Confirmation of Contents of Report

I confirm that in my opinion the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling contain an accurate and appropriate description of the environment, the actual and potential effects of the HAP, and the recommended actions to manage those effects within my area of expertise.

I confirm that in my opinion the contents of the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa Hydrodynamical Model and Water Quality Modelling may be relied on in making a decision on the approvals sought for the HAP and confirm that provided effects within my area of expertise are managed as proposed in the application those effects will not be unacceptable and will be managed to a standard that I consider meets good practice.

X ______________________________

[Name]
[Date]

Peter McComb

10/11/2025

Ngāi Tahu Seafood Resources Limited

Hananui Aquaculture Project

Review of Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa

Evidence of Dougal Greer regarding Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa

Dougal Greer
11-6-2025

Introduction

My name is Dougal Greer.

My role in relation to the Hananui Aquaculture Project ("**HAP**") has been to provide expert evidence in relation to hydrodynamic modelling. I wrote / was the lead author of the Review of Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa which is provided within Part Two of the application.

This evidence has been prepared to accompany the application by Ngāi Tahu Seafood Resources Limited ("**NTS**") for approvals required for the HAP under the Fast-track Approvals Act 2024 ("**FTAA**"). It has been prepared on the understanding that the process for determining applications under the FTAA does not require a hearing to be held, and accordingly the purpose of this evidence is to confirm that, relative to my area of expertise, the report Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa provides an appropriate description of the relevant environment.

My findings are set out in full in the Review of Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa included within Part Two of the application.

While this application is not being considered by the Environment Court, I confirm that I have read the Code of Conduct for expert witnesses contained in the Environment Court of New Zealand Practice Note 2023 and that I have complied with it when preparing this evidence. Other than when I state I am relying on the advice of another person, this evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

Qualifications and Experience

I am a Physical Oceanographer.

I graduated from University of Bath with a BSc in Physics with Computing, The University of Sussex with an MSc in Evolutionary and Adaptive Systems and University of Auckland with a Grad Dip in Statistics.

I have worked as an oceanographer for the past 18 years, I have co-authored 20 peer reviewed journal paper including in Nature. I have authored >100 technical reports and managed many projects involving numerical modelling at locations worldwide for a range of clients including, private coastal property owners, regional councils, Ports, NGOs and multinational banks. I have developed many calibrated hydrodynamic modelsin my time as a physical oceanographer.

In providing this evidence in relation to numerical modelling of oceanographic processes, I have considered the following matters as relevant to that topic:

- The project description provided by NTS as set out in section 6 of the application;

- The description of the existing environment;
- The technical assessments of previous attempts at modelling hydrodynamics in the Foveaux Strait; and
- The modelling report describing the development and calibration of the hydrodynamic model presented as part of this application.

Confirmation of Contents of Report and Proposed Conditions

I confirm that in my opinion the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa contain an accurate and appropriate description of the environment within my area of expertise.

I confirm that in my opinion the contents of the Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa may be relied on in making a decision on the approvals sought for the HAP.

[redacted]

Dougal Greer
7 November 2025

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

Prepared by:

SLR Consulting New Zealand Limited

SLR Project No.: 840.030141.00001

6 November 2025

Revision: 2.1

Revision Record

Revision	Date	Prepared By	Checked By	Authorised By
2.1	6 November 2025	Pete Wilson	Reid Forrest	Dan Govier
2.0	31 October 2025	Pete Wilson	Reid Forrest	Dan Govier
1.0	6 October 2025	Pete Wilson	Reid Forrest	Dan Govier

Basis of Report

This report has been prepared by SLR Consulting New Zealand Limited (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Ngāi Tahu Seafood (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

This report is for the exclusive use of the Client and may be disclosed by the Client to the Environmental Protection Authority and the EPA Hearing Panel as part of the Client environmental audit consent application. No warranties or guarantees are expressed or should be inferred by any third parties. This report may not be relied upon by other parties without written consent from SLR.

SLR disclaims any responsibility to the Client and others in respect of any matters outside the agreed scope of the work to add the following text to the first section of SLR’s report to further clarify SLR’s engagement and address the matter that the report will be provided to the EPA Hearing Panel as part of the environmental audit consent application.

Executive Summary

Ngāi Tahu Seafood (**NTS**) proposes to establish an offshore salmon farm in Foveaux Strait, approximately 2–6 km northeast of Rakiura / Stewart Island. The proposed Hananui Aquaculture Project would occupy a 1,285-ha area and be developed in two stages:

- Stage 1: Initial development in one block of 10 pens at each of the four farm sites, maximum annual feed input of 15,000 tonnes.
- Stage 2: Full development two blocks of 10 pens at each of the four farm sites, maximum annual feed input of 25,000 tonnes.

This assessment characterises the existing water column environment within and around the proposed farming area and evaluates the potential effects of the proposed activity on water quality, phytoplankton, and dissolved oxygen (DO), as well as the potential influence of artificial lighting.

Foveaux Strait is a high-energy, well-flushed marine environment with strong tidal currents (mean current speed 0.56 m/s near the surface) predominantly flowing along a northwest–southeast direction. Water temperatures measured in 2018/2019 and 2025 ranged from 11–15°C, with minimal vertical stratification. Baseline monitoring in 2025 recorded total nitrogen (TN) concentrations ranging from 190 to 700 µg/L (mean 405 µg/L), which is higher than at other offshore aquaculture sites in New Zealand and likely reflects natural upwelling and mixing processes occurring in this area. Total phosphorus (TP) concentrations ranged from 5 to 46 µg/L, and chlorophyll-a (chl-a) concentrations were typically low (0.1–1.5 µg/L), indicating low phytoplankton biomass despite the relatively high nutrient concentrations.

Phytoplankton communities were dominated by diatoms, although potentially toxin producing species such as *Pseudonitzschia* spp. and *Heterosigma akashiwo* were detected, particularly in nearby sheltered embayments during May 2025. Dissolved oxygen (DO) concentrations were high (8.1–9.1 mg/L; 101–106%), indicating well oxygenated waters.

A hydrodynamic model was developed for the area and water quality modelling was undertaken using this model to assess the potential effects of the proposed activity on the water column under Stage 1 and Stage 2 scenarios. The key potential water quality effects associated with finfish aquaculture are nutrient enrichment and reductions in DO concentrations.

The model predicted that the mean increase in TN concentration within 100 m of the pens would be 8.6 µg/L during Stage 1 and 9.2 µg/L during Stage 2. Short-lived maximum concentrations within 100 m of the pens were higher in Stage 1 (31.9 µg/L) than in Stage 2 (28.6 µg/L), reflecting the slightly higher stocking density proposed for Stage 1. These peak concentrations occurred in the hour following slack tide, when water movement and mixing is at its lowest.

Within the farming area during Stage 2, mean increases are predicted to be <8.5 µg/L (~2% and 7% increase from background concentrations in 2018/19 and 2025, respectively). Outside the proposed farming boundary, predicted changes are <4 µg/L (~1% and 4% increase from background concentrations in 2018/19 and 2025, respectively) up to 4 km from the farming area along the dominant northwest–southeast flow axis and negligible beyond this. In nearby embayments, increases are ≤1 µg/L, and in Patterson Inlet ≤0.5 µg/L. Overall, predicted changes in TN from the proposed farming activity are expected to be low and localised to the farming area and are unlikely to result in any ecologically significant changes in nutrient concentrations in the water column. Effects on the wider Foveaux Strait environment are considered to be negligible.

The small predicted TN increases, combined with strong flushing, mean that phytoplankton growth near the farm is unlikely to increase noticeably. Blooms have been observed to occur in nearby sheltered embayments under the existing natural conditions, but predicted TN inputs from the farm are low (≤1 µg/L) and are not anticipated to detectably influence phytoplankton growth.

Conservatively, if all nitrogen originating from the farm was assumed to be total ammoniacal nitrogen (potentially toxic at elevated concentrations), the maximum predicted TN (31.9 µg/L) is well below the ANZG (2018) toxicant default guideline values for marine aquatic ecosystems for the 99% level of species protection (500 µg/L). As such, there is negligible risk of ammonia toxicity resulting from the proposed farming activities.

Modelled DO reduction near fish pens is predicted to be low, with mean reductions of 0.18–0.20 mg/L and short-lived maxima of ~0.9 mg/L during slack tides. These reductions are highly localised to the fish pens. DO concentrations remain well above acknowledged ecological thresholds (>7 mg/L) under all scenarios. Effects of the proposed farming activities on DO beyond the farm boundary are negligible.

Effects from submerged LED lighting are expected to be highly localised (<10 m from pens) and very low, with no measurable impact on wider ecological processes.

The proposed farming activity is predicted to have low and localised effects on water quality. Strong hydrodynamic conditions in Foveaux Strait provide a high level of dilution and flushing, ensuring that nutrient enrichment, phytoplankton responses, and DO depletion remain within ecologically acceptable limits. Even though the effects have been assessed to be low, monitoring recommendations are provided. The intent of these is to verify that the nutrient and dissolved oxygen concentrations remain within the ranges predicted by the modelling.

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Figures

Appendices

Acronyms and Abbreviations

ANZECC 2000	Australian and New Zealand Environment and Conservation Council Guidelines for Fresh and Marine Water Quality
Cawthron	The Cawthron Institute
DoC	The Department of Conservation
DO	Dissolved oxygen
DRP	Dissolved reactive phosphorous
ESNZ	Earth Sciences New Zealand
NO_2^-	Nitrite-N
NO_3^-	Nitrate-N
NIWA	The National Institute of Water and Atmospheric Research (now ESNZ)
NNN	Nitrate and nitrite nitrogen
NTS	Ngai Tahu Seafood Limited
MPI	The Ministry of Primary Industry
SLR	SLR Consulting New Zealand Ltd
TN	Total dissolved nitrogen
TP	Total phosphorous
TAN	Total ammoniacal nitrogen
TKN	Total Kjeldahl nitrogen

1.0 Introduction

Ngāi Tahu Seafood (**NTS**) propose to develop an approximately 1,285-ha area to farm king salmon (*Oncorhynchus tshawytscha*) 2–6 km off the northeastern coast of Rakiura / Stewart Island, referred to as the Hananui Aquaculture Project (**Figure 1**). This area has been identified as having suitable characteristics for open-ocean finfish aquaculture (Taylor & Jary 2018; Bennett et al. 2018; Bennett et al 2025). SLR Consulting New Zealand Limited (**SLR**) was engaged by NTS to characterise the water quality within and surrounding the farming area and to assess the potential effects of the proposed farming activity on the water column.

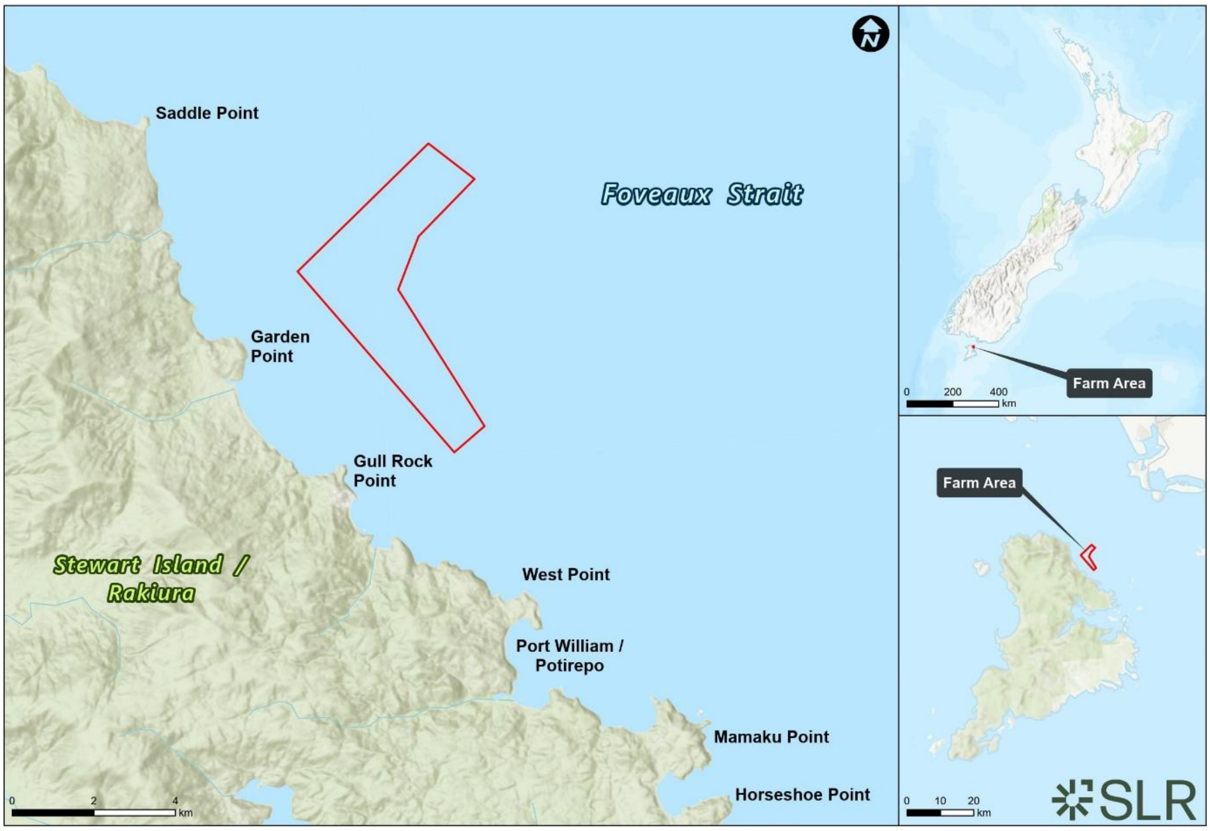

Figure 1: Location of the proposed farming area (red polygon) and nearby features.

NTS proposes to develop the c. 1,285-hectare area in two stages. Stage 1 involves establishing one block of 10 pens at each of the four farm sites (A blocks), with a combined total feed discharge of up to 15,000 tonnes per annum. Stage 2 would increase the feed discharge to 25,000 tonnes per annum by adding a second block of 10 pens at each site (B blocks). For further information on the staging and feed inputs, see the details contained within section 4 of the “Substantive Application under the Fast Track Approval Act 2024 for the Hananui Aquacultural Project” (“the Application”).

This report has been prepared to support the resource consent application to farm salmon offshore of Rakiura / Stewart Island. An application for a similar activity was made in 2020; however, the proposed activities assessed in this application have been refined from the previous application. The key differences between the previous and current proposed activities are set out in Table 4-1 of the Application.

1.1 Scope

This assessment includes a description of the water column in the existing environment where the fish farm is proposed to be located and the potential effects of the proposed activities on the water column. The following potential effects are assessed in this report:

- An increase in the concentrations of some nutrients resulting from the addition of feed and production of fish waste, and the potential changes in phytoplankton species abundance and composition;
- Reduction of dissolved oxygen (**DO**) primarily in response to fish respiration; and
- Attraction of marine organisms to submerged artificial lighting within the pens.

This assessment has been conducted following guidance on the ecological effects of aquaculture in New Zealand produced by Ministry for Primary Industries (**MPI**) in collaboration with the Cawthron Institute (**Cawthron**), the National Institute of Water and Atmospheric Research (**NIWA** – now Earth Science New Zealand (**ESNZ**)), the Department of Conservation (**DoC**), regional councils, the aquaculture industry, and others (MPI, 2013).

2.0 Existing Environment

The characteristics of water quality in Foveaux Strait and surrounds described in this report are based on existing information available in the published literature along with water sampling conducted to support the initial RMA application in 2018/19 and extended further in 2025. A summary of water quality information is provided in the following sections, with a focus on nutrients, phytoplankton (using chlorophyll-a as a proxy) and DO.

Direct effects from human activities on water quality in the Foveaux Strait relevant to this proposal are considered to be low to negligible; as such, the water quality described in this section reflects its natural state.

2.1 Water Quality Sampling

Water quality sampling and column profiling were conducted three times in 2018/19 (October and December 2019, January 2019) at sites Lease 1, Lease 2, and Lease 3 to support the initial 2020 consent application. The findings of this water quality sampling were reported in the Water Column Assessment with the original consent application (Campos et al., 2020).

In 2025, discrete water samples and profiles of the physical and chemical properties were collected on a further three occasions (March, May, and July) at each location shown in **Figure 2**, including sites within the proposed farm site (the Lease sites).

Figure 2: Water quality sampling locations.

Water samples were analysed for the following parameters:

- Total dissolved nitrogen (**TN**);
- Total ammoniacal nitrogen (**TAN**);

- Nitrate and nitrite nitrogen (**NNN**);
- Total phosphorus (**TP**);
- Dissolved reactive phosphorus (**DRP**);
- Chlorophyll-a (**chl-a**);
- Sulfate; and
- Total silica.

The following sections discuss the key parameters relating to the known effects of marine farming on water quality; these are TN, TAN, NNN, TP, DRP, and chl-a. Summaries of all parameters are included in **Appendix A**.

In 2018/19, water column profiles were conducted at a number of locations in the proposed farming area and Port William for temperature, salinity, and turbidity and data were reported in 7 m depth bins (Campos et al., 2020). In 2025, water column measurements were conducted using a high-frequency instrument at each of the locations in **Figure 2** at two depths (surface ~5 m depth; deep ~2 m from the seabed) where measurements were recorded approximately every 15 seconds for three to four minutes. The following parameters were measured at each site: conductivity, dissolved oxygen, salinity, oxidative-reductive potential, turbidity, pH, and temperature.

2.1.1 Data handling

There are only six data points for each of the three Lease sites (the locations situated within the proposed farming area) and Port William, and three data points for the other sites; therefore, data were pooled into three groups to increase sample size and improve the ability to conduct statistical analyses. These groups are intended to reflect similar water quality where notable differences would not be anticipated. The following groups were used:

- Hananui proposal area: Lease 1–3;
- Far-field sites: Boundary W, N, and E; and
- Sheltered embayments: Port William, Horseshoe, Halfmoon, and Paterson.

Data within groups were first tested using a Shapiro-Wilk test of normality to determine whether they were normally distributed. Not all groups were normally distributed, so non-parametric statistical approaches were used for all analyses for consistency. Outputs of statistical analyses are presented in **Appendix B** and the statistical outcomes are summarised below.

The following statistical comparisons were conducted:

1. **Difference between surface and bottom water measurements**. A Wilcoxon rank sum test (similar to a student's t-test) found no statistically significant differences between surface and bottom water measurements for all parameters within any group. As such, surface and bottom water measurements were pooled for further statistical analyses.
2. **Differences between sampling years (2018/19 and 2025)**. The farm area sites were measured in 2018/19 and 2025. Visual assessment of the data revealed notable differences in TN concentrations measured in each year. A Wilcoxon rank sum test confirmed a statistically significant difference in TN concentrations measured in 2018/19 and 2025 (but not for other parameters). As such, only data collected in 2025 were used for further analyses to assess differences among groups. This is further discussed in the relevant following section.

3. **Differences among groups (farm area, far-field, sheltered)**. A Kruskal-Wallis rank sum test (similar to a one-way ANOVA) found no statistically significant differences among groups, other than for DO (both % saturation and mg/L). This is further discussed in the relevant following subsection.

2.2 Physical Characteristics

The proposed farming area is situated in a high-energy environment characterised by strong tidal currents and frequent wave action. Water depths within the site range from approximately 20 to 40 m.

Water circulation in the Foveaux Strait is mainly influenced by the Southland Current, a flow of water of mainly subtropical origin associated with the Southland Front. The Southland Front moves eastward through the Foveaux Strait and drives local oceanographic conditions around the southern coasts of the South Island (Heath 1985; Sutton 2003). Occasionally, the Southland Current is influenced by colder, nitrate-rich sub-Antarctic waters (Heath 1975; Vincent et al. 1991; Chiswell 1996). Research from the Munida Time Series (located off the southeast coast near the influence zone of the Southland Current) reveals that the greatest horizontal transport of the nutrient-rich water occurs during summer (January/February) when the concentration differences between the waterbodies are greatest between nutrient-depleted surface water of the Southland Current and the nutrient-rich sub-Antarctic waters (Vance et al. 2024). Decadal variability between 2010 and 2019 was also significant (Vance et al. 2024), indicating that large changes in background nutrient concentrations among years is highly likely in Foveaux Strait. A less dominant and weaker flow moves anticlockwise around the southern tip of Stewart Island, through Foveaux Strait, and then north–eastward along the continental shelf and slope of the east coast of the South Island (Carter & Heath 1975; Hay 1990).

The predominant current direction follows a northwest–southeast axis, with a mean current speed of 0.56 m/s near the surface (Oceanum, 2025a). These current velocities are considered high relative to many coastal aquaculture sites in New Zealand and are a key factor in maintaining water quality by promoting rapid dispersion of farm-derived inputs. See Oceanum (2025a) for further details on oceanographic features of the proposed farming area and surrounds.

Other physical characteristics were measured using high-frequency instruments, either as water column profiles (2018/19) or for short periods (three to four minutes) in the upper and lower water column (2025). Measurements of temperature and salinity are described in this section to characterise the baseline physical characteristics of the water column in and surrounding the proposed farming area.

Temperature measurements collected during the 2018/19 and 2025 surveys indicate that the water column is well mixed throughout the year. In 2018/19, temperatures ranged from 11.7°C in October to 15.1°C in January, while in 2025, temperatures ranged from 11.4°C in July to 14.7°C in March. These results suggest a relatively narrow annual temperature range of approximately 11–15°C, with minimal vertical stratification, which is in agreement with the findings of Campos et al. (2020).

Salinity measurements were similarly consistent across depths and sampling periods. In 2025, salinity ranged from 34.5 to 35.3 ppt, which is typical of open coastal waters with limited freshwater influence. The absence of significant salinity gradients between surface and bottom waters further supports the conclusion that the water column is well mixed.

Overall, the physical characteristics of the proposed farming area indicate a dynamic and well-flushed environment with strong vertical and horizontal mixing. These conditions are favourable for open-ocean aquaculture, as they minimise the potential for nutrient accumulation, oxygen depletion, and phytoplankton blooms, while supporting the rapid dispersal of farm-derived wastes.

2.3 Nutrients and Phytoplankton

In this section, nutrient and phytoplankton (using chl-a as a proxy) data are summarised to characterise the background conditions of the existing environment. These are the key parameters relevant to fish farming activities and their potential effects on the water column. To provide context to results, TN, TP, and chl-a are presented alongside trophic state thresholds summarised by Smith et al. (1999). These trophic state (nutrient enrichment) classifications are discussed in more detail in **Section 2.3.5**. The other parameters are plotted against ANZECC (2000) default trigger values for physical and chemical stressors for south-east Australia for slightly disturbed ecosystems; these are acknowledged by resource managers as the most appropriate guidelines for New Zealand waters when there are no regional or site-specific guidelines available.

2.3.1 Nitrogen

TN concentrations measured across all sites in 2025 exhibited substantial variability, ranging from 190 to 700 µg/L (**Figure 3**). This wide range spans the full spectrum of trophic state categories defined by Smith et al. (1999), from oligotrophic (low nutrient supply) to hypertrophic (very high nutrient supply). Such variability reflects the dynamic nature of the Foveaux Strait environment, where strong tidal currents and episodic upwelling events influence nutrient availability. The elevated concentrations observed at times are likely associated with natural oceanographic processes rather than anthropogenic inputs, given the absence of significant land-based nutrient sources in the region.

TAN concentrations were consistently low during the 2025 surveys, with a mean of 2.7 µg/L and a maximum of 7.0 µg/L (**Figure 4**). These values are well below the ANZECC (2000) guideline for slightly disturbed marine ecosystems and are orders of magnitude lower than chronic toxicity thresholds for marine species (910 µg/L for 95% species protection). The low TAN concentrations indicate efficient nitrification processes in the well-oxygenated waters of Foveaux Strait, where ammonia is rapidly oxidised to nitrite (NO_2^-) and subsequently to nitrate (NO_3^-). This pattern is consistent with the high levels of vertical mixing and oxygen availability described further in **Section 2.4**.

NNN concentrations ranged from 26 to 46 µg/L, covering a broad range and substantially exceeding the ANZECC (2000) guideline of 5 µg/L (**Figure 5**). These elevated concentrations are characteristic of environments influenced by upwelling or strong mixing, where nutrient replenishment occurs more rapidly than phytoplankton uptake. This suggests that nitrogen is unlikely to be a limiting factor for primary production in the region. Instead, the high flushing rates and short water residence times in Foveaux Strait likely constrain phytoplankton growth despite the availability of dissolved inorganic nitrogen. Consequently, additional nitrogen inputs from the proposed farming activity are expected to have limited influence on phytoplankton biomass compared to more enclosed or stratified systems.

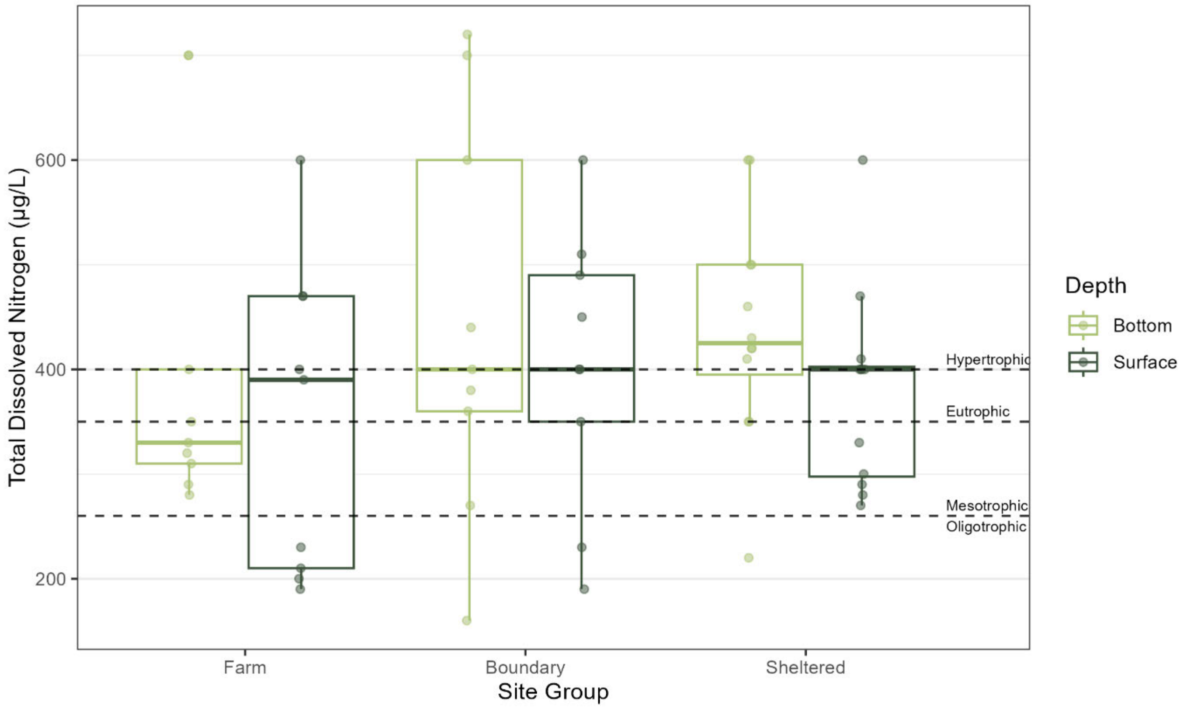

Figure 3: Total nitrogen concentrations measured in surface and bottom waters in 2025. Dashed lines indicate the trophic states as summarised by Smith et al. (1999).

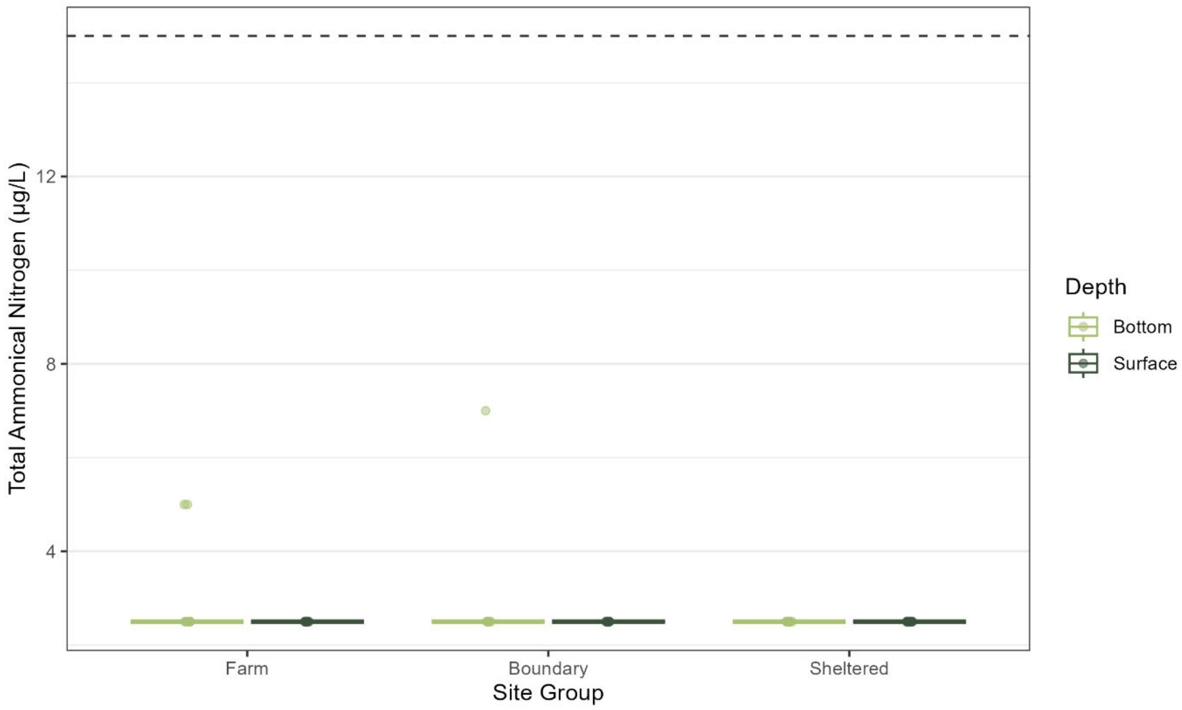

Figure 4: Total ammoniacal nitrogen concentrations measured in surface and bottom waters in 2025. The dashed line shows the ANZECC (2000) guideline value.

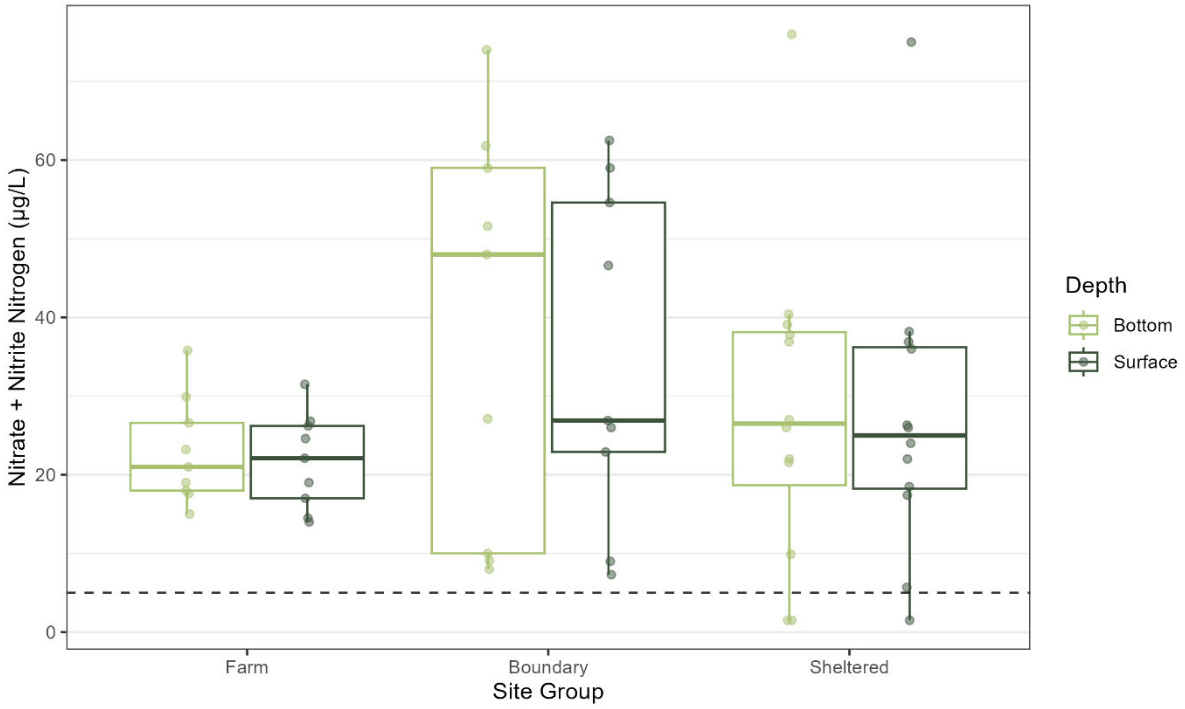

Figure 5: Nitrate and nitrite nitrogen concentrations measured in surface and bottom waters in 2025. The dashed line shows the ANZECC (2000) guideline value.

TN concentrations measured in 2025 were substantially higher than those typically reported for other offshore finfish farming sites in New Zealand that have recently applied for resource consents. For example, baseline monitoring at the Coromandel Marine Farming Zone recorded TN concentrations ranging from approximately 80 to 250 µg/L (James & Giles, 2020), while the Blue Endeavour site north of the Marlborough Sounds reported a narrower range of 137 to 185 µg/L (Newcombe et al., 2020). Similarly, water quality sampling undertaken for Sanford's Project South application in Foveaux Strait between November 2019 and January 2020 measured TN concentrations between 119 and 156 µg/L. In contrast, the 2025 measurements for the proposed farm site were markedly higher, with values extending up to 700 µg/L. The 2025 measurements were made during summer months when nitrogen concentrations are typically expected to be lower than at other times of the year due to increased phytoplankton growth. The high TN concentrations are more comparable to those observed in other high-energy, low freshwater-influence environments such as Port Gore, where TN concentrations have been reported in the range of 120–450 µg/L (Broekhuizen, 2015). This comparison highlights the naturally elevated nutrient status of the Foveaux Strait region, likely driven by oceanographic processes such as upwelling, the influence of sub-Antarctic waters, and strong tidal mixing rather than anthropogenic inputs.

The largest source of new nitrogen to nearshore waters around Stewart Island is nitrate (NO_3) from saline sub-Antarctic waters flowing through the Strait (Bradford-Grieve 1996). Freshwater discharges from rivers on the South Island coast are likely to have little effect on nutrient and phytoplankton dynamics in and around the proposed finfish farming site because rivers provide only a small fraction of the nutrient flux through Foveaux Strait (Bradford-Grieve 1996; Gillespie et al. 2009).

The difference between the two monitoring periods at the proposed farm site was also pronounced. Median TN concentrations within the farm area in 2025 were 390 µg/L[1] at the surface and 330 µg/L[2] near the seabed, compared to 107 µg/L[3] and 101 µg/L[4], respectively, in 2018/19 (**Figure 6**). Statistical analysis confirmed that these differences were significant, with no overlap between the two datasets; the highest concentration recorded in 2018/19 was lower than the lowest concentration measured in 2025. This suggests a substantial difference in background nutrient conditions between the two periods. While the cause of this change cannot be determined from these data alone, it is likely influenced by large-scale oceanographic variability, including processes such as coastal upwelling, influence from sub-Antarctic waters, and interannual climate oscillations (e.g., El Niño–Southern Oscillation), which can alter nutrient dynamics in open coastal systems.

Late 2018 had weak El Niño conditions, which are characterised by slightly cooler temperatures and strong or more frequently westerly winds. March 2025 was transitioning from weak La Niña to ENSO-neutral, which would be characterised by average temperatures and variable wind conditions. These conditions alone are unlikely to explain such large differences in nitrogen concentrations; however, this could suggest that there was enhanced influence from the Southland Current and sub-Antarctic waters in 2025, resulting in elevated nitrogen concentrations at the time.

These findings underscore the importance of considering natural variability when establishing baseline conditions and interpreting the effects of the proposed activities from ongoing monitoring.

[1] 2025 surface range: 190-600 µg/L

[2] 2025 bottom range: 280-700 µg/L

[3] 2018/29 surface range: 81-153 µg/L

[4] 2018/29 bottom range: 74-179 µg/L

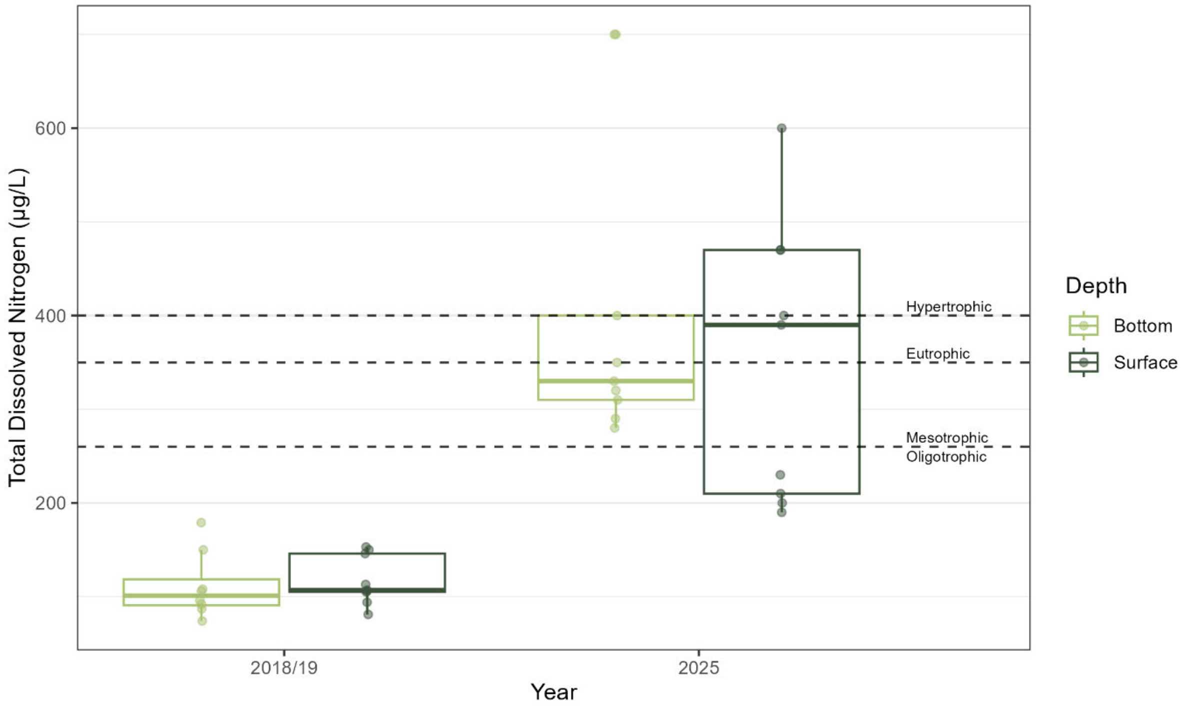

Figure 6: Total nitrogen concentrations measured in surface and bottom waters in 2018/19 and 2025 at locations within the proposed farming area. Dashed lines indicate the trophic states as summarised by Smith et al. (1999).

In contrast, the average NNN concentration was lower in 2025 (29 µg/L) than in 2018/19 (45 µg/L) (**Figure 7**). This indicates that organic nitrogen is likely responsible for the large difference between years because NNN and TAN typically make up the minor fraction of the TN pool (discussed further in **Section 2.3.1.1**). The cause of such difference in concentrations and the relative proportion of the TN pool in each year is not clear from these measurements alone; however, it could indicate the effects of broader coastal processes such as coastal upwelling. This is an oceanographic process where deep, cold, and nutrient-rich water rises to the surface, typically driven by wind patterns and the Earth's rotation (e.g., Kämpf & Chapman, 2016). This influx of nutrients supports high biological productivity, making upwelling zones important for marine ecosystems and fisheries.

This difference could also be influenced by the El Niño–Southern Oscillation, where El Niño conditions were present in 2018/19, generally associated with the presence of warmer waters and drier weather patterns. In early 2025, conditions were tending towards the opposite La Niña conditions, generally associated with cooler waters and wetter and windier weather patterns.

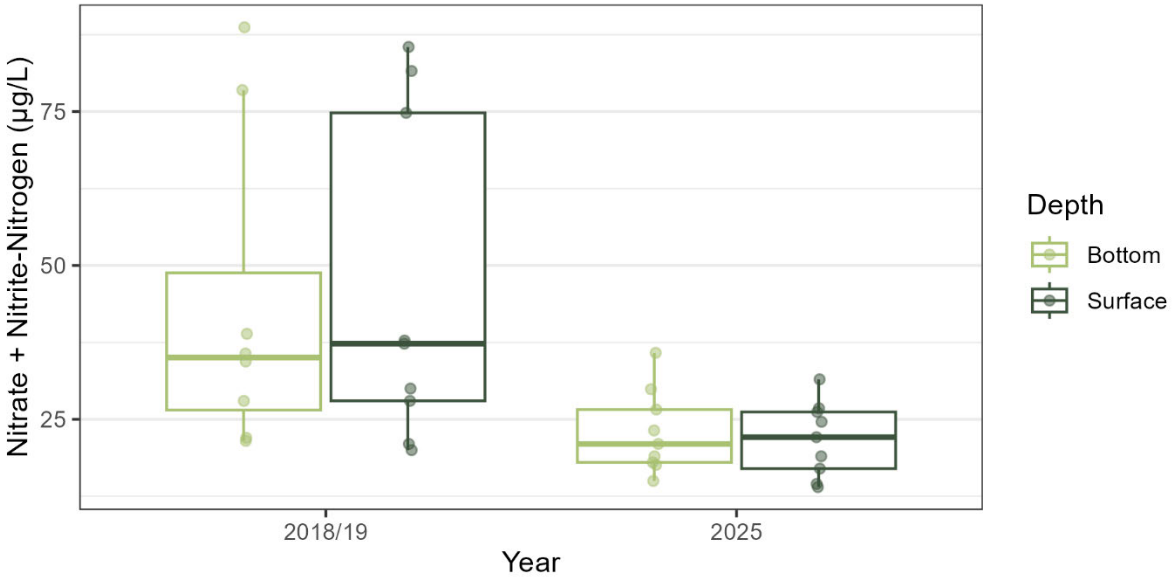

Figure 7: NNN concentrations measured in surface and bottom waters in 2018/19 and 2025 at locations within the proposed farming area.

2.3.1.1 Total Nitrogen Pool

Many forms of nitrogen contribute to the TN pool, and the varying proportions of TN components can provide insight into the potential sources of the nitrogen. The TN pool primarily comprises two inorganic forms of nitrogen (TAN and NNN), and organic nitrogen. Organic nitrogen is a broad group including amino acids, proteins, urea, and other organic nitrogen forms. On average, organic nitrogen can contribute from 18 to 85% of the TN pool, with the higher range of contribution typically measured in open coastal waters (Voss et al. 2013). Although organic nitrogen is one of the largest components of TN, the main sources of this pool and its accumulation and persistence in the marine environment are not well understood (Broek et al. 2023).

Organic nitrogen is rarely measured directly, but it can be calculated from Total Kjeldahl nitrogen (**TKN**), which is an analytical method that measures the combination of organic nitrogen and TAN. That is, organic nitrogen = TKN less TAN. Dissolved TKN was only measured during March and May 2025. As it wasn't measured in 2018/19, it cannot be calculated for 2018/19.

In May and March 2025, the dominant component of TN was organic nitrogen (91%), with TAN and NNN comprising the remaining 9% of the TN pool (Figure 8). This shows that the relatively poorly understood organic nitrogen fraction dominates the TN pool and that inorganic nitrogen components (TN and TAN), which are often a focus in water quality assessments, comprise less than 10%. Nutrients from the farm released into the surrounding environment will be predominantly in the dissolved inorganic nitrogen pool (TAN and NNN). This point is made to highlight the complexity of water quality and that the greatest proportion of nitrogen in the water column during 2025 was organic nitrogen.

