Before Southland Regional Council

APP-20157616-V1

under: the Resource Management Act 1991

in the matter of: Applications by Sanford Limited to change the conditions of various resource consents that authorise the farming of salmon in Big Glory Bay, Stewart Island

by: **Sanford Limited**
Applicant

Statement of evidence by Neil David Hartstein

Dated: 11 March 2019

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CHAPMAN TRIPP

INTRODUCTION

1 My full name is Neil David Hartstein. I reside at Kota Kinabalu, Sabah Malaysia. I am currently a Director and senior oceanographer at Aquadynamic Solutions Sdn Bhd (*ADS*).

QUALIFICATIONS AND EXPERIENCE

2 I hold the degrees of Bachelor of Science (1996) and Master of Science (1999), both from the Earth Sciences Department of Victoria University of Wellington and Doctor of Philosophy (2003) from Auckland University in the field of hydrodynamic modelling of the marine environment.

3 I am the founder and Managing Director of ADS, a specialist Malaysia-based marine sciences consulting practice that I established in 2012. Our firm specialises in undertaking detailed hydrodynamic computer modelling of coastal processes, with particular expertise and experience in modelling the effects of finfish farms on marine water quality and the benthic environment. We also have extensive experience in monitoring the effects of aquaculture developments, including in Big Glory Bay, on behalf of Sanford.

4 Prior to establishing my own firm I worked in the field of hydrodynamic modelling at the Danish Hydraulic Institute and prior to that at the National Institute of Water and Atmospheric Research (*NIWA*). I have some 18 years' experience in this field.

5 I have published 12 peer review publications relating to aquaculture environmental impacts.

6 In addition to the peer review papers, I have written more than 75 reports relating to aquaculture environmental interactions and have recently (2017/2018) undertaken several studies on the proposed marine farms in Storm Bay and Okehampton Bay (a multi-trophic farm), both of which are situated in Tasmania. I have also (in 2018) participated in both pelagic and benthic oxygen consumption studies in Macquarie Harbour. I have organized monitoring programmes and have analysed extensive datasets on the hydrodynamic interactions of aquaculture farms, benthic and water quality effects and sedimentation impacts for both government and aquaculture industry funded projects.

7 Over the past 15 years I have undertaken hydrodynamic, productivity, ecological and sediment assessments of more than 50 proposed and existing marine farm sites in New Zealand, Singapore, Canada, Oman, Brunei, Indonesia, Cambodia, Australia and Malaysia.

8 I have also written more than 100 additional reports on a wide range of topics including coastal erosion, sand sourcing, habitat mapping, environmental monitoring programs for oil and gas field developments as well as river and lake environmental related studies. In addition I have

appeared before the Environmental Court five times in relation to aquaculture developments and I gave evidence before the New Zealand King Salmon Board of Inquiry. I have also provided evidence as an expert witness before an Australian Federal aquaculture enquiry in 2016.

9 I have a detailed knowledge of the hydrodynamic environment in Big Glory Bay, and the ecosystems that are found there. Myself and my colleagues at ADS have undertaken 7 monitoring surveys of the Bay, and I have personally examined the seabed across the bay on 6 occasions.

10 In respect of the applications being considered here, I undertook the detailed modelling of Big Glory Bay that was used to support the applications (and which was appended to the Assessment of Environmental Effects).

CODE OF CONDUCT

11 Although these proceedings are not before the Environment Court I have read the Environment Court's Code of Conduct for Expert Witnesses and I agree to comply with it as if these proceedings were before the Court. My qualifications as an expert are set out above. I confirm that the issues addressed in this brief of evidence are within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed.

SCOPE OF EVIDENCE

12 The purpose of my evidence is to set out:

12.1 A summary of the environmental conditions in Big Glory Bay noting that **Dr James** has focused on this in greater detail in his evidence;

12.2 An explanation of the modelling I have undertaken, and the results obtained;

12.3 Based, on those results, why I consider the proposal is ecologically sustainable;

12.4 A summary of the monitoring that I consider would be prudent, noting that **Dr James** addresses this in greater detail in his evidence, while the proposed conditions of consent are addressed by **Dr Mitchell**;

12.5 My response to matters raised in submissions and in the section 42A report; and

12.6 My summary and conclusions.

BIG GLORY BAY ENVIRONMENT – WATER COLUMN AND SEABED

Water column

13 Big Glory Bay (*BGB* or *the Bay*) is located on the east side of Stewart Island, New Zealand and shares a channel with Paterson Inlet connecting it to Foveaux Strait (Figure 1). The bay is about 12km^2 in area and the mouth of the bay is 700 meters wide. BGB is sheltered and well protected from ocean derived waves.

14 Bathymetry in BGB is comparatively flat, and the bay has an average depth of approximately 20 meters. Shallow rocky reefs lie along the northern and southern sides of the bay. Along the western shoreline there is a flat shallow area (<6m deep and approximately 2.5km2) which appears to have been formed by riverine deposition. Currents within the bay are low (generally less than 5cm s-1) and stronger towards the mouth of the bay.

15 There is little, if any fresh water input into the Bay and one main stream with an estimated flow of approximately 1 cubic meter (Pridmore 1995). The catchment itself is mostly forested and there is very little nutrient run off. However, over the last 30 years there have been several upwelling events (outside of BGB) which have brought high levels of organic nitrogen compounds into the bay which can stimulate phytoplankton growth.

16 During 2016 and 2017 Total Ammonia Nitrogen (*TAN*) measurements have been collected as part of Sanford's monthly water quality monitoring program. The values display a clear seasonal cycle, with average values ranging between below the detection limit (< 10 µg L-1) and 38 µg L-1 in spring/summer, and between 15.5 µg L-1 and 58.5 µg L-1 in autumn/winter (Figure 2).

17 These values are similar to values previously reported in various documents and summarized in the literature review of DHI, 2010. A mussel monitoring programme (Stenton-Dozey and Brown, 2010) showed TAN values ranging between below detectable level (< 1 µg L-1) and 81 µg L-1; further back in time, Pridmore (1995) recorded available Nitrogen (equivalent to the sum of TAN and Nitrate, i.e. nitrogen available for plankton growth) between 60 µg L-1 in summer and close to 200 µg L-1 at the end of winter.

18 Estimated Total Nitrogen (which does not include Dissolved Organic Nitrogen) calculated from the same recent ongoing monitoring dataset has been observed to vary month to month from 20 to 170 µg L-1 (Figure 3). This is similar to observations made in the 1980's and 1990's.

19 For the same period (2012-2017), average monthly chlorophyll-a values have varied between 0.3 µg L-1 and 6.5 µg L-1 (Figure 4). In the past, the mussel monitoring programme has shown summer chlorophyll-a values ranging between 0.4 and 6.7 µg L-1, again a very similar range. In Pridmore, 1992, chlorophyll-a values of 9 µg L-1 were reported in 1989.