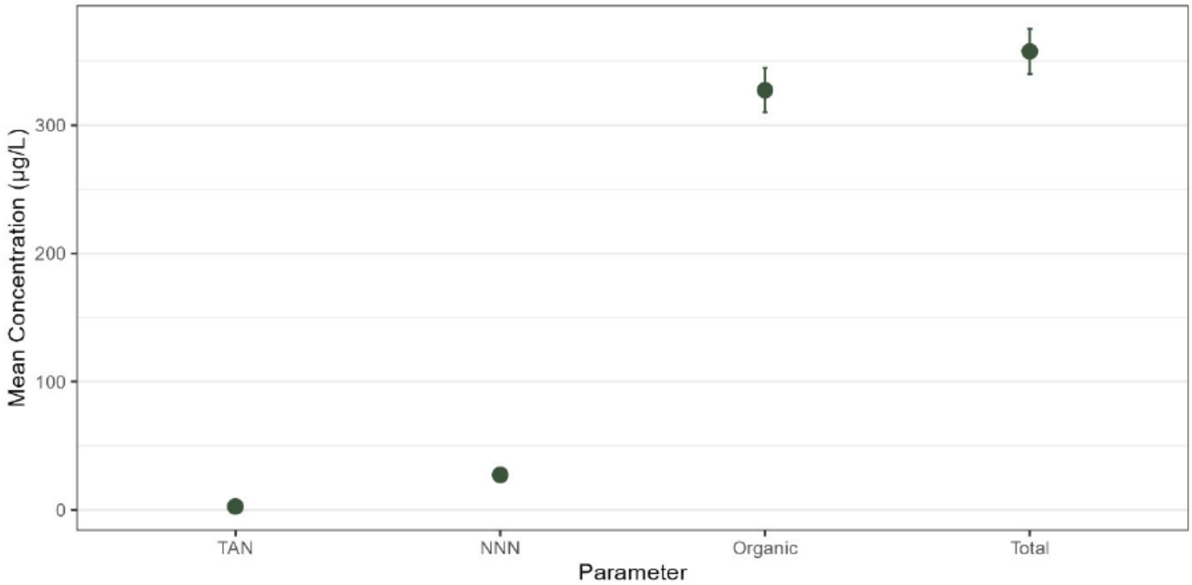

Figure 8: Mean concentrations of dissolved nitrogen components measured at all sites in May and March 2025. Error bars show the standard error of the mean (n = 40).

2.3.1.2 Nitrogen Conclusion

Overall, baseline measurements show that nitrogen concentrations (particularly NNN and TN) in Foveaux Strait have naturally high variability spanning a wide range of concentrations (Table 1). This will make the location of suitable reference sites especially important for the monitoring of the proposed activities as comparisons back to baseline concentrations at a point in time are likely to be misleading.

Table 1: Summary of nitrogen concentrations (µg/L) across all sites measured in 2018/19 and 2025.

Parameter	Min	10th %ile	25th %ile	Median	75th %ile	90th %ile	Max
2018/19							
TN	74	85	94	106	146	151	179
NNN	20.0	21.3	28.0	35.7	74.8	83.2	88.7
TAN	2.5	2.7	3.0	4.0	5.2	7.3	9.4
2025							
TN	160	229	308	400	470	600	720
NNN	1.5	8.9	17.6	26.0	37.1	59.0	76.0
TAN	2.5	2.5	2.5	2.5	2.5	2.5	7.0

2.3.2 Phosphorus

TP concentrations measured across all sites in 2025 ranged from 5 to 46 µg/L (**Figure 9**; **Table 2**). When assessed against the trophic state categories proposed by Smith et al. (1999), these concentrations span the oligotrophic (low nutrient supply) and mesotrophic (moderate nutrient supply) classifications, with all median values falling within the lower mesotrophic band. This indicates that, while phosphorus is present at levels sufficient to support moderate productivity, the system has lower phosphorus concentrations than would typically occur in more enclosed or estuarine environments.

A comparison of TP concentrations between the 2018/19 and 2025 surveys shows no significant difference, suggesting that phosphorus levels in Foveaux Strait are relatively stable over time (**Figure 10**). This consistency contrasts with the variability observed in total nitrogen concentrations.

Dissolved reactive phosphorus (**DRP**) concentrations in 2025 ranged from 1 to 13 µg/L, with a mean of 6.4 µg/L (**Table 2**). These concentrations are slightly lower than mean concentrations reported for more sheltered environments such as Big Glory Bay (27 µg/L; James et al. 2018), Port Pegasus (11 µg/L), Queen Charlotte Sound (14 µg/L), and Pelorus Sound (13 µg/L) (summarised in Campos et al. 2020). The lower DRP concentrations in Foveaux Strait likely reflect the high-energy, well-flushed nature of the system, which limits nutrient accumulation and promotes rapid dispersal. In contrast, locations such as Pelorus Sound receive large freshwater inputs and have longer water residence times, conditions that favour higher nutrient retention and elevated DRP concentrations.

Overall, the phosphorus data indicate that the proposed farming area is situated in an environment with relatively low to moderate phosphorus availability, consistent with its open-coastal setting and strong hydrodynamic regime.

Table 2: Summary of phosphorus concentrations (µg/L) across all sites measured in 2025.

Parameter	Min	10th %ile	25th %ile	Median	75th %ile	90th %ile	Max
TP	5	5	11	14	15	18	46
DRP	1	1	4	7	8	10	13

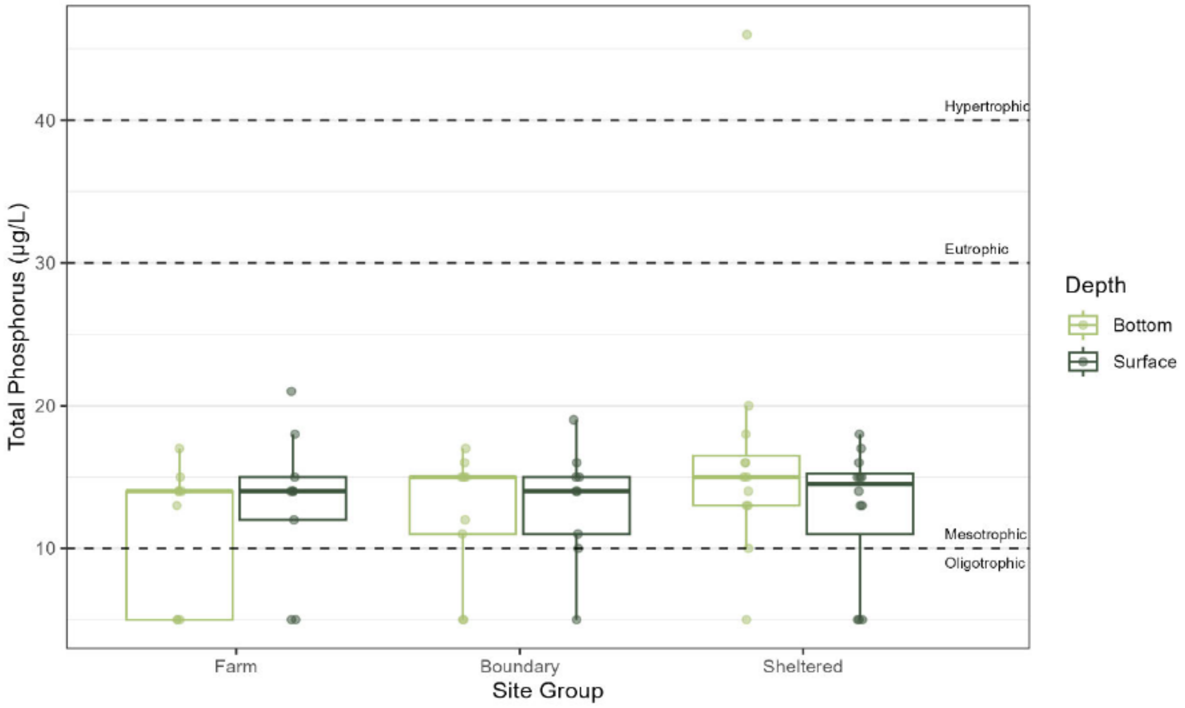

Figure 9: Total phosphorus concentrations measured in surface and bottom waters in 2025.

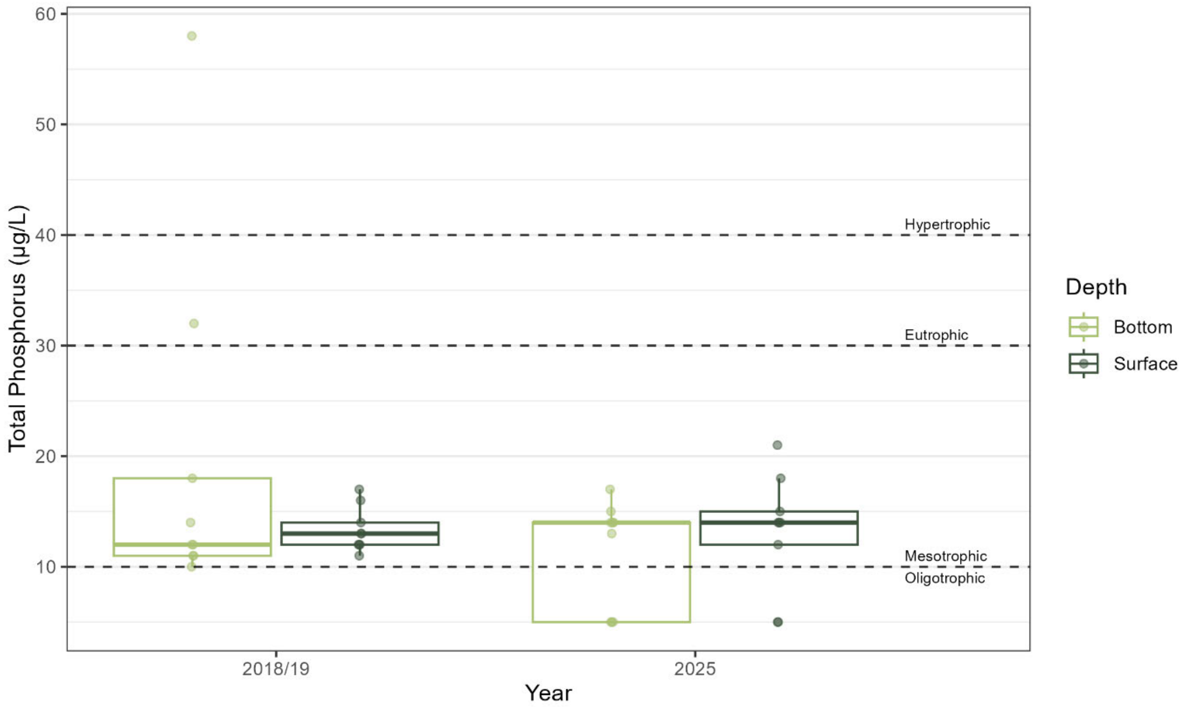

Figure 10: Total phosphorus concentrations measured in surface and bottom waters in 2018/19 and 2025 at locations within the proposed farming area. Dashed lines indicate the trophic states as summarised by Smith et al. (1999).

2.3.3 Chlorophyll-a

Chlorophyll-a (chl-a) concentrations measured during the 2025 surveys were typically low, with most values ranging from 0.1 to 1.5 µg/L (**Figure 11**; **Table 3**). When assessed against the trophic state categories proposed by Smith et al. (1999), these concentrations span the oligotrophic (low nutrient supply) and mesotrophic (moderate nutrient supply) classifications, with all median values falling within the mid-oligotrophic band. This indicates that phytoplankton biomass in the region is generally low, consistent with the high-energy, well-flushed nature of Foveaux Strait.

Two elevated chl-a concentrations of 3.1 and 4.0 µg/L were recorded at the entrance to Patterson Inlet in May 2025, in surface and bottom waters, respectively. These higher values likely reflect the movement of water masses with elevated phytoplankton biomass into or out of Patterson Inlet at the time of sampling, rather than a localised bloom near the proposed farming area.

Chl-a concentrations were similar between the 2018/19 and 2025 surveys, despite seasonal differences in sampling periods (**Figure 12**). Phytoplankton biomass in temperate marine systems typically peaks during spring and declines to its lowest levels in winter. Data collected in both monitoring periods generally follow this pattern; however, concentrations in March 2025 were atypically low, despite this being a period when higher values would normally be expected (**Figure 13**), and the notably high TN concentrations occurring at the time.

Overall, chl-a concentrations in both monitoring periods were low and did not capture the occurrence of algal bloom events. These findings suggest that, despite the relatively high nutrient concentrations observed in Foveaux Strait, the strong hydrodynamic regime limits phytoplankton accumulation and maintains low background biomass.

Table 3: Summary of chlorophyll-a concentrations (µg/L) across all sites measured in 2025.

Parameter	Min	10th %ile	25th %ile	Median	75th %ile	90th %ile	Max
Chl-a	0.1	0.1	0.1	0.6	1.5	1.5	4.0

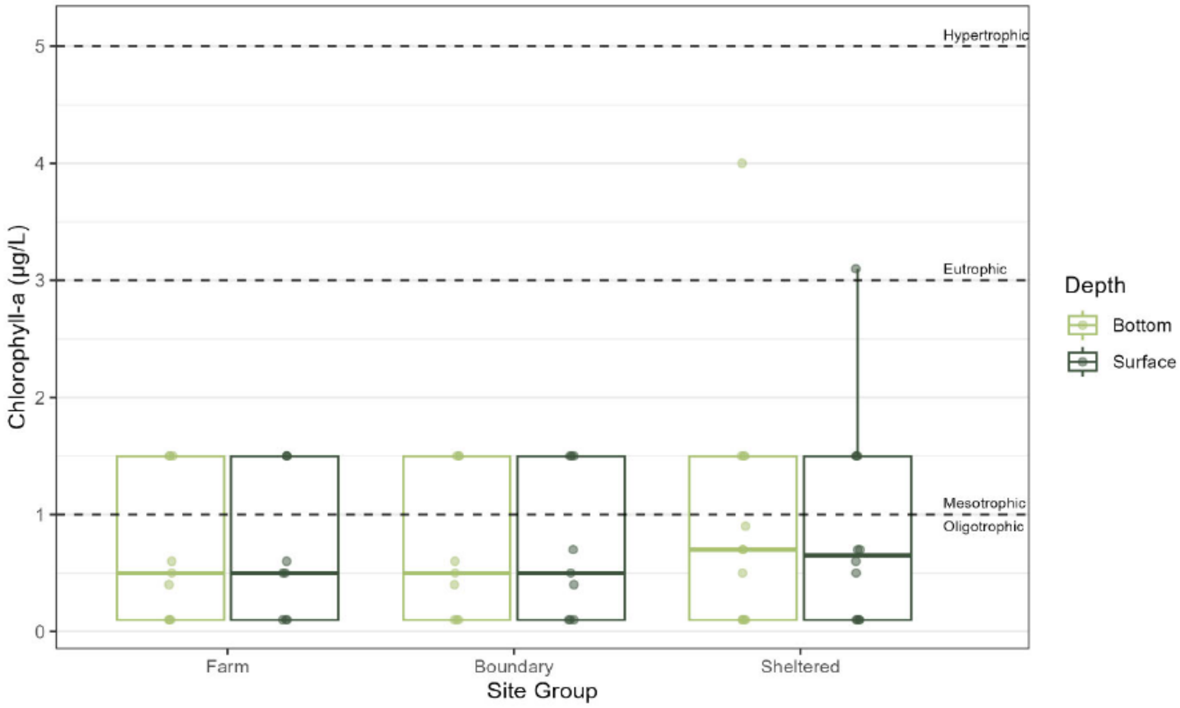

Figure 11: Chlorophyll-a concentrations measured in surface and bottom waters in 2025. Dashed lines indicate the trophic states as summarised by Smith et al. (1999).

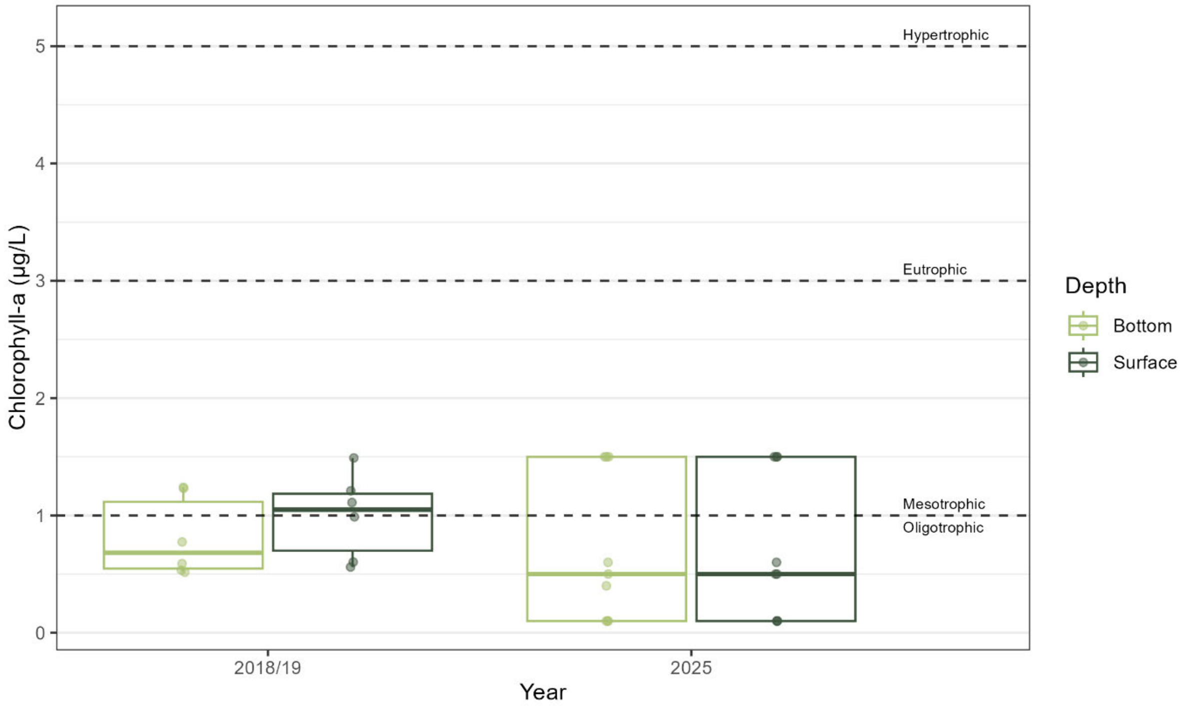

Figure 12: Chlorophyll-a concentrations measured in surface and bottom waters in 2018/19 and 2025 at locations within the proposed farming area. Dashed lines indicate the trophic states as summarised by Smith et al. (1999).

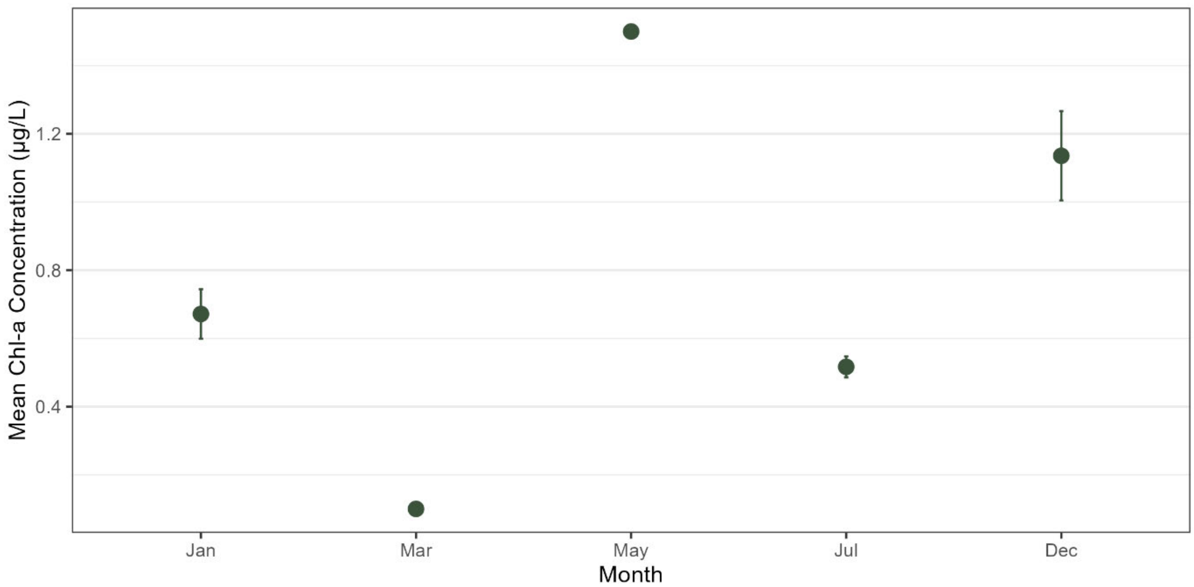

Figure 13: Mean chlorophyll-a concentrations at farm area sites. January and December were surveyed in 2018/19, and March, May, and July were surveyed in 2025. Error bars show the standard error (n = 6).

2.3.4 Phytoplankton

Phytoplankton samples were collected from surface waters at three locations within the proposed farm area (Lease 1–3 locations) and at Port William during the 2018/19 surveys. In 2025, only one round of sampling was conducted in May but the number of samples was expanded to include both surface and bottom waters at all locations shown in **Figure 2**, providing a more comprehensive assessment of spatial and vertical variability.

In 2018/19, the phytoplankton community was dominated by common diatom species, with *Skeletonema costatum*, *Chaetoceros* spp., and *Thalassiosira* spp. being the most abundant taxa (**Table 4**). Flagellates, including dinoflagellates, were rare, and only a few specimens of *Chrysochromulina* sp. were observed.

There was a notable shift in community composition during the 2025 surveys. *Chaetoceros convolutus* was even more abundant than in 2018/19, while *Skeletonema costatum* and *Thalassiosira* spp. were absent. Other dominant diatoms included *Leptocylindricus* spp. and *Pseudonitzschia* spp., the latter being of particular interest due to its potential toxicity. *Pseudonitzschia* spp. is a genus associated with harmful algal blooms (**HABs**) and amnesic shellfish poisoning. Concentrations of this genus were markedly higher in 2025, with cell densities exceeding the trigger threshold of 100,000 cells/L at several locations, including Port William and Lease 3 (the farm area closest to shore) (data for the additional sites are shown in **Appendix A**).

The broader, one off sampling in May 2025 confirmed that this trigger threshold for *Pseudonitzschia* spp. density was also exceeded at Boundary W (bottom water), Horseshoe Bay (surface and bottom), Halfmoon Bay (surface and bottom), and Patterson Inlet (surface and bottom). The highest concentrations were recorded in Patterson Inlet, where *Pseudonitzschia* spp. reached 16,700,000 cells/L in surface waters and 163,300,000 cells/L in bottom waters, which the laboratory report classified as 'Very High' risk. Such elevated concentrations suggest the occurrence of a bloom of these taxa at the time of sampling – particularly in Patterson Inlet; however, these elevated densities of potenitally harmful algal bloom forming taxa did not correlate with an increase in chl-a measurements at the same locations, as discussed in **Section 2.3.3**.

In addition to these changes, six diatom species not observed in 2018/19 were identified in 2025, including *Chaetoceros convolutus*, *Fragilaria* sp., *Thalassionema* spp., *Paralia* spp., *Rhizosolenia* spp., and *Proboscia* spp. Two species of Raphidophyceae (*Fibrocapsa japonica* and *Heterosigma akashiwo)* were also detected in 2025 but were absent in the earlier survey. Both species are recognised as potentially harmful, although their abundances were low.

Overall, these findings indicate that while the phytoplankton community in Foveaux Strait is typically dominated by diatoms, episodic elevations of potentially harmful species such as *Pseudonitzschia* spp. can occur, particularly in more sheltered environments such as Patterson Inlet and the nearby embayments. These observations highlight that harmful algal bloom forming species are present in the area prior to the proposed establishment of the offshore marine farm and can already reach elevated densities with the potential to pose risks to human health. This reinforces the importance of ongoing phytoplankton monitoring prior to the commencement of any farming operation.

Table 4: Phytoplankton taxa and cell counts (cells/L) in surface water samples collected during 2018, 2019, and 2025. Greater abundances are indicated by the red shading and lower abundances with progressively greener shading.

Date	19/10/2018				3/12/2018				17/01/2019				4/05/2025			
Sampling Site	**Port William**	**Lease 3**	**Lease 2**	**Lease 1**	**Port William**	**Lease 3**	**Lease 2**	**Lease 1**	**Port William**	**Lease 3**	**Lease 2**	**Lease 1**	**Port William**	**Lease 3**	**Lease 2**	**Lease 1**
Diatoms (Bacillariophycaea)																
Asterionellopsis sp.				200	2200	9000	3800	9400								
Cerataulina spp.	400	200		200			600									
Chaetoceros spp.	39000			200	12000	31000	14000	6600	4800	7800	8800	15000	192000	101000	17000	25000
Chaetoceros convolutus															800	1000
Corethron sp.									200	1000	600					
Cylindrotheca sp.										600		200				
Dactyliosolen spp.	400				400	200	800	200								
Eucampia spp.	400				400	1000										
Fragilaria sp.																
Guinardia sp.		200				200	200	200								
Cylindrotheca sp.												2800				
Hemiaulus sp.								200								
Lauderia sp.						200		600								
Leptocylindricus spp.						800	400			400			322000	70000	11000	
Navicula spp.	200		200	200	200		200					200				
Nitzschia spp.	1400				1400	200		400			200	400				
Paralia spp.																9800
Pleurosigma sp.				200			200									
Proboscia spp.																
Pseudonitzschia spp.						2600	1800	2000		800	400	1200	2149000	202000	64000	26000
Rhizosolenia spp.													2600	2800		400
Skeletonema costatum	5800	66000	29000	7800	53000	62000	60000	83000								
Thalassionema spp.																
Thalassiosira spp.	2400	1200	1400		13000	16000	12000	21000	200	600	400	1000				
Dinoflagellates (Dinophyceae)																
cf. *Azadinum* sp.												200				
Gymnodinium spp.					200			400		800						
Gyrodinium spp.			200							200	200					
Heterocapsa spp.										400						
Karlodinium sp.										200						
Oxytoxum sp.					200											
Protoperidinium spp.								400			200					
Prymnesiophceae																
Chrysochromulina spp.		400			200					200				400	1600	71000
Cryptophyceae																
Cryptomonas sp.	200					200				200						
Euglenophyceae																
Euglena sp.							1200		200		200	200				
Raphidophyceae																
Fibrocapsa japonica													600			
Heterosigma akashiwo													400			
Other																
Unidentified flagellates	800	200	400	3000	4800	1400	2600			1200	200	200				

2.3.5 Trophic State and Thresholds

Nutrient thresholds and guidelines have been proposed and applied to New Zealand coastal waters to assess their trophic (nutrient enrichment) state. There are no widely agreed or applied thresholds or guidelines directly applicable to Foveaux Strait; however, a multiple-lines-of-enquiry approach can be useful to estimate its trophic state. The following thresholds and trophic indices are applied in this section:

- Trophic state summarised by Smith et al. (1999), which was adapted from lake to coastal ecosystems; and
- ANZECC (2000).

2.3.5.1 Trophic state

The trophic state approach, summarised by Smith et al. (1999), provides bands for total nitrogen, total phosphorus, and chlorophyll-a in coastal ecosystems to broadly classify the nutrient status of marine environments (**Table 5**).

Table 5: Typical concentrations of key water quality parameters for trophic states in coastal waters. As summarised by Smith et al. (1999) based on the review by Håkanson (1994). Green shaded cells indicate the corresponding category of the median value of all measurements from Farm and Boundary sites in 2025.

Trophic state	Total nitrogen (µg/L)	Total phosphorus (µg/L)	Chlorophyll-a (µg/L)
Oligotrophic	<260	<10	<1
Mesotrophic	260-350	10-30	1-3
Eutrophic	350-400	30-40	3-5
Hypertrophic	>400	>40	>5

At this high classification level, the Foveaux Strait spans a broad trophic state from oligotrophic (low nutrient supply) based on chl-a, to eutrophic (high nutrient supply) based on TN. The high flow speeds in Foveaux Strait do not provide ideal conditions for algal blooms to remain in one location and be detected by discrete water quality samples. As such, it may be expected that chl-a concentrations (and hence phytoplankton abundances) are typically low in the area surrounding the proposed farm. Nutrients and phytoplankton will be transported out of the Foveaux Strait into the surrounding waters due to the high flows. Focussing on nutrient supply, the classification indicates intermediate (mesotrophic) to high (eutrophic) nutrient supply, which seems appropriate based on the analysis of data above. Overall, the collected data indicate that there is a high nutrient supply in the area, but no subsequent phytoplankton increases or blooms (based on chl-a measurements).

2.3.5.2 ANZECC (2000)

The ANZECC (2000) physical and chemical stressors used here are conservative thresholds developed for south-east Australian marine waters (**Table 6**). Although they are considered appropriate in the absence of regional or site-specific guidelines, they have not been developed specifically for New Zealand waters and the interpretation of results from Foveaux Strait using this approach should be done carefully. Mean and median TN and NNN at and around the proposed farm site both exceed the ANZECC (2000) threshold values, while TAN, DRP, and chlorophyll-a are below (within) the threshold.

Table 6: Mean (standard deviation) and median concentrations for measurements at Site and Boundary locations in 2025 (n = 37). The ANZECC (2000) guidelines for physical and chemical stressors in marine waters are shown for comparison.

Parameter	Mean (SD) [µg/L]	Median [µg/L]	ANZECC (2000) [µg/L]
Total Nitrogen	402 (158)	395	120
Total Ammoniacal Nitrogen	2.8 (0.9)	2.5	15
Nitrate + Nitrite Nitrogen	32 (18)	28.4	5
Dissolved Reactive Phosphorus	6.3 (2.8)	6	10
Chlorophyll-a	0.7 (0.5)	0.5	1

These guidelines are default trigger values for "slightly disturbed" ecosystems to avoid further significant adverse effects and are based on South-east Australian waters thus must be treated with caution and an exceedance of these guidelines does not imply that adverse effects are occurring. These guidelines provide a point of reference and highlight that nutrient concentrations, particularly NNN, are higher than might be expected in marine waters with few land-based pressures.

There is a footnote on Table 3.3.2 of the ANZECC (2000) guidelines used to derive the numbers in Table 6, noting that NO_x (NNN) and NH_4^+ (TAN) thresholds should be increased to 25 µg/L and 20 µg/L, respectively, in NSW due to frequent upwelling events. This acknowledges the natural occurrence of elevated nutrient concentrations in areas of upwelling, which also likely occur in Foveaux Strait.

Overall, this indicates that the existing environment has naturally elevated concentrations of total nitrogen and nitrate, and typical concentrations of TAN, DRP, and chlorophyll-a for marine water when assessed against the ANZECC (2000) guidelines.

2.3.5.3 Trophic state conclusion

Overall, these approaches suggest that there is an intermediate to high nutrient supply in Foveaux Strait. Although some median nutrient concentrations are elevated above conservative guidelines (e.g., TN and NNN against the ANZECC guidelines), median chlorophyll-a concentrations measured at the proposed farm site and surrounding areas are low and within the oligotrophic trophic state category. This indicates that the nutrient inputs are not resulting in high algal growth, which is likely the result of the high flow speeds in the area mixing nutrients and exporting phytoplankton away before nutrients can be fully utilised in plankton growth.

2.4 Dissolved Oxygen

DO concentrations measured during the 2025 surveys ranged from 98 to 106% saturation, equivalent to 8.1–9.1 mg/L (**Table 7**; **Figure 14**; **Figure 15**). These values are well within the ANZECC (2000) guideline range of 90–110% saturation, indicating that the waters in and around the proposed farming area are well oxygenated. The consistently high DO levels reflect the strong hydrodynamic conditions in Foveaux Strait, which promote vertical mixing and oxygen replenishment throughout the water column.

Measurements from the 2018/19 surveys were similarly high, although one low DO measurement of 7.4 mg/L was recorded in a sample collected at Port William. This concentration is still indicative of well-oxygenated water but shows that DO concentrations can be variable and that the sheltered embayments may be more susceptible to having lower DO concentrations than in more exposed areas.

No statistically significant differences were observed between surface and bottom water DO concentrations in 2025, indicating a well-mixed water column. This is consistent with the physical characteristics of the site, where high current speeds and wave action prevent stratification. Furthermore, DO concentrations were relatively consistent among sites during both the 2018/19 and 2025 surveys, suggesting that spatial variability in oxygen availability is minimal in and around the proposed farming area.

Table 7: Summary of DO concentrations across all sites measured in 2025.

Parameter	Min	10th %ile	25th %ile	Median	75th %ile	90th %ile	Max
DO (%)	98.4	99.0	99.8	101.4	102.3	103.6	106.4
DO (mg/L)	8.1	8.3	8.4	8.5	8.8	8.9	9.1

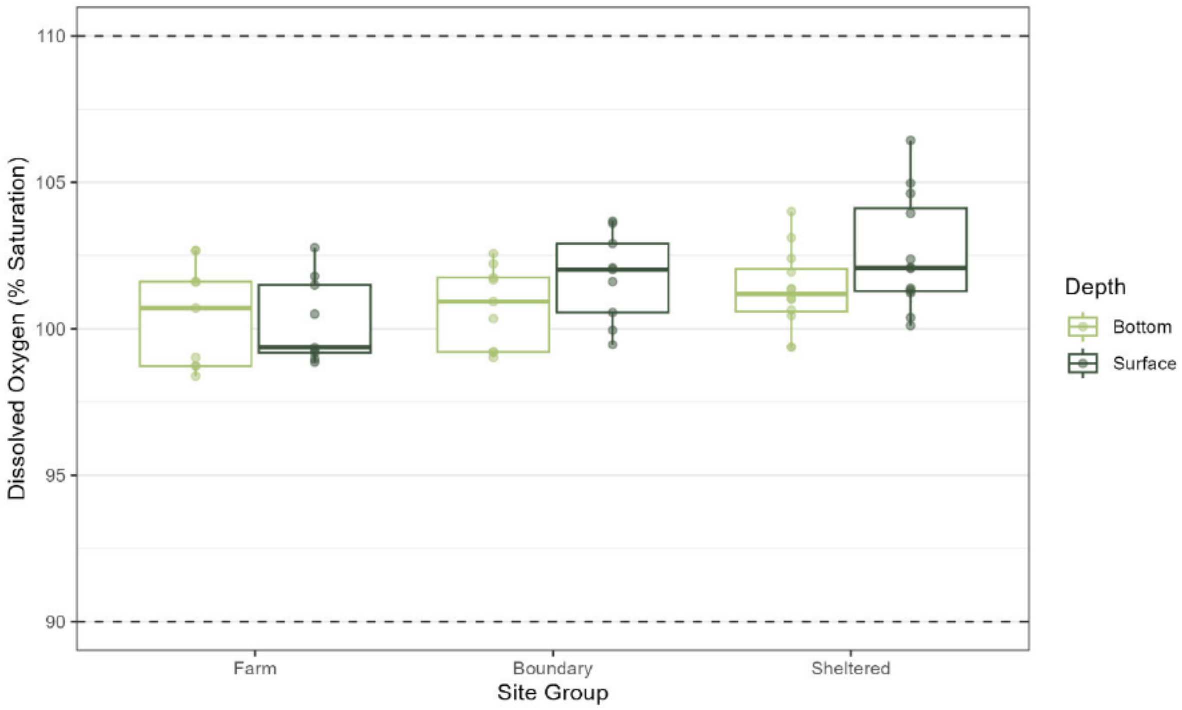

Figure 14: Dissolved oxygen (% saturation) measured in surface and bottom waters in 2025.

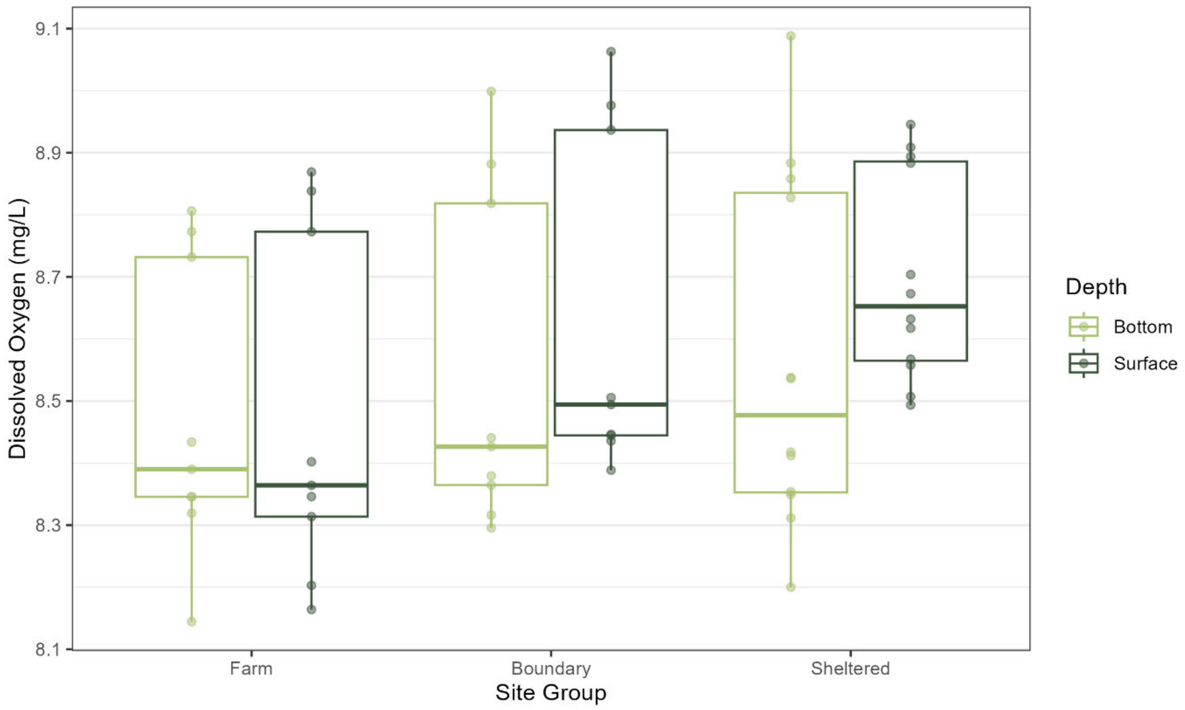

Figure 15: Dissolved oxygen concentrations measured in surface and bottom waters in 2025.

2.5 Natural State

Water in Foveaux Strait is classified in the Regional Coastal Plan as being in its "natural state"; however, the plan does not characterise what this state is. The proceeding analysis indicates that with respect to trophic state, the natural state of water in Foveaux Strait is characterised by:

1. High and variable nitrogen concentrations (TN range: 74–720 µg/L);
2. Low to moderate concentrations of phosphorus (TP range: 5–58 µg/L);
3. Low concentrations of chlorophyll-a (range 0.1–4 µg/L); and
4. High concentrations of dissolved oxygen (range: 8.1–9.1 mg/L).

3.0 Effects Assessment

The key potential water quality effects associated with finfish aquaculture are nutrient enrichment and reductions in DO concentrations (MPI, 2013).

A particularly important consideration is nutrient enrichment. Farmed fish excrete dissolved inorganic nutrients, and additional nutrients (primarily nitrogen and phosphorus) are released from faecal material, uneaten feed, and through the remineralisation of organic matter deposited on the seabed. In the water column, nutrient enrichment can stimulate phytoplankton growth, alter phytoplankton community composition through changes in nutrient ratios, and, under certain conditions, promote phytoplankton blooms. At high concentrations, TAN can be toxic to some marine organisms; however, such concentrations are unlikely to occur under well-managed farming conditions or in areas with high flushing capacity.

While nutrients and phytoplankton form the foundation of marine food webs, excessive nutrient inputs can lead to eutrophication. Eutrophic waters are characterised by high primary productivity, reduced water quality, and frequent algal blooms. Such conditions typically occur in estuaries, harbours, and small embayments with restricted flushing, rather than in high-energy offshore environments such as Foveaux Strait. Nevertheless, phytoplankton blooms can occur naturally in more offshore environments.

A related concern is the potential for harmful algal blooms (**HABs**), which may be influenced by nutrient enrichment. HABs can include species that produce biotoxins or have mechanical properties harmful to fish (MPI, 2013). While these events occur naturally, any increase in their frequency or severity as a result of additional anthropogenic nutrient inputs would represent an adverse ecological effect.

Another key consideration is the potential reduction of DO in the water column near finfish farms. Oxygen depletion can result from increased fish biomass and associated respiration, as well as microbial degradation of organic material, which consumes oxygen both in the water column and in sediments. Poor water quality, particularly low DO, can adversely affect the health and growth of farmed fish, making oxygenated waters critical for survival and optimal performance. These risks can be effectively managed through appropriate site selection, pen design, and effective farm management practices. Maintaining oxygen levels sufficient for the farmed fish also ensures that conditions remain suitable for wild fish and other marine organisms in the surrounding environment.

The following sections assess these potential effects in detail, drawing on hydrodynamic and water quality modelling for the area (Oceanum, 2025a – Appendix C; Oceanum, 2025b – Appendix D), baseline monitoring data collected at and around the proposed farm area, and relevant literature.

3.1 Nutrient Enrichment

Nitrogen is typically the limiting nutrient for phytoplankton production in New Zealand coastal ecosystems, and enhanced nitrogen concentrations in the water column can therefore stimulate phytoplankton growth. However, as discussed in **Section 2.3.1** of this assessment, this may not be the case in Foveaux Strait, where nutrient replenishment from upwelling and strong tidal mixing likely occurs more rapidly than phytoplankton uptake. This suggests that nitrogen may not be as strong a limiting factor for primary production in this environment compared to more enclosed or stratified systems.

Even with some nutrient enrichment, increases in phytoplankton biomass may not be observed immediately adjacent to finfish farms. This is because algal cells require several days to metabolise nutrients and reproduce (Olsen, 2007; Tett et al., 2018). A review of the effects of finfish farms on phytoplankton community composition and production found that most studies did not detect elevated chlorophyll-a concentrations near finfish farms as a result of nutrient inputs from the farms (Navarro, 2008). The review noted that the absence of measurable changes in chlorophyll-a near farms does not necessarily indicate a complete lack of phytoplankton response to nutrient inputs, but rather that any increase in growth may be offset by similar increases in grazing and mortality rates.

A global review of dissolved nutrient loading from marine finfish farms concluded that modern farm management practices, such as the use of formulated feeds and minimisation of feed waste, have reduced the effects of farms on water quality. Near-field nutrient enrichment is generally not detectable beyond 100 m of a farm under these conditions. Furthermore, nitrogen elevations resulting from finfish farms are largely periodic, associated with feeding and excretion patterns (Tomasso, 1994).

To assess the potential near-field effects of the proposed activity, a passive tracer dilution model was applied to the newly developed hydrodynamic model and used to predict changes in TN concentrations in the water column (Oceanum, 2025b). Two scenarios were modelled: (1) a 10-year simulation (using hydrodynamic conditions modelled for the period covering January 2011 to January 2021) representing full development at Stage 2, with a proposed annual feed input of 25,000 tonnes; and (2) a 1-year simulation (using the hydrodynamic conditions between July 2016 and July 2017) representing Stage 1 development, with a proposed annual feed input of 15,000 tonnes.

Varying loads of TN were applied to cells within the pens occupying the upper 16 m of the water column to simulate the changes in feed throughout the growing cycle. A passive tracer approach was used, which does not include complex biological conversions (e.g., growth, decay, or predation of phytoplankton), which is a conservative approach.

At the end of each simulation, mean and maximum depth-integrated TN concentrations were extracted from the model and plotted (i.e., averaged across the entire water column from surface to seabed) for Stage 1 (**Figure 16**) and Stage 2 (**Figure 17**) farming conditions. These are also presented in terms of percentage change relative to background concentrations in 2018/19 and 2025 (**Figure 18** and **Figure 19**). Summary statistics for a common 1-year period were also extracted for both stages to enable direct comparison (Table 8); That is, the figures showing model results for TN in this section show outputs from the full 10-year Stage 2 simulation or 1-year for Stage 1, while summary statistics are based on the common 1-year comparison for both stages. Further details on the modelling approach are provided in Oceanum (2025b).

Model predictions indicate that the mean increase in TN concentration within 100 m of the pens is 8.6 µg/L under Stage 1 (**Table 8**; **Figure 16**) and 9.2 µg/L under Stage 2 (**Table 8**; **Figure 17**). Short-lived maximum concentrations within 100 m of the pens were higher in Stage 1 (31.9 µg/L) than in Stage 2 (28.6 µg/L), reflecting the slightly higher stocking density proposed for Stage 1. These peak concentrations typically occurred during slack tide, when water movement and mixing are at their lowest. The 95th percentile for TN concentration increase in Stage 1 was substantially lower than the maximum at 18.6 µg/L, indicating that the greatest increases are infrequent and transient. This temporal variability is discussed further in **Section 3.3**.

Within the broader farming area (beyond 100 m from the pens), predicted TN concentration increases were slightly lower than those near the pens, with mean values of 7.7 µg/L for Stage 1 and 8.2 µg/L for Stage 2. These increases are very small relative to the mean background TN concentration of approximately 115 µg/L in 2018/19 and 405 µg/L in 2025, representing an increase of around 7% and 2% from background concentrations within the farming area, respectively. Such a small change would not be considered sufficient to alter the trophic state of the environment. Changes to TN concentrations outside the farming area are discussed in **Section 3.1.1.3**.

The TN changes for the proposed activities are substantially lower than those predicted for the 2020 application. Mean TN concentration changes predicted for the 2020 application are similar the maximum TN concentration changes for the current application. Such reduced effects are primarily due to reductions in proposed stock numbers and, therefore, feed inputs. There are also likely effects from the improved pen alignment and refined modelling approach.

Measured background TN concentrations in the proposed farming area and surrounding waters span a wide range (74–720 µg/L), with median values placing the system in the eutrophic category (see **Section 2.3.5**). Consequently, changes in TN concentration would need to be large (e.g., >100 µg/L) and sustained over extended periods (e.g., a year or more) to have a meaningful effect on trophic state and ecological function. In contrast, the mean modelled TN increase within the farming area is predicted to be 8.2 µg/L at full Stage 2 development. Such small increase is not expected to have any notable effect on the trophic state or ecological condition of the surrounding environment.

Overall, the effects of the proposed activities on water column TN are predicted to be generally localised to the farm area. The mean change to TN within the farm area is predicted to be no greater than 7% and 2% of the mean TN background concentrations measured in 2018/19 and 2025, respectively. Such a small change in the TN concentration is not considered sufficient to alter the trophic state of the environment. As such, the effects of the proposed activities on nutrient enrichment within the farm area are considered to be low.

Table 8: Summary statistics for estimated change in TN concentration (mg/L) relative to background from the hydrodynamic model for Stages 1 and 2. Statistics are extracted from each run for the July 2016 to July 2017 period. For context, the mean TN background concentration in 2025 was 405 µg/L.

Location/Area	Mean (SD)	Median	95th %ile	Maximum
Stage 1				
Pen (within 100 m)	8.6 (4.6)	7.0	18.6	31.9
Farm area (excluding near pen)	7.7 (3.7)	6.7	15.4	28.3
Port William	0.8 (0.6)	0.8	1.8	2.3
Halfmoon Bay	0.3 (0.2)	0.3	0.8	0.9
Patterson Inlet	0.1 (0.2)	0	0.5	1.4
Stage 2				
Pen (within 100 m)	9.2 (4.5)	7.9	17.9	28.6
Farm area (excluding near pen)	8.2 (3.7)	7.5	15.3	26.7
Port William	1.0 (0.7)	0.9	2.0	2.4
Halfmoon Bay	0.4 (0.3)	0.3	0.8	0.9
Patterson Inlet	0.1 (0.2)	0.2	0.5	1.5

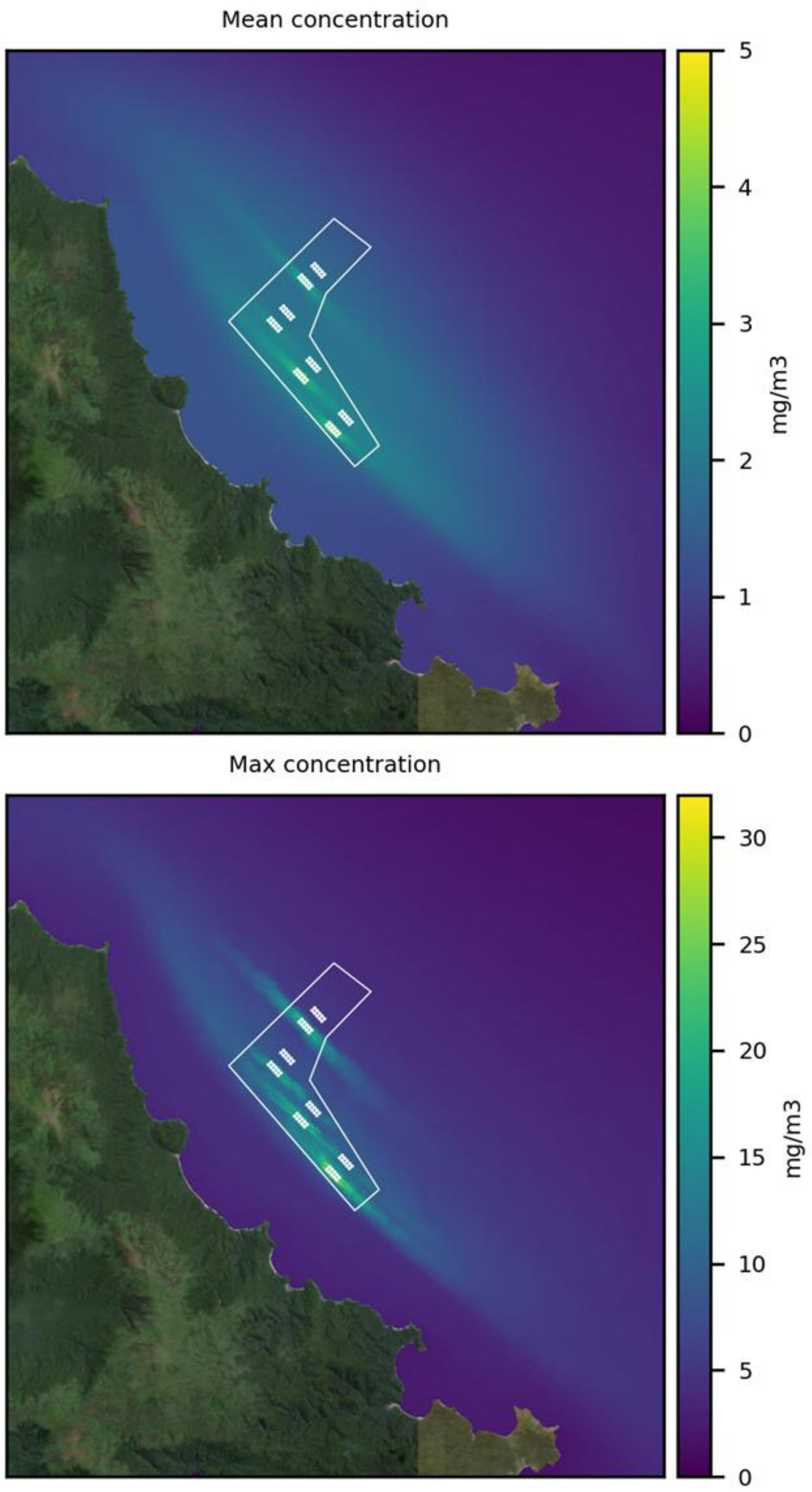

Figure 16: Modelled mean (upper) and maximum (lower) changes in TN concentration during Stage 1 development (mg/m^3 is equivalent to µg/L).

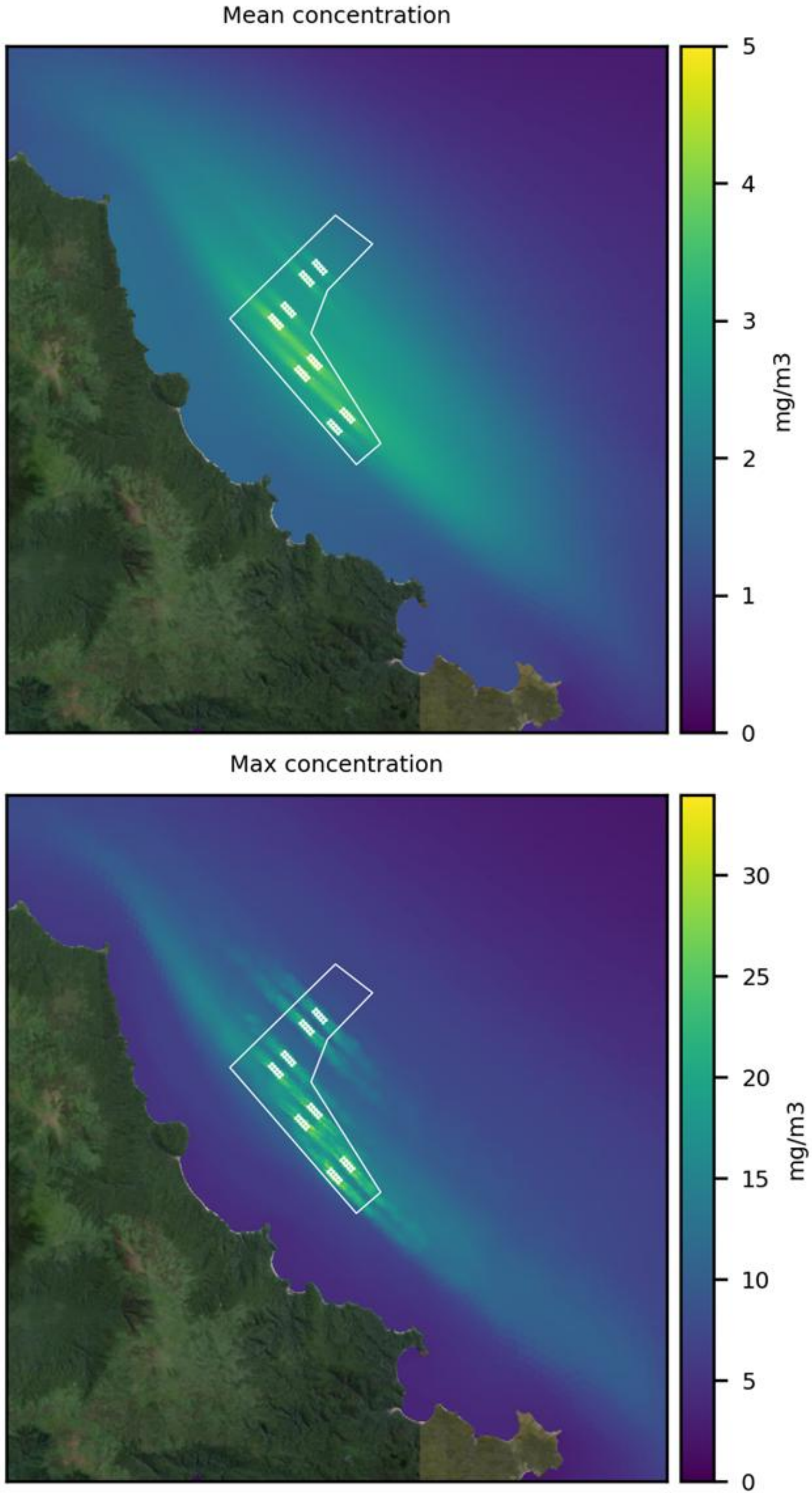

Figure 17: Modelled mean (upper) and maximum (lower) changes in TN concentration during Stage 2 development (mg/m^3 is equivalent to µg/L).

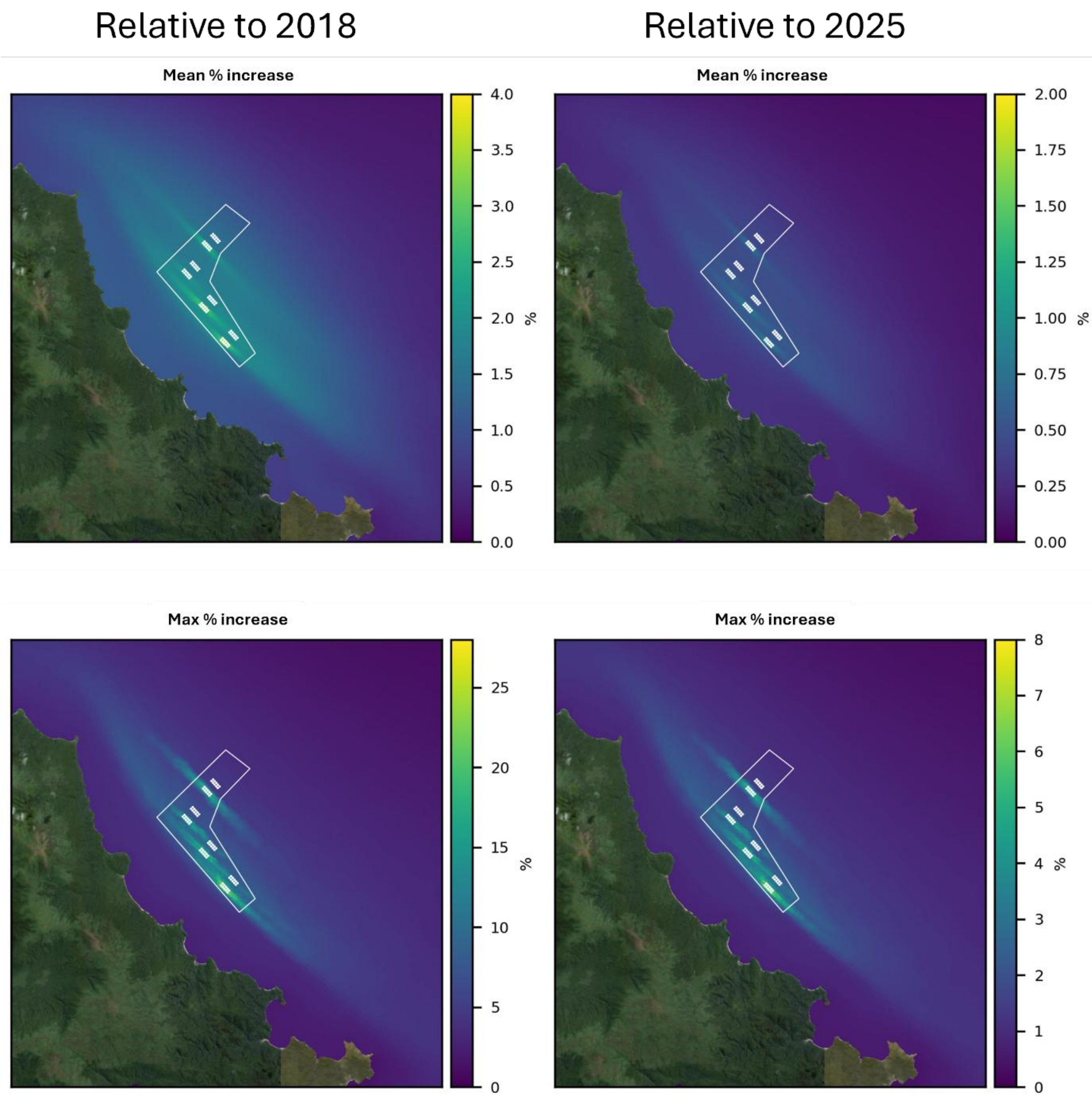

Figure 18: Modelled mean (upper) and maximum (lower) % changes in TN concentration during Stage 1 development relative to mean background concentrations in 2018 (115 µg/L; left) and 2025 (405 µg/L; right).

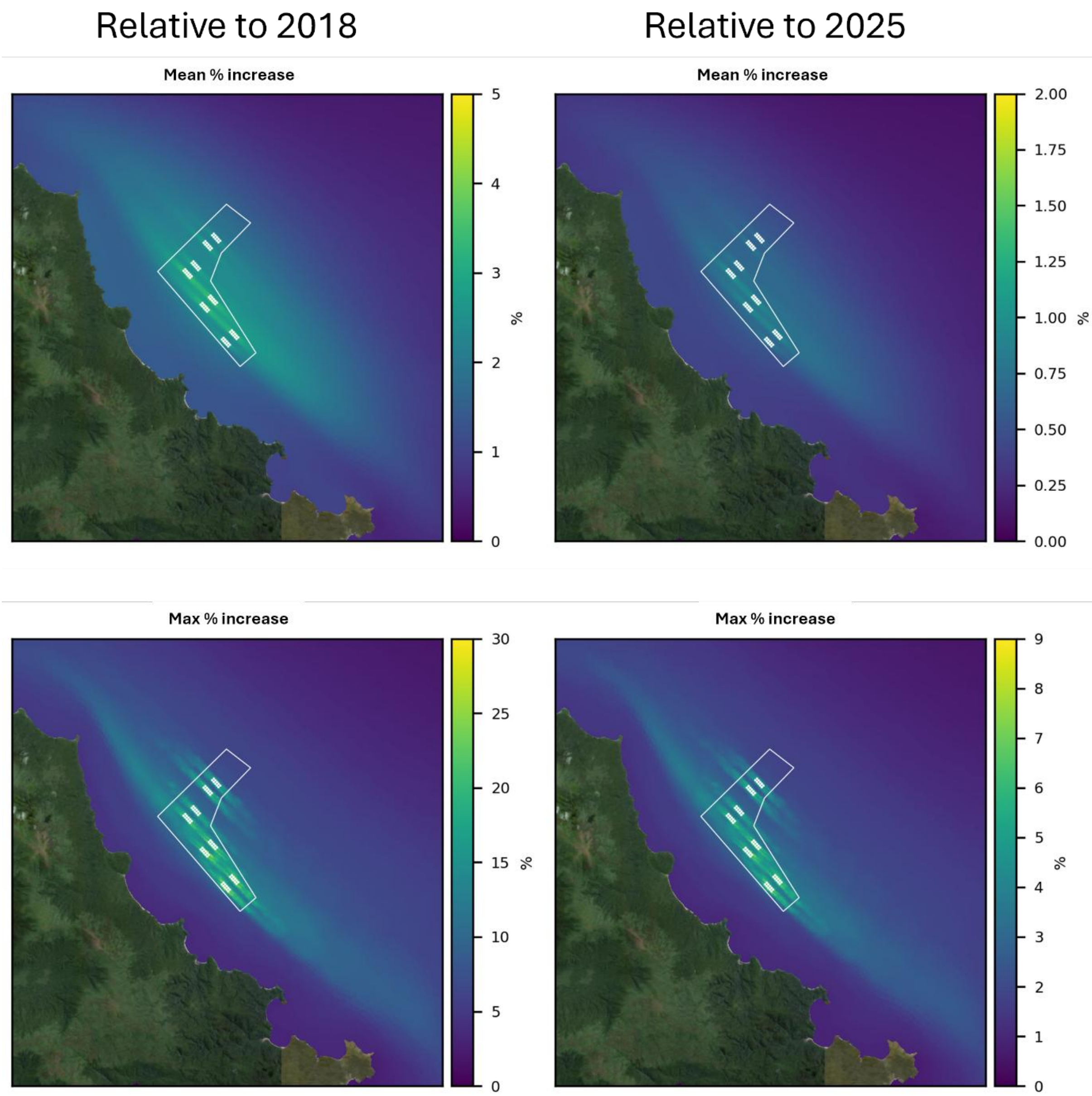

Figure 19: Modelled mean (upper) and maximum (lower) % changes in TN concentration during Stage 2 development relative to mean background concentrations in 2018 (115 µg/L; left) and 2025 (405 µg/L; right).

3.1.1 Far-field Effects

Foveaux Strait is a high-energy marine environment characterised by strong tidal currents and high levels of mixing and flushing, which provide an inherent capacity to disperse nutrients and minimise the risk of localised accumulation of nutrients. In contrast, nearby embayments such as Port William/Potirepo, Horseshoe Bay, and Halfmoon Bay, as well as Patterson Inlet, are more sheltered and have the potential to experience periods of stratification. These conditions can reduce mixing, increase residence times and create environments more conducive to phytoplankton growth. In some cases, this growth could include species known to potentially form harmful algal blooms. Such sheltered embayments may therefore be more susceptible to the effects of elevated nutrients.

This section also provides discussion on the effects of the proposed farming activity on water quality in the wider Foveaux Strait environment.

3.1.1.1 Nearby Embayments

Model predictions indicate that the majority of TN generated within the farming area is transported along the dominant northwest–southeast current axis, off the coast of and away from these embayments. Only very small increases of TN above background concentrations were modelled to occur within these sheltered areas, with median changes of less than 1.1 µg/L and 99th percentile values below 2.7 µg/L at full development (Stage 2). These predicted changes are extremely low and well below typical laboratory detection limits for TN.

Phytoplankton monitoring conducted in 2025 identified elevated concentrations of phytoplankton in some of these embayments, likely reflecting natural variability and localised conditions rather than effects related to the existing farming activities in the area. Given the minimal predicted increases in TN from the proposed farming activity, it is highly unlikely that these inputs would influence the frequency or magnitude of such events within the nearby embayments in the future. Accordingly, the effects of the proposed farming activity on nutrient enrichment in nearby sheltered embayments are considered to be very low.

3.1.1.2 Patterson Inlet

Model results show that there is little direct hydrodynamic connectivity between the proposed farming area and Patterson Inlet. Predicted changes in TN concentrations within the inlet as a result of the proposed farm operations (at either Stage 1 or 2 development) are considered negligible, with median and 99th percentile values of 0.2 µg/L and 0.9 µg/L, respectively at full development (Stage 2). These concentrations are well below typical laboratory detection limits and are not ecologically meaningful increases. Consequently, TN generated by the proposed farming activity is highly unlikely to have any adverse effect on nutrient concentrations within Patterson Inlet, and the overall effect is considered negligible.

3.1.1.3 Wider Environment

Water quality in Foveaux Strait is considered to be of high quality and is classified in the Regional Coastal Plan (**RCP**) as being in a Natural State, as the area is not subject to significant anthropogenic pressures. The RCP identifies that maintaining this status is an important consideration in managing activities within the region to ensure that water quality remains high and continues to reflect natural conditions.

Model predictions indicate that the mean change in TN concentration outside the farming area is very low, generally less than 4 µg/L at full Stage 2 development (**Figure 17**). Maximum predicted changes of up to 20 µg/L may occur immediately outside the farm boundary; however, these increases are highly localised and short-lived (see **Figure 17**,

Section 3.1.3, and **Figure 20**). Beyond this, small elevations in TN concentrations extend along the dominant current axis for approximately 4 km from the farm boundary. On average, the increase in TN concentrations from background outside the farming area remains below 4 µg/L, which is lower than the typical laboratory detection limit for TN and is unlikely to result in any meaningful or measurable ecological response or ecosystem change.

Although the model is capable of predicting such small changes in TN, these would be extremely difficult, if not impossible, to detect above natural variability (the natural range of which is highlighted within **Section 2.3.1**) using standard water quality sampling and analytical techniques. Consequently, the effect of the proposed farming activity on water quality within approximately 4 km of the farm along the dominant flow axis is considered to be very low. At distances beyond this, the effects are considered negligible and would not result in a change to the natural state of the water.

3.1.2 Phytoplankton

An increase in nitrogen concentration has the potential to stimulate phytoplankton growth, which in some cases could include HABs. Historical records show that algal blooms, including HAB events, have occurred in nearby Big Glory Bay. The most significant event was in 1989, following a prolonged period of warm, calm weather that resulted in water column stratification and long residence times (Chang et al., 1990; Mackenzie, 1991). These conditions are conducive to phytoplankton bloom development and led to substantial fish mortality, primarily due to the toxin-producing raphidophyte *Heterosigma akashiwo*.

The conditions described above, characterised by stratification and extended residence times, are unlikely to occur in the proposed farming area due to its high-energy, well-flushed environment. These conditions are unlikely to be significantly altered by events such as a prolonged period of warm calm weather. However, nearby sheltered embayments such as Port William, Horseshoe Bay, and Halfmoon Bay could experience conditions more similar to those in Big Glory Bay. Notably, low counts of *H. akashiwo* were detected in water samples collected from these bays in May 2025, along with elevated concentrations of *Pseudonitzschia* spp., a known toxin-producing species. These findings highlight the importance of ongoing phytoplankton monitoring in these areas.

The phytoplankton community within and surrounding the proposed farming area is typically dominated by diatoms (see **Section 2.3.4**). The most concerning HAB species in terms of toxin production are generally associated with phytoflagellates, which are unlikely to originate in the high-energy conditions of Foveaux Strait based on the existing phytoplankton communities. While blooms are unlikely to develop within the farm area itself due to the short residence time of water and the lag required for algal cells to metabolise nutrients and reproduce, sheltered embayments are more susceptible to bloom formation. However, model predictions indicate that TN increases within these embayments as a result of farming inputs are extremely small (≤1 µg/L; **Table 8**), which would not be expected to have a notable effect on phytoplankton growth.

However, due to the inherent uncertainty of models and the complex marine environment, monitoring at representative locations of these embayments is recommended. When interpreting monitoring results, it will be important to recognise that elevated levels of HAB species have been detected historically and are likely to occur again under favourable natural conditions, regardless of the presence of the proposed farm.

The water quality model estimates that the highest TN increases will occur directly following a slack tide. The elevated concentrations and decreased water movement during this time may provide conditions for some increased algal growth. However, within an hour, concentrations are predicted to rapidly decrease with the corresponding increase in flow, which provides a limited time for this to occur (**Figure 20**). This is unlikely to result in meaningful phytoplankton increases as a response by phytoplankton from nutrient inputs typically occurs over the timespan of at least one day (Ferreira et al. 2020).

Overall, the small predicted increases in TN concentrations are unlikely to result in notable increases in phytoplankton biomass. The strong tidal currents in Foveaux Strait will further mitigate the potential for bloom development, as phytoplankton cells require several days to metabolise nutrients and reproduce, and will not remain in nutrient-enriched waters for extended periods. While nearby embayments are inherently more susceptible to algal blooms, the low predicted changes in TN concentrations in these areas suggest that the proposed farming activity will not materially influence phytoplankton biomass. Accordingly, the effects of the proposed activity on phytoplankton abundance and community composition are considered to be low.

3.1.3 Nitrogen Concentration Changes Through the Water Column and Tidal State

Modelled TN concentrations presented throughout this assessment represent depth-integrated concentrations, meaning they are calculated as the mean or maximum concentration measured in any modelled cell across the entire water column from the surface to the seabed. While this provides a useful overall measure, it does not represent the vertical distribution of nitrogen. Further, when maximum concentrations are presented, they are concentrations that typically only occur for a short period following a slack low or high tide. The variability in TN concentrations with depth and over tidal cycles is discussed in this section.

The design of the fish pens in the proposed farm only occupies the upper portion of the water column, side wall of nets extending to approximately 16 m depth. Consequently, the modelled nitrogen inputs originate from this upper layer. To better understand how these inputs influence nitrogen concentrations at different depths and under varying tidal conditions, additional model outputs were generated to illustrate vertical and temporal variability (**Figure 20**).

The upper plot in **Figure 20** shows that the small increases in TN associated with the farming activity are largely confined to the upper 20 m of the water column, consistent with the depth of the pens and the location of nutrient release.

The lower plot in **Figure 20** demonstrates that TN concentrations peak in the hour following slack tide, when current speeds are minimal. As tidal currents strengthen, concentrations decline rapidly due to enhanced mixing and dispersion. This plot also shows lower TN concentrations coinciding with stronger tides (i.e., concentrations generally decrease from left to right, from neap tides occurring on the left of the plot to spring tides on the right). There is a strong correlation (albeit with some lag) between the current speed and the TN concentration. This pattern highlights the transient nature of elevated nitrogen levels and the strong influence of tidal cycles on water quality dynamics. Importantly, these results confirm that the maximum concentrations presented in this assessment occur only for short periods and under specific hydrodynamic conditions, rather than representing sustained changes in the water column. As such, phytoplankton in the vicinity will not interact with these elevated concentrations for sufficient length to notably alter their grow and the effects would be considered low to negligible.

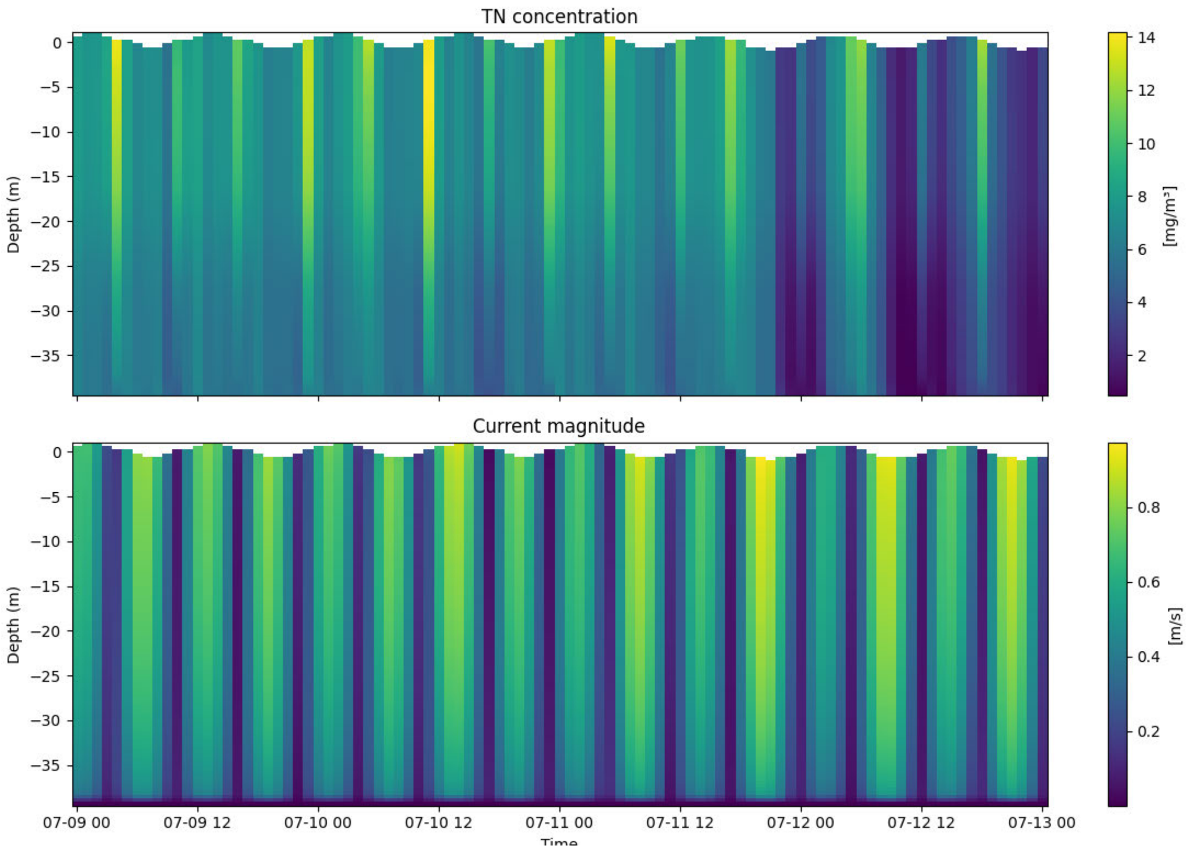

Figure 20: Modelled TN changes throughout the water column and over multiple tidal cycles for Stage 2 development. The upper plot shows the TN concentration, and the lower plot shows the current speed.

3.1.4 Effects of Remineralised Nitrogen into the Lower Water Column

Fish waste and uneaten feed that settle to the seabed contribute to the organic matter content of the benthic environment. This material undergoes decomposition through a combination of physical, chemical, and microbially mediated processes collectively referred to as remineralisation. During this process, organic nitrogen is converted into inorganic forms, which can be released back into the overlying water column. Understanding the magnitude of this effect is important for assessing potential contributions to nutrient enrichment beyond direct excretion from farmed fish.

To evaluate the potential influence of remineralisation on water column nitrogen concentrations, hydrodynamic modelling was undertaken for a representative 25-day period (1–25 January 2016), encompassing one spring tide and one neap tide. The model incorporated nitrogen deposition fields (g/m^2) generated by benthic deposition modelling conducted by Cawthron (Bennett et al. 2025) and assumed that 1% of deposited nitrogen was remineralised and transferred into the water column as inorganic nitrogen (as per the suggestions of Lin et al, 2023, and references within; Hargreaves, 1998). This assumption provides a conservative estimate of potential nitrogen release back into the overlying water column.

Model outputs indicate that the concentrations of nitrogen released into the lower water column from remineralisation are extremely low. The predicted change in bottom water TN concentration was less than 0.8 µg/L, with the changes being localised near the farm blocks (**Figure 21**). The nitrogen released into the lower water column predominantly remains within approximately 1 m of the seabed and exhibits little, if any, vertical mixing into the mid water column. The predicted concentrations are below the detection limits of standard laboratory analytical methods, which typically have reporting thresholds of around 10 µg/L for total nitrogen and 1 µg/L for nitrate nitrogen, indicating that the predicted changes are very low.

Given these findings, the contribution of remineralised nitrogen from seabed deposits to overall water column nutrient concentrations under the proposed operational parameters is considered negligible.

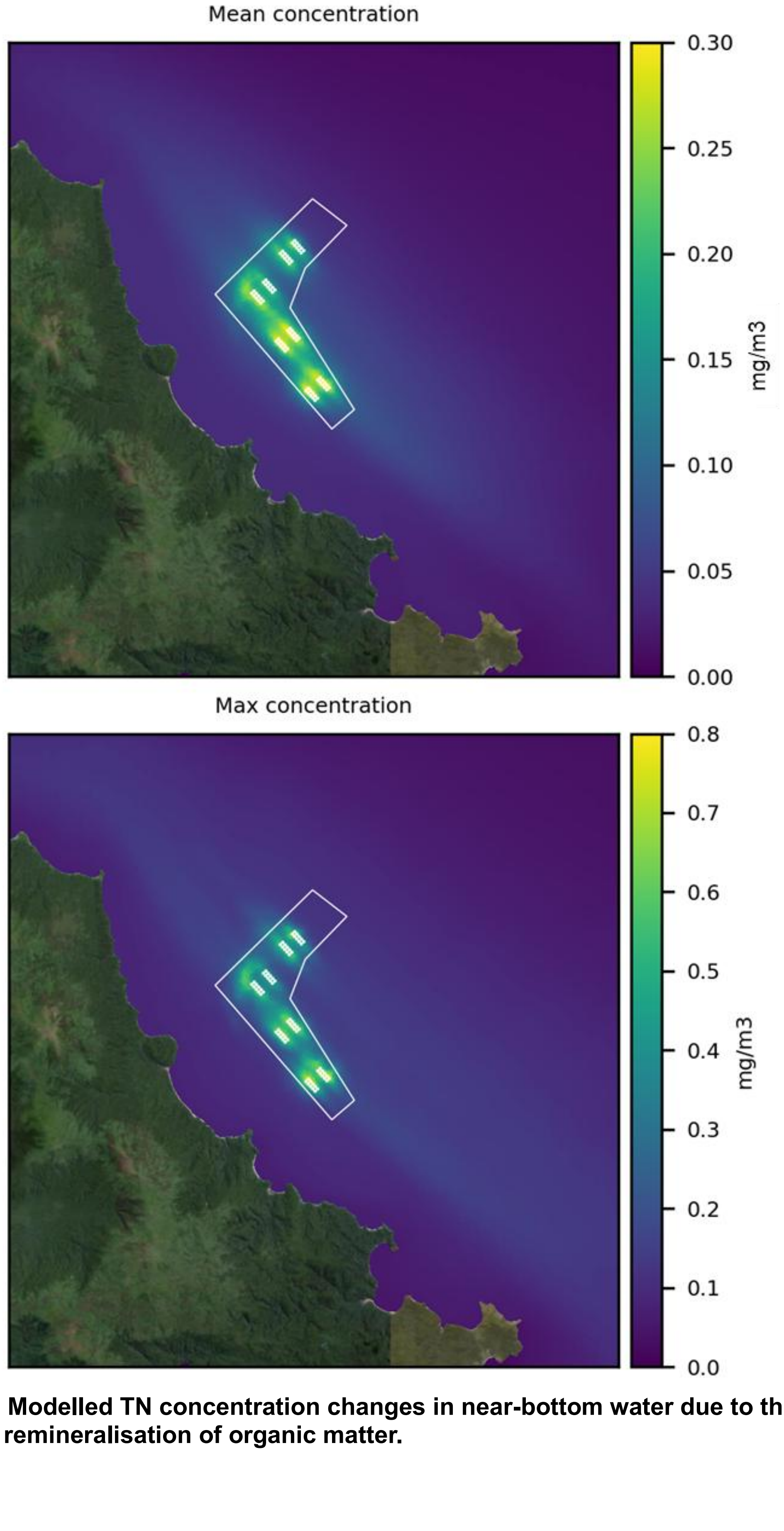

Figure 21: Modelled TN concentration changes in near-bottom water due to the remineralisation of organic matter.

3.1.5 Ammonia Toxicity

Ammonia is one of the main forms of nitrogen in fish waste. At elevated concentrations, it can be toxic to aquatic organisms. Total ammonia, as typically measured by the laboratory, exists in two forms in aqueous solutions: the un-ionised form, ammonia (NH_3); and the ionized form, ammonium (NH_4^+). Toxicity is primarily associated with the un-ionised form, NH_3, which represents the minor fraction of the two forms.

Ammonia toxicity is not an issue for marine farms with appropriate stocking densities in well-flushed locations, such as Foveaux Strait.

The maximum TN concentration predicted by the water quality model was during Stage 1, when stocking densities are slightly higher than during Stage 2, within 100 m of the pens, and occurring for up to an hour following slack tide. This maximum concentration was 31.9 µg/L. Conservatively, if all is nitrogen is assumed to be total ammoniacal nitrogen (i.e., NH_3 and NH_4^+), this concentration is well below the ANZG (2018) toxicant default guideline values for marine aquatic ecosystems for the 99% level of species protection (500 µg/L). As such, there is negligible risk of ammonia toxicity resulting from the proposed farming activities.

3.1.6 Nutrient Enrichment Conclusions

Hydrodynamic modelling results indicate that the effects of the proposed farming activity on nutrient concentrations in the water column will be low and highly localised. Within 100 m of the pens, mean increases in TN are predicted to be less than 10 µg/L, with short-lived maximum concentrations of up to approximately 30 µg/L occurring in the hour following slack tides when water movement is least. These peak concentrations are infrequent and transient and rapidly decline as tidal currents increase. Within the broader farm area (beyond 100 m from the pens), mean TN increases are predicted to be less than 8.5 µg/L, representing an approximate 2% increase relative to the mean background concentration (405 µg/L). Such small changes are not considered sufficient to alter the trophic state of the environment.

Outside the farming area, predicted changes in TN concentrations are very low, generally less than 4 µg/L (representing a 1% increase from background), and extend along the dominant current axis for approximately 4 km before becoming negligible. These changes are below typical laboratory detection limits and would be extremely difficult to distinguish from natural variability. In nearby sheltered embayments, including Port William, Horseshoe Bay, and Halfmoon Bay, predicted TN increases are less than 1 µg/L, and in Patterson Inlet, less than 0.5 µg/L. These changes are not ecologically meaningful and are unlikely to noticeably influence phytoplankton growth or bloom dynamics in these areas.

The potential for increased phytoplankton growth as a result of nutrient enrichment from the proposed farming activity is considered low. While nitrogen is typically the limiting nutrient in coastal systems, strong tidal currents and rapid flushing in Foveaux Strait limit the residence time of water and prevent sustained nutrient accumulation. Modelled TN increases in nearby embayments are very small (≤1 µg/L), and blooms are unlikely to develop within the farm area due to short exposure times and the lag required for algal growth. Consequently, the proposed activity is not expected to materially influence phytoplankton biomass or harmful algal bloom dynamics.

Model outputs show that TN increases from the proposed farming activity are largely confined to the upper 20 m of the water column, consistent with the depth of the pens. Concentrations peak immediately following slack tide, when water movement is at its least, and decline rapidly as tidal currents strengthen. These peak concentrations are short-lived and occur under specific hydrodynamic conditions, confirming that maximum modelled concentrations presented in this assessment do not represent sustained changes.

The contribution of remineralised nitrogen from seabed deposits to the water column is predicted to be negligible, with modelled increases in TN concentrations of less than 0.8 µg/L and predominantly confined to within 1 m of the seabed.

If all nitrogen originating from was assumed to be total ammoniacal nitrogen its concentration (31.9 µg/L) is well below the ANZG (2018) toxicant default guideline values for marine aquatic ecosystems for the 99% level of species protection (500 µg/L). As such, there is negligible risk of ammonia toxicity resulting from the proposed farming activities.

Overall, predicted changes in TN from the proposed farming activity are expected to be low and localised to the farming area and areas immediately downcurrent (up to 4 km from the farm boundary, but at low concentrations) and are unlikely to result in any ecologically significant changes in nutrient concentrations in the wider water column or subsequent detectable effects on phytoplankton growth. The strong hydrodynamic conditions in Foveaux Strait provide a high level of dilution and flushing, which will mitigate the potential for nutrient accumulation within the water column. Accordingly, the effects of nutrient enrichment on water quality and ecological processes are considered to be low within the farming area and negligible outside of the farming area.

3.2 Oxygen Depletion

Dissolved oxygen (**DO**) concentrations near fish farms can be reduced, primarily due to fish respiration consuming oxygen but also due to the microbial degradation of phytoplankton or waste material (Stenton-Dozey, 2013). There are two types of potential effects that can occur from reductions in oxygen (oxygen depletion) depending on the magnitude and time of exposure:

- **Sublethal effects**: includes reductions in growth rates, feeding behaviours, swimming ability, fecundity, immune resistance, etc., as a result of reduced DO availability or chronic exposure to depleted DO; and
- **Lethal effects**: results in animal mortality.

Both effects are more likely to impact slow-moving, sessile (non-moving) or penned animals (such as the farmed salmon), which are less able to avoid or move out of areas of reduced oxygen. Reduced levels of DO can affect the growth and survival of salmonids in different ways at different stages of life. Decreasing feeding activity in adult salmonids is usually observed under low DO concentrations (<6 mg/L) and may also cause mortalities in “extreme” conditions (<3 mg/L) (Carter, 2005). Bjornn and Reiser (1991) also stated that DO concentrations <5 mg/L can adversely affect growth, food conversion efficiency, and swimming performance in salmonids. Vaquer-Sunyer and Duarte (2008) specified a threshold of 5 mg/L, the point at which less than 10% of assessed animals experienced sublethal effects. Overall, adverse effects would only be anticipated at DO concentrations <5 mg/L and the extent of such effects would be a factor of the DO concentration and the length of time exposed to depleted (<5 mg/L) oxygen levels.

Salmon farming is largely self-regulating with regard to DO in that farms will lose stock, or fish will lose condition and show slower growth if they are stressed by low oxygen levels in the pens. Similarly, if oxygen levels in the farm sustain the farmed fish, so too would oxygen levels in the wider environment be expected to be sufficient to sustain natural fish populations.

Hydrodynamic modelling was undertaken to predict the potential effects of the proposed farming activity on DO concentrations in the water column under Stage 1 and Stage 2 development scenarios. The model incorporated fish respiration as the primary oxygen demand and accounted for site-specific hydrodynamic conditions during the period 1

January 2014 to 1 January 2015. Note that during Stage 1, the densities of fish are slightly higher (~85,000 fish per pen) than at Stage 2 (~80,000 fish per pen). See the Hydrodynamic Modelling Report (Oceanum, 2025) for further details on the model.

The potential effects on the depth-integrated (i.e., the mean or maximum concentration from the surface to the seabed) water column and lower water column (~bottom 2 m) are discussed separately in the following sections.

3.2.1 Water Column

Results indicate that the mean DO depletion in the area within 100 m of the pens is 0.20 mg/L under Stage 1 farming conditions (**Figure 22**; **Table 9**) and 0.18 mg/L for Stage 2 (**Figure 23**; **Table 9**). These are equivalent to approximately 1.9% and 1.7% saturation at the mean water temperature of 13°C. These reductions are minor relative to baseline concentrations and would result in mean DO levels remaining above 7.8 mg/L, well within the range considered safe for marine organisms. The mean DO reduction is an appropriate metric to consider the potential chronic effects on nearby fauna. As expected, the estimated oxygen depletion was slightly higher under Stage 1 development due to the higher stocking density.

Table 9: Summary statistics for estimated oxygen depletion (mg/L) from the hydrodynamic model for Stages 1 and 2.

Location/Area	Mean (SD)	Median	95th percentile	Maximum
Stage 1				
Pen (within 100 m)	0.20 (0.13)	0.158	0.472	0.866
Farm area (excluding near pen)	0.18 (0.15)	0.147	0.384	0.918
Port William	0.013 (0.009)	0.012	0.029	0.040
Halfmoon Bay	0.003 (0.003)	0.002	0.008	0.019
Patterson Inlet	0.006 (0.004)	0.005	0.014	0.035
Stage 2				
Pen (within 100 m)	0.18 (0.09)	0.156	0.376	0.641
Farm area (excluding near pen)	0.16 (0.08)	0.146	0.318	0.585
Port William	0.017 (0.009)	0.016	0.035	0.047
Halfmoon Bay	0.007 (0.004)	0.006	0.014	0.018
Patterson Inlet	0.003 (0.003)	0.002	0.009	0.034

The maximum predicted DO depletion was 0.918 mg/L during Stage 1, occurring within the farm area but more than 100 m from the pens. Such events were modelled to be short-lived and typically coincide with slack tide when water movement is at its lowest. The 95th percentile depletion values are substantially lower (0.384 mg/L), indicating that significant reductions are infrequent and transient. Beyond the farm boundary, predicted changes are negligible, with average reductions of <0.04 mg/L up to 1 km from the site—well below levels that could be detected against natural variability and not ecologically meaningful. Similarly, the predicted DO depletion at nearby sheltered embayments is low, with a mean depletion <0.02 mg/L and maximum depletion <0.05 mg/L. **Figure 22** and **Figure 23** illustrate that even under maximum depletion scenarios, DO concentrations remain well above thresholds for sublethal or lethal effects to either farm stock or organisms within the surrounding environment.