20 Overall, both from a nutrient and a chlorophyll-a (proxy for algae biomass) perspective, the environmental conditions appear to have remained similar if not identical for nearly 30 years, despite the significant increases in farmed fish biomass.

21 Oxygen levels, a requirement for life and healthy environmental conditions, are high and generally observed between 6 and 9 mg L-1 depending on the season (ADS, 2016 & 2017)..

Benthic environment

22 The benthic environment has been described in some detail (in **Dr James**' evidence including the recent surveys which I have undertaken over the last 3 years) so I will not go into that detail here other than to describe briefly the seabed environment based on our observations.

23 Sediments across the Bay vary greatly from predominately mud and sand in the middle of the Bay to mostly sand and some mud and coarser clasts around the bay edges. Mud dominates at the westerns end of the bay near the mouth of the only sizable stream. Organic content can vary considerably with generally higher levels found beneath the farms i.e. 6-10%, though similar levels have also been observed at the control sites especially control station M located at the head of the bay, (Figure 6).

24 A wide range of benthic invertebrates have been observed within BGB including polychaetes, gastropods, malacostraca and bivalve. Total abundance and diversity can vary from year and seasonal. Benthic diversity appears to greatest near the mouth of BGB and around the edges of the bay.

25 Organic deposition (i.e. faeces) has been observed under all finfish sites but little or no deposition has been observed 50 or 100 meters from the edge of the cages. Under the farm sediments are dominated by opportunistic polychaete worms such as Dorvilleid which act to break down organic inputs and re-oxygenate the sediments. Generally under the farms diversity is low but abundance can be higher than control sites and other areas of the bay. Such observations are similar to those I have observed across numerous farm sites around the world.

MODEL DESCRIPTION AND RESULTS

Introduction

26 Impacts to the water column and seabed are the primary components of any assessment dealing with open cage aquaculture. The fate of both soluble (in the form of inorganic nitrogen) and solid wastes (faeces and feed) released by farming operations is determined by the flow conditions prevailing at the farm location.

27 Predicting potential impacts requires not only knowledge about the current, or historic flow conditions, but also the ability to predict future conditions or farming scenarios. Hydrodynamic models are used to simulate any period

of time, provided that sufficient inputs of bathymetry for the model extent as well as forcings (tides, wind, etc.) are available. To make sure that the model is accurate a calibration/validation process is also required.

28 Hydrodynamics govern the prevailing patterns of flow at the area of interest, however hydrodynamic results are not sufficient by themselves to define the potential impacts to the water column and seabed. The current flow fields need to be associated with additional numerical modelling modules in order to simulate the fate of waste generated by the farms.

29 For this study we used DELFT3D which is a suite of modelling tools that have undergone over 30 years of development. DELFT3D offers the flexibility to develop numerical models of different dimensions (2D, 3D) and has a number of modules to answer almost any water related question.

30 These modules are grouped around a mutual interface, which allows for interaction between each module (Figure 7). The core module is Delft3D-FLOW.

31 Delft3D-FLOW is a multi-dimensional (2D or 3D) hydrodynamic (and transport) simulation program which calculates non-steady flow and transport phenomena that result from tidal and meteorological forcing on a rectilinear or a curvilinear, boundary fitted grid.

Hydrodynamic model

32 The hydrodynamic model is the core of the numerical modelling and is used to simulate water movement within Big Glory Bay and across the entire model domain. The hydrodynamic model was run for a period of one year to allow for full seasonal effects. Results of these simulations were also used to drive water movement within the water quality module.

33 Two model grids were created which comprise a larger scale regional 2D model to cover the waters around Stewart Island and a local 3D model that only covers the south-east of Stewart Island. Both the regional and local models were run for a period of one year from September 2015 to September 2016.

34 Boundary conditions (water level, wind, pressure, current speed and direction) for the local model were provided by the regional model (grid resolution of 1 km) whose domain covers the entire Stewart Island and its surrounding waters. This model included regional tidal, wind and current information provided by international recognised global models (see below for further description).

35 This regional model was used to transfer information to a smaller, but more detailed, local three-dimensional model that included the waters within Big Glory Bay and its immediate surrounds. Unlike the regional model, the local model could be used to account for both thermal stratification and variations in current speed and direction with depth.

36 The local model has a horizontal resolution of 40 meters in Big Glory Bay and is comprised of 10 vertical layers, with higher vertical resolution at the surface. Each layer in Big Glory Bay has an average thickness of approximately 2.3m, and ranges from approximately 1m at the surface to 4m towards the seabed. The extent for both grids is shown in Figure 8 and Figure 9. Orange lines show the transfer boundary between the local and regional model.

37 For the present study, regional drivers of wind, currents, and tide data (water level) are provided by high-quality, globally vetted models designed to be integrated into coastal hydrodynamic models, such as the one developed for this study (note data was extracted for the period between September 2015 and September 2016). The data extraction period matches the model run length of 1 year.

38 Regional and model boundary tide data (water level data) were provided by the Oregon State University's TOPEX/Poseidon Global Inverse Solution (**Egbert 1997; Egbert and Erofeeva 2002**), a global oceanic tidal model (Figure 10). Additional descriptions and detailed information concerning the TPXO model can be found at http://volkov.oce.orst.edu/tides/global.html

39 Offshore wind forcing's for the regional model are provided by the National Oceanic and Atmospheric Administration (*NOAA*) National Centre for Environmental Information (*NCEI*) Global Forecast System (*GFS*) model (Figure 11). The GFS is a weather forecast model that covers the entire globe at a base resolution of ~28 km and is used worldwide for weather predictions. Additional information concerning GFS data can be found at https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs.

40 Bathymetry data were obtained across the model domain from data collected by Land Information New Zealand and Sanford (within Big Glory Bay itself). A summary of the main data sources used to build both the regional and local hydrodynamic models is provided in Table 1.

Hydrodynamic model calibration

41 An accurate calibration is vital to ensuring the accuracy of the hydrodynamic model and its ability to simulate real world conditions within Big Glory Bay. The hydrodynamic model was calibrated against current speed and direction collected at two locations within the bay (see Figure 4 for ADCP locations) and water level from tidal harmonics in Paterson Inlet. The calibration period was from the 6th of September 2010 to the 22nd of September 2010. For Validation, the model was then run (without altering any parameters) and compared against ADCP and water level data collected from the 22nd of September to the 6th of October 2010.

42 At ADCP 1 (the mouth of Big Glory Bay) the model matches current speed well, though tends to slightly under predict the flow in places (Figure 12). When comparing the current direction between the model and actual ADCP measurements, there is a very good comparison (Figure 13). At ADCP 2 (to

the south and centre of the bay) there is a good comparison in places between modelled current speed and a relatively poor comparison in current direction (Figure 14 & Figure 15).