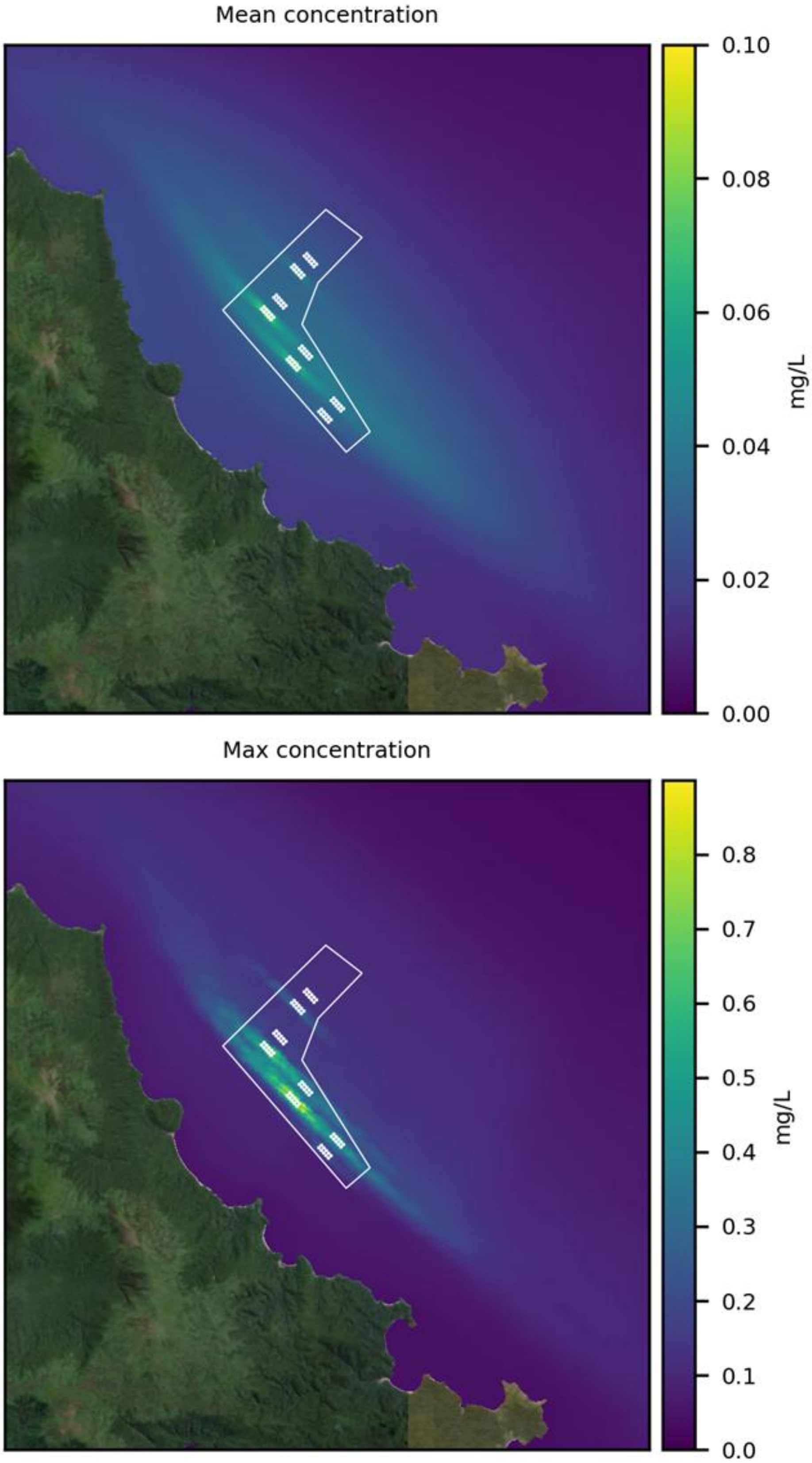

Figure 22: Mean (upper) and maximum (lower) dissolved oxygen consumption estimated by the model relative to background concentrations at Stage 1.

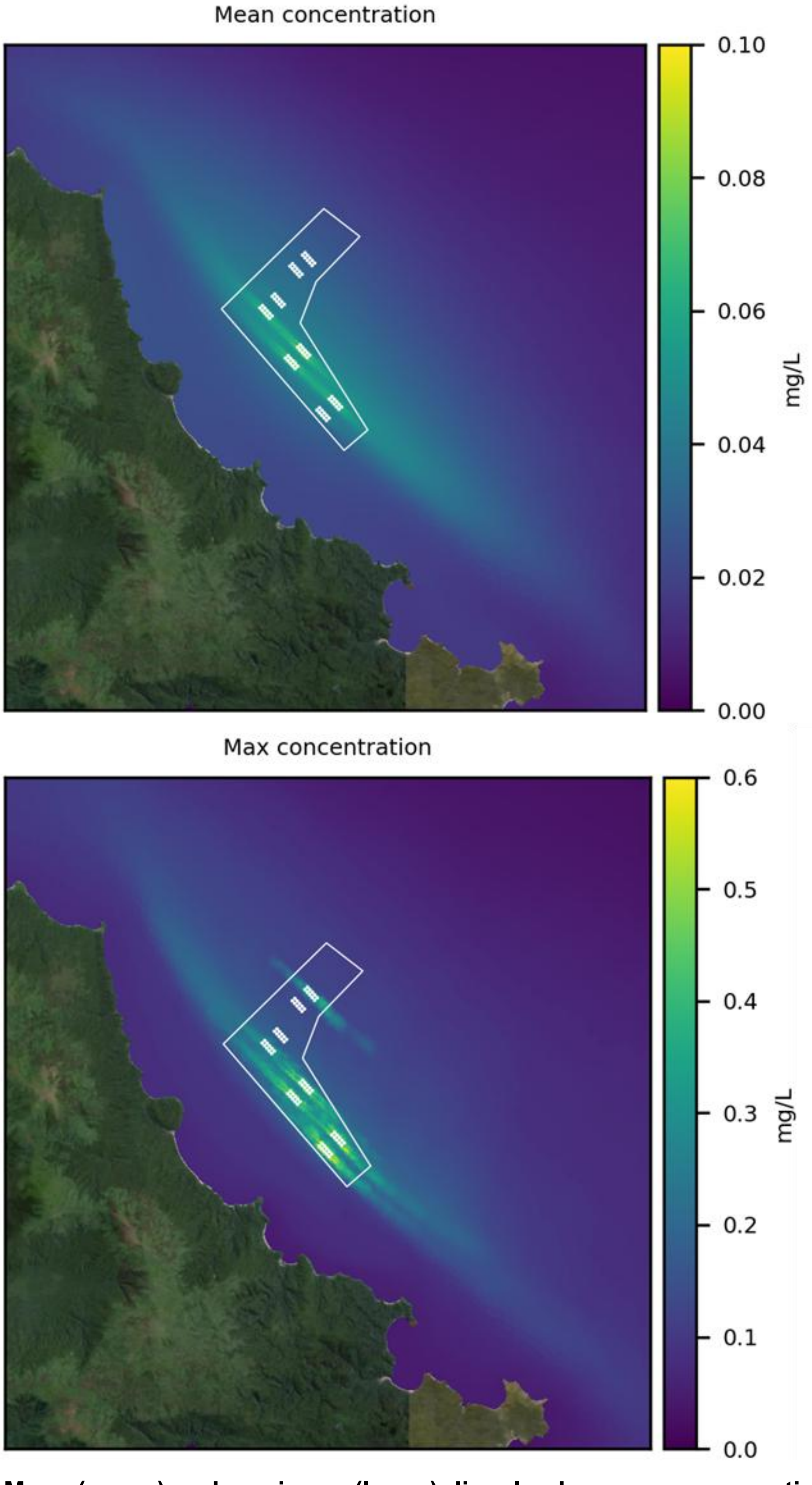

Figure 23: Mean (upper) and maximum (lower) dissolved oxygen consumption estimated by the model relative to background concentrations at Stage 2.

3.2.2 Bottom Water

The depletion of oxygen in near-seabed water could also potentially result from the microbial degradation of waste (derived from farming related discharge) on the seabed where the demand for oxygen is greater than the supply from the lower water column. Such effects are most likely to occur in stratified water columns, which is highly unlikely in Foveaux Strait, as observed from the well-mixed nature of the water column in water column profiles collected in 2018/19 (Campos et al., 2020). Organically enriched sediments will have a substantial oxygen demand; however, this is mitigated by high flow and oxygen supply from the water column at this site. Further, the likelihood of this occurring is low without substantial deposition of waste to the seabed, which if occurring would also result in substantial adverse benthic effects.

3.2.3 Dissolved Oxygen Conclusions

Hydrodynamic modelling estimates that, on average, DO will be depleted by 0.2 mg/L near the pens with short-lived maximum depletion of up to 0.9 mg/L. Such decreases in DO from background concentrations of 8.0 mg/L as measured during baseline surveys (i.e., depleted to a minimum of 7.1 mg/L) is highly unlikely to result in adverse effects occurring to the farmed fish or nearby fauna as 5 mg/L is the threshold at which sublethal effects are typically reported to occur.

Modelling indicates that any reduction of DO will be localised to the farm blocks where the effect is considered to be low, and there will be no ecologically meaningful effects from oxygen depletion in the surrounding environment during either development stage.

Near-seabed oxygen depletion at this site is only likely to occur under conditions where the benthic effects are unacceptable, a point at which there are also likely to be adverse effects to the farmed fish occurring and hence are highly unlikely to occur with the proposed activities.

3.3 Mixing

The extent to which nutrient and dissolved oxygen (**DO**) concentrations may change in the surrounding environment as a result of the proposed farming activity is primarily governed by dilution and mixing with the ambient waters of Foveaux Strait. This region is characterised by strong tidal currents and high levels of vertical and horizontal mixing, which provide a high potential to disperse farm-derived inputs and minimise the potential for localised accumulation.

The predominant current direction in the proposed farming area follows a northwest–southeast axis. Consequently, the mixing zone is expected to be asymmetric, extending further along this northwest–southeast axis and more limited along the perpendicular southwest–northeast axis; this can be visualised in modelling results presented in the following subsections. Adopting a conservative approach, an assessment of mixing was undertaken along the dominant current axis, where the greatest horizontal extension of a ‘plume’ of effects from the farm will occur.

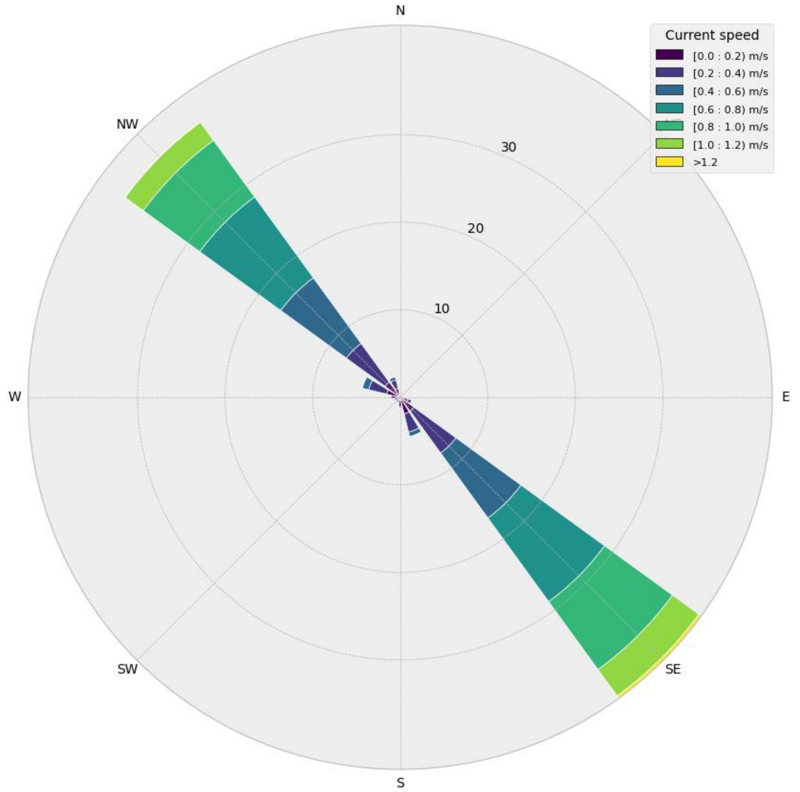

Figure 24: Annual surface current speed and direction rose for the 10yr hindcast model at location P1 (see Oceanum, 2025a).

To assess the spatial extent of predicted changes in water quality, data were extracted from the hydrodynamic model, using TN concentrations during Stage 2 development as an example, based on the following method. A transect line was defined along the northwest–southeast axis through the centre of the proposed farming area (the red line shown in **Figure 25**). The area 500 m either side of this transect was included to capture variability across the mixing zone. Distance along the transect was grouped into 100 m bins, and the mean and standard deviation of predicted TN concentrations were calculated for each bin. This approach provides a robust representation of how TN concentrations, as an example, attenuate with distance from the farm and allows for the identification of the distance at which the greatest changes occur leading away from the pens.

Figure 25: Transect line and area either side extracted from the model to assess the distance over which mixing occurs.

Based on the model outputs, the decrease in nutrient concentrations with increasing distance from the pens is relatively consistent along the transect (**Figure 26**). There is a weak indication that the greatest rate of decrease in mean TN occurs within approximately 200 m of the pen edge (upper graph in **Figure 26**); however, this pattern is not strong due to the high variability in predicted concentrations as a result of the dynamic mixing that is occurring. The maximum concentration plot (lower graph in **Figure 26**) suggests a more pronounced decline within the first 500 m from the pen edge, after which changes become progressively smaller and variable.

The transect extends approximately 4 km beyond each end of the farming area boundary and shows that predicted concentrations remain very slightly elevated above background levels even at this distance. This persistence is partly attributable to the sensitivity of the model, which can resolve small changes that would in reality be undetectable against natural variability in the field. For context, the typical laboratory reporting limit for total nitrogen is 10 µg/L; the mean predicted changes are below this value, and the maximum predicted concentrations are not much greater than this. For further context (and as introduced in **Section 2.3.1** and discussed further in **Section 3.1**), measured background TN concentrations at the proposed farm area ranged from 160 to 720 µg/L and hence the average predicted increases within 4 km of the farming area boundary are very small (~1%).

Identifying mixing zones in dynamic marine environments such as Foveaux Strait is inherently complex due to the influence of tides, currents, and episodic events (such as short events like storms or longer alterations like ENSO). In this context, the primary purpose of defining a mixing zone is to establish distances from the activity at which compliance metrics should be met (e.g., total nitrogen concentrations not exceeding a specified increment above background). We consider that objectives to manage nutrient and DO effects are best addressed more specifically in the following sections where their effects are discussed in the

Monitoring and Management section of this report (**Section 4.0**), and more specifically within an Environmental Monitoring Plan (**EMP**) to be developed for the proposed farm outlining specific monitoring locations, parameters, and trigger values. This approach provides a more practical and adaptive basis for managing water quality effects than attempting to define a single mixing zone applicable to all parameters.

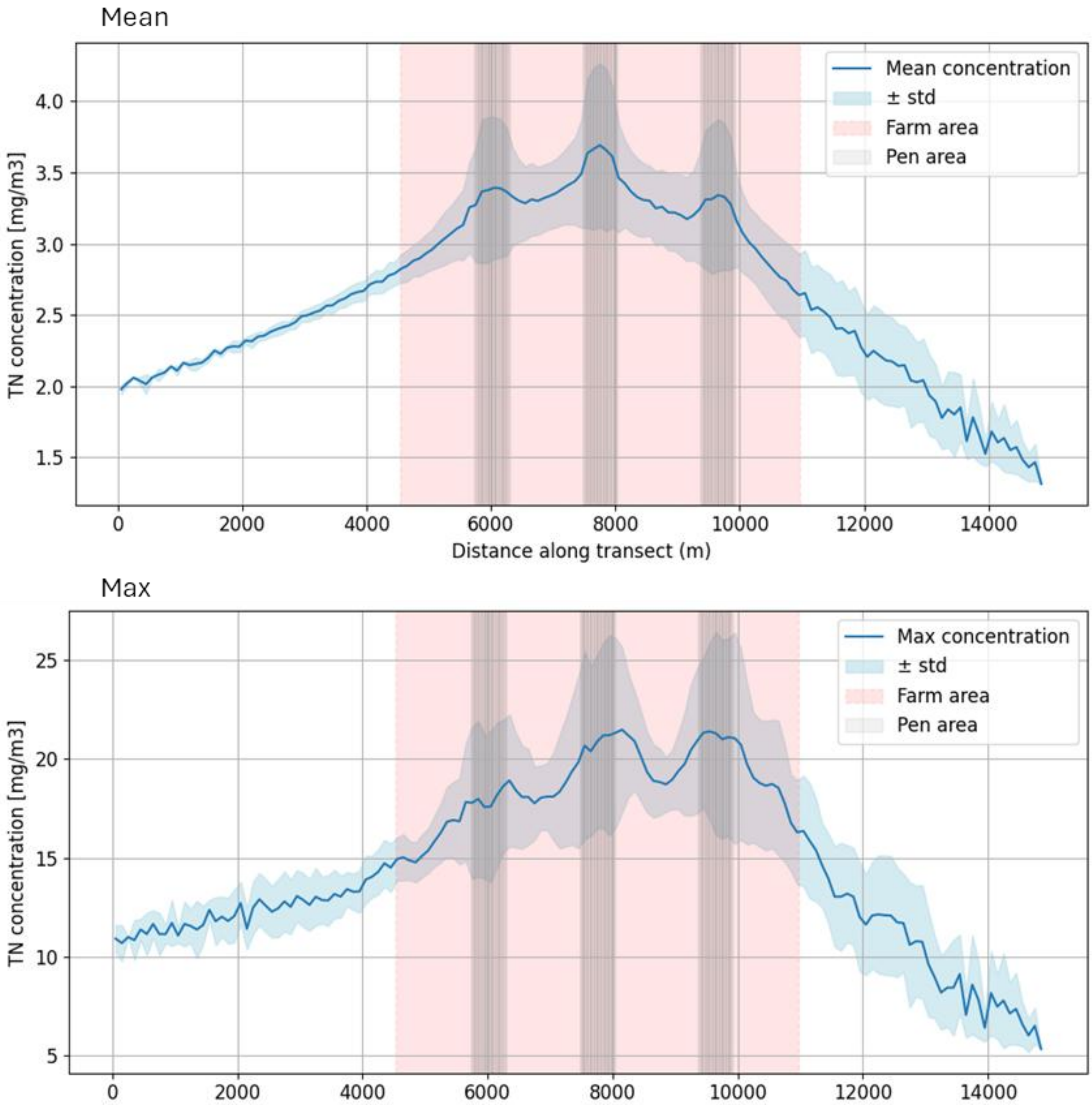

Figure 26: Mean (upper) and maximum (lower) TN concentrations extracted from the model along the transect shown in Figure 26.

3.4 Artificial Lighting

Within the first year, the proposed farm will install submerged artificial lighting in the grow-out pens. The lighting will be similar to those used on other salmon farms in New Zealand (e.g., New Zealand King Salmon farms in the Marlborough Sounds). The proposed lighting will include a maximum of six 680-watt LED lights per pen at approximately 3-7 m water depth.

Artificial lighting is widely used on marine farms overseas and is increasing in use in New Zealand. It is primarily used to manage fish maturation speed prior to harvest (e.g., Porter et al. 1999; Unwin et al. 2005) by removing changes in light as an environmental variable so that farms can increase production. Placing light at depth during nighttime hours also encourages more even fish distribution in net pens, reducing densities near the surface (Juell et al. 2003).

Introducing artificial lighting to the marine environment has the potential to affect biological processes within and adjacent to the lit pens. The potential effects of artificial lighting from finfish farms on the water column biology have been summarised here based on the available literature and observations of active artificial lighting arrays made on salmon farms in New Zealand in Cornelisen (2011). The identified potential effects and the following assessments are summarised from Campos et al. (2020) as follows:

1. **Attraction of phototactic organisms.** Organisms such as zooplankton and larval fish may be attracted to the lights and accumulate near and/or within the farm structures.
2. **Vertical migration and benthic settlement.** Some phytoplankton and zooplankton species may migrate vertically in response to the light. There could also be increased settlement of organisms attracted by the light onto the seabed near the farm structures.
3. **Aggregation and visibility of prey and enhanced predation.** Baitfish may aggregate near the lights and be more visible to prey during night. Subsequently, predation rates of baitfish could increase near the pens by farmed salmon and other fish and marine mammals.

The potential area affected by artificial lighting is dependent on the type of lighting used, the water clarity and the subsequent visual footprint created (i.e., the light's horizontal and vertical extent and wavelengths produced). LED lights are proposed to be used, which have a considerably smaller footprint compared to halogen bulbs (Bennett & Cornelisen, 2018). The visual footprint from LED bulbs used on salmon farms in the Marlborough Sounds was reported to be only a weak glow within 10 m of the farm. Above water, measurable levels of light could only be detected within the pen. Underwater and outside the pens, light was measurable at very low levels (<1 $\mu mol/m^2/s^{-1}$) around the depth the lights were installed. As such, any effects resulting from artificial lighting are highly localised.

3.4.1 Attraction of Phototactic Organisms

Some phototactic organisms (including larval fish) may be attracted to the light source at the edge of the pen and/or inside the pens for those small enough to fit through the mesh.

Salmon farms in the Marlborough Sounds with high currents did not find measurable effects on the aggregation and distribution of zooplankton (Bennett & Cornelisen, 2018; Cornelisen et al., 2013). Any larval fish that enter the pens would be unlikely to remain within the pen for long due to the high current speeds in the area, other than during slack tide periods. Further, the level of predation of zooplankton remaining within the pens by farmed salmon will also likely be limited as they are regularly fed manufactured feed.

Overall, the effects of artificial lighting on phototactic organisms are likely to be very low and highly localised.

3.4.2 Vertical Migration and Benthic Settlement

The vertical migration of some zooplankton may be affected by the artificial lighting increasing the downward flux of some taxa. The extent of this effect is limited by the extent of the visual footprint, which as described above, is likely to be small (within 10 m of the lighting), and the length of time organisms are exposed to the artificial light. In a low-flow environment, a small increase in the benthic settlement of some organisms may be anticipated near the pens due to attraction to artificial lighting. This could have the potential to increase the organic matter content of the seabed and influence the benthic community structure or biogeochemical processes. The proposed site, however, has high currents, which limit the amount of time organisms remain exposed to the effects of the artificial lighting and provide a high dispersal level. Subsequently, very little, if any, increase in benthic settlement would be anticipated near the proposed farm.

Overall, the effects of artificial lighting on vertical migration and benthic settlement are likely to be very low to negligible and highly localised.

3.4.3 Aggregation and Visibility of Prey and Enhanced Predation

Some fish species are known to aggregate around artificial lighting, which can increase the visibility of prey and increase their potential for predation (McConnell et al. 2010). The predation of attracted fish within the pens by the farmed salmon is likely mitigated due to the regular feeding of salmon with manufactured feed. The presence of other fish, marine mammals, or seabirds could potentially be enhanced by the aggregated baitfish; however, evening site surveys at Marlborough Sounds salmon farms did not show any evidence of enhanced predator activity by fish, marine mammals, or seabirds (Cornelisen et al. 2013; Bennett & Cornelisen 2018).

Overall, there is the potential that artificial lighting could attract baitfish and larger zooplankton that could be subject to enhanced levels of predation; however, the effects of such enhanced predation are likely to be very low to negligible.

3.4.4 Artificial Lighting Conclusions

The potential effects of artificial lighting on the surrounding environment include the attraction of phototactic organisms, vertical migration and settlement of attracted organisms near the pens, and aggregation and increased visibility of baitfish. Overall, the effects are likely to be very low and highly localised to pens with artificial lighting.

4.0 Monitoring Recommendations

The effects of the proposed farming activity on water quality have been assessed as low and localised to the farming area based on hydrodynamic modelling and supporting analyses. However, all models contain inherent uncertainty, particularly in dynamic marine environments such as Foveaux Strait. To address this uncertainty and provide confidence that actual effects align with predictions, monitoring recommendations are presented in this section. The intent of these recommendations is to verify that nutrient and dissolved oxygen concentrations, and phytoplankton responses, remain within the ranges anticipated by the modelling and analyses.

This section outlines recommended monitoring requirements in light of the findings of this water quality assessment. The key considerations for the water column are the potential increase in TN, which can stimulate phytoplankton growth, and the reduction of DO near the fish pens due to fish respiration.

To ensure that representative water quality conditions are measured, monitoring should be conducted between one and five hours after a slack tide.

It is recommended that more detailed monitoring requirements and specific methodologies are included in an environmental monitoring plan (**EMP**) to be prepared during the pre-farm development period.

4.1 Monitoring Locations

Exact monitoring locations shall be specified in the EMP; however, at a minimum, monitoring shall be conducted at:

- The edge of the farming area boundary or other location(s) that takes into account reasonable mixing;
- At least two background/reference sites; and
- Nearby, sheltered embayments, including Potirepo/Port William, Horseshoe Bay, and Halfmoon Bay.

4.2 Baseline Monitoring

Large differences in TN and phytoplankton communities were measured between 2018/19 and 2025 surveys, indicating complex and dynamic water quality conditions in and surrounding the proposed marine farm. As such, a minimum of 12 months of monthly baseline water quality monitoring is recommended prior to farm development to further understand the natural range of key water quality indicators including seasonal change. The recommended water quality parameters to be analysed from a water column profile or an integrated water sample extending between the surface and 15 m depth include:

- Water column profiles of DO, temperature, and salinity;
- TN (dissolved; recommend analysis using direct method rather than via TKN);
- TAN;
- NNN;
- TP (dissolved);
- DRP;
- Chl-a; and

- Phytoplankton community analysis (taxa identification and cell count).

4.3 Nutrient Enrichment

The following is recommended to monitor nutrient concentrations at the proposed farming area boundary during farming operations. The primary purpose is to confirm that TN concentrations are similar to those predicted by the water quality model:

- TN concentrations at the farm boundary shall not exceed 30 µg/L above the highest concentration measured at any reference site in the same month.

Note this value is rounded down from the maximum predicted TN concentration near the pens during Stage 1 (31.9 µg/L) and is the same as proposed for Blue Endeavour during expert caucusing.

4.4 Phytoplankton

The following is recommended to monitor the potential effects of nutrient enrichment on phytoplankton growth:

- The farm operation shall not cause chlorophyll-a concentrations at the farm boundary to exceed 3.5 µg/L at two or more farm boundary monitoring stations within one month or at the same monitoring station in two consecutive months.
- Phytoplankton identification and cell count of the dominant taxa from representative locations. Interpretation of the results will require expert judgement in the context of natural variability and wider system influences (i.e., there are no specific triggers recommended for phytoplankton).

Note the chl-a trigger of 3.5 µg/L and requirement for number of sites per month/consecutive months is that same as proposed for Blue Endeavour during expert caucusing and is consistent with the Water Quality Standard limit used in the Marlborough Sounds.

4.5 DO Depletion

The following is recommended to monitor DO concentrations at the proposed farming area boundary:

- The farm operation shall not cause DO concentrations at the farming area boundary to fall below 5 mg/L. DO concentration shall be measured from a depth profile with data averaged within 5 m depth bins.

5.0 Closure

This assessment characterises the existing water column environment within and around the proposed farming area and evaluates the potential effects of the proposed marine farming activity on water quality, phytoplankton, and dissolved oxygen (DO), as well as the potential influence of artificial lighting.

Sincerely,

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[redacted]

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6.0 References

Bjornn TC, Reiser DW, 1991. Habitat requirements of salmonids in streams. American Fisheries Society Special Publication, 19(837), 138.

Bennett H, Cornelisen C, 2018. Effects of underwater lighting on the marine environment at the Kopaua salmon farm. Prepared for New Zealand King Salmon Co. Ltd. Cawthron Report No. 3149. 16 p.

Bennett H, Smeaton M, Floerl L, Casanovas P, 2025. Assessment of seabed effects associated with farming salmon offshore of northern Stewart Island / Rakiura. Cawthron Report 4188. Prepared for Ngāi Tahu Seafood Resources.

Bennett H, Smeaton M, Jary M, Taylor D, 2018. Aquaculture site scoping: Northern Stewart Island Stage 1b. Prepared for Ministry for Primary Industries. Cawthron Report No. 3221. 48 p. plus appendices.

Bradford-Grieve JM. 1996. Assessment of the impact of reduced flows in the Waiau River since 1969 on the ecosystem of Foveaux Strait. NIWA Client report prepared for the Electricity Corporation of New Zealand Ltd. 36 p.

Broek TAB, McCarthy MD, Ianiri H, Knapp AN, 2023. Dominant heterocyclic composition of dissolved organic nitrogen in the ocean: A new paradigm for cycling and persistence. PNAS 120(49) e2305763120.

Broekhuizen N, 2015. Water quality in the Marlborough Sounds: annual monitoring report July 2014–June 2015. NIWA Client Report (for Marlborough District Council) HAM2015-094 (project MDC15201).

Campos C, Smeaton M, Bennett H, Mackenzie L, Scheel M, Vennell R, Newcombe E, Knight B, 2020. Assessment of water column effects associated with farming salmon offshore of northern Stewart Island / Rakiura. Report prepared for Ngāi Tahu Seafood Resources by Cawthron Institute.

Carter K, 2005. The effects of dissolved oxygen on steelhead trout, coho salmon, and chinook salmon biology and function by life stage. California Regional Water Quality Control Board, North Coast Region.

Carter L, Heath RA. 1975. Role of mean circulation, tides, and waves in the transport of bottom sediment on the New Zealand continental shelf. New Zealand Journal of Marine and Freshwater Research 9(4): 423-448.

Chang FH, Anderson C, Boustead NC, 1990. First record of a *Heterosigma* (Raphidophyceae) bloom with associated mortality of cage-reared salmon in Big Glory Bay, New Zealand. New Zealand Journal of Marine and Freshwater Research 24: 461-469.

Chiswell SM. 1996. Variability in the Southland Current, New Zealand. New Zealand Journal of Marine and Freshwater Research 30: 1–17.

Cornelisen C, 2011. The New Zealand King Salmon Company Limited: assessment of environmental effects - submerged artificial lighting. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 1982. 17 p. https://www.epa.govt.nz/assets/FileAPI/proposal/NSP000002/Applicants-proposal-documents/9e7954ad98/Appendix-12-Artificial-Lighting-Report.pdf

Cornelisen C, Forrest R, Quarterman A, 2013. Effects of artificial lighting on the marine environment at the Te Pangu Bay salmon farm. Prepared for New Zealand King Salmon Company Limited. Cawthron Report No. 2374. 18 p.

Ferreira A, Sá C, Silva N, Beltrán C, Dias AM, Brito AC. 2020. Phytoplankton response to nutrient pulses in an upwelling system assessed through a microcosm experiment (Algarrobo Bay, Chile). Ocean & Coastal Management. 190:105167.

Gillespie P, Young R, Knight B. 2009. Potential implications of the Manapouri Tailrace Amended Discharge (MTAD) for the coastal environment of Te Waewae Bay. Cawthron Report No. 1569 prepared for Meridian Energy Ltd. 36 p.

Hargreaves JA, 1998. Nitrogen biogeochemistry of aquaculture ponds. Aquaculture, 166(3-4), pp.181-212.

Hay CH. 1990. The distribution of Macrocystis (Phaeophyta: Laminareales) as a biological indicator of cool sea surface temperature, with special reference to New Zealand waters. Journal of the Royal Society of New Zealand 20(4): 313-336.

Heath RA. 1975. Oceanic circulation and hydrology off the southern half of South Island, New Zealand. New Zealand Oceanographic Institute Memoir 72: 1-36.

Heath RA. 1985. A review of the physical oceanography of the seas around New Zealand - 1982. New Zealand Journal of Marine and Freshwater Research 19:79-124.

James M, Giles H, 2020. Kingfish and marine farming in the Coromandel Marine Farming Zone: Overall assessment of ecological effects. Report prepared for Pare Hauraki Kaimoana by Aquatic Environmental Science Ltd and Pisces Consulting Ltd.

James M, Hartstein N, Giles H, 2018. Assessment of ecological effects of expanding salmon farming in Big Glory Bay, Stewart Island - Part 1 Description of aquatic ecology. Report prepared by Aquatic Environmental Services Ltd, Aquadynamics Solutions Sdn Bhd, and Pices Consulting Ltd for Sanford Ltd.

Juell JE, Oppedal F, Boxaspen K, Taranger GL, 2003. Submerged light increases swimming depth and reduces fish density of Atlantic salmon *Salmo salar* L. in production cages. Aquaculture Research 34(6): 469-477.

Kämpf J, Chapman P, 2016. Seasonal wind-driven coastal upwelling systems. In Kämpf J & Chapman P (Eds.), Upwelling Systems of the World (pp. 315–361).

Lin X, Lin G, Zheng Y, Li W, Guo P, Fan S, Kong T, Tian D, Sun D, Shen Z, 2023. Nitrogen mineralization and immobilization in surface sediments of coastal reclaimed aquaculture ecosystems. Frontiers in Marine Science, 9, p.1093279.

MacKenzie AL, 1991. Toxic and noxious phytoplankton in Big Glory Bay, Stewart Island, New Zealand. Journal of Applied Phycology 3: 19-34.

McConnell A, Routledge R, Connors BM, 2010. Effect of artificial light on marine invertebrate and fish abundance in an area of salmon farming. Marine Ecology Progress Series 419: 147–156.

MPI, 2013. Overview of ecological effects of aquaculture. Ministry for Primary Industries, Wellington.

Newcombe E, Knight B, Smeaton M, Bennett H, Macenzie L, Scheel M, Vennell R, Campos C, 2020. Water column assessment for a proposed salmon farm offshore of the Marlborough Sounds. Report prepared for The New Zealand Salmon Co. Limited by Cawthron Institute.

Oceanum, 2025a. Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa: Report 1 - Hydrodynamic Model. Report prepared for Ngāi Tahu Seafood.

Oceanum, 2025b. Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa: Report 2 – Water Quality Modelling. Report prepared for Ngāi Tahu Seafood.

Porter MJR, Duncan NJ, Mitchell D, Bromage NR, 1999. The use of cage lighting to reduce plasma melatonin in Atlantic salmon (*Salmo salar*) and its effect on the inhibition of grilsing. Aquaculture 176: 237-244.

Smith V, Tilman G, Nekola J, 1999. Eutrophication: impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. Environmental Pollution 100(1-3), 179-196.

Stenton-Dozey J, 2013. Literature review of ecological effects of Aquaculture: Pelagic effects. Report prepared for the Ministry for Primary Industries.

Sutton PJH. 2003. The Southland Current: A subantarctic current, New Zealand. Journal of Marine and Freshwater Research 37(3): 645–652.

Taylor DI, Jary M, 2018. Aquaculture Site Scoping: Northern Stewart Island Stage 1a. Prepared for Ministry for Primary Industries. Cawthron Report No. 3163. 31 p. plus appendices.

Unwin MJ, Rowe DK, Poortenaar CW, Boustead NC, 2005. Suppression of maturation in 2-year-old Chinook salmon (*Oncorhynchus tshawytscha*) reared under continuous photoperiod. Aquaculture 246(1-4): 239-250.

Vance JM, Currie K, Suanda SH, Law CS. 2024. Drivers of seasonal to decadal mixed layer carbon cycle variability in subantarctic water in the Munida Time Series. Frontiers in Marine Science 11.

Vaquer-Sunyer R, Duarte CM. 1998. Thresholds of hypoxia for marine biodiversity. Proceedings of the National Academy of Sciences 105(40): 15452-15457.

Vincent WF, Howard-Williams C, Tildesley P, Butler E. 1991. Distribution and biological properties of oceanic water masses around the South Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 25: 21-42.

Voss M, Bange HW, Dippner JW, Middelburg JJ, Montoya JP, Ward B., 2013. The marine nitrogen cycle: recent discoveries, uncertainties and the potential relevance of climate change. Philos Trans R Soc Lond B Biol Sci. 368(1621), 20130121.

Appendix A Water Quality Data Summary

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

6 November 2025

SLR

A.1 Water quality data summary

Table A-1: Summary of water quality data collected in 2018/19 and 2025.

Year	Parameter	n	mean	sd	min	p10	p25	median	p75	p90	max
2018/19	Chl-a	12	0.90	0.35	0.52	0.54	0.58	0.88	1.22	1.24	1.49
2018/19	DIN	17	49.48	26.75	24.10	24.38	32.90	38.70	82.30	89.22	96.50
2018/19	DRP	17	10.33	1.38	6.40	9.16	9.40	10.90	11.20	11.44	12.20
2018/19	Nitrate	17	42.95	24.38	19.00	20.60	27.00	33.70	71.80	79.56	84.70
2018/19	Nitrite	17	1.97	1.10	0.50	1.00	1.00	2.00	3.00	3.40	4.00
2018/19	Si	17	100.07	39.79	42.90	55.84	75.00	90.00	130.00	151.40	173.00
2018/19	TAN	17	4.56	1.96	2.50	2.72	3.00	4.10	5.20	7.26	9.40
2018/19	Total Dissolved Nitrogen	17	114.53	29.87	74.00	84.60	94.00	106.00	146.00	151.20	179.00
2018/19	Total Nitrogen	18	162.33	81.28	90.00	92.40	106.25	151.50	171.25	232.50	426.00
2018/19	Total Oxidised Nitrogen	17	44.92	25.41	20.00	21.30	28.00	35.70	74.80	83.16	88.70
2018/19	Total Phosphorus	18	16.56	11.47	10.00	11.00	12.00	12.50	15.50	22.20	58.00
2025	Chl-a	60	0.79	0.78	0.10	0.10	0.10	0.55	1.50	1.50	4.00
2025	DIN	60	31.53	18.37	4.00	11.40	20.05	28.50	39.63	61.50	78.50
2025	DRP	60	6.32	3.22	1.00	1.00	4.00	7.00	8.00	10.10	13.00
2025	Nitrate	60	26.14	17.64	1.00	7.00	14.75	22.80	33.53	57.00	74.00
2025	Nitrite	60	2.78	1.83	0.50	0.50	1.55	2.00	4.00	5.31	7.80
2025	Si	60	1960.50	1891.28	500	500	500	805	3050	4620	8500
2025	Sulfate	60	2713.67	78.55	2490	2630	2667.5	2720	2780	2791	2870
2025	TAN	60	2.66	0.73	2.5	2.5	2.5	2.5	2.5	2.5	7.0
2025	Total Dissolved Kjeldahl Nitrogen	40	330	109.45	150	199	255	320	402.5	441	720
2025	Total Dissolved Nitrogen	60	405	137.82	160	229	307.5	400	470	600	720
2025	Total Kjeldahl Nitrogen	40	501.75	153.87	200	320	397.5	500	600	707	900
2025	Total Nitrogen	40	538.25	173.99	200	340	417.5	500	600	801	1000
2025	Total Oxidised Nitrogen	60	28.87	18.40	1.5	8.9	17.6	26.0	37.1	59.0	76.0
2025	Total Phosphorus	60	13.37	6.18	5.0	5.0	11.0	14.0	15.3	18.0	46.0
2025	ODO % SAT	60	101.27	1.75	98.38	99.02	99.83	101.36	102.26	103.61	106.43
2025	ODO MG/L	60	8.57	0.25	8.14	8.31	8.36	8.50	8.82	8.91	9.09
2025	PH	60	8.53	0.81	7.87	7.94	7.95	7.98	9.65	9.68	9.75
2025	SAL PPT	60	34.77	0.42	34.16	34.40	34.47	34.54	35.31	35.39	35.44
2025	TEMP °C	60	13.14	1.40	10.74	11.18	11.55	13.29	14.44	14.90	15.32
2025	TURBIDITY FNU	60	1.69	0.80	0.61	1.10	1.23	1.57	1.89	2.37	6.59

A.2 Phytoplankton

Table A-2: Phytoplankton taxa identification and cell counts (cells/L) for samples collected in 2018/19 and 2025. Greater abundances are indicated by the red shading and lower abundances with progressively greener shading.

Date	19/10/2018				3/12/2018				17/01/2019				4/05/2025																			
Sampling Site	Port William	Lease 3	Lease 2	Lease 1	Port William	Lease 3	Lease 2	Lease 1	Port William	Lease 3	Lease 2	Lease 1	Port William	Lease 3	Lease 2	Lease 1	Horseshoe Bay	Halfmoon Bay	Paterson Inlet	Boundary W	Boundary E	Boundary N	Port William	Lease 3	Lease 2	Lease 1	Horseshoe Bay	Halfmoon Bay	Paterson Inlet	Boundary W	Boundary E	Boundary N
Sampling Depth	Surface				Surface				Surface				Surface										Bottom									
Diatoms (Bacillariophycaea)																																
Asterionellopsis sp.				200	2200	9000	3800	9400																								
Cerataulina spp.	400	200		200			600																									
Chaetoceros spp.	39000			200	12000	31000	14000	6600	4800	7800	8800	15000	192000	101000	17000	25000	42900	2595000	12120000	7400	6600	35000	380000	31000	48000	4400	1486000	912000	41031000	51000	253000	108000
Chaetoceros convolutus															800	1000		2000			1200		1200	600	200		1800					2200
Corethron sp.									200	1000	600																					
Cylindrotheca sp.										600		200																				
Dactyliosolen spp.	400				400	200	800	200																								
Eucampia spp.	400				400	1000																										
Fragilaria sp.																					41000											
Guinardia sp.		200				200	200	200																								
Cylindrotheca sp.												2800																				
Hemiaulus sp.								200																								
Lauderia sp.						200		600																								
Leptocylindricus spp.						800	400			400			322000	70000	11000		612000	1392000	12045000				486000	54000	20000	16000	2268000	822000	83617000		212000	41000
Navicula spp.	200		200	200	200		200					200																				
Nitzschia spp.	1400				1400	200		400			200	400																				
Paralia spp.																9800																
Pleurosigma sp.				200			200																									
Proboscia spp.																								3600				2200	2000		4800	
Pseudonitzschia spp.						2600	1800	2000		800	400	1200	2149000	202000	64000	26000	2075000	10826000	16684000	37000	134000	29000	3694000	284000	159000	80000	7809000	40136000	163270000	132000	1363000	66000
Rhizosolenia spp.													2600	2800		400	4600	11000		800	3200	7000	31000	1400		800	65000	74000	3000			2600
Skeletonema costatum	5800	66000	29000	7800	53000	62000	60000	83000												5800										37000		
Thalassionema spp.																						29000										
Thalassiosira spp.	2400	1200	1400		13000	16000	12000	21000	200	600	400	1000																				
Dinoflagellates (Dinophyceae)																																
cf. *Azadinum* sp.												200																				
Gymnodinium spp.					200			400		800																						
Gyrodinium spp.			200							200	200																					
Heterocapsa spp.										400																						
Karlodinium sp.										200																						
Oxytoxum sp.					200																											
Protoperidinium spp.								400			200																					
Prymnesiophceae																																
Chrysochromulina spp.		400			200					200				400	1600	71000				84000		200		67000	800				418000			
Cryptophyceae																																
Cryptomonas sp.	200					200				200																						
Euglenophyceae																																
Euglena sp.							1200		200		200	200																				
Raphidophyceae																																
Fibrocapsa japonica													600																			
Heterosigma akashiwo													400				600															
Other																																
Unidentified flagellates	800	200	400	3000	4800	1400	2600			1200	200	200																				

Appendix B Statistical Analysis Result Summary

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

6 November 2025

B.1 Normal data distribution

Data were tested using Shapiro Wilk tests of normality by Year, Parameter, Group, and Depth to determine whether they were normally distributed. A p-value >0.05 indicates that data are normally distributed.

Not all groups had data that were normally distributed so non-parametric tests were used for all further statistical analysis for consistency.

Table B-1: Summary from Shapiro Wilk tests of normality. A p-value >0.05 indicates that data are normally distributed (shaded in green).