43 The reason that the current direction does not fully match reality at ADCP 2 is that there are numerous mussel farm and fish farm structures within Big Glory Bay. A number of studies have observed that such structures can affect localised current flow and current direction (**Hartstein 2003, Plew et al 2005, Stevens et al 2008**). It is beyond the capabilities of the model to take into account hundreds of mussel lines and other associated structures that can be found within the Big Glory Bay water column, noting that this has minimal implications for the overall modelling results.

44 The model utilised for this study replicates water level data collected from Paterson Inlet very well in terms of both amplitude and phase during spring and neap tidal periods (Figure 16).

45 Overall I consider that the model is well calibrated and fit for purpose.

46 Further details of the model calibration/validation process can be found in (ADS 2017c hydrodynamic modelling report).

Hydrodynamic model results

47 Representative depth averaged local current patterns (during Spring/October conditions) are presented for spring and neap ebb and flood tidal periods within Big Glory Bay (Figure 17). Model results show that average flow within the bay is weak (generally less than 5cm s-1) and that average flow is stronger (5-15-cm s-1) towards the mouth of the bay. Current direction is variable and there are several eddies within the bay. In all scenarios, there is a general mouth-ward flow along the northern banks of the embayment, as well as along the southern banks.

48 Representative seasonal regional model results are presented in Figure 18. Regional model results show that the regional flow is generally to the east around the bottom of Stewart Island and heads up along the east coast of the South Island.

49 As well as developing a hydrodynamic model that will be later used to simulate the fate of waste generated by the farms this model can also be used to estimate the retention/flushing time of BGB.

50 Flushing is defined as the average time it takes a conservative (not decaying over time due to biology or chemistry) substance to leave a water body (time it takes to fully exchange the water within Big Glory Bay).

51 Flushing time is important as this provides an indication of how rapidly oxygen and nutrients will be exchanged from within the farming area to the ocean. Faster flushing will result in more rapid diluting of nutrient releases (i.e. Total Ammonia Nitrogen for solute fish waste) within the Bay. The water outside of coastal embayments (like Big Glory Bay) generally has less

nutrients and more dissolved oxygen than the water inside the Bay, especially Total Ammonia Nitrogen which is rare at the surface of the ocean.

52 Previous attempts to estimate the retention time of Big Glory Bay by Rutherford et al. (1988) mentioned "10-13 days during light winds (<5 m s-1) to 7-9 days during moderate winds (5-10 m s-1)". These estimates were obtained solely on the basis of simple desktop calculations using the tidal prism and with the assumption that water leaving the bay does not return. The new estimates presented in this study correspond to more robust calculations based on physical equations and a calibrated three dimensional model.

53 In this part of the study, a conservative tracer was used to represent the entire water column of Big Glory Bay. The hydrodynamic model was then run to calculate how long this tracer takes to be exchanged (flushed out) with water from outside of the bay. Given that there may be seasonal differences in the flushing time, four flushing simulations were run to represent each season (Spring, Summer, Autumn and Winter). Each simulation was run for a period of 90 days.

54 The goal of this modelling exercise is to determine the number of days required for the tracer to be flushed out of the bay for each of the 4 seasons modelled (see Figure 19 to Figure 27). Results show that the flushing various little across seasons and is predominately tidally driven. After 28 days approximately 85-90% of water within Big Glory Bay has been flushed out. The remaining water is slowly transported out over the next 20-30 days or so. Results show that the initial exchange of the tracer is quite rapid and that the remaining 10-15% of the tracer takes considerably longer to be transported out of BGB.

WATER QUALITY MODELLING

Introduction

55 Once a calibrated/validated hydrodynamic model has been finalised, extra modules can be added (i.e. to combine the flow field with nutrient release) in order to define the concentrations of the effluent released from the farms. The carrying capacity of marine embayments for fish farming (from a water quality perspective) is limited by 2 main parameters: nutrients and oxygen and are hence the focus of the water quality assessment.

56 Nutrients refer to the soluble wastes released by the fish, while oxygen refers to the degradation of ambient oxygen conditions due to fish respiration. While oxygen is relatively straightforward (it involves no chemical reaction), the handling of nutrients need to consider the biogeochemical reactions that occur in the water column. The main limiting nutrient in marine systems is Nitrogen (**Boynton et al. 1982**). This was confirmed by analysis of the in-situ data. Hence the modelling of water quality impacts focused solely on Nitrogen. Solute N is released by the fish in the form of Total Ammonia Nitrogen (*TAN*), a term that corresponds to

both the innocuous ionized version of Ammonia (*NH4+*) and the toxic variety (*NH3-*).

57 DELFT3D's water quality module was used to predict the impacts of the farm-derived release of TAN, its impact on chlorophyll a and the consumption of dissolved oxygen as a result of expanded farming activities in Big Glory Bay. To accomplish this, a tracer approach was used which focuses solely on the excess loadings from the farms, while foregoing the natural background concentrations. This approach was used during the New Zealand King Salmon new permit application in the Marlborough Sounds. The use of a tracer can be considered conservative or worst case as there is no biological break down involved (which can act to reduce concentrations). In short a tracer highlights the maximum possible concentrations i.e. the worst case.

58 The modelling period remains the same as that of the local hydrodynamic model and runs from September 2015 to September 2016. A full description of the model set up can be found in (ADS 2017d).

59 In a tracer model, the aim is to simulate the excess concentrations of a particular effluent. Initial conditions (values that the model starts with) are typically set to 0 throughout the domain. This leads to a so-called "warm-up period" during which the model will adjust the start conditions towards a point at which the model is in "equilibrium". In order to prevent this, the water quality models were run once with initial conditions set to zero, and then a second time with starting conditions taken from the final time step of the first run (i.e. first day of September). This way, the initial conditions at the start of September are representative of the existing farm conditions. The initial conditions for oxygen are based on HYCOM model records and measurements collected in BGB.

Modelled scenarios and water quality assumptions

60 For the TAN release modelling, 2 scenarios were undertaken: Both of these scenarios are directly related to a cap of allowable nitrogen that could be released into BGB. These two scenarios are:

60.1 Mid-level expansion Scenario: Proposed scenario representative of farming releases of TAN under conditions just below the maximum carrying capacity. Total TAN release in this scenario into the system totalled 358.28 tons which corresponded to a feed input of 621.4 tons. The baseline oxygen drawdown was set to 8.85 tons day-1.

60.2 Higher-level expansion Scenario: Proposed scenario representative of a higher level of farming TAN release according to the current, but conservative assessment of Big Glory Bay's carrying capacity. Total TAN release in this scenario into the system totalled 381.2 tons which corresponded to a feed input of 659 tons. The baseline oxygen drawdown was set to 9.315 tons day-1.

61 All scenarios were based on feed data supplied by Skretting and Sanford in the form of monthly schedules (further information on feed information can be found in **Mr Wybourne's** evidence). The load inputs for the 2 scenarios expressed as tons of TAN and total N in the feed per month are presented in Table 2. The modelling assumed that 57.66 percent of the nitrogen in the feed would be converted into soluble Nitrogen in the form of TAN (this is based on Skretting's measurements). Concentrations of TAN were released every second within the model domain at the proposed cage locations (inside every cage) and at a depth of 5 meters (approximately the centre of each cage).

62 The remaining nitrogen is either released with faeces to the seabed or incorporated into the fish as part of the growth process. This relationship is described in further detail in the seabed modelling section. Three farms were modelled to represent the locations where the Nitrogen feed input of 621.4 and 659 tonnes will be released, these being the farms in use at the time the modelling was undertaken. These farms are MF246, MF320 and MF320 (their locations are depicted as square boxes in all water quality result figures).

63 Modelling of oxygen impacts consists of subtracting quantities of oxygen in farming sites based on fish respiration. The oxygen drawdown is set to match a daily feeding schedule with feeding occurring daily for approximately 30 minutes. The rates of oxygen consumption are in line with values from the literature which were also used in the previous carrying capacity assessment (DHI, 2010): 50 mgO2 kg fish-1 hour-1 for non-feeding time and 450 mgO2 kg fish-1 hour-1 during feeding. The high rates of oxygen consumption during feeding were adjusted to reflect the intense energy expenditure of the feeding process (fish swim faster). The final quantities of oxygen consumption in the model (Table 3) were based on the N release, using typical cage stocking rates varying between 12 and 14 kg m-3.

64 In addition to the TAN and oxygen modelling Chlorophyll-a was also examined. As a conservative worst case, all TAN has been assumed to be converted to phytoplankton biomass and represented by an increase in the chlorophyll-a concentration. In reality, only some nutrients will be used for plankton growth, as the nutrient seasonal cycle clearly shows that winter algae concentrations are generally depressed compared to spring and summer. Furthermore, while the sampling datasets show that levels of TAN are sometimes depleted below detectability, TAN levels rarely fall to zero. This shows that there are factors that limit algal consumption of nutrients.

65 Converting the TAN results from the model to chlorophyll-a was a two step process. First, the TAN (nitrogen) was converted to its C equivalent in plankton. This is done using the widely used Redfield ratio which corresponds to the statistical average composition of plankton in the sea, with a ratio of C to N of 106:16. The second step consists in calculating the amount of chlorophyll-a associated with algal C, using a C to Chlorophyll-a ratio for phytoplankton. The C to Chlorophyll-a ratio is subject to

significant variability. In the Marlborough Sounds, it was found to vary between 25 and 500 seasonally depending on the algal species composition (**Ren and Ross, 2005**). Data collected in Big Glory Bay varied between 1 and almost 900. Given this large variability, a C:Chl-a ratio was applied that is representative of average conditions within the bay. Based on the work Sathyendranath et al., 2005 and information on the various algae groups within the bay a value of 50 was selected.

WATER QUALITY AND MODELLING RESULTS

TAN and Chlorophyll-a

66 Water quality modelling shows that TAN levels would increase in Big Glory Bay by up to 30µg L-1 (Figure 27) during the maximum feeding scenario. Small TAN concentrations (less than 5 µg L-1) were also observed in Paterson Inlet. Details of the mid level scenario results can be found in (**ADS 2017d**), though increases are obviously less than during the maximum feeding scenario and it was predicted TAN would increase by up to 25µg L-.

67 For the maximum feeding scenario, the model is predicting Total N levels to increase by approximately 10% when compared to Total N observations made during Sanford’s monthly water quality monitoring program. Interestingly higher levels of available N (TAN and nitrate) have been recorded in the past (i.e. **Pridmore, 1995 <200 µg L-1**).

68 There is also evidence from the same Total N data that there is either (or both) a mechanism consuming N in the Bay, which could point at mussel consumption of plankton and particulates, and/or a large source of external influx N during Autumn-Winter.

69 Model results show an increase in chlorophyll-a of between 2 and 4 µg L-1 for the maximum feeding scenario (Figure 28). However, it is clear that this is an overestimation (especially during spring and summer) as mussels grown in the bay will contribute to keep the measured levels down (by consuming phytoplankton). The mid level scenario results show a chlorophyll-a increase of between 2-3.5 µg L-1

Oxygen

70 Dissolved oxygen effects from the model shows that there is no significant variation in dissolved oxygen drawdown between surface and bottom layers, except near the cage groups. There are predicted temperature driven seasonal variations in oxygen drawdown (Figure 29), with oxygen concentrations towards the end of summer and beginning of autumn reaching minimum values of close to 6 mg L-1 (Figure 30). Dissolved oxygen concentrations of this magnitude are needed to maintain healthy farmed salmon (Stein et al. 2013).

71 The difference between the two modelled scenarios is only marginal. Dissolved oxygen reductions are expected to reach 0.25mg L-1 inside the Bay and up to 1.5mg L-1 within the cages.

SEABED DEPOSITION

Introduction

72 Fish farming primarily impacts the seabed through over-enrichment of the benthos through the deposition of organic rich faeces and uneaten food wastes. This deposition results in a change to the seabed chemistry as these wastes are processed by the sediment microbial community. These bacteria utilise aerobic metabolic pathways and consume dissolved oxygen (DO) until the supply of DO is extinguished. After the available supply DO is exhausted, decomposition will occur via anaerobic pathways, the products of which are toxic compounds such as H2S (hydrogen sulphide) and NH4+/NH3 (ammonium/a, the sum of which is also referred to as Total Ammonia Nitrogen or TAN).

73 Shifts in the physiochemistry of sediments results in ecological shifts in the benthos whereby species rich, well-oxygenated sediment communities shift to species poor, but opportunistically dominated oxygen-poor sediment communities. Extreme organic enrichment of the seabed can lead sediments to become anoxic (devoid of oxygen). The severity of the impacts to the benthos is directly related to the degree of organic deposition.

74 At elevated enrichment levels, the overall diversity of the benthic infaunal communities begins to diminish, and become dominated by opportunistic fauna (albeit with much less diversity) (Figure 31). Peak faunal abundance occurs when diversity is in a decreased state, but it is at this state where the benthos has the greatest potential for processing farming wastes (Keeley and Taylor 2011). Beyond this stage of enrichment (i.e. greater organic matter deposition) the functional capacity for the benthos to process farm wastes diminishes as the infaunal biomass decreases until the benthos becomes azoic (devoid of life) and eventually shifts to an anaerobic state.

75 These effects are most prominent at the source of the enrichment (e.g. area of seabed impacted by farm wastes) and decrease with increasing distance / time from the enrichment source.