Year	Parameter	Group	Depth	P-value	n
2018/19	Chl-a	Farm	Bottom	0.0575	6
2018/19	Chl-a	Farm	Surface	0.6403	6
2018/19	DIN	Farm	Bottom	0.0208	8
2018/19	DIN	Farm	Surface	0.0216	9
2018/19	DRP	Farm	Bottom	0.4255	8
2018/19	DRP	Farm	Surface	0.0375	9
2018/19	Nitrate	Farm	Bottom	0.0186	8
2018/19	Nitrate	Farm	Surface	0.0350	9
2018/19	Nitrite	Farm	Bottom	0.5011	8
2018/19	Nitrite	Farm	Surface	0.0648	9
2018/19	Si	Farm	Bottom	0.4351	8
2018/19	Si	Farm	Surface	0.2289	9
2018/19	TAN	Farm	Bottom	0.0860	8
2018/19	TAN	Farm	Surface	0.1814	9
2018/19	Total Dissolved Nitrogen	Farm	Bottom	0.1368	8
2018/19	Total Dissolved Nitrogen	Farm	Surface	0.1773	9
2018/19	Total Nitrogen	Farm	Bottom	0.0146	9
2018/19	Total Nitrogen	Farm	Surface	0.2626	9
2018/19	Total Oxidised Nitrogen	Farm	Bottom	0.0239	8
2018/19	Total Oxidised Nitrogen	Farm	Surface	0.0339	9
2018/19	Total Phosphorus	Farm	Bottom	0.0006	9
2018/19	Total Phosphorus	Farm	Surface	0.1756	9
2025	Chl-a	Boundary	Bottom	0.0155	9
2025	Chl-a	Boundary	Surface	0.0215	9
2025	Chl-a	Farm	Bottom	0.0155	9
2025	Chl-a	Farm	Surface	0.0170	9
2025	Chl-a	Sheltered	Bottom	0.0032	12

Year	Parameter	Group	Depth	P-value	n
2025	Chl-a	Sheltered	Surface	0.0144	12
2025	DIN	Boundary	Bottom	0.1936	9
2025	DIN	Boundary	Surface	0.2767	9
2025	DIN	Farm	Bottom	0.6593	9
2025	DIN	Farm	Surface	0.7012	9
2025	DIN	Sheltered	Bottom	0.2259	12
2025	DIN	Sheltered	Surface	0.1037	12
2025	DRP	Boundary	Bottom	0.5871	9
2025	DRP	Boundary	Surface	0.3459	9
2025	DRP	Farm	Bottom	0.7796	9
2025	DRP	Farm	Surface	0.8505	9
2025	DRP	Sheltered	Bottom	0.1385	12
2025	DRP	Sheltered	Surface	0.1133	12
2025	Nitrate	Boundary	Bottom	0.2538	9
2025	Nitrate	Boundary	Surface	0.3197	9
2025	Nitrate	Farm	Bottom	0.6544	9
2025	Nitrate	Farm	Surface	0.7455	9
2025	Nitrate	Sheltered	Bottom	0.0822	12
2025	Nitrate	Sheltered	Surface	0.0406	12
2025	Nitrite	Boundary	Bottom	0.1332	9
2025	Nitrite	Boundary	Surface	0.2038	9
2025	Nitrite	Farm	Bottom	0.4296	9
2025	Nitrite	Farm	Surface	0.0180	9
2025	Nitrite	Sheltered	Bottom	0.2113	12
2025	Nitrite	Sheltered	Surface	0.2648	12
2025	ODO % SAT	Boundary	Bottom	0.2231	9
2025	ODO % SAT	Boundary	Surface	0.5628	9
2025	ODO % SAT	Farm	Bottom	0.0958	9
2025	ODO % SAT	Farm	Surface	0.0828	9
2025	ODO % SAT	Sheltered	Bottom	0.7986	12
2025	ODO % SAT	Sheltered	Surface	0.3099	12
2025	ODO MG/L	Boundary	Bottom	0.0263	9
2025	ODO MG/L	Boundary	Surface	0.0073	9
2025	ODO MG/L	Farm	Bottom	0.1474	9
2025	ODO MG/L	Farm	Surface	0.0707	9

Year	Parameter	Group	Depth	P-value	n
2025	ODO MG/L	Sheltered	Bottom	0.1993	12
2025	ODO MG/L	Sheltered	Surface	0.0996	12
2025	PH	Boundary	Bottom	0.0006	9
2025	PH	Boundary	Surface	0.0006	9
2025	PH	Farm	Bottom	0.0003	9
2025	PH	Farm	Surface	0.0003	9
2025	PH	Sheltered	Bottom	0.0002	12
2025	PH	Sheltered	Surface	0.0002	12
2025	SAL PPT	Boundary	Bottom	0.2812	9
2025	SAL PPT	Boundary	Surface	0.4577	9
2025	SAL PPT	Farm	Bottom	0.0015	9
2025	SAL PPT	Farm	Surface	0.0004	9
2025	SAL PPT	Sheltered	Bottom	0.0042	12
2025	SAL PPT	Sheltered	Surface	0.0035	12
2025	Si	Boundary	Bottom	0.0127	9
2025	Si	Boundary	Surface	0.0157	9
2025	Si	Farm	Bottom	0.0103	9
2025	Si	Farm	Surface	0.0262	9
2025	Si	Sheltered	Bottom	0.0002	12
2025	Si	Sheltered	Surface	0.0148	12
2025	Sulfate	Boundary	Bottom	0.9437	9
2025	Sulfate	Boundary	Surface	0.2844	9
2025	Sulfate	Farm	Bottom	0.8129	9
2025	Sulfate	Farm	Surface	0.2346	9
2025	Sulfate	Sheltered	Bottom	0.0701	12
2025	Sulfate	Sheltered	Surface	0.7429	12
2025	TAN	Boundary	Bottom	0.0000	9
2025	TAN	Boundary	Surface	*	9
2025	TAN	Farm	Bottom	0.0000	9
2025	TAN	Farm	Surface	*	9
2025	TAN	Sheltered	Bottom	*	12
2025	TAN	Sheltered	Surface	*	12
2025	TEMP °C	Boundary	Bottom	0.1255	9
2025	TEMP °C	Boundary	Surface	0.1606	9
2025	TEMP °C	Farm	Bottom	0.4746	9

Year	Parameter	Group	Depth	P-value	n
2025	TEMP °C	Farm	Surface	0.1330	9
2025	TEMP °C	Sheltered	Bottom	0.1358	12
2025	TEMP °C	Sheltered	Surface	0.1361	12
2025	Total Dissolved Kjeldahl Nitrogen	Boundary	Bottom	0.2304	6
2025	Total Dissolved Kjeldahl Nitrogen	Boundary	Surface	0.3951	6
2025	Total Dissolved Kjeldahl Nitrogen	Farm	Bottom	0.7939	6
2025	Total Dissolved Kjeldahl Nitrogen	Farm	Surface	0.0666	6
2025	Total Dissolved Kjeldahl Nitrogen	Sheltered	Bottom	0.1806	8
2025	Total Dissolved Kjeldahl Nitrogen	Sheltered	Surface	0.7270	8
2025	Total Dissolved Nitrogen	Boundary	Bottom	0.5929	9
2025	Total Dissolved Nitrogen	Boundary	Surface	0.8237	9
2025	Total Dissolved Nitrogen	Farm	Bottom	0.0017	9
2025	Total Dissolved Nitrogen	Farm	Surface	0.1823	9
2025	Total Dissolved Nitrogen	Sheltered	Bottom	0.6223	12
2025	Total Dissolved Nitrogen	Sheltered	Surface	0.0964	12
2025	Total Kjeldahl Nitrogen	Boundary	Bottom	0.0107	6
2025	Total Kjeldahl Nitrogen	Boundary	Surface	0.0107	6
2025	Total Kjeldahl Nitrogen	Farm	Bottom	0.7665	6
2025	Total Kjeldahl Nitrogen	Farm	Surface	0.6899	6
2025	Total Kjeldahl Nitrogen	Sheltered	Bottom	0.2308	8
2025	Total Kjeldahl Nitrogen	Sheltered	Surface	0.7717	8
2025	Total Nitrogen	Boundary	Bottom	0.0108	6
2025	Total Nitrogen	Boundary	Surface	0.0052	6
2025	Total Nitrogen	Farm	Bottom	0.7630	6
2025	Total Nitrogen	Farm	Surface	0.4213	6
2025	Total Nitrogen	Sheltered	Bottom	0.0559	8
2025	Total Nitrogen	Sheltered	Surface	0.9351	8
2025	Total Oxidised Nitrogen	Boundary	Bottom	0.1775	9
2025	Total Oxidised Nitrogen	Boundary	Surface	0.2767	9
2025	Total Oxidised Nitrogen	Farm	Bottom	0.4577	9
2025	Total Oxidised Nitrogen	Farm	Surface	0.7012	9
2025	Total Oxidised Nitrogen	Sheltered	Bottom	0.2259	12
2025	Total Oxidised Nitrogen	Sheltered	Surface	0.1037	12
2025	Total Phosphorus	Boundary	Bottom	0.0402	9
2025	Total Phosphorus	Boundary	Surface	0.5036	9

Year	Parameter	Group	Depth	P-value	n
2025	Total Phosphorus	Farm	Bottom	0.0125	9
2025	Total Phosphorus	Farm	Surface	0.2535	9
2025	Total Phosphorus	Sheltered	Bottom	0.0008	12
2025	Total Phosphorus	Sheltered	Surface	0.0093	12
2025	TURBIDITY FNU	Boundary	Bottom	0.0003	9
2025	TURBIDITY FNU	Boundary	Surface	0.0696	9
2025	TURBIDITY FNU	Farm	Bottom	0.6714	9
2025	TURBIDITY FNU	Farm	Surface	0.3022	9
2025	TURBIDITY FNU	Sheltered	Bottom	0.2992	12
2025	TURBIDITY FNU	Sheltered	Surface	0.1092	12

* All values were the same (laboratory level of reporting) so p-values could not be calculated.

B.2 Differences between surface and bottom water

Wilcoxon rank sum tests (similar to a student's t-test) were used for each group for data collected in 2025 to determine whether there were statistically significant differences between surface and bottom water measurements. A p-value <0.05 indicates a statistically significant difference (for which there were none).

Table B-2: Summary from Wilcoxon rank sum tests. A p-value >0.05 indicates that data are normally distributed.

Group	Parameter	P-value	N Surface	N Bottom
Boundary	Chl-a	1.000	9	9
Boundary	DIN	0.627	9	9
Boundary	DRP	0.528	9	9
Boundary	Nitrate	0.596	9	9
Boundary	Nitrite	1.000	9	9
Boundary	ODO % SAT	0.190	9	9
Boundary	ODO MG/L	0.136	9	9
Boundary	PH	0.860	9	9
Boundary	SAL PPT	0.730	9	9
Boundary	Si	0.594	9	9
Boundary	Sulfate	0.723	9	9
Boundary	TAN	0.374	9	9
Boundary	TEMP °C	1.000	9	9
Boundary	Total Dissolved Kjeldahl Nitrogen	0.873	6	6
Boundary	Total Dissolved Nitrogen	0.825	9	9
Boundary	Total Kjeldahl Nitrogen	0.228	6	6
Boundary	Total Nitrogen	0.229	6	6
Boundary	Total Oxidised Nitrogen	0.627	9	9
Boundary	Total Phosphorus	1.000	9	9
Boundary	TURBIDITY FNU	0.387	9	9
Farm	Chl-a	0.963	9	9
Farm	DIN	0.627	9	9
Farm	DRP	0.755	9	9
Farm	Nitrate	0.757	9	9
Farm	Nitrite	0.929	9	9
Farm	ODO % SAT	0.860	9	9
Farm	ODO MG/L	1.000	9	9
Farm	PH	0.860	9	9
Farm	SAL PPT	0.860	9	9

Group	Parameter	P-value	N Surface	N Bottom
Farm	Si	1.000	9	9
Farm	Sulfate	0.376	9	9
Farm	TAN	0.169	9	9
Farm	TEMP °C	0.930	9	9
Farm	Total Dissolved Kjeldahl Nitrogen	1.000	6	6
Farm	Total Dissolved Nitrogen	0.565	9	9
Farm	Total Kjeldahl Nitrogen	0.469	6	6
Farm	Total Nitrogen	0.294	6	6
Farm	Total Oxidised Nitrogen	0.757	9	9
Farm	Total Phosphorus	0.524	9	9
Farm	TURBIDITY FNU	0.185	9	9
Sheltered	Chl-a	0.882	12	12
Sheltered	DIN	0.665	12	12
Sheltered	DRP	0.704	12	12
Sheltered	Nitrate	0.686	12	12
Sheltered	Nitrite	0.640	12	12
Sheltered	ODO % SAT	0.143	12	12
Sheltered	ODO MG/L	0.078	12	12
Sheltered	PH	0.977	12	12
Sheltered	SAL PPT	0.551	12	12
Sheltered	Si	0.498	12	12
Sheltered	Sulfate	0.523	12	12
Sheltered	TAN	*	12	12
Sheltered	TEMP °C	0.755	12	12
Sheltered	Total Dissolved Kjeldahl Nitrogen	0.430	8	8
Sheltered	Total Dissolved Nitrogen	0.064	12	12
Sheltered	Total Kjeldahl Nitrogen	1.000	8	8
Sheltered	Total Nitrogen	0.752	8	8
Sheltered	Total Oxidised Nitrogen	0.665	12	12
Sheltered	Total Phosphorus	0.382	12	12
Sheltered	TURBIDITY FNU	0.101	12	12

* All values were the same (laboratory level of reporting) so p-values could not be calculated.

B.3 Differences among groups

Kruskal-Wallis rank sum tests (similar to an ANOVA) were used for each group for data collected in 2025 to determine whether there were statistically significant differences among groups (Farm, Sheltered, Boundary). A p-value <0.05 indicates a statistically significant difference.

Table B-3: Summary from Kruskal-Wallis rank sum tests. A p-value >0.05 indicates that data are normally distributed (shaded in green).

Parameter	P-value
Chl-a	0.802
DIN	0.153
DRP	0.585
Nitrate	0.173
Nitrite	0.600
Si	0.378
Sulfate	0.152
TAN	0.277
Total Dissolved Kjeldahl Nitrogen	0.332
Total Dissolved Nitrogen	0.392
Total Kjeldahl Nitrogen	0.068
Total Nitrogen	0.052
Total Oxidised Nitrogen	0.149
Total Phosphorus	0.494
ODO % SAT	0.025
ODO MG/L	0.046
PH	0.481
SAL PPT	0.977
TEMP °C	0.839
TURBIDITY FNU	0.848

B.4 Differences between sampling years

Wilcoxon rank sum tests (similar to a student's t-test) were used for each parameter to determine whether there were statistically significant differences between data collected in 2018/19 and 2025. A p-value <0.05 indicates a statistically significant difference.

Table B-4: Summary from Wilcoxon rank sum tests. A p-value >0.05 indicates that data are normally distributed (shaded in green).

Parameter	P-value	N 2018	N 2025	Median 2018	Median 2025
Chl-a	0.2404	12	18	0.881	0.5
DIN	0.0004	17	18	38.7	25.3
DRP	0.0000	17	18	10.9	6
Nitrate	0.0004	17	18	33.7	19.8
Nitrite	0.3657	17	18	2	2
Si	0.0001	17	18	90	1535
Sulfate	—	0	18		2680
TAN	0.0001	17	18	4.1	2.5
Total Dissolved Kjeldahl Nitrogen	—	0	12		285
Total Dissolved Nitrogen	0.0001	17	18	106	340
Total Kjeldahl Nitrogen	—	0	12		400
Total Nitrogen	0.0001	18	12	151.5	425
Total Oxidised Nitrogen	0.0005	17	18	35.7	21.55
Total Phosphorus	0.9745	18	18	12.5	14

Appendix C Hydrodynamic Modelling Report

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

6 November 2025

Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa

Report One – Hydrodynamical Model

Prepared by:	Zyngfogel, McComb and Weppe
Reviewed by:	McComb
Date:	8 October 2025
Revision:	Rev1 - approved for release
Reference No.:	P25-05-01

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1. INTRODUCTION

Oceanum Ltd with support from Calypso Science Ltd have been commissioned by SLR Consulting Ltd to undertake oceanographic modelling in Te Ara a Kiwa. The scope of this work is to inform a broader assessment of effects for the proposed Hananui Aquaculture Project (HAP)).

The purpose of this report is to document the establishment and validation of a hydrodynamical model of Te Ara a Kiwa, including the proposed salmon farming area. Specifically:

- Establish and calibrate a 3D hydrodynamic model of the Te Ara a Kiwa region, with suitably high spatial resolution in the vicinity of the proposed farm. This exercise will build upon previous modelling of the area but use oceanographic measurements from the farm to ensure the model is tuned to best replicate the observed flow regime and the vertical structure of the water column.

- Apply that model to hindcast an historical period of one decade, creating an hour-by-hour digital twin of the 3D flows due to the combined effects of tides, local and regional winds, and the influence of larger scale oceanic currents on the local dynamics.

- Analyse this hindcast data at the proposed farm site to characterise the flow regime at monthly, seasonal and interannual scales.

The structure of this report is as follows. A description of the numerical modelling methods is provided in Section 2. Results of the hydrodynamical model validation are presented in Section 3, along with a summary of the assumptions and limitations. In Section 4, the 10-year hindcast is used to characterise the flow regime with summary statistics. Conclusions are presented in Section 5, and the references cited are listed in Section 6.

2. HYDRODYNAMICAL MODELLING METHODOLOGY

2.1. Model description

The Semi Implicit Cross-scale Hydroscience Integrated System Model (SCHISM) was used for this project. SCHISM is a robust, open-source, community-supported modelling system based on unstructured grids, suitable for 2D or 3D baroclinic/barotropic circulation from ocean to coastal regions. A detailed description of the SCHISM model can be found in the original publication by Zhang and Baptista (2008). SCHISM uses a LSC^2 in the vertical dimension (Zhang et al., 2015) which enhances accuracy nearbed layer. It is based on a localized sigma coordinate resulting in a better definition of the seafloor and reduced the pressure gradient errors. This type of grid has been especially used during studies over steep slopes (Wu et al. 2023, Zheng et al., 2024). SCHISM utilizes an unstructured grid, which allows implementation of a single domain that efficiently captures the relevant spatial scales across the study area.

2.2. Domain

The model domain covers all Foveaux Strait (Figure 2.1), with mesh size of <30 m in the farm footprint, relaxing to 800-900 m at the deep-water boundaries. The bathymetric data used to generate this mesh was sourced from GEBCO 2024, LINZ (digitised chart sounding points and chart contours) and client provided MBES (Figure 2.2). Note, while the model mesh size in the farm area is suitable to resolve the local hydrodynamics, it is not intended to fully resolve the dynamics at pen scales.

2.3. Vertical discretisation and mixing

The model was established in 3D barotropic mode, recognising that the water column here is typically well mixed (Vincent et al., 1991). Vertical discretisation involved 20 sigma layers, with higher resolution at the surface and seabed, with an example provided in Figure 2.2.

Turbulence in the model is represented using a two-equation closure approach based on the Generic Length Scale (GLS) framework of Umlauf and Burchard (2003). The model employed the closure scheme of Mellor-Yamada and the Kantha and Clayson stability function. The mixing length scale constant was set to 0.1, with minimum and maximum turbulent diffusivity values constrained to $1 \times 10^{-7}\ m^2\ s^{-1}$ and $1\ m^2\ s^{-1}$, respectively.

Imposed onto the model mesh is a variable bed friction scheme, as presented in Figure 2.3. Here, drag coefficients ranging from 0.0015 (low drag muddy seabed) to 0.003 (high drag rocky seabed) per the consensus published in the scientific literature. The seabed characterisation used to create this scheme was supplied by the client.

Following the recommendation in Zhang et al. (2015), and the SCHISM user manual (SCHISM Development Team, 2023), the model was set using the configuration design for non-eddying regime for coastal modelling (i.e. a Shapiro filter without explicit horizontal viscosity). Since this configuration showed good validation, it was adopted in this study.

2.4. Boundary conditions

The Te Ara a Kiwa model domain is nested within a national SCHISM hindcast that is described by Oceanum (2022). That model uses a 3D boundary from Copernicus Marine Services, with current residual velocities, sea surface elevation, temperature and salinity sourced from GLORYS, a global 1/12-degree reanalysis product. Atmospheric forcing data, including 10 m wind speed, mean sea-level pressure, precipitation, temperature, humidity and solar radiation were sourced from the ERA5 reanalysis. Tidal elevations and depth-averaged currents are prescribed from the Oceanum 400 m resolution tide database. Here, the tidal constituents have been downscaled from TPXO9 global tidal solution using the OTIS model of barotropic ocean tides (Egbert and Erofeeva, 2002).

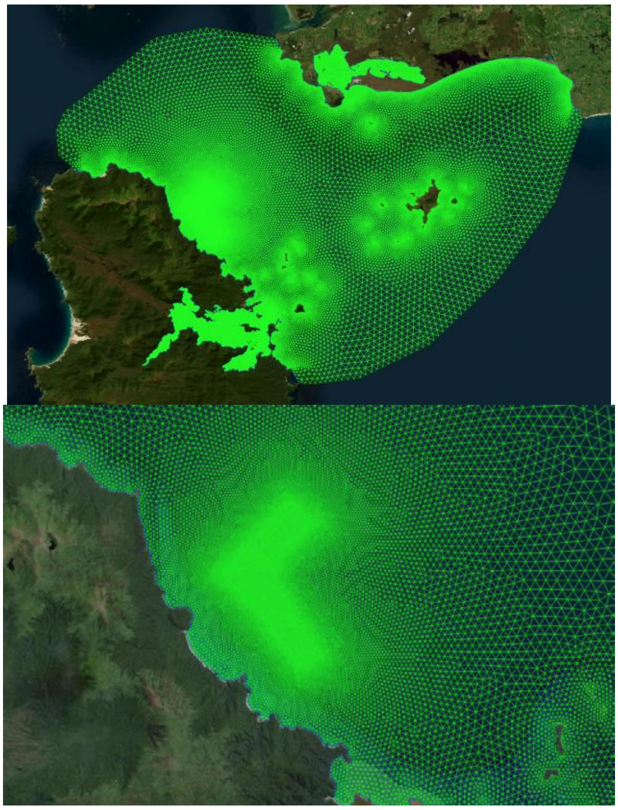

Figure 2.1 Extent of the SCHISM domain (left) showing the triangular mesh and a zoom in for the farm area (right).

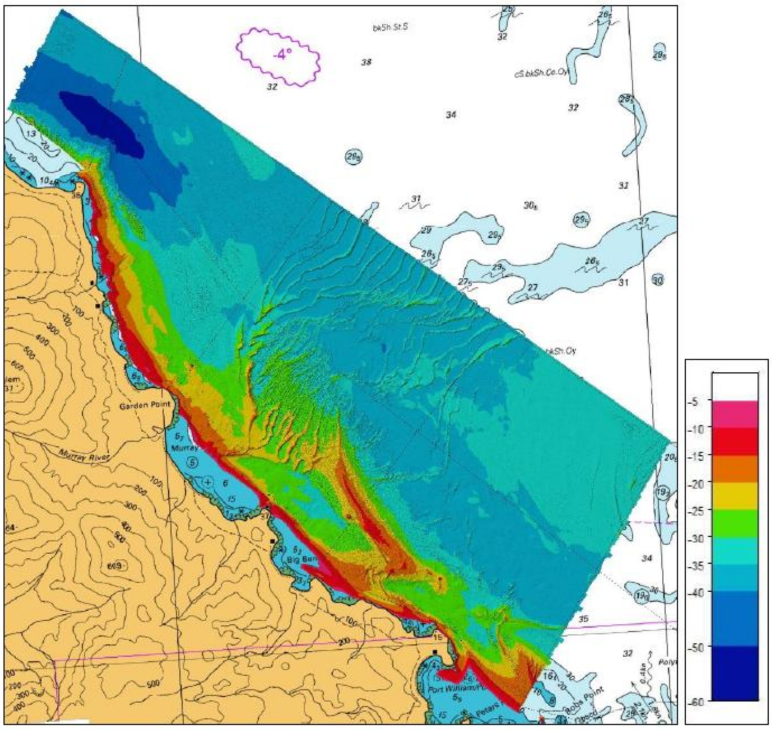

Figure 2.2 Client-supplied MBES coverage and bathymetry map.

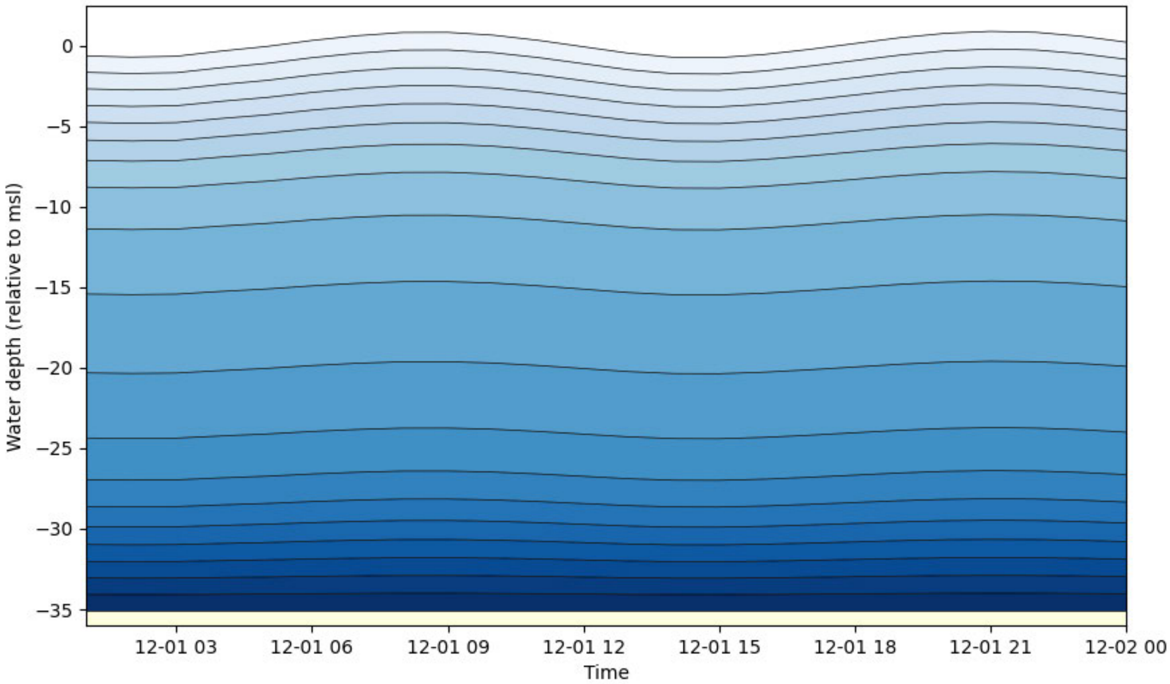

Figure 2.3 Example of the vertical discretisation within the model.

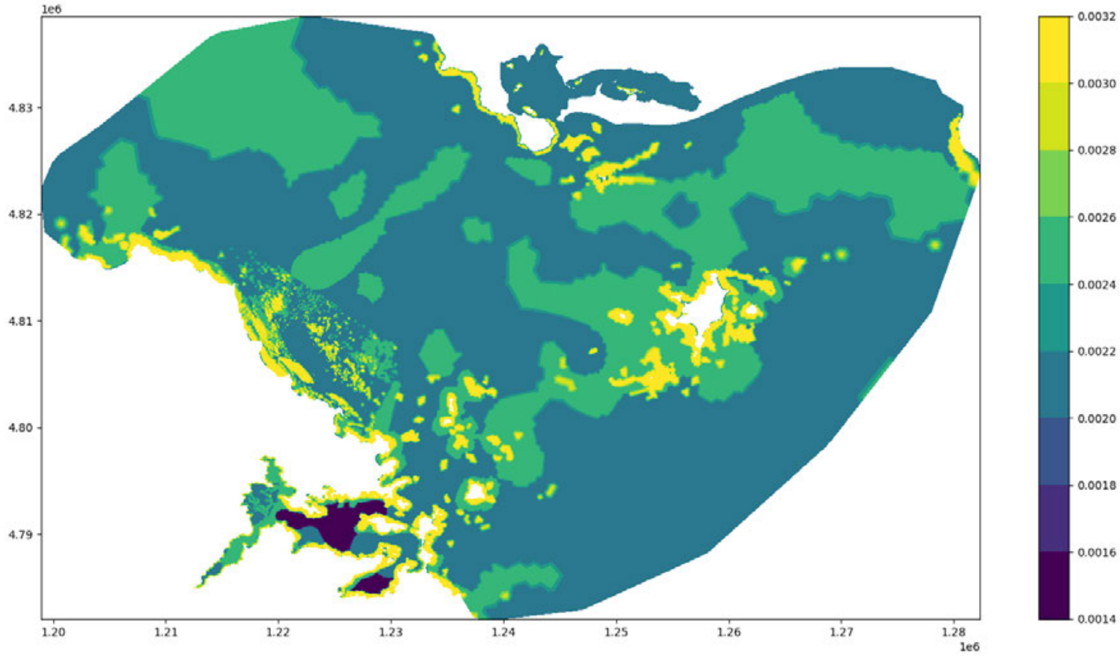

Figure 2.4 Variable drag coefficients used in the SCHISM domain.

2.5. Summary of model settings

Table 2.1 Summary of model settings.

Mode	3D barotropic
Layers	20 sigma layers
Hydrodynamic dt [s]	100 s
Minimum water depth [m]	0.1 m
Friction	Drag coefficient varying (0.0015 - 0.0030)
Hydrodynamic boundary	3D NZ SCHISM domain (tide+residual)
Atmospheric boundary	ERA5 reanalysis

3. MODEL CALIBRATION

An extensive series of model tests were performed to ensure the most appropriate settings and boundary conditions were applied. To achieve this, modelled currents and water levels were directly compared with the available measurements within the model domain.

Quantitative assessment of the agreement between model and observations was made using the standard metrics of accuracy (Mean absolute error, MAE; Root Mean Square Error, RMSE; Mean relative absolute error, MRAE, Bias and Scatter Index, SI). Additionally, time series data plots and parameter distributions as Quantile-Quantiles (QQ) are presented to demonstrate the degree of agreement (or otherwise) between modelled and measured data.

This section describes the available measured data and presents the final results of the validation tests.

3.1. Measured data

Historical oceanographic data were available near the proposed farm, as shown on Figure 3.1 and detailed in Table 3.1. ADCP were deployed at three sites (labelled P1, P2 and P3) to measure the current velocity profiles as 5-minute means at hourly intervals at 1 m depth increments. Site P1 and P3 were bottom mounted instruments while P2 was downward facing on a wave buoy. Previous QC checks had confirmed that P1 and P3 data were reliable, while the data from the buoy (P2) was not. Accordingly, only P1 and P3 were used in the validation tests.

A further QC check was performed on the P1 and P3 using the instrument pressure sensors. A time series plot of depth variation (Figure 3.2) indicates that P1 was not stationary during the deployment as two abrupt shifts to ~0.4 m deeper are evident. While not appearing to compromise the velocity data, it is likely that the instrument moved horizontally over a tidal cycle. The consequence of this is a potential positional error when making the comparison with the model.

The ADCP profiles were post-processed to allow definition within specific layers as follows:

- Surface (4-8 m below sea surface)
- Mid water (11-18 m below sea surface)
- Nearbed (2-3 m above seabed)
- P3 depth-averaged (8-33 m below sea surface)
- P1 depth-averaged (4-22 m below sea surface)

Table 3.1 Location and duration of oceanographic measurements.

Site	Sensor	Position (WGS84)	Depth (m)	Start	Stop
P1	Sentinel	-46.7567, 168.0668	37	03/12/2018	16/01/2019
P2	RDI	-46.7703, 168.0614	32	02/12/2018	03/01/2019
P3	Workhorse	-46.7884, 168.0538	25	03/12/2018	16/01/2019

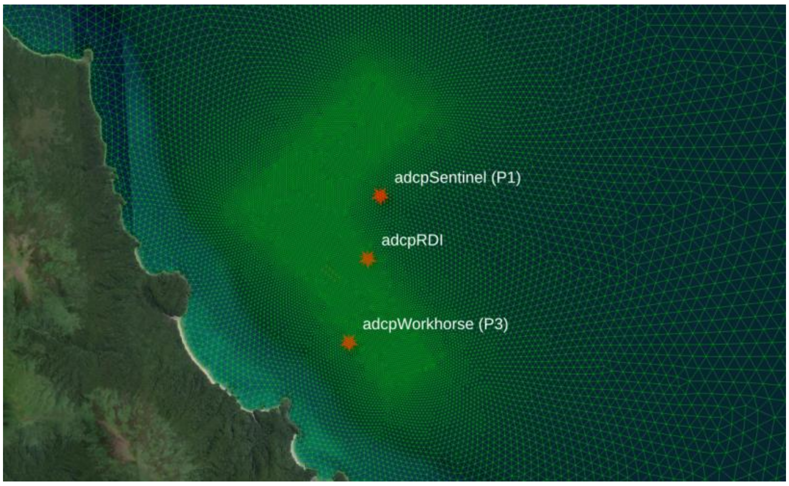

Figure 3.1 Map showing the model grid with the locations of oceanographic instrumentation.

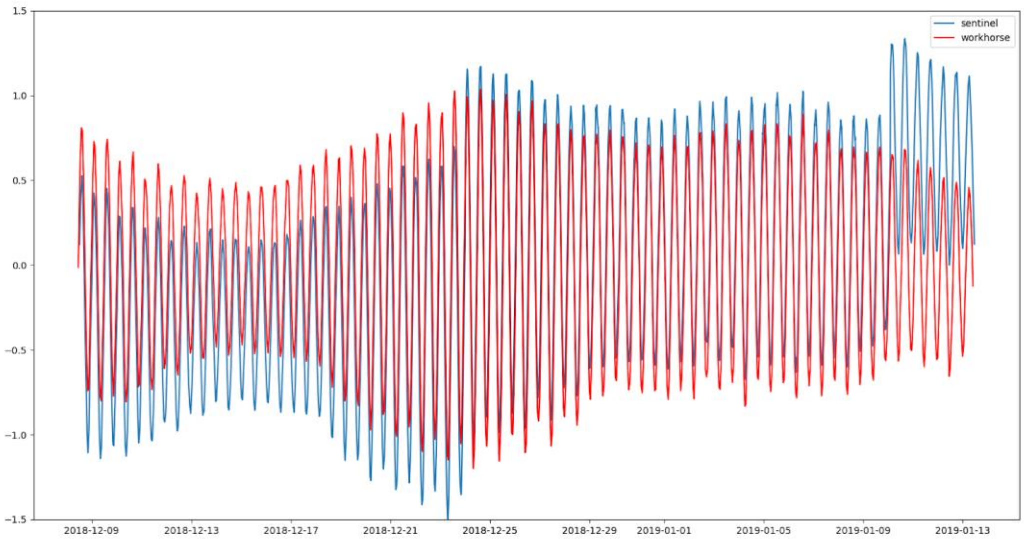

Figure 3.2 Time series plot showing the variation in depth as measured by pressure sensors on the ADCPs at P1 (sentinel, blue) and P3 (workhorse, red).

3.2. Results

A time series comparison of measured and modelled elevations at the Bluff Harbour tide gauge and site P3 is presented in Figure 3.3. For Bluff, the agreement between model and tide gauge is near perfect, while at P3 there are very slight differences. In Figure 3.4, the time series of tidal elevations is provided, showing excellent agreement at Bluff and acceptable agreement at P3. Notably, the measured tide at P3 is derived from a short record and therefore the harmonic analysis won't include all constituents or fully resolve the phase. The ADCP is sampling at a higher er

Time series and QQ comparisons are provided for sites P3 and P1 for the surface, mid-water and nearbed levels in Figures 3.5 - 3.10. Included here are results for the total, tidal and residual (i.e. non-tidal) flows. Metrics of accuracy for speed are given in Table 3.2. These results indicate the main features of the flow regime are being replicated by the model, without significant bias or evidence of any systematic under- or over-prediction. While dominated by tides, the regime also exhibits residuals at about 10% of the tidal magnitudes. While the speed distribution of these residuals is being adequately replicated, the event coherence in the time domain is poor.

The mean profile for measured and modelled speeds is presented in Figure 3.11 for sites P1 and P3. At P3, the mean profiles are almost perfectly matched, while at P1 the slope is very similar but with a small bias of about 0.05 m/s throughout the water column.

For the consideration of directionality, Progressive Vector Diagrams are provided for sites P1 and P3 in Figure 2.12. This type of plot highlights small differences in direction, which is helpful to visualise differences between measured and modelled flow regimes for a tidally dominated environment.

Table 3.2 Standard metrics of accuracy for current speed (m/s).

	P1			**P3**		
	Surface	**Mid-water**	**Nearbed**	**Surface**	**Mid-water**	**Nearbed**
MAE	0.09	0.08	0.07	0.11	0.09	0.08
RMSE	0.04	0.03	0.00	0.04	0.01	0.04
MRAE	0.72	0.37	0.33	0.63	0.47	0.70
BIAS	0.04	0.03	0.00	0.04	0.01	0.04
SI	0.09	0.06	0.01	0.09	0.03	0.15

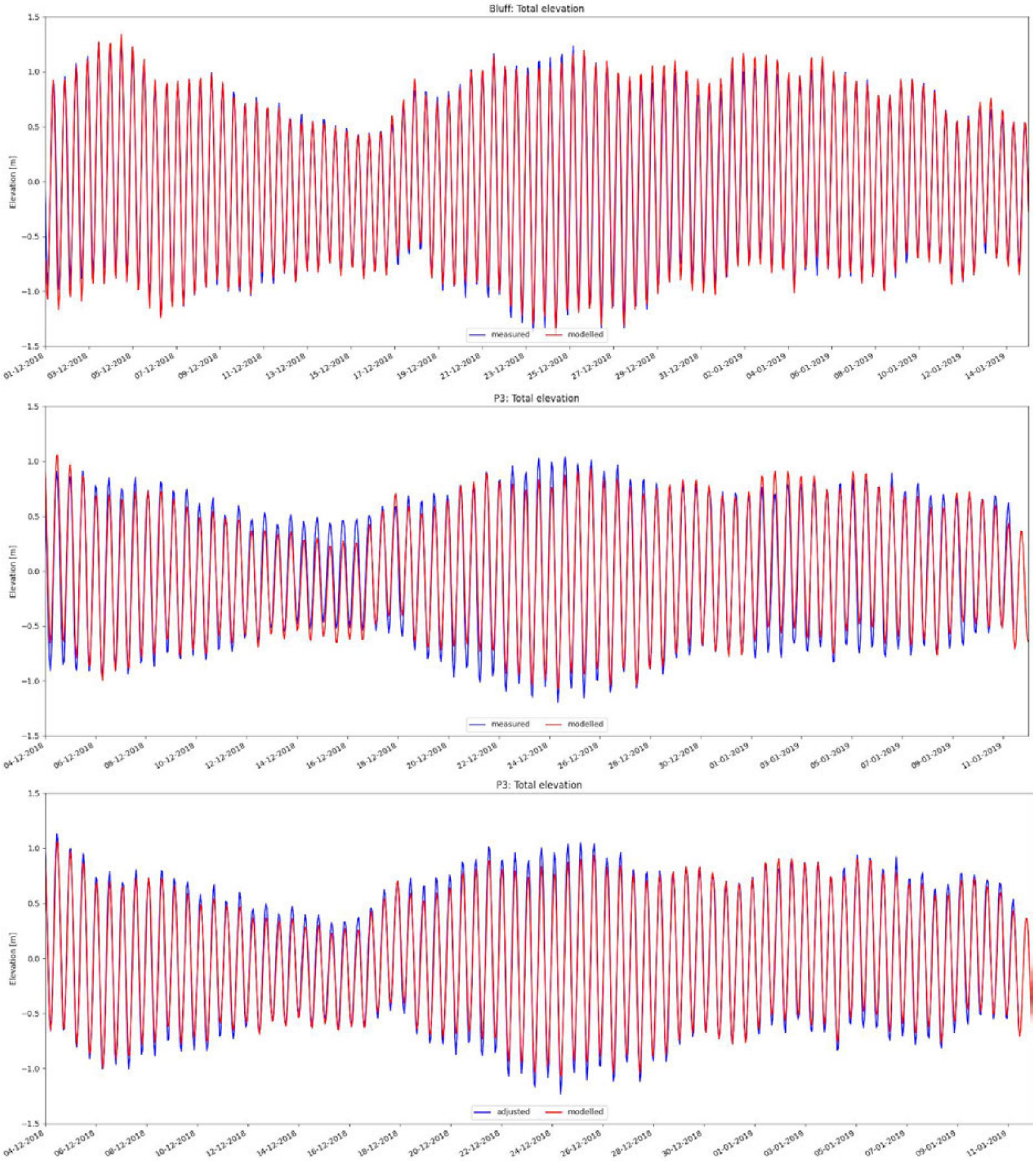

Figure 3.3 Time series of measured (blue) and modelled (red) total water level at Bluff Harbour (upper) and site P3 (middle). Site P3 observations are from a pressure sensor and therefore include atmospheric pressure, which means the storm surge is not resolved. The lower graph shows P3 adjusted for atmospheric pressure.

Figure 3.4 Time series of measured (blue) and modelled (red) tidal water level at Bluff Harbour (upper) and site P3 (lower). Note, the measured tides are derived from a short record and therefore don't include all constituents or fully resolve the phase.

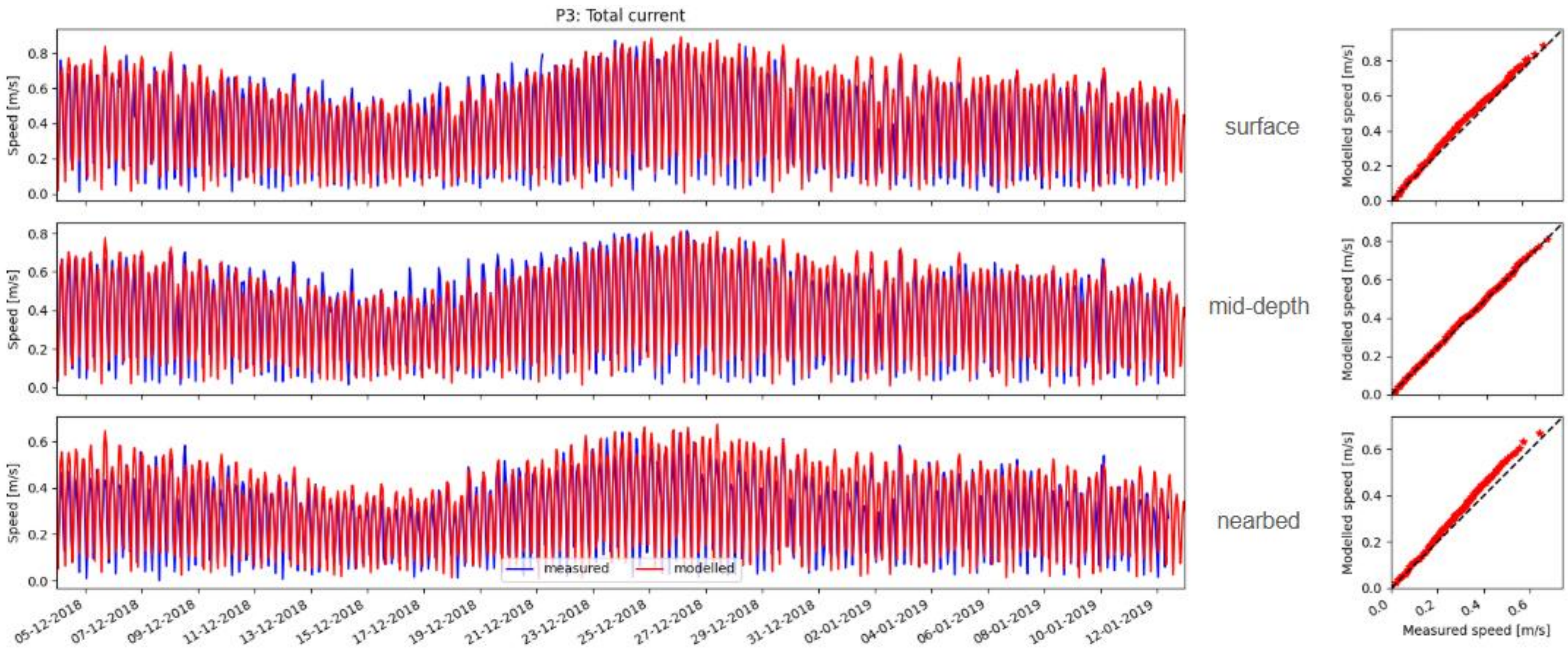

Figure 3.5 Time series of P3 measured (blue) and modelled (red) total current speeds (left) and the QQ of speed distributions (right).

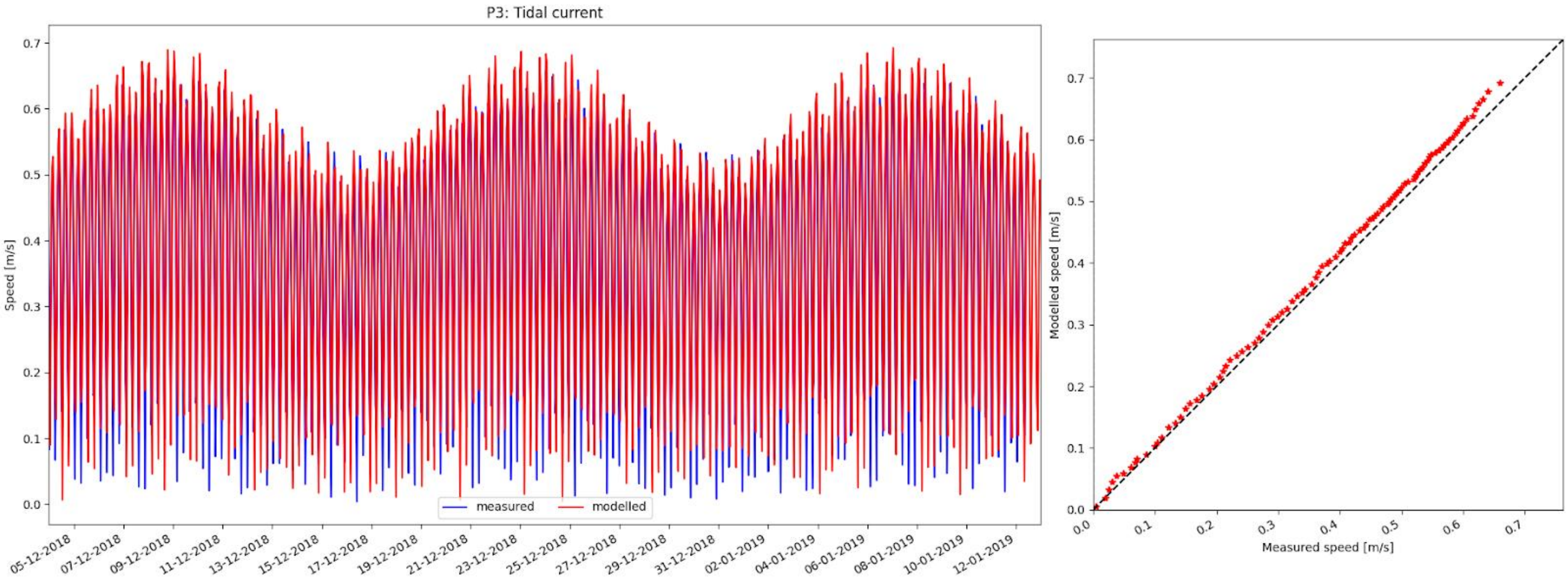

Figure 3.6 Time series of P3 measured (blue) and modelled (red) depth-average tidal current speeds (left) and the QQ of speed distributions (right). Note, the hourly model output is less frequent than the observations, so slack tide is sometimes not aligned in this plot.

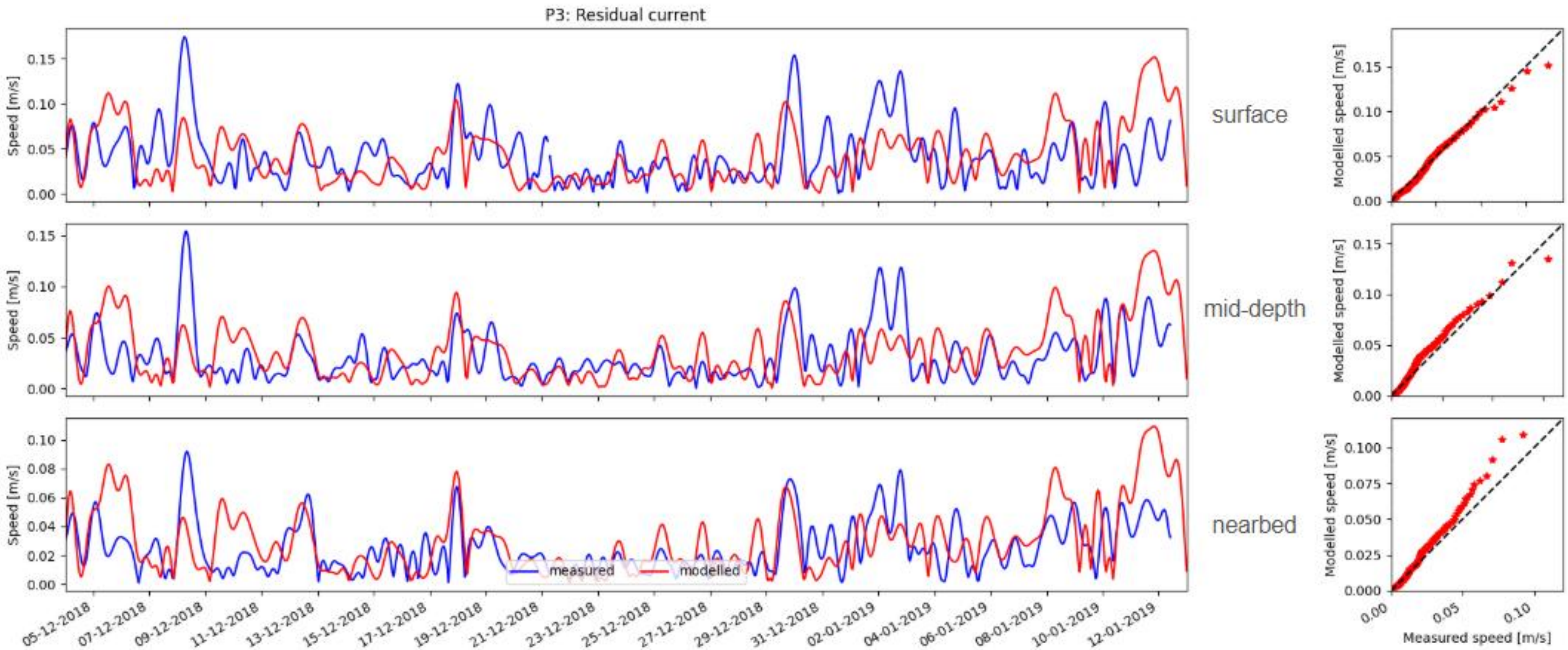

Figure 3.7 Time series of P3 measured (blue) and modelled (red) residual current speeds (left) and the QQ of speed distributions (right).

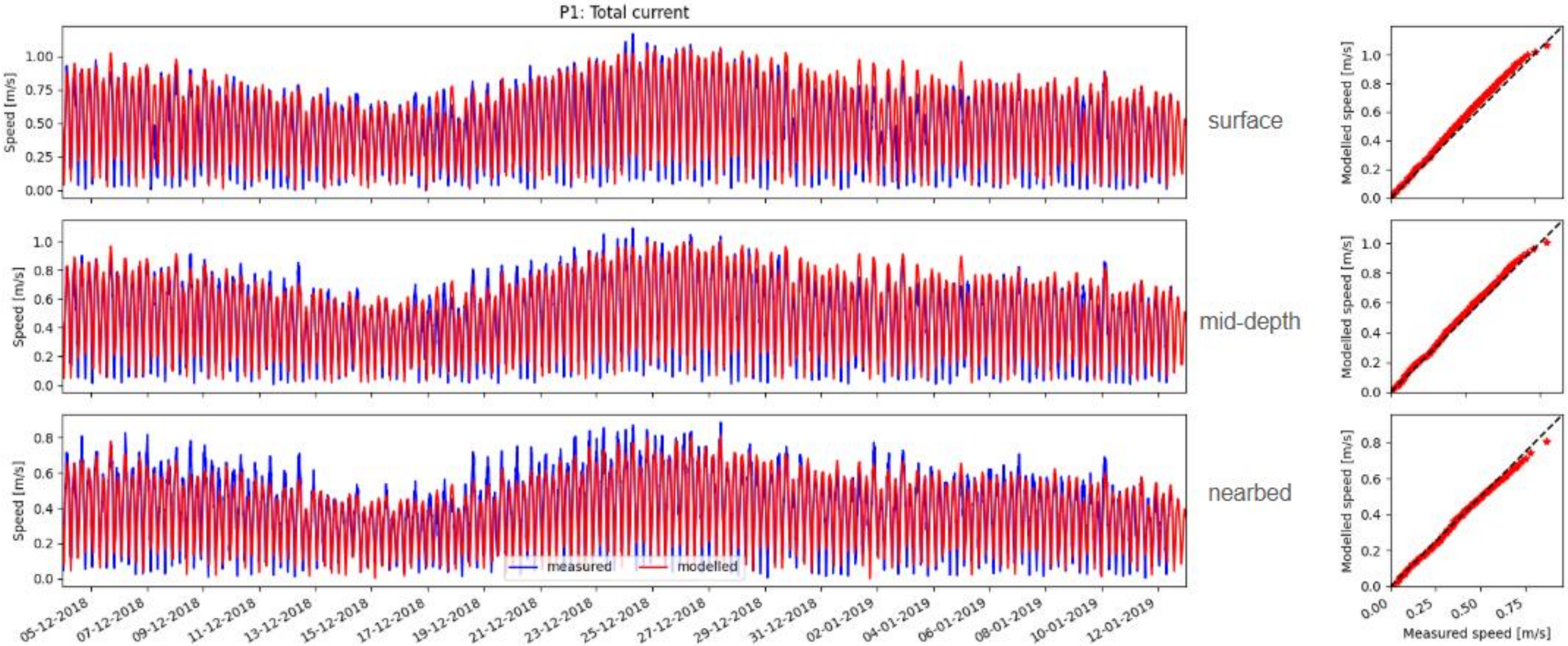

Figure 3.8 Time series of P1 measured (blue) and modelled (red) total current speeds (left) and the QQ of speed distributions (right).

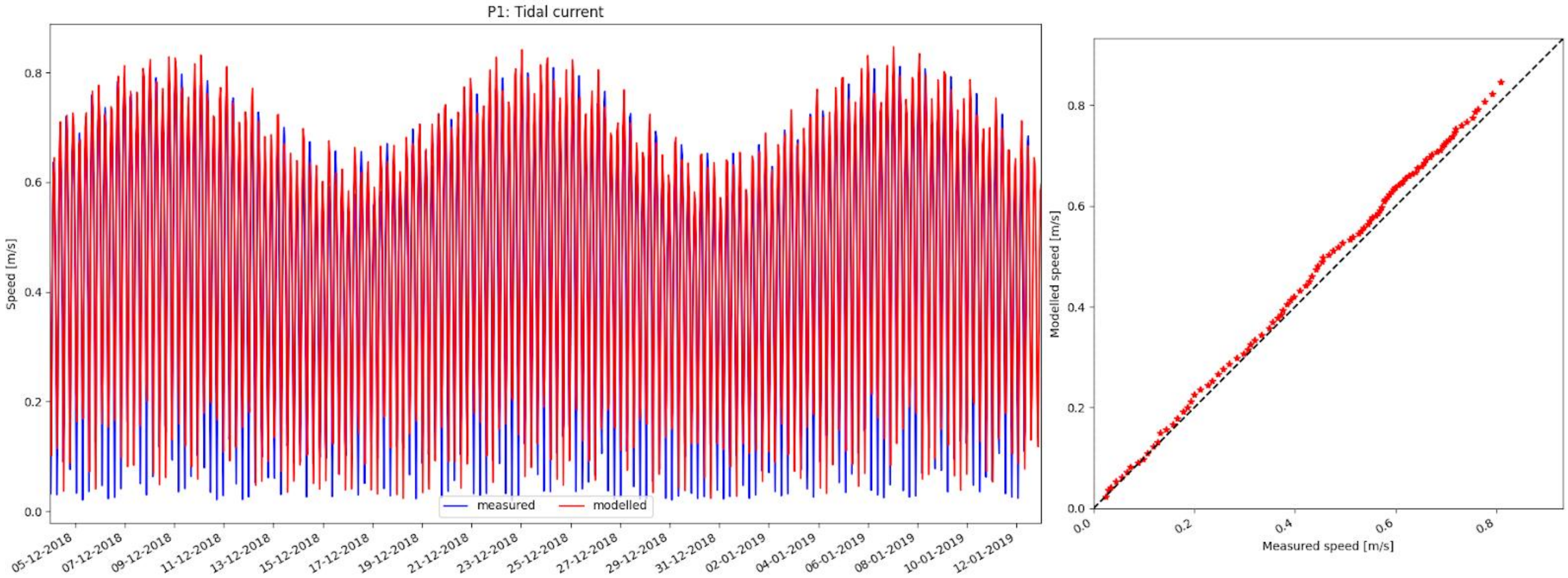

Figure 3.9 Time series of P1 measured (blue) and modelled (red) depth-average tidal current speeds (left) and the QQ of speed distributions (right). Note, the hourly model output is less frequent than the observations, so slack tide is sometimes not aligned in this plot.

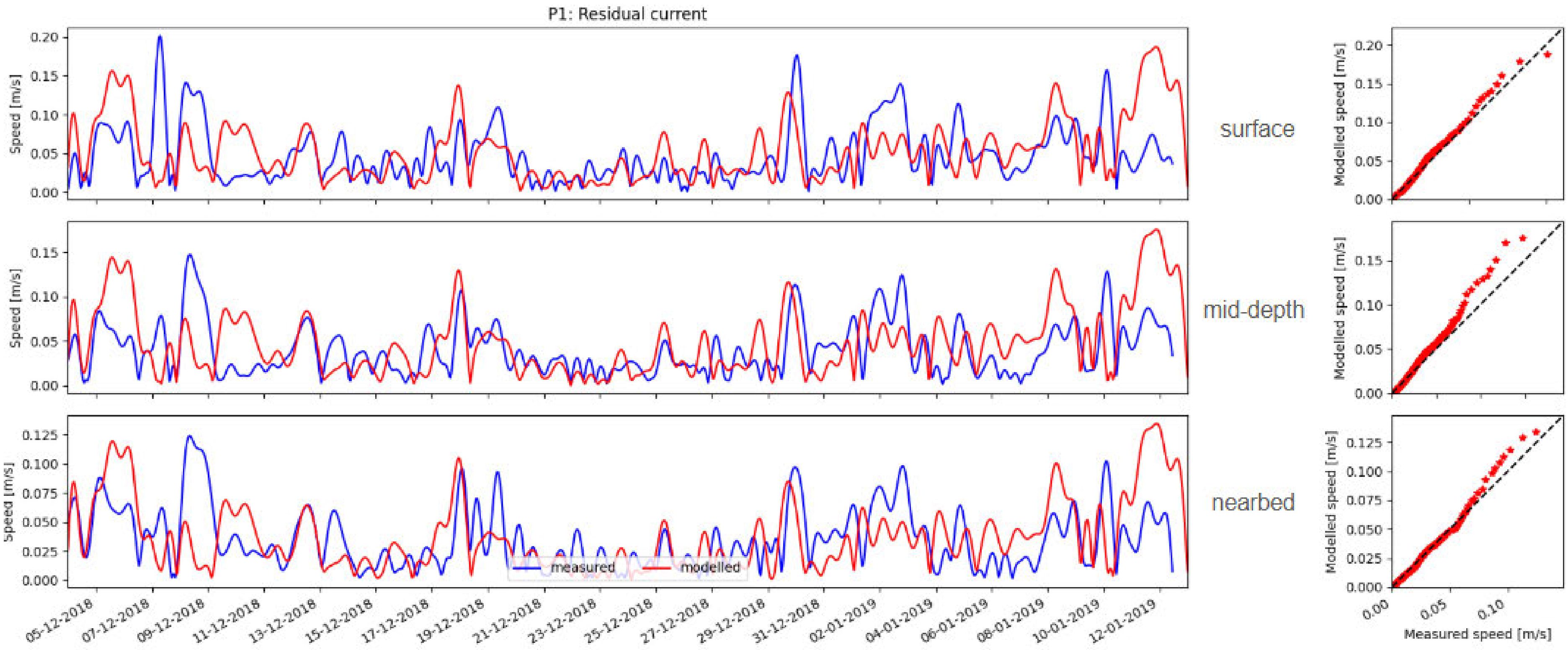

Figure 3.10 Time series of P1 measured (blue) and modelled (red) residual current speeds (left) and the QQ of speed distributions (right).

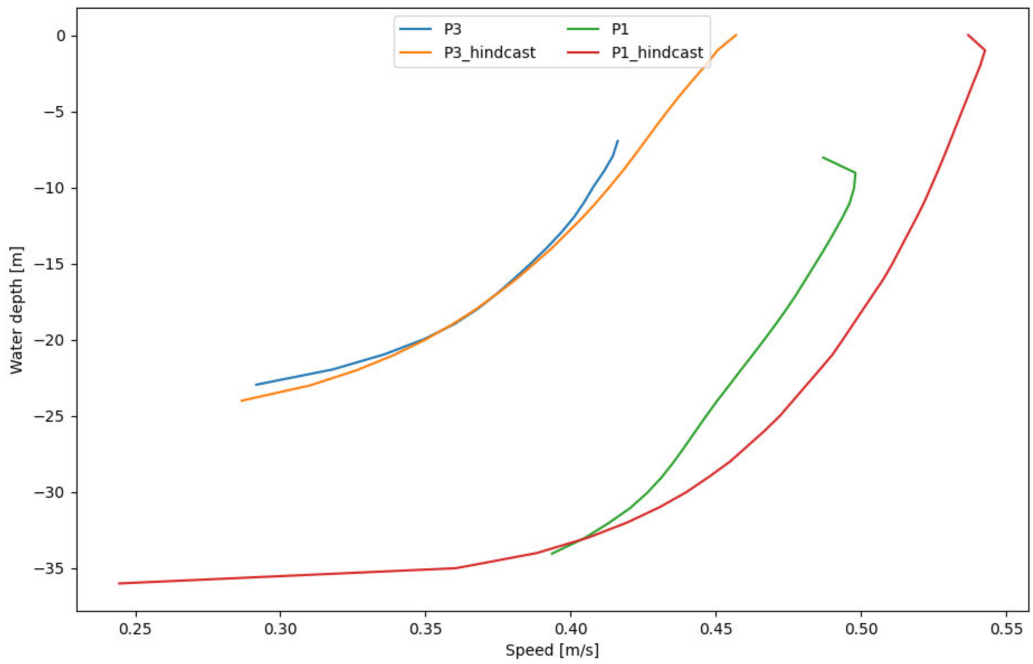

Figure 3.11 Mean speed profiles from the cotemporal measured and modelled data at sites P1 and P3.

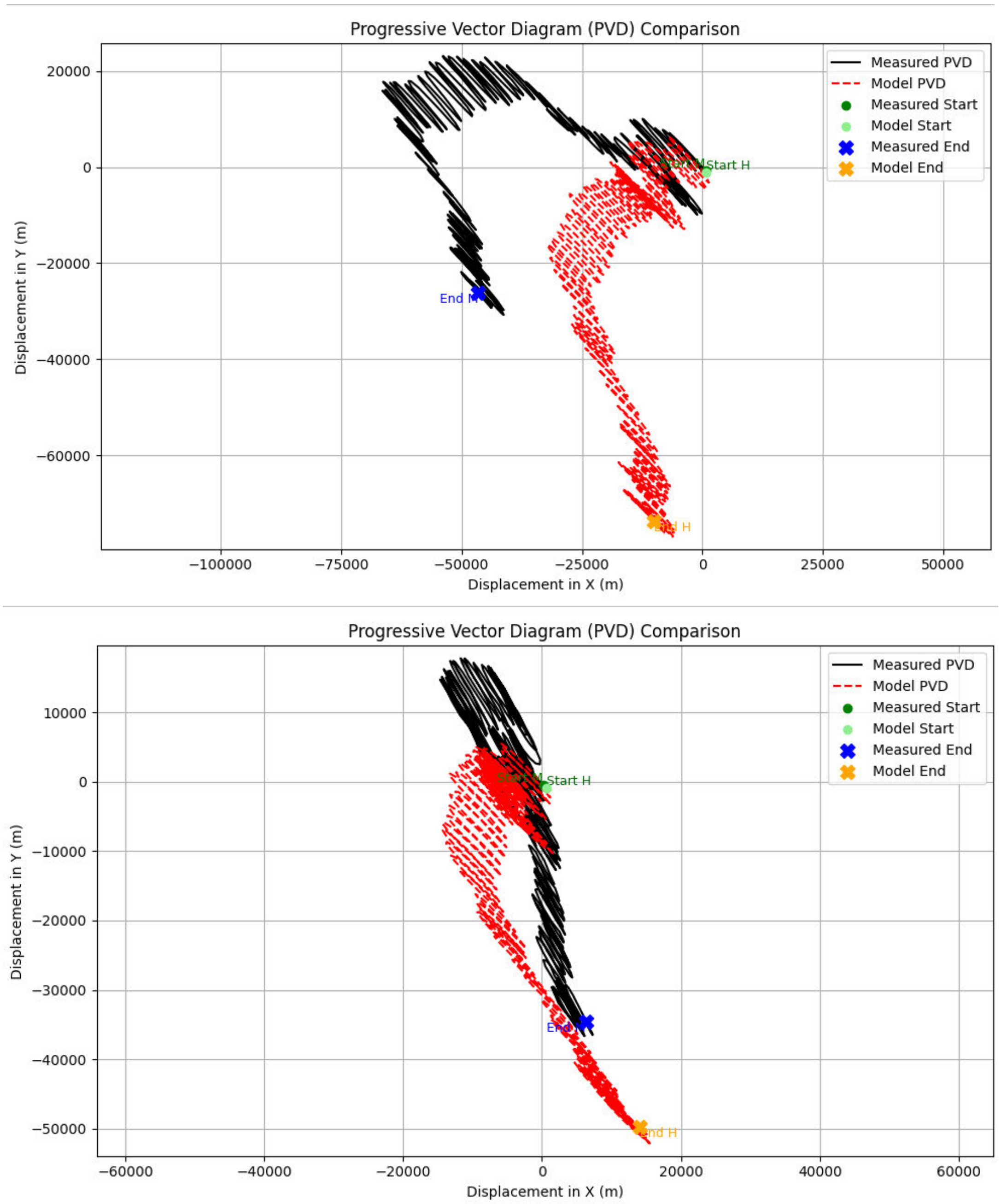

Figure 3.12 Progressive Vector Diagrams for depth-averaged total flow at P1 (upper) and P3 (lower). Measured is solid black, and modelled is dashed red.

3.3. Discussion

The validation results show the model is faithfully replicating the core hydrodynamical features at the farm site. The distributions of speed at three levels in the water column are reliably reproduced for both the tidal and non-tidal compliments of flow, and the modelled mean speed profile is sufficiently similar to the measurements to suggest the vertical mixing and drag coefficients in the model are appropriate. The near perfect agreement for water level at Bluff gives additional confidence that the model will be replicating the dynamics of the wider Foveaux Strait as well.

The time series of residuals indicates the model is predicting some but not all the periods of elevated flow, while the Progressive Vector Diagram suggests that the gross flow patterns of residual reversals are generally being reproduced. To further consider the behaviour of non-tidal flow, a model map showing the vector averaged speed and direction over the validation period is presented in Figure 3.13. It is clear from this map that the instruments were located in a zone of low residual flows, with adjacent gradients in speed and direction that include rotational features. Spatial context such as this is helpful for interpreting the small differences between the model and the observations.

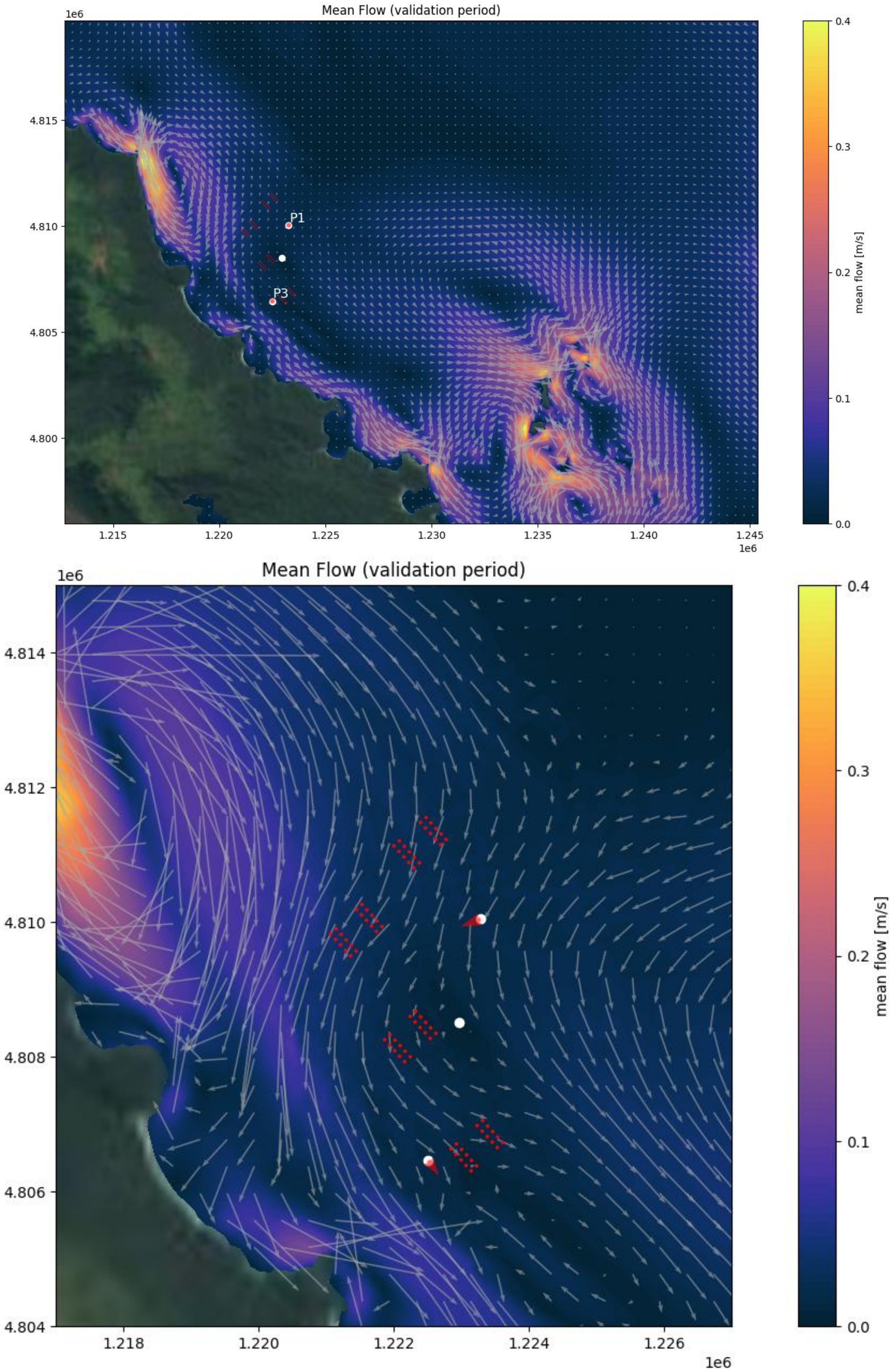

Figure 3.13 Model map (top) and a zoom-in near the farm area (bottom) showing the vector-averaged flows over the validation period, with an overlay showing the vector-averaged values from the instruments at P1 and P3 (red arrow, depth-averaged).

4. STATISTICS OF THE FLOW REGIME

The 10-year hindcast has been used to derive statistics that summarise the flow regime at site P1. Tables of the monthly, seasonal and annual statistics for speed at three levels in the water column are presented in tables 4.1 - 4.3. Current roses for the same levels are provided in Figures 4.1 - 4.3.

Table 4.1 Statistics of total current speed hindcast over the period January 2011 – January 2021 for surface at P1.

m/s	mean	std	P10	P50	P90	P95	P99	max
January	0.57	0.30	0.15	0.58	0.95	1.03	1.16	1.43
February	0.57	0.30	0.15	0.59	0.96	1.04	1.16	1.32
March	0.57	0.30	0.15	0.58	0.97	1.05	1.17	1.55
April	0.57	0.30	0.15	0.58	0.95	1.05	1.17	1.48
May	0.56	0.29	0.15	0.58	0.94	1.02	1.14	1.35
June	0.56	0.29	0.14	0.58	0.93	1.01	1.12	1.32
July	0.56	0.29	0.14	0.58	0.93	1.01	1.14	1.41
August	0.56	0.29	0.15	0.57	0.95	1.03	1.14	1.45
September	0.56	0.30	0.14	0.57	0.95	1.04	1.16	1.33
October	0.56	0.30	0.14	0.57	0.95	1.04	1.17	1.46
November	0.56	0.29	0.14	0.58	0.94	1.03	1.15	1.50
December	0.56	0.29	0.15	0.58	0.94	1.02	1.12	1.39
2011	0.56	0.29	0.14	0.57	0.93	1.02	1.15	1.47
2012	0.56	0.29	0.14	0.57	0.94	1.02	1.12	1.39
2013	0.57	0.30	0.15	0.58	0.96	1.03	1.14	1.37
2014	0.57	0.30	0.15	0.59	0.96	1.04	1.17	1.43
2015	0.57	0.30	0.15	0.59	0.96	1.05	1.18	1.50
2016	0.57	0.30	0.15	0.58	0.96	1.04	1.17	1.55
2017	0.57	0.30	0.15	0.58	0.95	1.03	1.14	1.48
2018	0.57	0.29	0.15	0.58	0.95	1.04	1.15	1.33
2019	0.56	0.29	0.14	0.58	0.94	1.02	1.16	1.37
2020	0.55	0.29	0.14	0.56	0.93	1.01	1.13	1.50
Winter	0.56	0.29	0.14	0.58	0.94	1.02	1.13	1.45
Spring	0.56	0.30	0.14	0.57	0.95	1.04	1.16	1.50
Summer	0.57	0.29	0.15	0.58	0.95	1.03	1.15	1.43
Autumn	0.57	0.30	0.15	0.58	0.95	1.04	1.17	1.55
Total	0.56	0.29	0.15	0.58	0.95	1.03	1.15	1.55

Table 4.2 Statistics of total current speed hindcast over the period January 2011 – January 2021 for mid water at P1.

m/s	mean	std	P10	P50	P90	P95	P99	max
January	0.52	0.26	0.13	0.54	0.85	0.92	1.03	1.23
February	0.52	0.27	0.13	0.54	0.86	0.94	1.03	1.16
March	0.52	0.27	0.13	0.54	0.87	0.95	1.05	1.31
April	0.52	0.27	0.13	0.54	0.86	0.94	1.04	1.29
May	0.52	0.26	0.14	0.54	0.85	0.91	1.02	1.16
June	0.51	0.26	0.13	0.54	0.84	0.91	1.00	1.13
July	0.51	0.26	0.13	0.53	0.84	0.91	1.01	1.22
August	0.51	0.26	0.13	0.53	0.86	0.93	1.02	1.26
September	0.51	0.27	0.13	0.54	0.86	0.93	1.03	1.14
October	0.51	0.26	0.13	0.54	0.85	0.92	1.03	1.25
November	0.51	0.26	0.13	0.54	0.85	0.92	1.02	1.26
December	0.51	0.26	0.13	0.54	0.85	0.91	1.00	1.21
2011	0.51	0.26	0.13	0.53	0.84	0.92	1.02	1.24
2012	0.51	0.26	0.13	0.54	0.85	0.91	1.00	1.21
2013	0.52	0.26	0.13	0.54	0.86	0.92	1.01	1.18
2014	0.52	0.27	0.13	0.55	0.87	0.94	1.04	1.23
2015	0.52	0.27	0.13	0.55	0.86	0.94	1.05	1.26
2016	0.52	0.27	0.13	0.54	0.86	0.93	1.03	1.31
2017	0.52	0.26	0.13	0.54	0.86	0.92	1.01	1.29
2018	0.52	0.26	0.13	0.54	0.86	0.93	1.02	1.13
2019	0.51	0.26	0.13	0.54	0.84	0.92	1.03	1.15
2020	0.50	0.26	0.13	0.52	0.83	0.91	1.02	1.25
Winter	0.51	0.26	0.13	0.53	0.85	0.91	1.01	1.26
Spring	0.51	0.26	0.13	0.54	0.85	0.93	1.03	1.26
Summer	0.52	0.26	0.13	0.54	0.85	0.92	1.02	1.23
Autumn	0.52	0.26	0.13	0.54	0.86	0.93	1.04	1.31
Total	0.52	0.26	0.13	0.54	0.85	0.92	1.03	1.31

Table 4.3 Statistics of total current speed hindcast over the period January 2011 – January 2021 for 1m above seabed at P1.

m/s	mean	std	P10	P50	P90	P95	P99	max
January	0.34	0.17	0.09	0.35	0.56	0.62	0.72	0.79
February	0.34	0.17	0.10	0.35	0.57	0.62	0.73	0.82
March	0.34	0.18	0.10	0.35	0.58	0.63	0.75	0.85
April	0.34	0.17	0.09	0.35	0.57	0.62	0.73	0.82
May	0.34	0.17	0.10	0.35	0.56	0.61	0.71	0.82
June	0.34	0.17	0.09	0.35	0.56	0.61	0.72	0.83
July	0.34	0.17	0.09	0.34	0.56	0.61	0.71	0.82
August	0.34	0.17	0.09	0.35	0.56	0.62	0.71	0.82
September	0.34	0.17	0.09	0.35	0.56	0.61	0.72	0.80
October	0.34	0.17	0.09	0.35	0.56	0.62	0.72	0.83
November	0.34	0.17	0.09	0.35	0.56	0.61	0.71	0.81
December	0.34	0.17	0.10	0.35	0.55	0.61	0.70	0.80
2011	0.33	0.17	0.10	0.34	0.56	0.61	0.72	0.85
2012	0.34	0.17	0.09	0.35	0.56	0.61	0.71	0.83
2013	0.34	0.17	0.09	0.35	0.56	0.61	0.71	0.82
2014	0.34	0.17	0.10	0.35	0.57	0.62	0.73	0.83
2015	0.34	0.17	0.10	0.35	0.57	0.63	0.74	0.83
2016	0.34	0.17	0.10	0.35	0.56	0.62	0.73	0.85
2017	0.34	0.17	0.09	0.35	0.57	0.62	0.71	0.82
2018	0.34	0.17	0.09	0.35	0.57	0.62	0.72	0.82
2019	0.34	0.17	0.09	0.35	0.55	0.61	0.71	0.82
2020	0.33	0.17	0.09	0.34	0.55	0.60	0.72	0.82
Winter	0.34	0.17	0.09	0.35	0.56	0.61	0.71	0.83
Spring	0.34	0.17	0.09	0.35	0.56	0.61	0.71	0.83
Summer	0.34	0.17	0.10	0.35	0.56	0.62	0.72	0.82
Autumn	0.34	0.17	0.10	0.35	0.57	0.62	0.73	0.85
Total	0.34	0.17	0.09	0.35	0.56	0.62	0.72	0.85

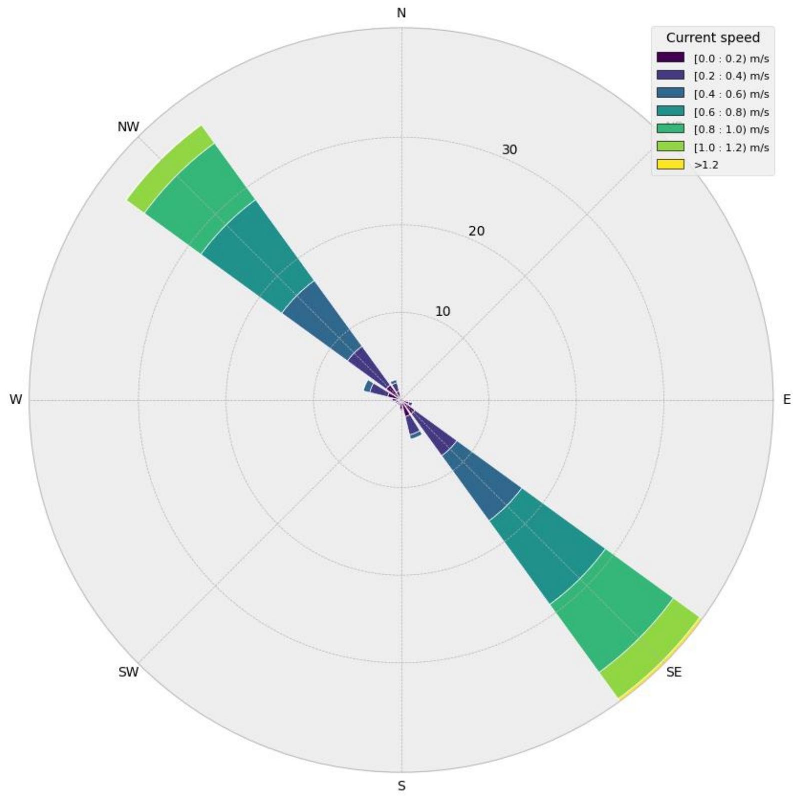

Figure 4.1 Annual surface current rose for the 10 year hindcast at P1.

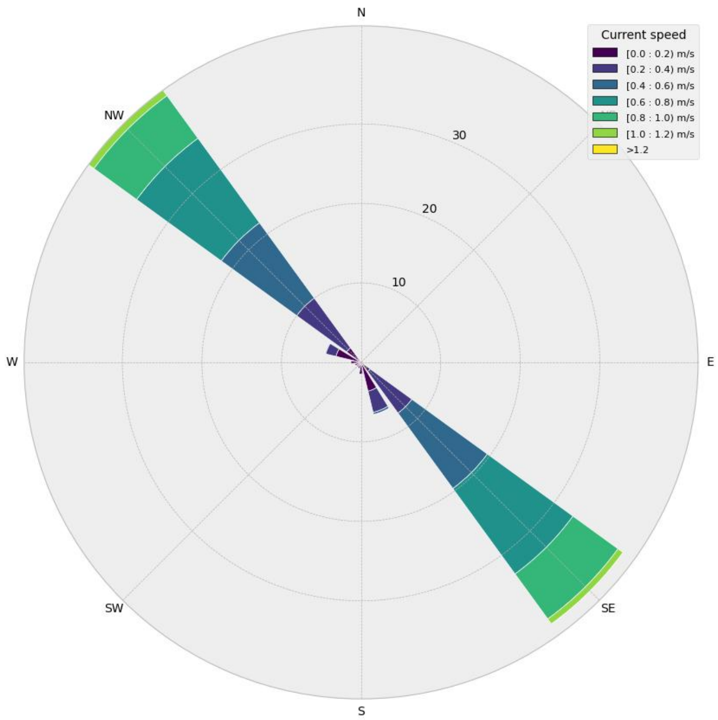

Figure 4.2 Annual mid-depth current rose for the 10 year hindcast at P1.

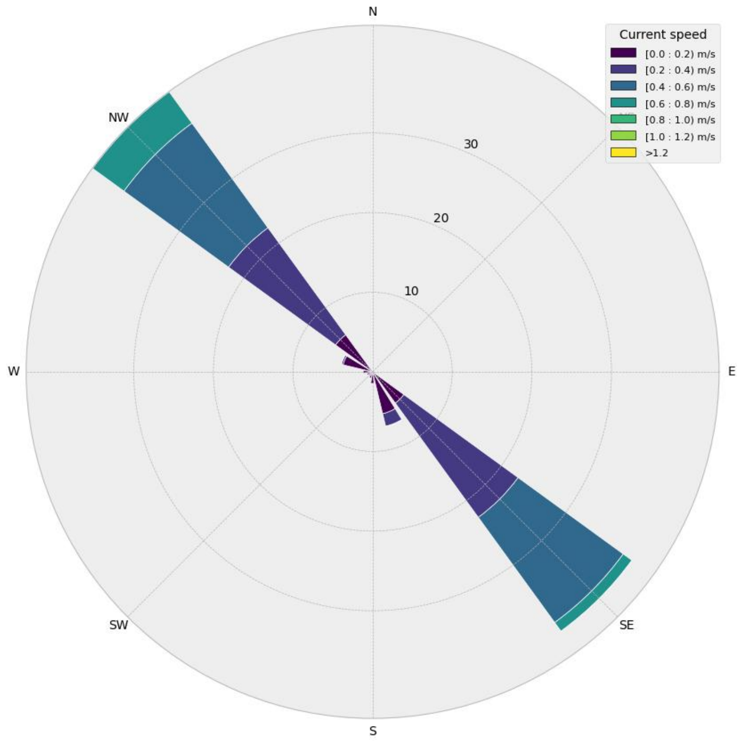

Figure 4.3 Annual near seabed current rose for the 10 year hindcast at P1.

5. CONCLUSIONS

The Foveaux Strait has complex and rapidly changing hydrodynamics, and the site of the HAP appears to be well positioned in terms of ventilation by the tidal flows, while maintaining adequate shelter from the Southern Ocean wave climate.

The ADCP measurements within the HAP footprint provide a reliable set of current profile data for calibration of the hydrodynamical model. The results show that the governing dynamics are being replicated by the model, and that a decadal hindcast with the same boundary conditions will provide fit-for-purpose spatial and temporal outputs.

6. REFERENCES

CMEMS – Global Ocean Physics Reanalysis. E.U. Copernicus Marine Service Information (CMEMS). Marine Data Store (MDS). DOI: https://doi.org/10.48670/moi-00021. Accessed April

GEBCO Bathymetric Compilation Group 2024 (2024). The GEBCO_2024 Grid – a continuous terrain model of the global oceans and land. NERC EDS British Oceanographic Data Centre NOC. DOI: 10.5285/1c44ce99-0a0d-5f4f-e063-7086abc0ea0f. https://www.gebco.net/

Hersbach, H., Bell, B., Berrisford, P., Biavati, G., Horányi, A., Muñoz Sabater, J., Nicolas, J., Peubey, C., Radu, R., Rozum, I., Schepers, D., Simmons, A., Soci, C., Dee, D., & Thépaut, J.-N. (2023). ERA5 hourly data on single levels from 1940 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). DOI: 10.24381/cds.adbb2d47. Dataset link.

List, E., Gartrell, G., & Winant, C. (1990). Diffusion and dispersion in coastal waters. Journal of Hydraulic Engineering, 116(10), 1158–1179.

Oceanum (2022). Environmental DataCube for the Ocean Estate of New Zealand. Technical Note prepared for the Ministry of Primary Industries and the New Zealand Plant and Food Research Institute, July 2022. Download link

Okubo, A. (1971). Oceanic diffusion diagrams. Deep-Sea Research, 18, 789–802.

Okubo, A. (1974). Some speculations on oceanic diffusion diagrams. Rapp. Procès-Verbaux Réun. Cons. Perm. Int. Pour L'Exploration Mer.

SCHISM Development Team. (2023). *SCHISM User Manual* (Version 5.11). Retrieved from https://schism-dev.github.io/schism/.

Silverman, B. W. (1986). Density Estimation for Statistics and Data Analysis. London: Chapman & Hall.

Umlauf, L. and H. Burchard (2003) A generic length-scale equation for geophysical turbulence models. J. Mar. Res., 6, pp. 235-265.

Vincent WF, Howard-Williams C, Tildesley P, Butler E 1991. Distribution and biological properties of oceanic water masses around the South Island, New Zealand. New Zealand Journal of Marine and Freshwater Research 25: 21-42.

Zhang, Yinglong & Ye, Fei & Stanev, Emil & Grashorn, Sebastian. 2016. "Seamless cross-scale modelling with SCHISM". Ocean Modelling. 102. 10.1016/j.ocemod.2016.05.002.

Zhang, Y. L., and A. M. Baptista. 2008. "A Semi-Implicit Eulerian-Lagrangian Finite Element Model for Cross-Scale Ocean Circulation." Ocean Modelling 21: 71–96.

Appendix D Water Column Monitoring Report

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

6 November 2025

SLR

Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa

Report Two – Water Quality Modelling

Prepared by:	Zyngfogel, McComb and Weppe
Reviewed by:	McComb
Date:	5 October 2025
Revision:	Rev0 - approved for release
Reference No.:	P25-05-02

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1. INTRODUCTION

Oceanum Ltd with support from Calypso Science Ltd have been commissioned by SLR Consulting Ltd to undertake oceanographic modelling in Te Ara a Kiwa. The scope of this work is to inform a broader assessment of effects to the water column for a proposed salmon farm (the Hananui Aquaculture Project - HAP).

The purpose of this report is to document the application of a eulerian tracer technique to quantify key aspects of water quality that relate to the proposed activity. Specifically, to model the introduction and subsequent dispersion and dilution of:

- Total Nitrogen (TN) from fish urine,
- Remineralised TN from benthic detritus, and
- Reduction of Dissolved Oxygen (DO) due to fish respiration.

This scope applies the validated hydrodynamical model of the area, described in Report 1, to simulate two distinct stages of the HAP.

The structure of this report is as follows. A description of the numerical modelling methods is provided in Section 2, including a summary of the boundary conditions for the simulations. Results for TN from fish urine and benthic detritus are provided in Section 3. The results for DO are provided in Section 4. A discussion of the results is provided in Section 5, and the references cited are listed in Section 6.