76 Depositional footprints (those areas of the seabed impacted by farming activities) associated with salmon farms are often used as a basis for management. The local bathymetry and hydrodynamic regime are the primary drivers controlling the shape, extent, and waste concentration of the deposition field. Depositional footprints associated with fish farms are often skewed in an elliptical pattern, fanning out in the direction of the prevailing currents and with the greatest deposition observed directly under the farm pens. Strong gradients in physiochemical conditions and ecological community composition/function occur along gradients in organic matter deposition. Pearson and Rosenberg (1978) and Hartstein and Stevens (2004) describe the ecological shifts in benthic faunal communities associated with farming deposition (Figure 31).

Model description and setup

77 Depositional footprints around farm sites were predicted using the software newDEPOMOD, a widely used and internationally recognized (**SEPA 2005, ASC 2012**) particle tracking model designed for predicting salmon farm deposition (**Cromey et al. 1998, Thetmeyer et al. 2003, Cromey and Black 2005, Cook et al. 2006, Magill et al. 2006**).

78 This software is a stand-alone package, meaning that it does not interface with DELFT3D, as described in the Water Quality Modelling section above. Instead, newDEPOMOD incorporates the same sources of data describing local bathymetry and current fields (using ADCP and Delft model extraction results) into its own particle tracking features as well as specific information regarding farming practices such as pen layouts, feed input, and stocking density.

79 The domain of this depositional model consisted of bathymetric data provided by C-Map and interpolated to 15m grid resolution. Specific location coordinates of the domain boundary along with the positions of the pens referenced by their respective permit number can be found in Figure 32.

80 This depositional model employed square pens 30m x 30m on each side and 15m deep (pen volume of 13,500 m3). While this basic pen design was shared among all the sites modelled, each site had a different number of pens (and resulting total pen volume on the site) and its own unique layout and orientation in the bay. Permit MF246 was modelled with 3 rows of 8 pens, giving this a total pen volume of 324,000 m3 (Table 4). Li320 was modelled with 2 rows of 5 pens giving a total pen volume of 135,000m3. Permit Li339 was modelled with 2 rows of 4 pens giving this site a total pen volume of 108,000m3.

81 Three farm locations have been modelled each with varying amounts of feed input. These permits are 246, 320, and 339 (Table 5).

82 For MFL246, two model simulations were undertaken. The first of these was to assume typical feed properties (feed without the use of binding agents) at a daily feeding rate of 18.6 tons. Stronger current flows observed at this site resulted in resuspension and subsequent scattering of feed and faeces wastes along the seabed. Upon observing this it was decided to try a second scenario that modelled the effect of a binding agent in the feed. Binding agents are added to the feed to ensure that the feed falls more rapidly (and is stickier so once on the seabed it is more difficult to erode) to the seabed thereby restricting the spread of the depositional footprint to areas within the farm site. The total yearly Nitrogen input is 415.1 tons which is representing the maximum potential carrying capacity of this site.

83 Stocking density was set to 12 kg m-3 for both scenarios for Permit MF246 and the mid-level stocking density scenario for Li320. The higher-level stocking density scenario for Li320 ran with 14 kg m-3. Both mid-level and higher-level stocking scenarios on Li339 were assumed to house smolts and

thus the stocking densities was set to 3 kg m-3 and 4.3 kg m-3 respectively. All pens assume a stock to feed ratio (average daily feed input divided by the annual stocking) of 0.479.

84 The DEPOMOD software computes the feed mass inputs and biomass for the pen internally based on pen volume, stocking density, and stock to feed ratio. Both scenarios (traditional feed and feed with binders) for MF246 were computed to have a daily feed input of 18.6 tons (Table 5). The mid-level stocking scenario for Li320 has a daily input of 7.76 tons and the higher-level stocking scenario was computed to have a daily feed input of 9.05 tons. Both the mid-level and higher-level stocking density scenarios for the smolt pens on Li339 had daily inputs of 1.55 tons and 2.1 tons respectively. Each of the scenarios use a stock to feed ratio of 0.479. Specific feed loadings, C and N content, computed biomass, and other input parameters can be found in Table 5 below.

85 Feed property data were provided by Skretting from a series of settling tank tests performed at the University of Tasmania Institute of Marine and Antarctic Studies in May 2017 (Ben Wybourne pers. comm).

86 DEPOMOD assumes that all feed inputs are distributed evenly across all pens from the duration of the model simulation; in this case the model simulated 1 year of farm faeces and feed waste deposition.

87 In practice feeding schedules and individual pen stocking will vary, with pens unevenly stocked throughout the growing season and feeding schedules adjusted to growth phase and the surrounding environmental conditions present at the farm.

Deposition Model Results

88 Results are expressed in kilograms of carbon per meter squared per year (kgC m-2 yr-1) and total mass of feed and faeces solid waste in kilograms per meter squared per year (kg m-2 yr-1). A number of studies have observed the impact of organic deposition on macrobenthic communities. Cromey et al. (2001) observed macro-faunal community responses at carbon deposition rates of approximately 3.3g m-2 day-1. Other studies such as Hargrave (1994) and Gilibrand et al. (2002), concluded that long term benthic loading of approximately 2g m-2 day-1 of carbon deposition would start to have some impact on benthic conditions.

89 Based on these observations, we have placed a 0.73 kg per year (2 g C m2 day-1) contour which represents a conservative zone of known ecological impact in all carbon deposition plots below. Areas inside this line are expected to experience an impact (and are, by definition, within the depositional footprint), while areas outside of the line can be considered free of measurable impacts, as they are within the assimilative capacity of the seabed. Regular monitoring (**ADS, 2016, 2017**) of near bed oxygen levels shows that seabed oxygen is good (generally greater than 6 mg/L). Such levels of oxygen will aid in assimilating fallen faeces material and uneaten food.

90 Information regarding nitrogen (N) inputs from feed, N removal via fish harvests (biomass removal), and N release into the surrounding environment is listed in Table 6.

Permit MF246

91 Figure 33 and Figure 34 show the depositional footprint of farm 246. The total annual feed input modelled is 6978 tons (412 tons of N).

92 The majority of the deposition was concentrated within the boundaries of the site, with the exception of the eastern site boundary, where the depositional footprint was moderately skewed in the direction of the prevailing currents. Much of the organic carbon and solids deposition ends inside the site boundary settled in concentrations ranging from 1 to 12 kgC m^{-2} yr^{-1} (Figure 33) and <5 to 40 kg $m^{-2}yr^{-1}$ (Figure 34) respectively.

Permit LI320

93 Figure 35 and Figure 36 below show the depositional footprint from the mid-level scenario of the farm covered by Li320. The total annual feed input modelled in this scenario is 2,832 tons (171.4 tons of N).

94 Most of the deposition was concentrated well within the boundaries of the site, with only a small footprint extending a few meters outside of the site area along its NE and SW boundary (<20m). Organic carbon and solids concentrations, outside of site boundary, are predicted to range from <1 to 2 kgC m-2 yr-1 (Figure 35) and 5 to 10 kg m-2yr-1 (Figure 36) respectively.

95 Figure 37 and Figure 38 show the depositional footprint from the higher-level scenario at farm 320. The total annual feed input modelled in this scenario was 3,303 tons (200.6 tons of Nitrogen).

96 Again most of the deposition was concentrated well within the boundaries of the site, with only a small footprint extending a few meters outside of the site along its NE and SW boundary (<20m). Organic carbon and solids concentrations, outside of site boundary, are predicted to range from <1 to 4 kgC m-2 yr-1 and 5 to 15 kg m-2yr-1 respectively, slightly higher concentrations are predicted when compare d to the conservative (Mid level) stocking scenario

Permit LI339

97 Figure 39 and Figure 40 below shows the depositional footprint for the maximum stocking scenario at the farm covered by LI339, with total annual feed input of 1,132 (tonnes of total feed).

98 Again nearly all the deposition is concentrated well within the boundaries of the site. Organic carbon and solids concentrations are predicted to range from <1 to 7 kgC m-2 yr-1 (Figure 39) and <5 to 25 kg m-2 yr-1 (Figure 40) respectively. Further descriptions of the modelling scenarios can be found in (ADS 2017e).

OFFICERS REPORT AND MATTERS RAISED BY SUBMITTERS

99 **Dr Grange** was commissioned by Environment Southland to provide technical advice on Sanford's application. This included reviewing the application, various meetings and teleconferences, and reviewing and reporting on matters of concern. I will address concerns in regard to numerical modelling and also in regard to my observations in terms of seabed fallowing inside of BGB.

100 **Dr Grange** states in his evidence he has two key concerns. One of these is the length of time allowed for farms to fallow and questions whether 5 years of fallowing is sufficient. As was noted by **Dr James** in his evidence, 5 years is the minimum required period of fallowing and will be determined based on monitoring. I will also add that after having undertaken a number of seabed monitoring programs across the bay I have observed that visually the seabed appears to have fully recovered after 3-4 years. The other concern has been address in **Dr James'** evidence.

101 More specifically in regards to numerical modelling **Dr Grange** has asked why we did not use a more complicated model that includes interactions between "nutrients, phytoplankton, zooplankton and detritus", particularly given I have developed such a model previously. **Dr Grange** then mentions "we do believe, however that the DELFT3D model probably provides a worst case scenario in terms of Chl-a enchantment" As **Dr Grange** rightly states we have chosen a worst case approach in this study where we treated the release of nutrients much like a conservative tracer and didn't include any subsequent breakdown. This results in the highest possible conversion of nutrients to Chl-a. Additional analysis by **Dr James** and myself have found that this worst case scenarios still appears to be sustainable and within the carrying capacity of the BGB as a whole. Modelling a worst case scenario so to speak provides a greater certainty in the results of the model. i.e. if worst case assumptions indicate that a proposed development is still sustainable then the likelihood of this development indeed being sustainable once it's actually built is much higher. It should be pointed out the DELFT3D model used in this study was well calibrated and fit for purpose.

SUMMARY AND CONCLUSIONS

102 Overall, both from a nutrient and a chlorophyll-a (proxy for algae biomass) perspective, water column environmental conditions within Big Glory Bay appear to have remained similar if not identical for nearly 30 years. This is despite the significant increases in farmed fish biomass from the 1980's until today.

103 A potential reason for this is that during spring and summer, it appears that something is removing N from the system. Based on literature and a simple N budget, it seems quite likely that the difference is due to farmed mussels

present in large quantities in Big Glory Bay. Periods of peak feeding and hence increases in soluble nutrient release, Missing nutrients correspond to the timing of the mussels' largest growth (when water temperatures are high).

Oxygen levels, a requirement for life and conditions, are generally observed between 6 and 9 mg L-1 depending on the season since measurements began in the 1980's. Oxygen levels are not predicted to determinate due to the proposed expansion.

104 Big Glory Bay has generally weak currents (5cm s^{-1}) across much of the bay but stronger flows towards the mouth of the bay (including at the existing MF246 farm site). Flushing models indicate that after 7 days, the bay is approx. 30% flushed and after 14 days the bay is approx. 60% flushed. After 28 days only 10-15% of the original water remains in the bay.

105 Given this flushing capacity, excess TAN levels in the bay are predicted to increase up to 30µg L^{-1} with additional N inputs from feed of 659 tons, resulting in 381.2 tons of released TAN in the higher production scenario. Assuming all excess released TAN is converted to phytoplankton biomass, chlorophyll-a levels are predicted to increase by up to 4 µg L^{-1}.

106 With predicted temperature driven seasonal drawdown of oxygen in conjunction with expanded farm production, oxygen levels in the water towards the end of summer and beginning of autumn are predicted to reach minimum values of close to 6 mg L^{-1}, this being the level needed to maintain healthy farmed salmon. Dissolved oxygen reductions are expected to reach 0.25mg L^{-1} inside the Bay and up to 1.5mg L^{-1} within the cages.

107 There is not expected to be any reduction in oxygen with water depth.

108 The deposition models show that faeces and solids deposition should generally remain within the boundaries of the site, with only limited (<100m) deposition outside site boundaries, provided binding agents are used in higher flow sites (specifically MF246). Without binding agents, higher current flows due to the proximity to the mouth of the bay are predicted to skew the depositional footprint of MF246 100's of meters NNE of the site boundary. Some of this deposition (up to 3%) will be mineralised by the benthic microbial community and released back into the water column as NH4+.

109 Based on observations of nutrients and chlorophyll-a evolution for the last 30 years through various datasets, and even though farmed fish biomass has increased over the years, the overall range of measurements appears to have remained the same. This highlights the fact that the Big Glory Bay ecosystem has assimilated the increases in nutrient loading occurring over the years, without signs of adverse effects.

110 Based on the calculations of estimated Total N there is evidence that N consumption occurs, and this is hypothesized to be a direct consequence of the large amount of mussels biomass in the bay, as filter feeders need to

extract the food for their growth from their surrounding environment. Mussel farms act, albeit indirectly, as a mitigation measure limiting the impacts of extra loadings to the environment by consuming the algae as they grow from the additional nutrient loadings from the fish farms.

111 Finally, taking into account, flushing, oxygen levels, TAN, and Chlorophyll a concentrations we have assessed a maximum carrying capacity of N sourced from fish feed as being 659 tons.