2. METHODOLOGY

2.1. Model settings and boundary conditions

The validated SCHISM hydrodynamical model (described in Report 1) has been used here for elurian tracing, with two particular modifications:

- The tracer calculation applies an upwind transport scheme, which is more efficient for 10-year duration run (Rodrigues et al., 2017).
- Nudging is 1 at the boundary, so that water entering the model has a concentration of 0.

Within the model domain, each pen is represented by 2 mesh elements, which best approximates the design pen area. This is shown in Figure 2.1. The SCHISM code was modified to allow tracer release in each of the elements representing the pens, from 0 to 16 m depth.

There are two farm stages being modelled (HAP1 and HAP2) which are shown on Figure 2.2, applying a time series of feed type and feed rates provided by Skretting. That time series had a small drop in feed inputs during February, which was smoothed out to allow the time series to be adopted for farm cycles to start in any month of the year - see Figure 2.3. Feed inputs are transformed to TN depending on the specific makeup of the artificial feed (which changes throughout the feeding cycle), and the details of that transformation are provided in Tables 2.1 - 2.3. A plot showing the TN load during HAP2 is presented in Figure 2.4. Note, within the model the daily load is transformed to a per second rate and released uniformly from 0 to 16 m depth within the model elements that define the pens.

Table 2.1 Period model for each load input and HAP scenarios.

	Start	End
TN HAP1	01/07/2016	01/07/2017
TN HAP2	01/01/2011	01/01/2021
DO HAP1	01/01/2014	01/01/2015
DO HAP2	01/01/2014	01/01/2015
TN remineralisation	01/01/2016	25/01/2016

Table 2.2 Food type and associated ratio used to derive TN load.

	Ratio	Number of days
Orient Plus 100 4mm	4.50	90
Orient Plus 500 6mm	4.21	90
Glory N 1000 8mm	3.49	90
Glory N 2000 9mm	2.99	210

Table 2.3 Summary of inputs for HAP1 and HAP2.

	HAP1	HAP2
Number of fish per pen	85,000	80,000
Target bFCR	1.7	1.7
Total feed per pen (T)	656	617
Total TN per pen (T)	21	20
Number of blocks	4	8
Fallow period per block (month)	4	7

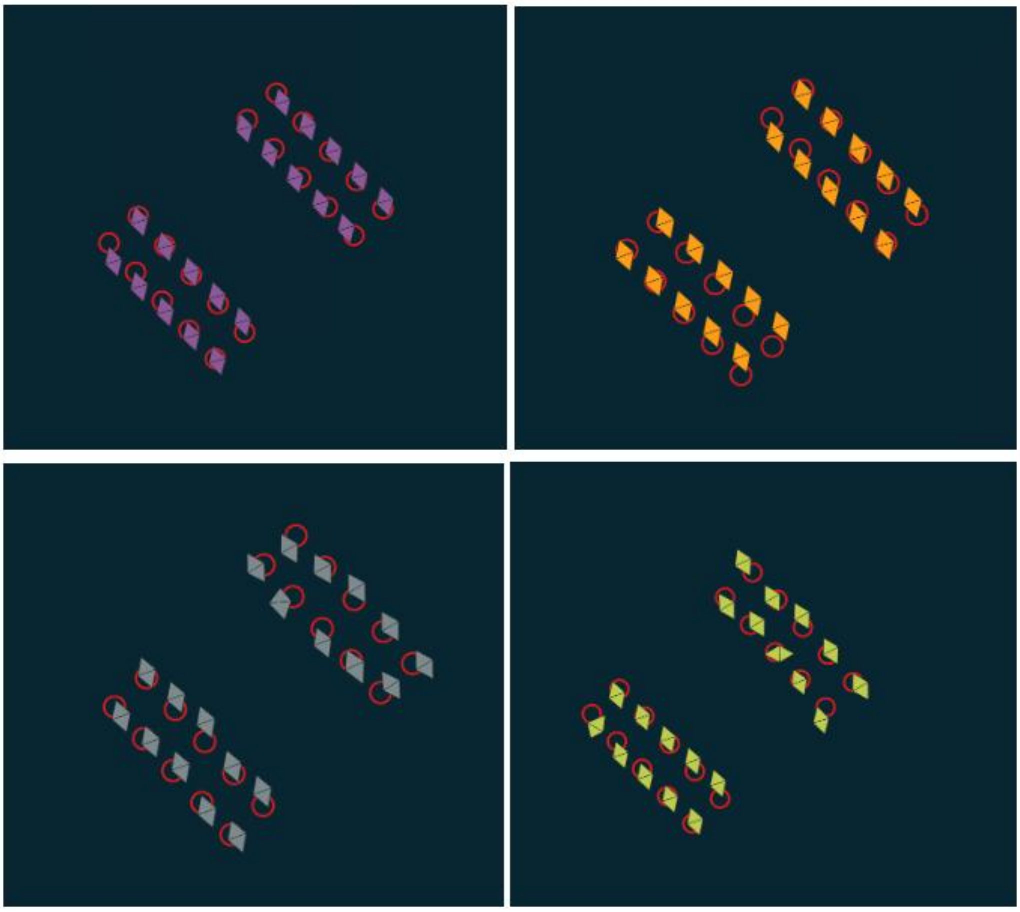

Figure 2.1 Descritisation of farm1 (top left), farm2 (top right), farm3 (bottom left) and farm 4 (bottom right) pens within the model mesh.

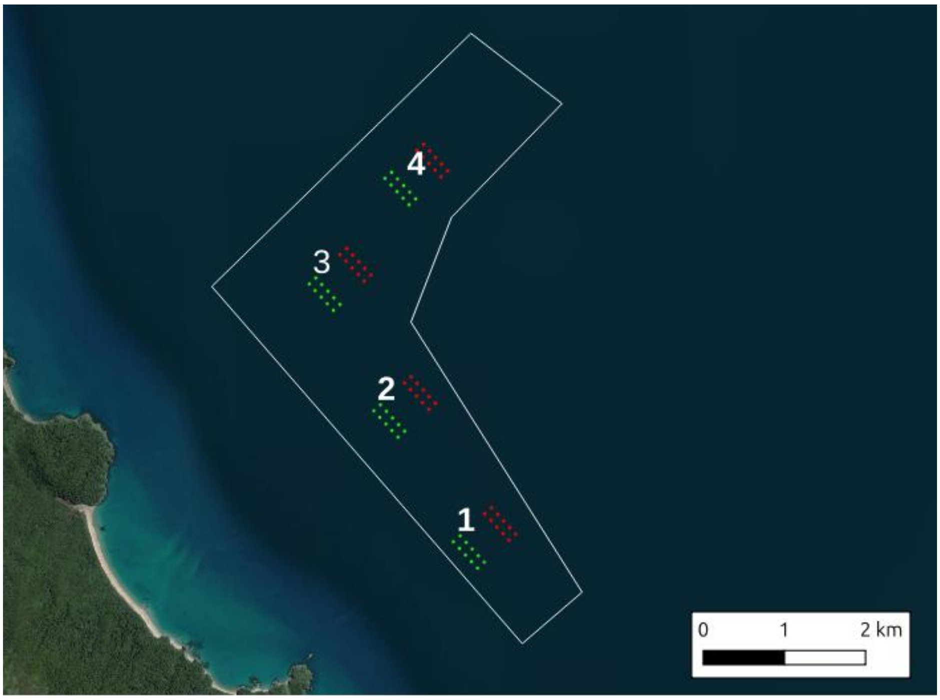

Figure 2.2 Map showing the HAP boundaries, block numbers and farms from HAP1 (green) and HAP2 (green and red).

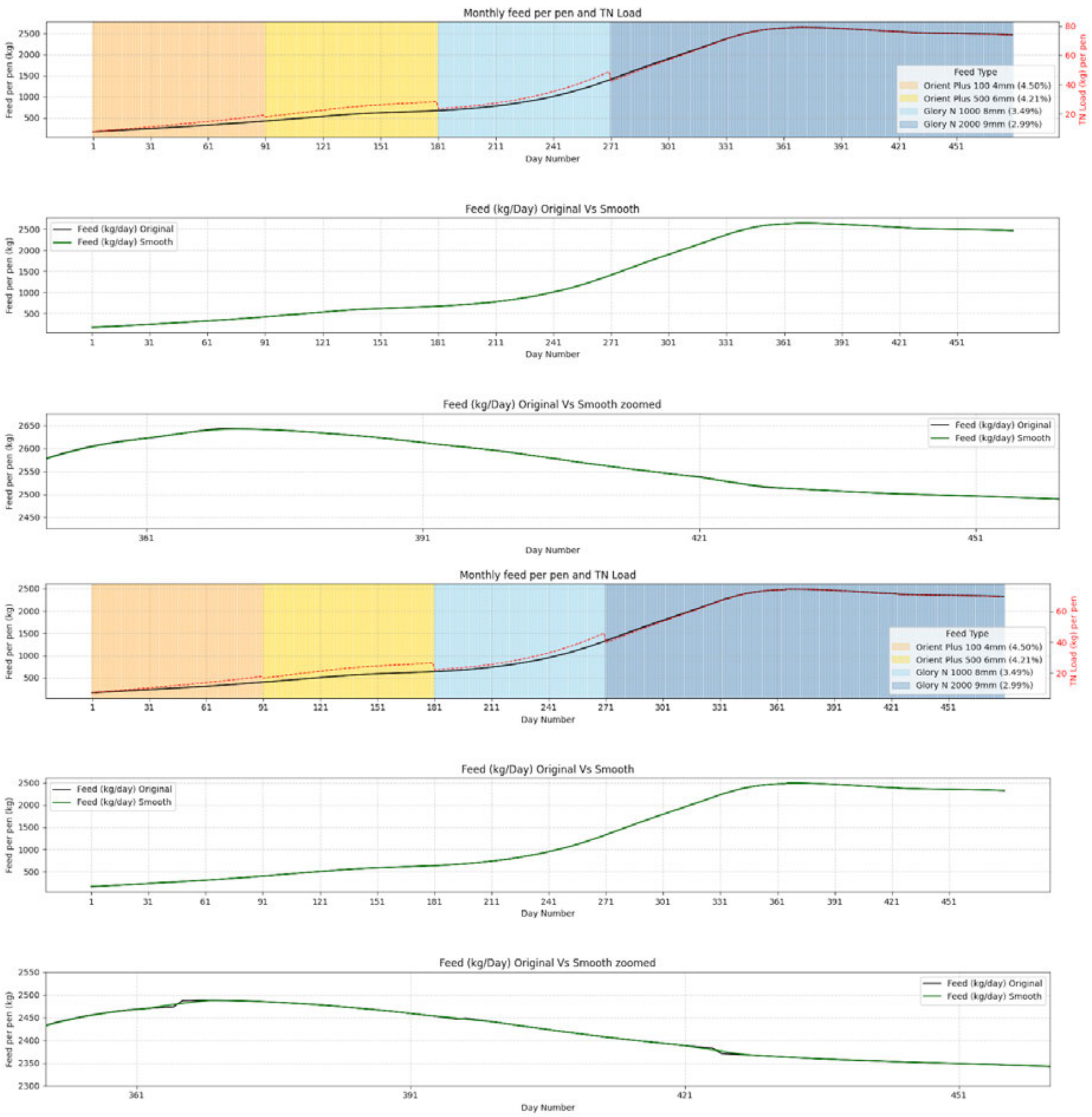

Figure 2.3 Feed inputs and resultant TN loads for HAP1 (upper) and HAP2 (lower).

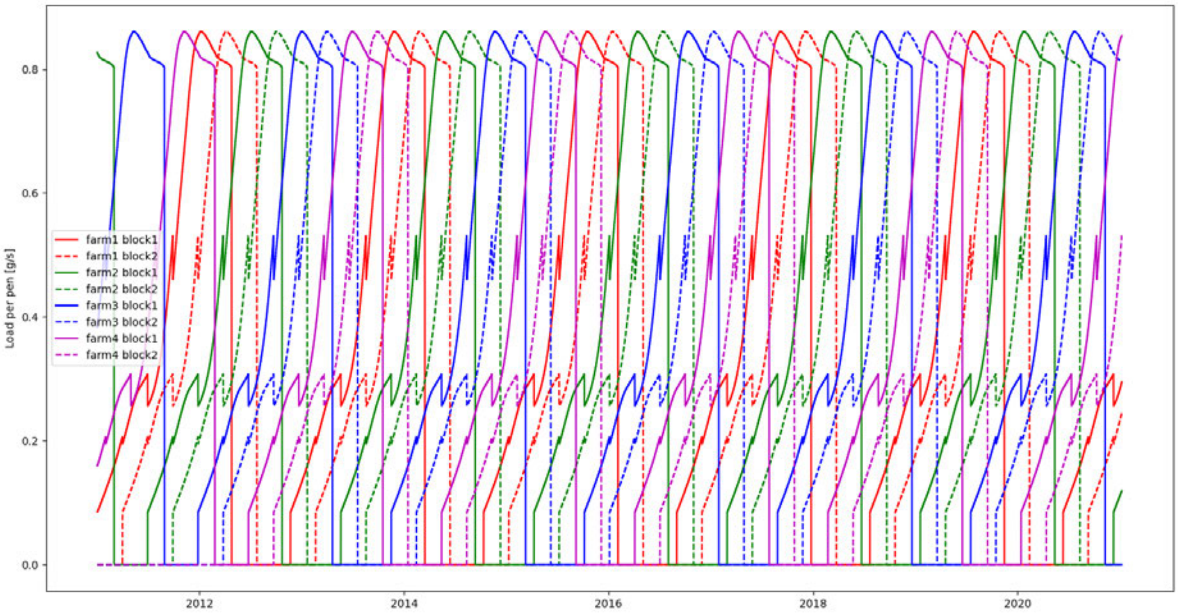

Figure 2.4 Load of TN per block of pens for each farm during the 10-year simulation for HAP2.

2.2. Dissolved oxygen

The modelling of DO has used the same method described by Campos et al (2020) and Stewart and Ibarra (1991), with the following assumptions:

- Average fish size of 1 kg
- Sea temperature of 17 °C
- Fish swimming velocity of 12 cm/s

The resultant oxygen consumption rate for smolt is estimated to be 207 mg O_2/ kg-fish/hour.

Noting that smolt have a higher O_2 consumption rate than the adult fish, this was adopted as the conservative rate in a simulation of the O_2 demand for the farm operation from stocking until harvest. Stock mortality is assumed to be zero, thereby maintaining a conservative approach. The time varying biomass was determined from the target bFCR of 1.7, allowing feed rates to estimate the cumulative biomass per pen and the corresponding daily oxygen demand (kg/day) - see Figure 2.5. Therefore, just before harvest, the fish in one pen have been modelled to consume 1803 kg of O_2 per day.

Since the farms do not reach peak biomass simultaneously, the period from 1st January 2014 to 15 February 2014 (coinciding with summer and lowest currents), was selected as a conservative representative period as it corresponds to the month with the highest DO consumption peak (Figure 2.6). The O_2 consumption for all the farms in the simulation is ~ 36000 kg per day.

The DO simulation extends from the 1st of January 2014 to the 1st of January 2015, and the results for January and February 2014 are analysed. Note - due to cycling, farm 4 block 1 is fallow during this simulation.

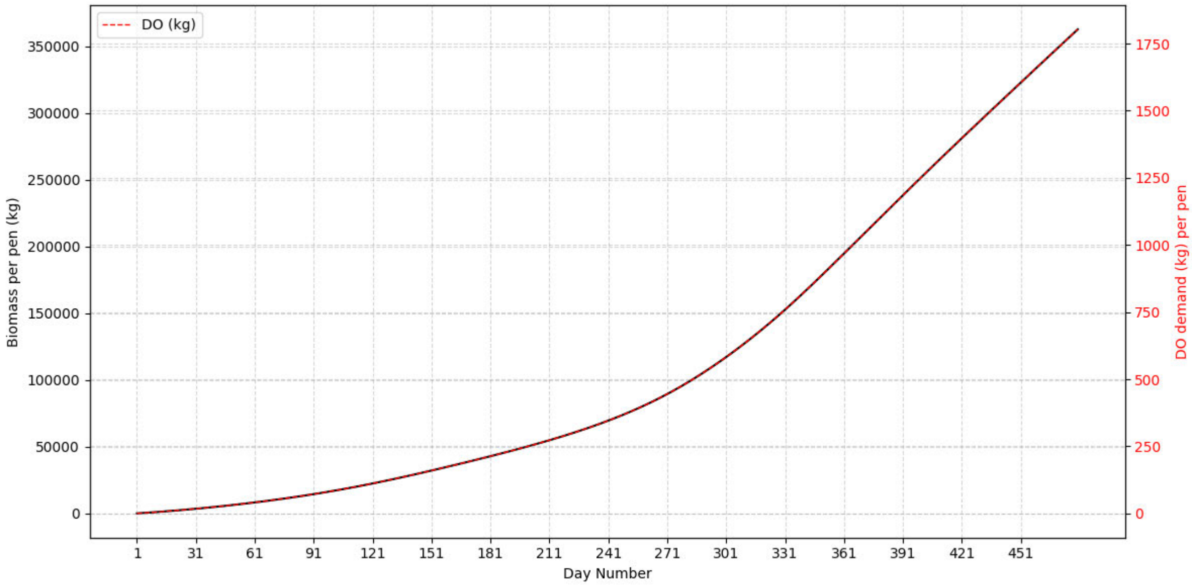

Figure 2.5 Cumulative biomass per pen and the related DO demand in kg/day.

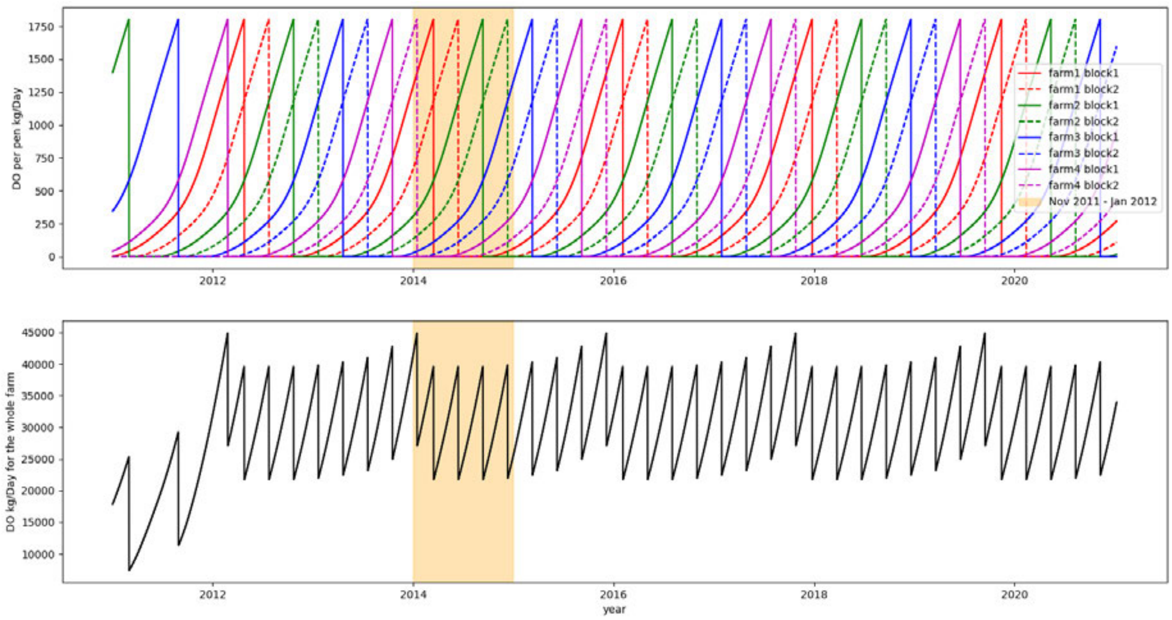

Figure 2.6 Time series of DO demand in kg/day/pen for 10 years (top), and time series of DO demand in kg/day across all pens / farms in HAP2 (lower). The highlighted orange area represents the farming cycle that was modelled.

2.3. Nitrogen remineralisation

Benthic detritus from the HAP (i.e. uneaten fish feed and faeces deposited on the seabed) is expected to accumulate on the seabed and would be expected to contribute organic nitrogen back to the water column near the seabed. This remineralisation process transforms the organic nitrogen into dissolved inorganic nitrogen.

A time series of gridded nitrogen deposition fields [g/m^2] were provided by Cawthron for HAP1 and HAP2 farm phases. From these, a representative nitrogen deposition footprint was defined that can be considered a steady state seabed source of nitrogen. While this is a numerical experiment rather than a fully realistic simulation, it does quantify the expected contribution of nitrogen to the water column, within the bounds of the assumptions being made.

The mean deposition over the duration of HAP2 is shown on Figure 2.7.

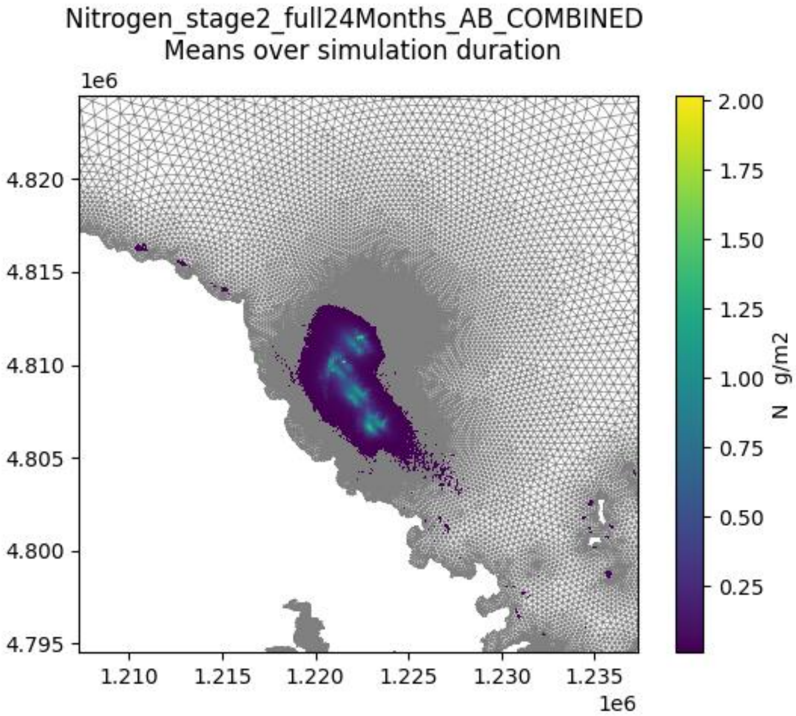

Figure 2.7 Mean nitrogen deposition [g/m^2] through the HAP2.

To estimate the fraction of the deposited nitrogen transferred to the water column as inorganic nitrogen effluent, a generic nitrogen remineralization rate of 1% per day was prescribed, based on empirical measurements in aquaculture ecosystems (see Lin et al, 2023, and references herein). This metric is referred to as PAM in the literature i.e. Percentage Ammonium (NH_4^+) Mineralized.

This 1% value is conservative as measured PAM values usually within a [0-1%] range. Furthermore, only a fraction of the mineralised nitrogen will be immobilised by nitrification/denitrification, as microbial action and sediment burial which will act to reduce the amount of nitrogen that becomes transferred to the water column. However, given the complexity and variability of these processes, they are neglected and instead only the total PAM is assessed here. A steady-state release over the duration of the spring / neap simulation was applied, rather than reducing nitrogen input over time as the initial nitrogen mass is mineralised.

For a nitrogen deposition of 2 g/m^2 (see Figure 2.6), the resulting nitrogen flux to water column, assuming a PAM of 1% per day, is 0.02 g/m^2/day, which is consistent with the measurements summarised by Hargreaves (1998).

2.4. Post processing

Results are provided as maps and statistics at defined locations, as shown on Figure 2.8. For the purpose of defining statistics, a 'pen zone' was defined as the area within 100 m of a pen, and the 'farm zone' was the farm polygon minus the 'pen zones'.

Figure 2.8 Location of results for statistics.

3. TOTAL NITROGEN RESULTS

3.1. Fish urine

To capture a full annual cycle, HAP1 was modelled for a one-year period (July 2016 - July 2017) with a time-varying load of TN applied evenly to all pens and integrated from surface to 16 m depth. The results for the mean and maximum concentrations are provided in Figure 3.1, and the statistics are listed in Table 3.1.

HAP2 was modelled for a ten-year period (January 2011 to January 2021) with a time-varying load of TN applied evenly to all pens and integrated from surface to 16 m depth. The results for the mean and maximum concentrations are provided in Figure 3.2, and the statistics are listed in Table 3.2.

To illustrate the time-varying nature of TN concentration and the influence of currents, a vertical distribution of TN near farm 4 block 2 (Figure 3.3). For HAP2, a horizontal transect was prepared (see Figure 3.4), providing statistics of TN over the 10-year simulation. The results are provided for the mean and maximum concentrations in Figure 3.5.

Table 3.1 TN results for HAP1.

Statistic (mg/m^3)	Pen zone	Farm zone	Port Williams	Patterson Inlet	Halfmoon Bay
Mean	8.6	7.7	0.8	0.1	0.3
SD	4.6	3.7	0.6	0.2	0.2
Min	2.4	2.1	0.0	0.0	0.0
Max	31.9	28.3	2.3	1.4	0.9
p01	3.2	2.9	0.0	0.0	0.0
p05	4.0	3.7	0.2	0.0	0.0
p10	4.4	4.1	0.2	0.0	0.0
p50	7.0	6.7	0.8	0.0	0.3
p90	15.7	12.8	1.7	0.3	0.6
p95	18.6	15.4	1.8	0.5	0.8
p99	23.5	20.3	2.3	0.8	0.9

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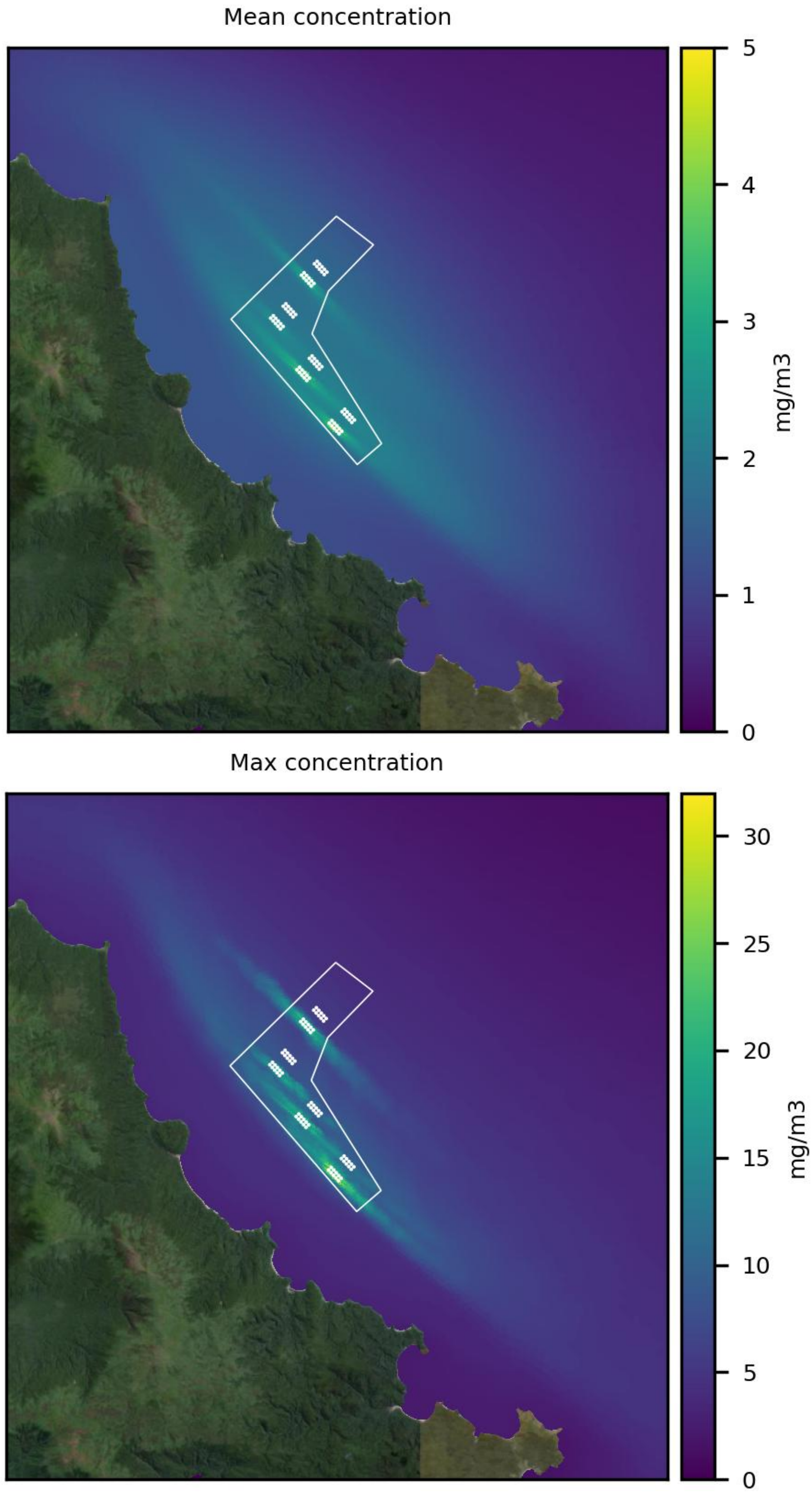

Figure 3.1 TN results for HAP1, showing the mean concentration (upper) and the maximum concentration (lower) from a one-year simulation.

Table 3.2 TN results for HAP2.

Statistic (mg/m^3)	Pen zone	Farm zone	Port Williams	Patterson Inlet	Halfmoon Bay
Mean	9.6	8.7	1.2	0.2	0.4
SD	4.5	3.7	0.7	0.2	0.3
Min	1.5	1.4	0.0	0.0	0.0
Max	33.8	30.9	3.8	2.6	1.2
p01	3.2	2.9	0.0	0.0	0.0
p05	4.3	4.0	0.2	0.0	0.2
p10	5.0	4.7	0.3	0.0	0.2
p50	8.4	7.9	1.1	0.2	0.5
p90	16.3	13.7	2.0	0.5	0.8
p95	18.8	16.0	2.3	0.6	0.9
p99	22.9	20.5	2.7	0.9	1.1

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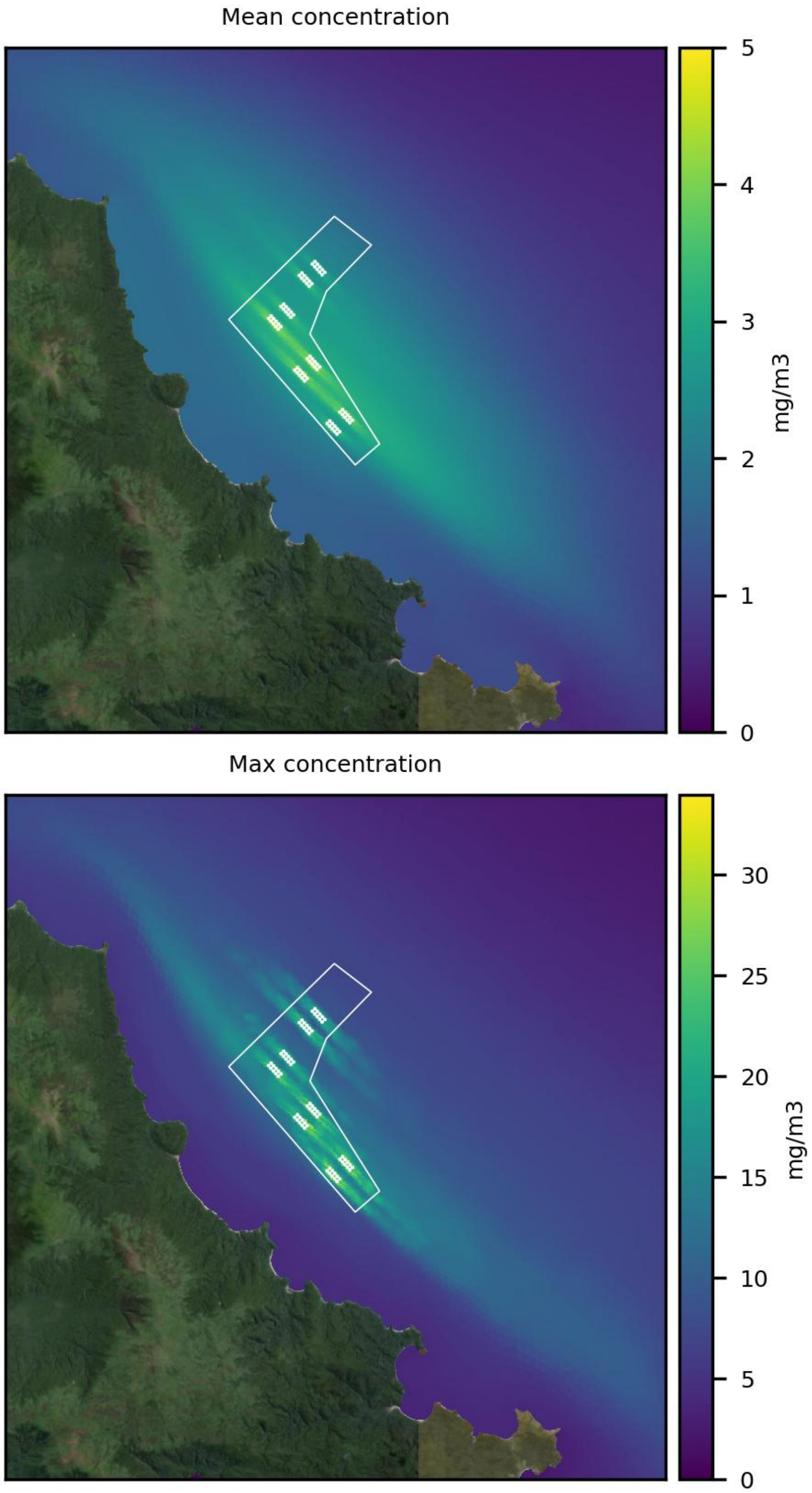

Figure 3.2 TN results for HAP2, showing the mean concentration (upper) and the maximum concentration (lower) from a ten-year simulation.

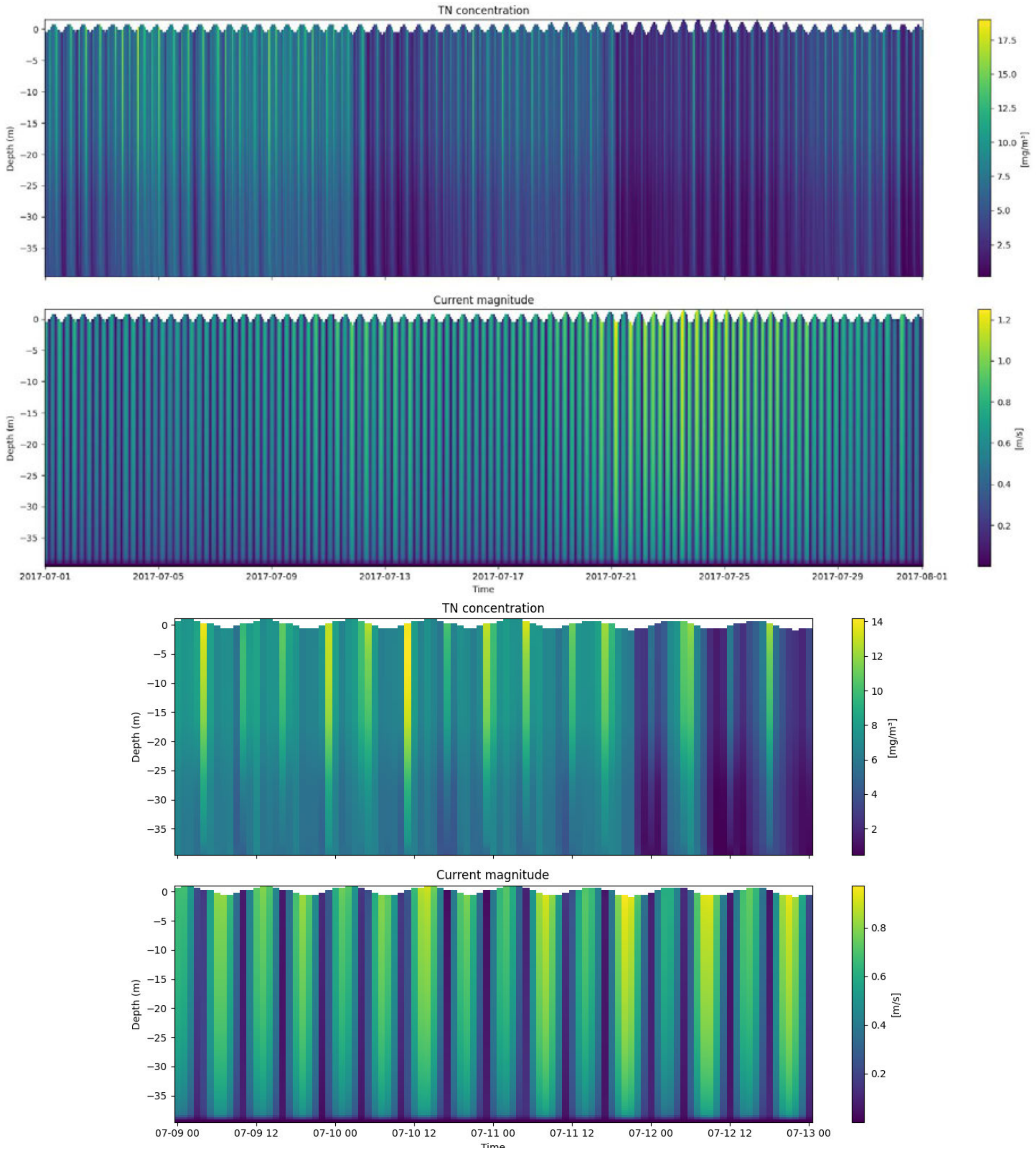

Figure 3.3 The vertical distribution of TN concentration near [Farm 4 Block 2] during one month (upper) and one week (lower) for HAP2, showing the effect of current velocity on the predicted concentrations.

Figure 3.4 The location of a horizontal transect (red line) and a bounding box (green line) for the calculation of vertically averaged statistics over the HAP2 10-year simulation.

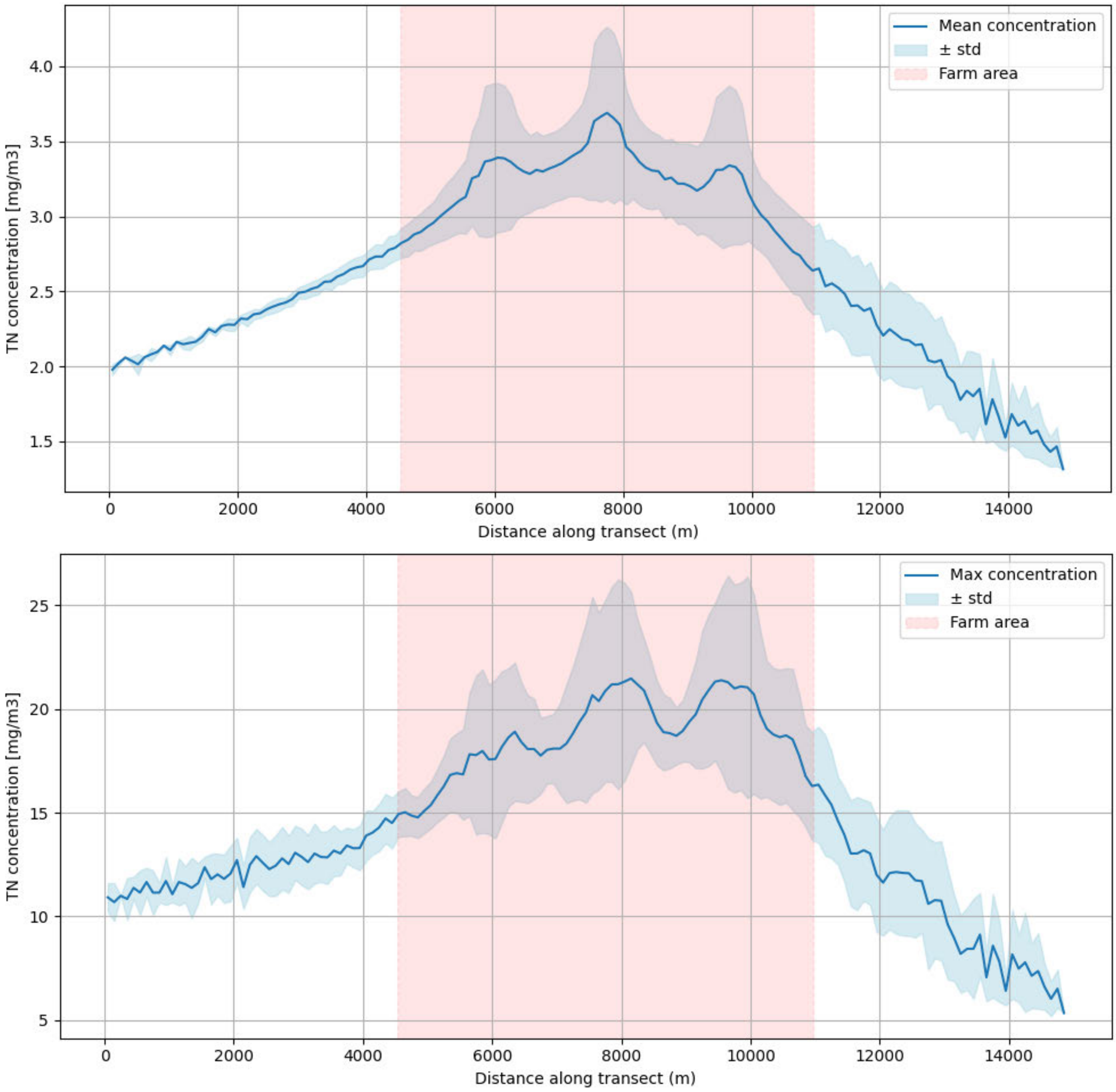

Figure 3.5 The vertically-averaged concentrations along a transect (Figure 3.4) showing mean (upper) and maximum (lower) TN for HAP2 over a 10-year simulation.

3.2. Benthic detritus

The results for the remineralisation of benthic detritus to release TN into the water column are presented in Figure 3.6, showing the mean and maximum values (vertically integrated) that were resolved during a 25-day simulation of HAP2. The period 1 - 25 January 2016 was modelled, based on the gridded nitrogen deposition fields expressed in g/m^3, and including a spring / neap cycle.

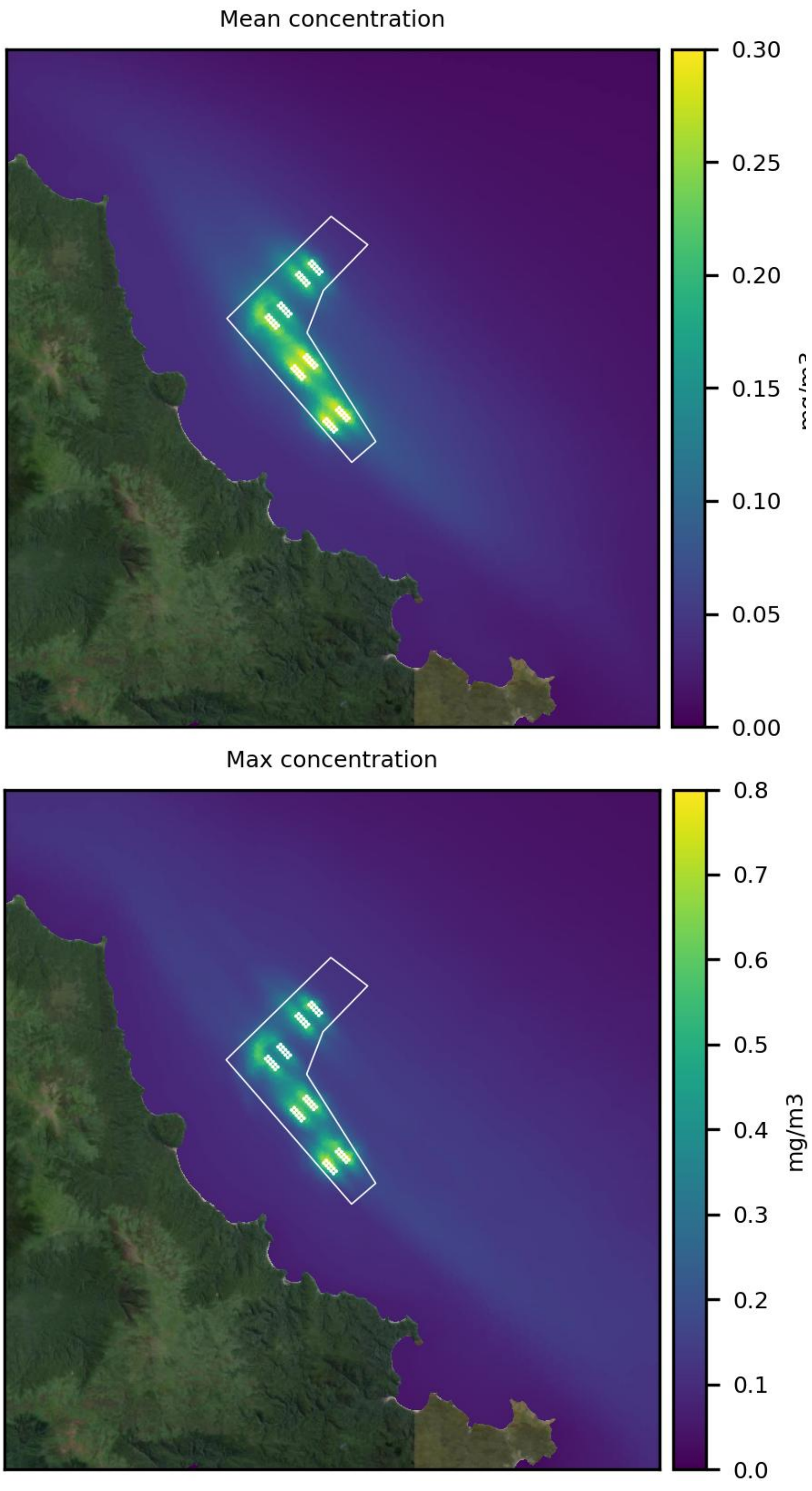

Figure 3.6 The mean (upper) and maximum (lower) TN concentrations from remineralisation of benthic detritus from HAP2 over a 10-year simulation.