Neil David Hartstein

11 March 2019

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***Table 1** - Summary of main data sources used to build the Hydrodynamic model.*

Data Type	Sources
Predicted Tidal Elevation	TPXO Global Tidal Solution and WX tidal data
Current (ADCP)	ADCP1: 168.140293, -46.965581 ADCP2: 168.117658, -46.987192
Wind	Global Forecast System by National Oceanic and Atmospheric Administration (GFS)
Regional Current data	HYCOM
Bathymetry	Chart data from Land Information New Zealand

Table 1 *– Big Glory Bay Model TAN Load Inputs*

	Mid-level	Higher-level
January	32.18	34.03
February	31.05	32.68
March	29.61	32.33
April	30.21	32.80
May	31.49	33.36
June	29.16	30.69
July	27.50	29.05
August	26.03	27.45
September	26.13	27.55
October	27.66	28.21
November	32.86	35.69
December	34.40	37.42
TOTAL TAN	358.28	381.2
TOTAL N in FEED	621.4	659

Table 2 *– Big Glory Bay Model Oxygen Drawdown Inputs*

Big Glory Bay Oxygen Drawdown Inputs (tons day^{-1})

	Mid-level	Higher-level
	8.85	9.315

Table 4 *- Pen designs, locations, layouts, and volumes used for this depositional model. Pens locations are reported as they are entered into DEPOMOD (i.e. referencing the center of the top left pen before adjusting the bearing of the pen set). Coordinates are given in NZGD2000.*

	Lease 246 Pens	Lease 320 Pens	Lease 339
X Position	1229774.23	1228119.06	1229441.56
Y Position	4785964.45	4786123.51	4784879.658
Layout (row x column)	3 x 8	2 x 5	2 x 4
Pen Dimensions (m)	30 x 30	30 x 30	30 x 30
Pen Depth (m)	15	15	15

Bearing (°N)	79.15	23.35	44.38
Total Volume (m^3)	324,000	135,000	108,000

Table 5 *- Depositional model loading input parameters. Stock to Feed Ratio is defined as the average daily feed rate (tons day^{-1}) divided by the annual production (tons yr^{-1}).*

	Lease 246 all scenarios	**Lease 320** Mid-level scenario	**Lease 320** Higher-level scenario	**Lease 339** Mid-level scenario	**Lease 339** Higher-level scenario
Stocking Density/Biomass in the cage (kg m^{-3})	12.0	12.0	14.0	3.0	4.3
Stock: Feed	0.479	0.479	0.479	0.479	0.479
Feed Mass (tons day^{-1})	18.6	7.76	9.05	1.55	4.1
% Feed Wastage	3	3	3	3	3
% Feed Digested	85	85	85	85	85
% Water Content	9	9	9	9	9
Feed % C	49	49	49	49	49
Faeces % C	30	30	30	30	30
Feed % N	6.1	6.1	6.1	6.1	6.1
Faeces % N	17.3	17.3	17.3	17.3	17.3
Bay Salinity (ppt)	35	35	35	35	35
Bay Temperature	10	10	10	10	10

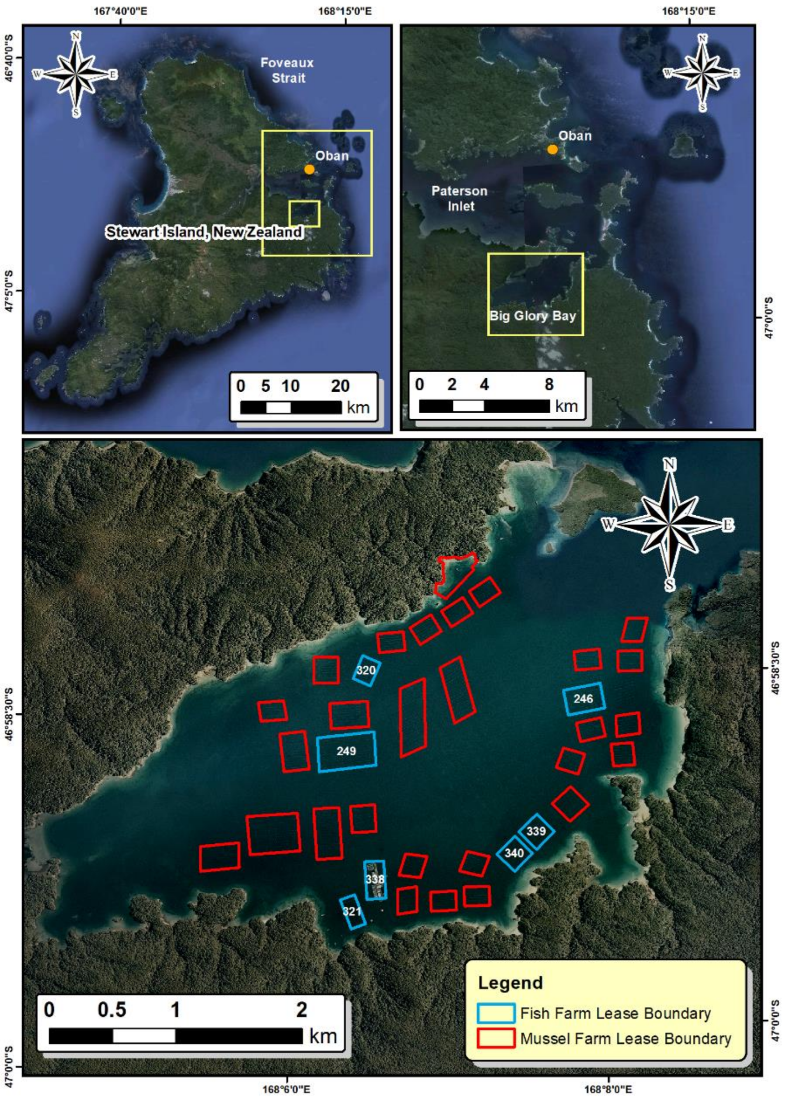


Figure 1 *–Overview of Big Glory Bay and Paterson Inlet on Stewart Island, South Island, New Zealand.*