4. DISSOLVED OXYGEN RESULTS

Statistics for DO consumption are first computed within each area, then the maximum value (i.e. "worst-case" decrease in DO concentration) is selected. The maximum value is the greatest decrease measured across all modelled depth levels. The model was run for a full farm cycle from stocking to harvest.

The results are presented in Table 4.1 and 4.2 for HAP1 and HAP2, respectively. Maps of the same are provided in Figures 4.1 and 4.1. Note, the units of concentration presented are µg/l.

Table 4.1 DO consumption results for HAP1.

Statistic (µg/l)	Pen zone	Farm zone	Port Williams	Patterson Inlet	Halfmoon Bay
Mean	197.5	175.6	13.1	2.5	5.5
SD	127.7	104.4	8.6	3.1	4.1
Min	32.4	25.7	0.5	0.0	0.4
Max	866.4	918.8	39.5	35.2	19.1
p01	52.3	47.2	0.7	0.1	0.7
p05	68.6	63.8	0.9	0.3	1.0
p10	81.1	75.7	2.1	0.4	1.5
p50	157.9	146.9	12.4	1.6	4.5
p90	375.1	312.4	25.0	5.5	11.5
p95	472.3	384.3	28.5	8.0	14.0
p99	639.9	553.7	36.6	14.9	18.1

Table 4.2 DO consumption results for HAP2.

Statistic (µg/l)	Pen zone	Farm zone	Port Williams	Patterson Inlet	Halfmoon Bay
Mean	183.7	164.6	16.7	3.0	6.9
SD	91.7	75.1	9.4	3.2	3.8
Min	40.7	35.4	0.9	0.1	0.7
Max	641.2	584.8	47.1	34.4	18.1
p01	64.4	58.1	1.0	0.2	1.0
p05	82.7	77.5	1.5	0.4	1.6
p10	94.5	89.5	3.3	0.6	2.5
p50	155.9	146.4	16.3	2.1	6.4
p90	320.6	268.2	28.0	6.4	12.6
p95	375.7	318.3	35.1	9.3	14.1
p99	468.4	412.0	42.6	15.6	17.3

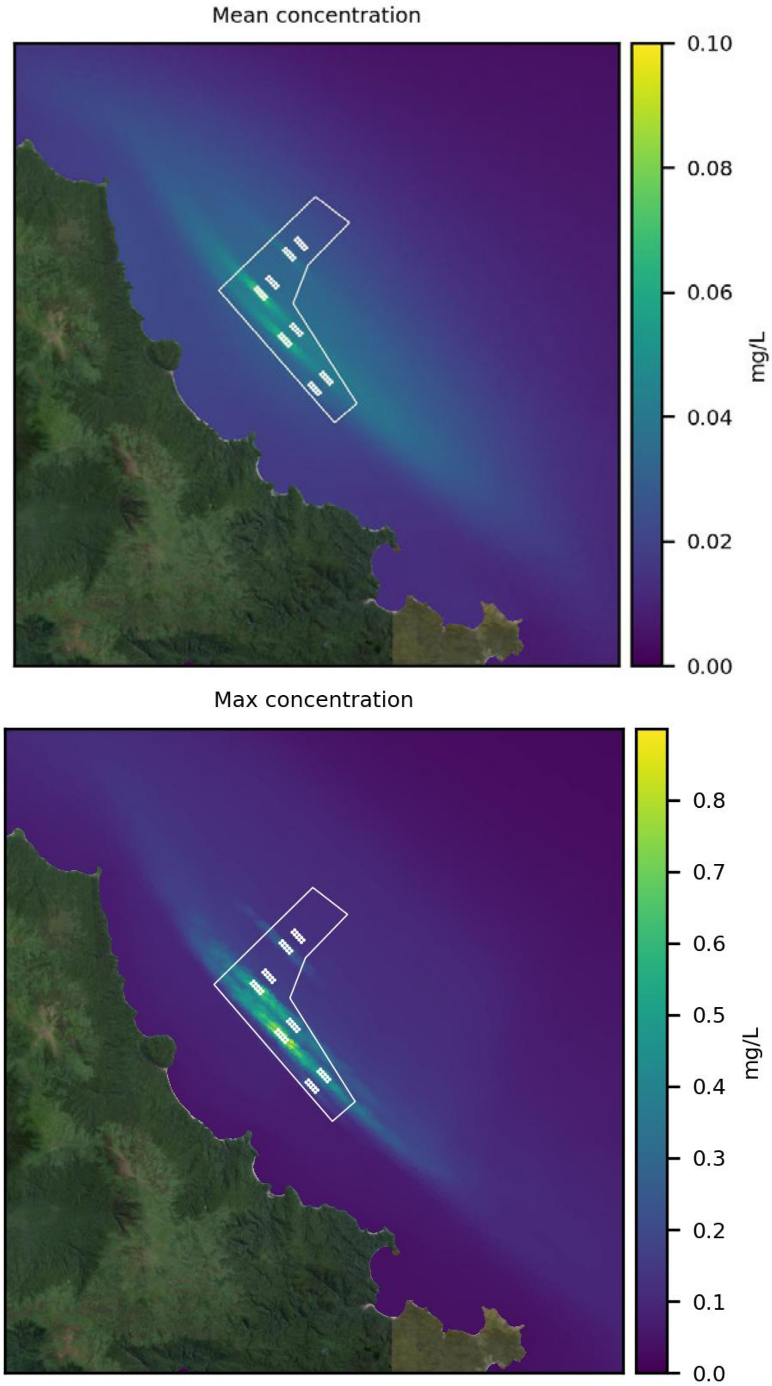

Figure 4.1 The mean (upper) and maximum (lower) DO consumptions from one farm cycle in HAP1.

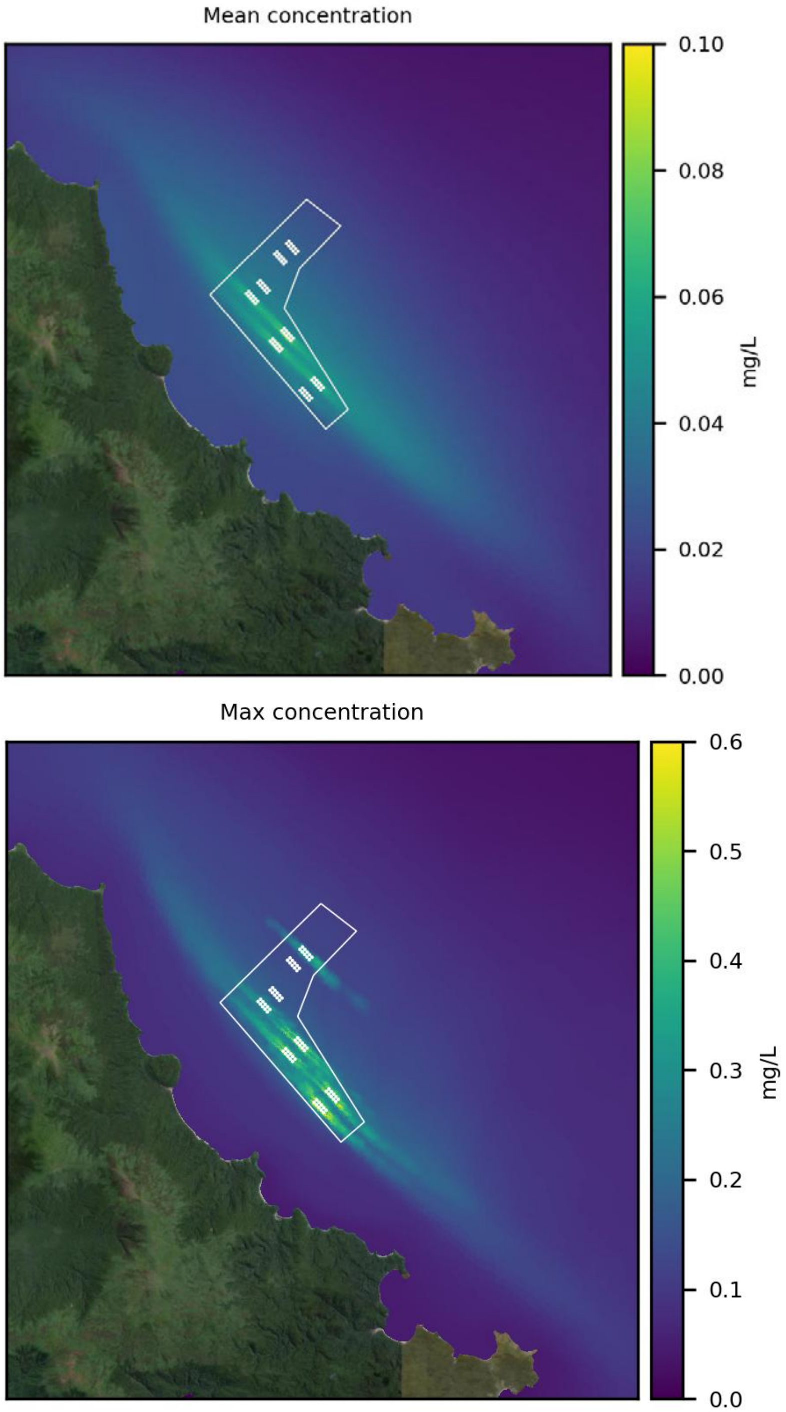

Figure 4.2 The mean (upper) and maximum (lower) DO consumptions from one farm cycle in HAP2.

5. DISCUSSION

While the water quality predictions presented in this report are based on a validated hydrodynamical model, a number of additional assumptions have been made to simulate potential effects of the HAP. However, wherever possible these assumptions have erred toward a reasonable and conservative estimate, discussed further as follows:

For Total Nitrogen from fish urine:

- The load released is uniform (vertically and horizontally) in each pen.
- The daily load is released constantly throughout the day.
- Each pen within a farm block has the same stage of their cycle (i.e. no staggering).

For Dissolved Oxygen from fish respiration:

- DO consumption is uniform vertically and horizontally in each pen.
- DO consumption is constant throughout the day.
- Each pen within a farm has the same stock density.
- There is no regeneration of DO.

For Total Nitrogen released from benthic detritus:

- TN is defined as 1% of the detritus mass and is released constantly during the simulation.
- Burial and microbial degradation are neglected.

Another potentially important topic is the effect of the farm structures on hydrodynamics, as the pens will create zones of lower flow within and in the lee, and higher flows adjacent and below. To model these effects would require detailed information on the drag from the structures, with measurements being needed to calibrate. In the absence of such data, modelling would simply introduce more assumptions and uncertain outcomes. Hence, the modelling results presented here have neglected all effects of the farm structures on flow and resultant concentration fields.

However, a series of tests were made with generic drag values to determine the potential length scales of influence. The results showed that only near field effects were expected, predominantly constrained within the farm footprint and as expected within the pens. Note also the disruption to flow did not affect dispersal rates.

6. REFERENCES

Campos C, Smeaton M, Bennett H, Mackenzie L, Scheel M, Vennell R, Newcombe E, Knight B. 2020. Assessment of water column effects associated with farming salmon offshore of northern Stewart Island / Rakiura. Prepared for Ngāi Tahu Seafood Resources. Cawthron Report No. 3326. 106 p. plus appendices

Hargreaves, J.A., 1998. Nitrogen biogeochemistry of aquaculture ponds. Aquaculture, 166(3-4), pp.181-212.

Lin, X., Lin, G., Zheng, Y., Li, W., Guo, P., Fan, S., Kong, T., Tian, D., Sun, D. and Shen, Z., 2023. Nitrogen mineralization and immobilization in surface sediments of coastal reclaimed aquaculture ecosystems. Frontiers in Marine Science, 9, p.1093279.

Rodrigues, Marta, & Fortunato, André B. (2017). *Assessment of a three-dimensional baroclinic circulation model of the Tagus estuary (Portugal). AIMS Environmental Science*, **4**(6), 763-787. https://doi.org/10.3934/environsci.2017.6.763

Stewart DJ, Ibarra M 1991. Predation and production by salmonine fishes in Lake Michigan, 1978–88. Canadian Journal of Fisheries and Aquatic Sciences 48: 909-922.

Appendix E Hydrodynamic Model Review

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

6 November 2025

Dougal Greer
Director
[redacted]

7 October2025

SLR, LTD,
Reid Forrest,
6/A Cambridge Street
Nelson
New Zealand, 7020

Re: Review of Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa

Dear Reid,

This letter provides a review of the hydrodynamic modelling of the Te Ara a Kiwa region undertaken by Oceanum and makes reference to the modelling, reporting and reviews of hydrodynamic modelling undertaken by Metocean Solutions from a previous application for this project.

Introduction

The review principally focuses on the following report:

Oceanum, 2025, Oceanographic Modeling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa, Report 1 - Hydrodynamical Model, prepared for SLR Consulting (In preparation, Draft 12 September 2025)

We note that this report is still in draft format.

It also considers the initial modelling undertaken by Metocean in 2020:

Campos C., Smeaton M., Bennett H., Mackenzie L., Scheel M., Vennell R., Newcombe E., Knight B. 2020. Assessment of water column effects associated with farming salmon offshore of northern Stewart Island/Rakiura. Prepared for Ngāi Tahu Seafood Resources. Cawthron Report No. 3326. 106 p. plus appendices.

and the subsequent external review of the initial modelling undertaken by Jon Oldman from DHI:

Oldman, J., Evidence of John Warwick Oldman for Environment Southland 11th August 2021

Summary

Overall, the hydrodynamic modelling makes use of appropriate tools and boundary conditions. SCHISM is an established industry standard modelling platform, the model setup is sound, and the calibration demonstrates that it can reasonably reproduce observed water levels and currents though some uncertainty remains around some of the presented calibration. Apart from the specific open questions, the modelling appears robust and provides a suitable basis for subsequent water quality modelling. If being used for seabed deposition modelling, the modellers should assess whether wave action, in addition to the hydrodynamic model, needs to be considered.

We provide the following comments and recommendations:

- The modelled hindcast period (2011–2021) should be clearly presented in the report.
- The coverage of MBES bathymetric data should be shown alongside the LINZ chart data.

- Justification for the implementation of Horizontal Eddy Viscosity (HEV) should be provided to explain its omission or treatment in the model.
- Sections describing model/observed data comparisons should be referred to as 'calibration' rather than 'validation' where the model has been adjusted to improve performance.
- The P3 sea level record should include pressure correction using hindcast products.
- Wording should be included to clarify that hourly model outputs may miss slack or peak flow events, and the implications of this for the QQ plots.
- Analysis of modelled residual current directions should be included to provide a more complete assessment of performance.
- Residual current direction arrows at P1 and P3 should be added to the relevant plots.

Despite the uncertainty around projected impacts of climate change, the report should discuss the potential effects of climate change on the model outputs.

Hydrodynamic Modelling Review

The hydrodynamic modelling provides the basis for subsequent water quality modelling and it is important that it provides an accurate representation of current speed and direction. If current speeds are underestimated, dispersion modelling will underpredict the spatial extent of the plume. Conversely, if currents are overestimated, the model may overstate the degree of plume dilution.

Tidal currents are highly cyclical, moving water quality constituents back and forth with limited net transport over a tidal cycle. In contrast, residual currents are usually more persistent and act over longer timescales. Consequently, residual currents are important and can exert a stronger influence on the net drift and ultimate transport of constituents than tides.

Tides are, however, still important in hydrodynamic models of this type. Tidal currents often have some asymmetry and do result in net transport. In addition, water quality constituents get moved through non-tidal flow fields during each tidal excursion which is an important part of the advection process.

The modelling uses the SCHISM model which is a well-established industry standard for hydrodynamic modelling and is appropriate for use in this study.

Hydrodynamic Modelling Setup

The model simulates a 10-year hindcast period. The 10-year period is Jan 2011 to Jan 2021 (Remy Zyngfogel., pers. comm., 24 Sep 2025). This provides an ample model period to quantify current characteristics in Foveaux Strait. We recommend that the modelled period should be added to the report.

Boundary condition sources are all industry standard products and are appropriate for use in a modelling study of this type.

The model bathymetry uses global bathymetric datasets along with LINZ hydrographic chart data and local MBES data. The LINZ chart data (Figure 1) provides reasonable coverage over the model domain. It would be useful to have the coverage of the MBES data presented in the report. The model domain uses a flexible mesh approach and resolution up to 30 m over the study site which is appropriate for this type of modelling exercise.

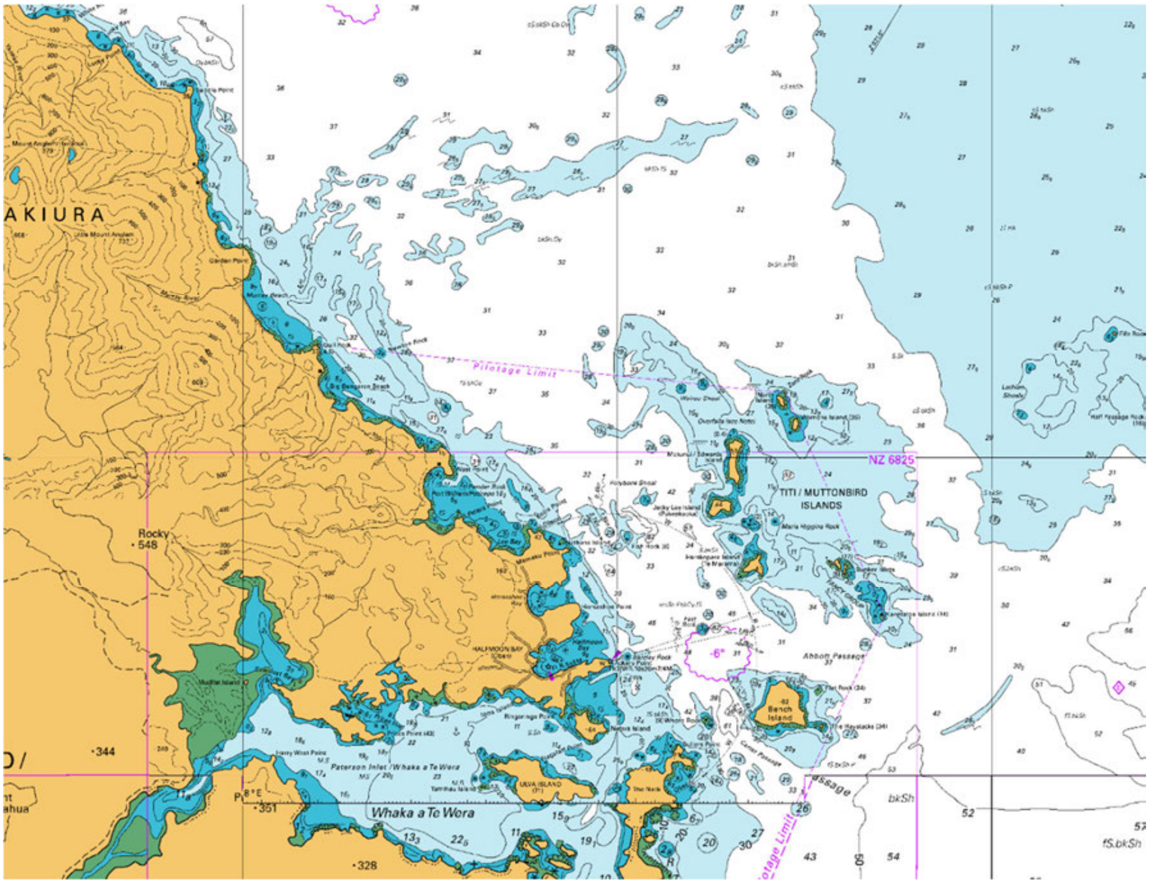

Figure 1: LINZ chart coverage over the broader study area.

The model uses 20 vertical layers with higher resolution near the surface. This is an appropriate number of layers and approach to layer thickness.

The model does not explicitly include Horizontal Eddy Viscosity (HEV) (Remy Zyngfogel., pers. comm., 22 Sep 2025) and rather it relies on a Shapiro filtering to introduce numerical diffusion into the model which is dependent on the resolution of the model grid. While this implementation in SCHISM is discussed in (Zhang et al, 2016), HEV is usually included in hydrodynamic models, and the report would benefit from further justification of this approach.

Hydrodynamic Modelling Validation/Calibration

The model has been calibrated against various sea level and current datasets. These include data from two ADCPs (P1 and P2) and the Bluff tide gauge. A third downward ADCP (P2) is discussed but not used due to data quality issues. Such data quality issues are not uncommon when using downward looking ADCPs.

It appears that the measured datasets have been used to tune the model. If this is the case, we would therefore recommend that the relevant sections be referred to as ‘calibration’ rather than ‘validation’.

The water level calibration at Bluff is excellent. The modelled and measured sea levels are less aligned at the P3 site. The report notes that the record at P3 has not been pressure corrected. We recommend that pressure correction be undertaken for the measured record using a hindcast product. The previous modelling report, Campos et al (2020) provide a sea level comparison at P3 and appear to obtain a better description of tidal sea level at the P3 location. While this may be in part due to the inclusion of atmospheric pressure in the current analysis, it appears that some of the model constituents may not be fully described by the model at this location. We note that for subsequent use in water quality modelling, the modelled water levels are less important than modelled currents.

Comparison of modelled total current speeds against measured values indicates much improved model performance compared with Campos et al (2020). Q-Q plots indicate that the distribution of modelled total current speeds is generally similar to that of the measured values. At P3, near the bed, the model slightly overestimates current speeds when flows are strong. At mid-depth and the surface, the measured and modelled distributions align closely. At P1 the Q-Q-plots show that the distributions of nearbed, mid-depth and surface total current speeds are similar. However, it is worth noting that at P1 near the bed (Figure 3.8), the line plot indicates that the strongest measured currents are generally larger than the strongest modelled currents. This does not appear to be reflected in the Q-Q plot. Similarly, in Figure 3.9, the measured total current speed frequently approaches 0 m/s throughout the record whereas the modelled currents rarely do so. Nonetheless the Q-Q plot shows strong agreement at lower percentiles which seems unexpected. The author (Remy Zyngfogel., pers. comm., 19 Sep 2025) suggested that this may be because the model outputs are available only hourly, and thus sometimes miss the exact timing of slack water. We recommend that some wording to this effect be added to the report. With the exception of this issue, the total current speeds are well represented by the model.

Comparisons of measured and modelled residual current time series at P3 and P1 are shown in Figures 3.7 and 3.10, respectively. The time series plots indicate that the model does not reproduce the observed sequence of variability particularly well, with peaks and troughs often occurring at different times. The Q-Q plots show that the model generally reproduces the overall distribution and magnitude of residual current speeds, although there are some systematic deviations. At P3, the model slightly overestimates residual current speeds near the bed. Similarly, at P1, the model slightly overestimates current speeds at both the near-bed and mid-depth locations. This suggests that, while the timing of individual events may not be accurately represented, the model provides a reasonably reliable characterization of the typical strength and variability of residual currents. Residual current directions are not presented in the analysis and should be included to provide a more complete assessment of model performance.

Figure 3.13 shows useful images of residual current speeds and magnitudes. We recommend that the residual current directions at P1 and P3 also be added to these images as arrow annotations.

Depth averaged progressive vector diagrams provide a useful comparison between measured and modelled residual currents. These are presented only for depth-averaged residual currents. The measured and modelled residual currents deviate near the start of the model run but exhibit much more similar behaviour after this initial period. While additional analysis of residual current directions through the water column would be beneficial (see previous comments), the progressive vector diagrams indicate that the model broadly captures residual current behaviour.

The report does not contain analysis of the expected effects of climate change. The report would benefit from a discussion of expected effects of climate change on predicted current patterns.

Apart from the issues raised above, the modelling appears robust and provides a suitable basis for subsequent water quality modelling. If being used for seabed deposition modelling, the modellers should assess whether wave action, in addition to the hydrodynamic model, needs to be considered.

Review of Comments from John Oldman

Oldman (2021) provided a number of comments around the hydrodynamic modelling. Here we address the main comments with reference to the updated modelling.

Issue: Quantification of the performance of the hydrodynamic model in terms of predicted currents (Appendix 4, Campos et al. 2020) would appear to only consider depth-averaged currents

The updated modelling provides analysis of current speeds at the surface mid water column and nearbed. This provides an improved level of analysis of model performance.

Issue: The [Q-Q]plots show that the model, on average, consistently overpredicts depth-averaged currents across the range of observed currents at the three sites by around 20%

Q-Q plots are presented in the analysis of the updated modelling. While there are some apparent inconsistencies between the timeseries plots and the Q-Q plots. These plots show improvement over the previous modelling.

Issue: There is no quantification of the errors in the near-bed currents so the errors relating to how far particulate material may move cannot be determined.

Quantification of errors in nearbed currents has been provided for the updated modelling.

Issue: Data in Figure 5-10 of Appendix D, Campos et al. (2020) show predicted residual surface and near-bed currents moving in different directions, whereas the observations show relatively uniform current direction for surface and near-bed currents. This has clear implications in terms of the movement passive tracers in the water column.

The updated model report would benefit from further analysis of residual current direction.

Issue: [The model] only considers conditions in Foveaux Strait over relatively short time frames (i.e. days–weeks) and there is no discussion of how representative (or otherwise) the chosen periods are in the context of the potential highly variable nature of the hydrodynamics of the area.

The updated modelling simulated hydrodynamics for a 10-year period. This is ample for characterising current speeds in Foveaux Strait.

Yours sincerely,

[redacted]

Dougal Greer
Director and Senior Consultant
ORCAS Consulting Ltd.

References

Zhang, Y. J., Ye, F., Stanev, E. V., & Grashorn, S. (2016). Seamless cross-scale modeling with SCHISM. Ocean Modelling, 102, 64-81.

Appendix F Response to Hydrodynamic Review

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

6 November 2025

OCEANUM

8 October 2025

SLR Ltd
Reid Forrest
6a Cambridge Street, Nelson
New Zealand, 7020

Re: Response to the paper review of Oceanum Report P25-05-01 (Oceanographic Modelling for the Proposed Hananui Aquaculture Project in Te Ara a Kiwa - Report One)

Dear Reid,

We have appreciated the constructive peer review comments made by Mr Greer, and make note of his recommendations and how we have addressed them, as follows:

The modelled hindcast period (2011–2021) should be clearly presented in the report.

- The modelled hindcast period is now clearly presented in Section 4.

The coverage of MBES bathymetric data should be shown alongside the LINZ chart data.

- The coverage of the MBES data collected at and around the proposed site is now presented in Figure 2.2.

Justification for the implementation of Horizontal Eddy Viscosity (HEV) should be provided to explain its omission or treatment in the model.

- Further detail around HEV was added to Section 2.3 to address this.

Sections describing model/observed data comparisons should be referred to as 'calibration' rather than 'validation' where the model has been adjusted to improve performance.

- Further clarification has been provided in Section 3 and terminology has been updated where appropriate.

The P3 sea level record should include pressure correction using hindcast products.

- This has been addressed in Figure 3.3

Wording should be included to clarify that hourly model outputs may miss slack or peak flow events, and the implications of this for the QQ plots.

- The caption on Figure 3.6 has been modified to clarify this.

Analysis of modelled residual current directions should be included to provide a more complete assessment of performance.

- The PVDs provide a quantification of this, and the discussion in Section 3.3 makes note of the low / rotating residual flows in the ADCP locations.

Residual current direction arrows at P1 and P3 should be added to the relevant plots.

- Figure 3.13 nas been updated to show residual current directions.

Sincerely

[redacted]

Dr Peter McComb
Managing Director
Oceanum Ltd

Appendix G Water Column Assessment Review

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

6 November 2025

SLR

Peer review of Assessment of "Water column Assessment Hananui Aquaculture Project, Ngai Tahu Seafood, SLR Project No.: 840.030141.00001).

Nigel Keeley

Also provided to me for background information were:

- Appendix C – Hydrodynamic model
- Appendix D – WQ modelling report
- Appendix E – Hydrodynamic model review
- Appendix F – Response to hydrodynamic modelling

NB: the modelling reports were provided for context only and have been reviewed by other parties.

NB: In the absence of any specific questions to address, I have undertaken a general read through and highlighted any potential technical issues or errors, limitations or inadequacies that arise.

Synopsis & comments:

Overall, I agree with the authors findings about the relative significance (or more appropriately insignificance) of the nutrient discharges from the farm in relation to the receiving environment and the potential for subsequent downstream ecological effects. The proposed Hananui farm area is a highly dispersive site closely connected to very large and dynamic water bodies, leaving little scope for nutrients to accumulate sufficiently to cause appreciable changes to the local oxygen status or water column ecology. This, however, does not negate the need for staged development coupled with a strategic monitoring program to safeguard against the unforeseen, at least in the short-medium-term. In my opinion, the primary areas of interest from a water quality perspective, albeit assessed to be at low risk by the model, would be the less dynamic, more sheltered neighbouring coastal embayment's.

Water column sampling periods (for my clarification):

- Sampled 10 stations (3 outer – channel, 4 embayment's, 3 at lease)
- Oct 2018, Dec 2019 (should this be 2018?), Dec 2019. (autumn – summer)
    - Water profiles, 7 depth bins
    - TN, TAN, NNN, TP and DRP
    - Time over which sample were collected on each survey? Standardized to tidal cycle? 1 day? Multiple days?
- March, May, and July 2025 (spring – winter)

- High freq sensor at 2 depths: 5m below survey, 2m above seabed
- Same nutrients + Cond., DO, Sal., ORP, turb. pH and temp.

Specific comments and questions:

Are you able to find any further information on the source of the nitrogen pulses to the area? This seems like an important (and unusual) site characteristic that warrants better understanding. Especially as it pertains to temporal variability (time scales) with respect to your sampling design. From what I can see, the position of the convergence zone between subtropical and subantarctic fronts could be part of the picture. Subantarctic currents can be nutrient rich and upwell near that area. Internal tides are also a possible influencing factor? Good to get a better handle on the relevant process/es for site management purposes – but I accept, this maybe more of a fundamental research question (i.e., beyond the scope of the application) as the overall take home message stands, i.e. that the extraneous farm nutrients are likely insignificant.

The temporal dynamics of the natural variations are important for setting the temporal timeframe for monitoring (in addition to the spatial component). Tidal? Seasonal? Climatic? SOI? Others, like internal waves?

If possible, set these findings in the context of the oceanographic climate at the point of sampling? Without which, you are basically doing the assessment blindfolded.

Section 2.3.5.1 Interesting and I agree with the conclusion on this, but also raises the question of where are the nutrients and possible downstream effects (chl a) going? Just dispersed, mixed diluted and assimilated in Foveaux Strait? Somewhere it would be good to have some perspective about the predominant direction of current flows what the fate might be?

P8: Useful to give a measure of variance about the means in the text?

P28, last para. Worst case scenario here seems to be related to TN near to the farm during periods of slack tide, when background levels are naturally low (lowest you measured was 78, correct?). In this case, farm nutrients could contribute to background by 41%. Would that be an issue? Probably not due to flushing? Could there be a scenario whereby the farm nutrients maintain a low-level supply during the troughs (in natural supply), thereby maintain certain populations of plankton for more rapid response when the natural fluxes come? I would add to that, you currently don't know how low (or high) TN actually gets naturally. Are there periods when it is negligible?

I am not overly surprised about how low the farm contribution is predicted to be, but I will attach a reference to a report from Storm Bay (comparable dispersive site in Tasmania) which appears to have similar natural TN concentrations (250-300 ug/L). The modelling work they undertook showed appreciable farm contributions in terms of surface DIN (Strain et al. 2023). That was based on the addition of 2k tonnes of nitrogen. I am not sure how this total input compares and will stop short of doing my own back of the envelope calculations or going back into the Oceanum dilution model to check. Just something for you to be aware of and maybe crosscheck yourself. The report also provides some potentially useful findings regarding monitoring designs.

Perhaps it is useful to also present the model output figures (aka Figs 16 & 17) as % contribution of TN relative to background, for the two survey periods?

Regarding S 3.1.1.1: I would still recommend some sort of visual monitoring program in these bays. I don't think we know everything about what a small but persistent / stable increase in N does for production and subsequent environmental biodeposition in neighbouring quiescent bays. This could be coupled with 16S eDNA monitoring (b-MBI - see the benthic report), and potential compound specific isotopes, which can discern farm influences.

Regarding HAB's: it would be prudent to start a monitoring program for this sooner rather than later to establish a meaningful pre-farm baseline at the embayment localities. This would normal require more than 1 year of data collection… (depending on the temporal cycle of the dominant driving force – mentioned above)

Section 3.1.4: "…lower water column from remineralisation are extremely low, with predicted values less than 0.8 µg/L…" Per what? From a 25 day cycle run? Is this a constant addition at stable state? Please clarify? It would be useful to see some rates per unit area to crosscheck this against measured fluxes.

Figure 20: I think this would be better expressed as % saturation, both for ecological relevance and interpretation for the lay-person?

Section 3.2.3: last para. Largely agree, but not entirely true. ES5 equivalent sediments (permitted) will have a substantial oxygen demand. If you were to take a core and incubate it, it would crash the DO in minutes. So it is mainly mitigated by flow, unlimited O_2 delivery and mixing.

Recommendations:

Pressing (prior to submission)

- Do a quick deeper dive into the oceanography of the area to better understand temporal dynamics of water movements and nutrient delivery.
- Use the above to give some broader context to the two sampling periods.
- Present the model figures (aka Figs 16 & 17) also as % contribution of TN relative to background, for the two survey periods
- Ensure some sort of sensible monitoring program in neighbouring embayment's. (this may ultimately fall under the benthic monitoring program)

Useful to resolve going forward (i.e. at baseline or during ongoing monitoring)

- Consider undertaking a temporal WQ sampling program spanning various time periods form short to long-term.
- Consider timeline for pre-farm baseline for HAB's in neighbouring embayment's (start monitoring soon)
- Farm will need an HAB monitoring program (I see already suggested)
- The water quality monitoring program should demonstrate how it deals with temporal variability – you have shown that the M2 tidal component has a big influence, as does stronger current mixing events. Large anticyclones (storm surge) and long-period wave events will also have a big influence. Should you constrain when you measure for relevance and comparability?

Strain E, White C, Hartog M, Hortle J, Coutts A, Brasier M, Hadley S, Ross J (2023) An evaluation of the sampling parameters and design for assessing the performance of salmon aquaculture. December 2023. In: FRDC Project No 2018/131

Appendix H Response to Water Column Assessment Review

Water Column Assessment

Hananui Aquaculture Project

Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

6 November 2025

SLR Consulting New Zealand Limited
Level 2, 214 Collingwood Street, Hamilton 3204, New Zealand

31 October 2025

SLR Ref No.: 840.030141.00001_L01_v1.0_Response to Water Column Assessment Review_20251031.docx

Attention: Thomas Hildebrand
Ngāi Tahu Seafood

SLR Project No.: 840.030141.00001

RE: Hananui Aquaculture Project Response to Water Column Assessment

SLR Consulting New Zealand Limited (**SLR**), on behalf of Ngāi Tahu Seafood, engaged Dr Nigel Keeley to conduct a technical peer review of the Water Column Assessment prepared to support the resource consent application for the Hananui Aquaculture Project. The letter prepared by Dr Keeley is presented in Appendix G of the Water Column Assessment.

Our responses to his review comments, including changes incorporated into version 1.1 of the Water Column Assessment, are detailed below.

Dr Keeley Comment	Response
Are you able to find any further information on the source of the nitrogen pulses to the area? This seems like an important (and unusual) site characteristic that warrants better understanding. Especially as it pertains to temporal variability (time scales) with respect to your sampling design. From what I can see, the position of the convergence zone between subtropical and subantarctic fronts could be part of the picture. Subantarctic currents can be nutrient rich and upwell near that area. Internal tides are also a possible influencing factor? Good to get a better handle on the relevant process/es for site management purposes – but I accept, this maybe more of a fundamental research question (i.e., beyond the scope of the application) as the overall take home message stands, i.e. that the extraneous farm nutrients are likely insignificant.	As noted in Dr Keeley's comment, we agree that defining the specific source of the high background nitrogen concentrations is more of a fundamental research question and not essential for consenting purposes. However, further information has now been provided in the SLR report on the potential source of nutrients from upwelling and the sub-Antarctic current (Sections 2.2 and 2.3.1).
The temporal dynamics of the natural variations are important for setting the temporal timeframe for monitoring (in addition to the spatial component). Tidal? Seasonal? Climatic? SOI? Others, like internal waves?	Monthly water quality monitoring is recommended (Section 4.1) and will be included in a Baseline Monitoring Plan (BLMP) and Environmental Monitoring and Management Plan (EMMP) (required by draft conditions 70 and 75). Monthly frequency will accommodate assessments of temporal changes, including seasonal, climatic, etc.

Dr Keeley Comment	Response
If possible, set these findings in the context of the oceanographic climate at the point of sampling? Without which, you are basically doing the assessment blindfolded	Additional information has been provided in Section 2.3.1 about the El Niño–Southern Oscillation (ENSO) state during each of the sampling years and the potential influence of the nutrient-rich Southland Current and sub-Antarctic waters. As noted in Dr Keeley's earlier comment, we consider the assessment of a specific source of the high background nitrogen concentrations to be more of a fundamental research question and not essential for consenting purposes.
Section 2.3.5.1 Interesting and I agree with the conclusion on this, but also raises the question of where are the nutrients and possible downstream effects (chl a) going? Just dispersed, mixed diluted and assimilated in Foveaux Strait? Somewhere it would be good to have some perspective about the predominant direction of current flows what the fate might be?	As noted in the report (Section 2.3.5.1), the high flow speed in the Foveaux Strait do not provide ideal conditions for algal blooms. Due to the high flow and mixing, nutrients and phytoplankton will be primarily transported out of Foveaux Strait into the surrounding waters. Text has been added to this section to clarify.
P8: Useful to give a measure of variance about the means in the text?	The range of measurements has been included as text in footnotes in v1.1 of the report. SLR notes that the range of data is also visualised in Figure 6 following this paragraph.
P28, last para. Worst case scenario here seems to be related to TN near to the farm during periods of slack tide, when background levels are naturally low (lowest you measured was 78, correct?). In this case, farm nutrients could contribute to background by 41%. Would that be an issue? Probably not due to flushing? Could there be a scenario whereby the farm nutrients maintain a low-level supply during the troughs (in natural supply), thereby maintain certain populations of plankton for more rapid response when the natural fluxes come? I would add to that, you currently don't know how low (or high) TN actually gets naturally. Are there periods when it is negligible?	Further text has been added to this section (3.1.2) acknowledging the elevated TN concentrations following a slack tide and the flushing that occurs shortly afterwards.
Perhaps it is useful to also present the model output figures (aka Figs 16 & 17) as % contribution of TN relative to background, for the two survey periods?	New Figures have been prepared and included in v1.1 of the report (new Figures 18 and 19).
Regarding S 3.1.1.1: I would still recommend some sort of visual monitoring program in these bays. I don't think we know everything about what a small but persistent / stable increase in N does for production and subsequent environmental biodeposition in neighbouring quiescent bays. This could be coupled with 16S eDNA monitoring (b-MBI - see the benthic report), and potential compound specific isotopes, which can discern farm influences.	A requirement to record visual observations can be included in the Environmental Monitoring Plan.

Dr Keeley Comment	Response
Regarding HAB's: it would be prudent to start a monitoring program for this sooner rather than later to establish a meaningful pre-farm baseline at the embayment localities. This would normal require more than 1 year of data collection… (depending on the temporal cycle of the dominant driving force – mentioned above)	The Baseline Monitoring Plan (BLMP; required by draft condition 70) will include one year of baseline water quality monitoring, including phytoplankton, prior to any farmed fish being introduced to the site.
Section 3.1.4: "…lower water column from remineralisation are extremely low, with predicted values less than 0.8 µg/L…" Per what? From a 25 day cycle run? Is this a constant addition at stable state? Please clarify? It would be useful to see some rates per unit area to crosscheck this against measured fluxes.	These values are the predicted concentration change from background as a result of remineralisation rather than the flux of nitrogen from the seabed into the water column. Phrasing has been tweaked in Section 3.1.4 to clarify.
Figure 20: I think this would be better expressed as % saturation, both for ecological relevance and interpretation for the lay-person?	Due to how the model was run, this would not be a simple exercise. As the thresholds for adverse effects on aquatic organisms and the recommended trigger values are presented in mg/L, SLR considers this plot to be appropriate to represent the level of change. An additional sentence has been added to Section 3.2.1 to show what the equivalent change in % saturation would be.
Section 3.2.3: last para. Largely agree, but not entirely true. ES5 equivalent sediments (permitted) will have a substantial oxygen demand. If you were to take a core and incubate it, it would crash the DO in minutes. So it is mainly mitigated by flow, unlimited O_2 delivery and mixing.	Further text has been added to Sections 3.2.2 and 3.2.2 to acknowledge this point.

Dr Keeley also provided recommendations. Some of these are addressed by specific comments above, but area also included here for completeness.

Dr Keeley Comment	Response
Pressing (prior to submission)	
Do a quick deeper dive into the oceanography of the area to better understand temporal dynamics of water movements and nutrient delivery.	Further information on the potential source of nutrients from upwelling and the sub-Antarctic current has been included in Sections 2.2 and 2.3.1.
Use the above to give some broader context to the two sampling periods.	Additional information has been provided in Section 2.3.1 about the El Niño–Southern Oscillation (ENSO) state during each of the sampling years and the potential influence of the nutrient-rich Southland Current and sub-Antarctic waters.
Present the model figures (aka Figs 16 & 17) also as % contribution of TN relative to background, for the two survey periods	Included as new Figures 18 and 19.

Dr Keeley Comment	Response
Ensure some sort of sensible monitoring program in neighbouring embayment's. (this may ultimately fall under the benthic monitoring program)	A new Section 4.1 has been added to the monitoring recommendations requiring sites to be located in nearby sheltered embayments.
Useful to resolve going forward (i.e. at baseline or during ongoing monitoring)	
Consider undertaking a temporal WQ sampling program spanning various time periods form short to long-term.	Monthly baseline monitoring is proposed in draft condition 37(c) and ongoing monitoring will be required in the Environmental Monitoring and Management Plan. This sufficiently addresses this point.
Consider timeline for pre-farm baseline for HAB's in neighbouring embayment's (start monitoring soon)	One year of baseline water quality monitoring, including phytoplankton, will be required prior to fish being introduced at the site (draft condition 70).
Farm will need an HAB monitoring program (I see already suggested)	One year of baseline water quality monitoring, including phytoplankton species known to be associated with HAB's, will be required prior to fish being introduced at the site (draft condition 70).
The water quality monitoring program should demonstrate how it deals with temporal variability – you have shown that the M2 tidal component has a big influence, as does stronger current mixing events. Large anticyclones (storm surge) and long-period wave events will also have a big influence. Should you constrain when you measure for relevance and comparability?	Additional text has been included in Section 4.0 to clarify the recommended sampling timeframe (avoiding sampling at slack tide). SLR notes that sampling is unlikely to be conducted during storm events to unacceptable health and safety risk.

Regards,

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[redacted]

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