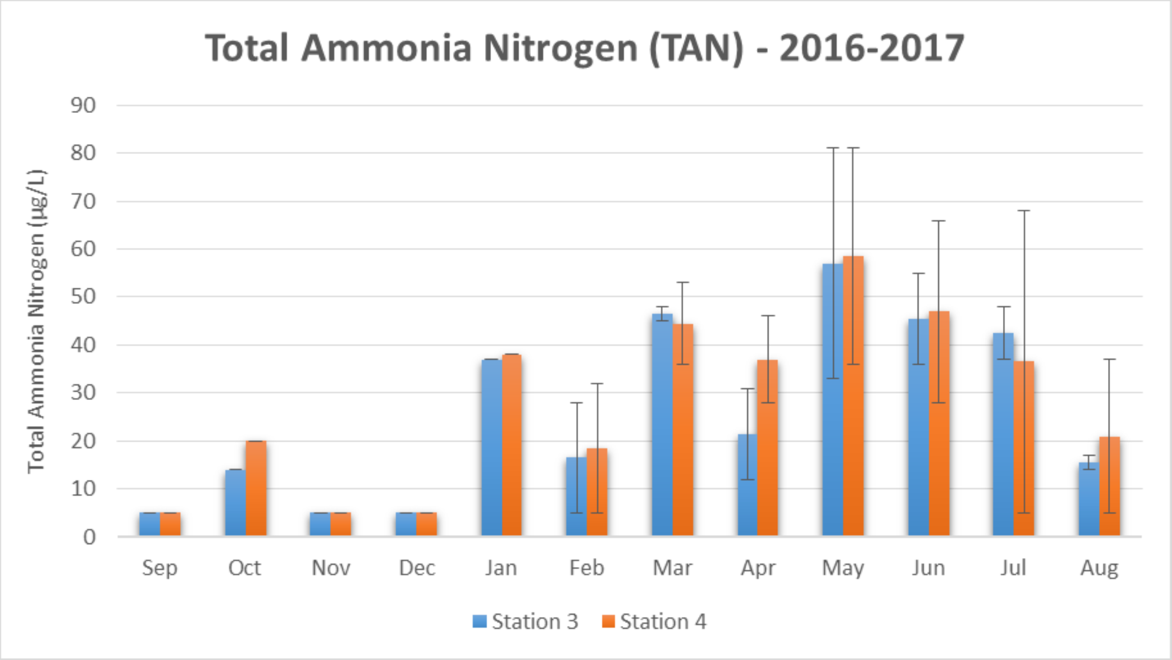


Figure 2 *- Total Ammonia Nitrogen (TAN) concentrations in 2016-2017 from Sanford monthly monitoring.*

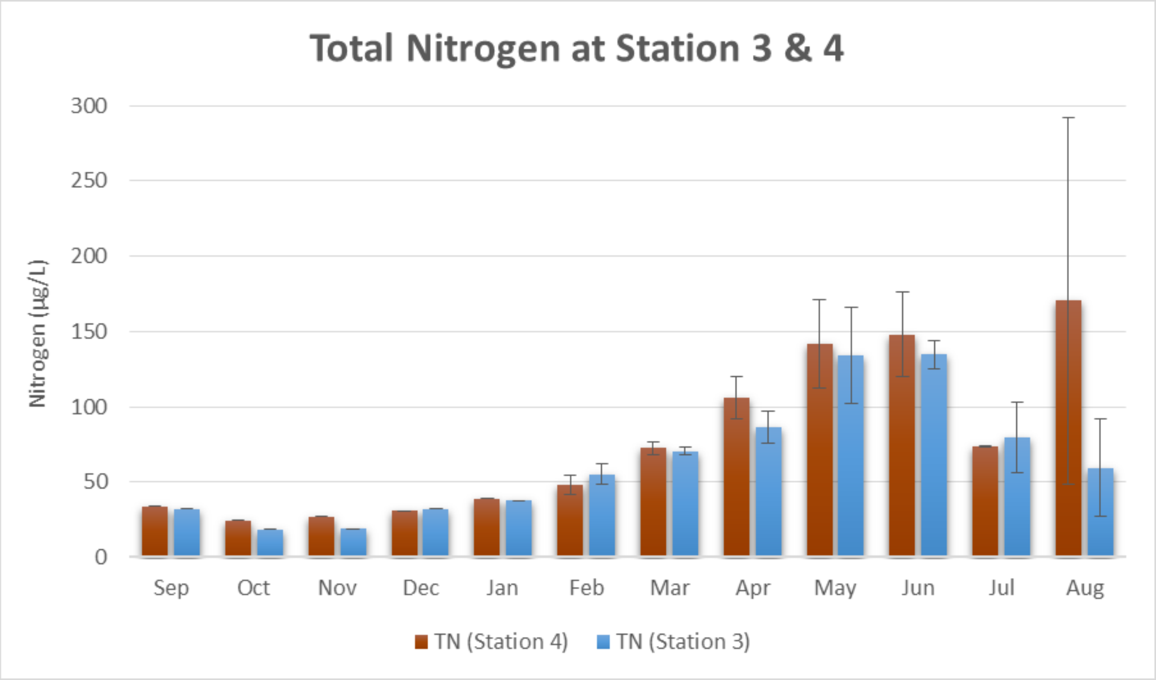


Figure 3 *- Total Nitrogen (sum of TAN, nitrate and Particulate Nitrogen) measurements taken in 2016 and 2017. Note: the estimated Total Nitrogen does not include Dissolved Organic Nitrogen (DON) for which measurements are not available.*

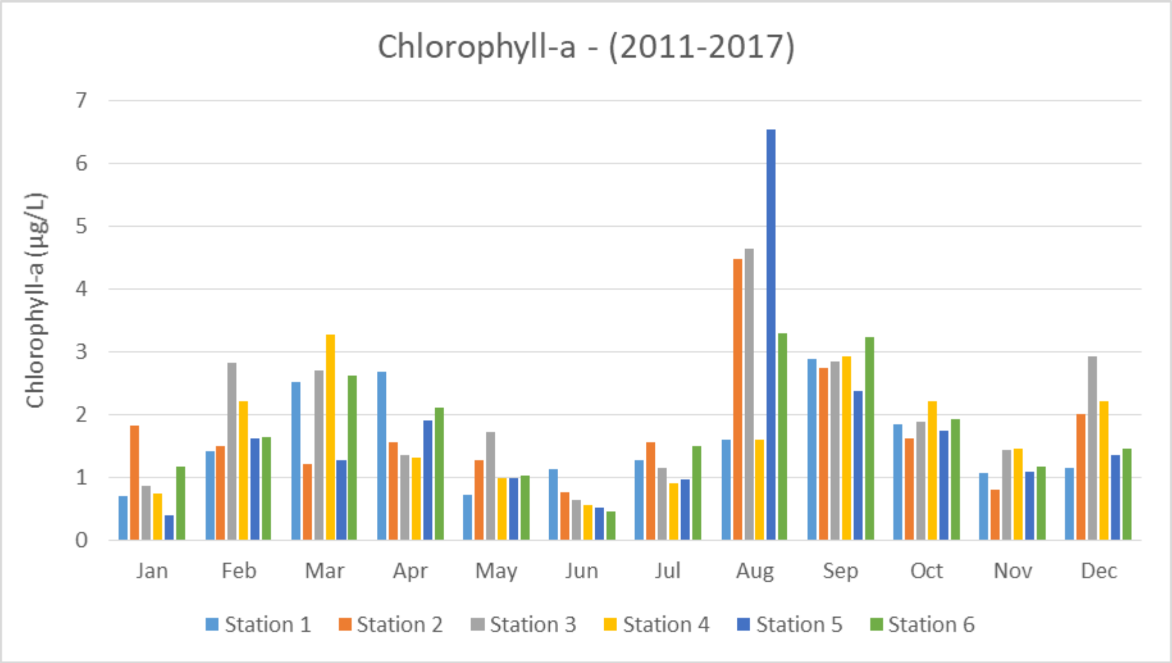


Figure 4 *– Monthly averaged Chlorophyll-a concentrations collected as part of Sanford's monthly water quality monitoring program.*

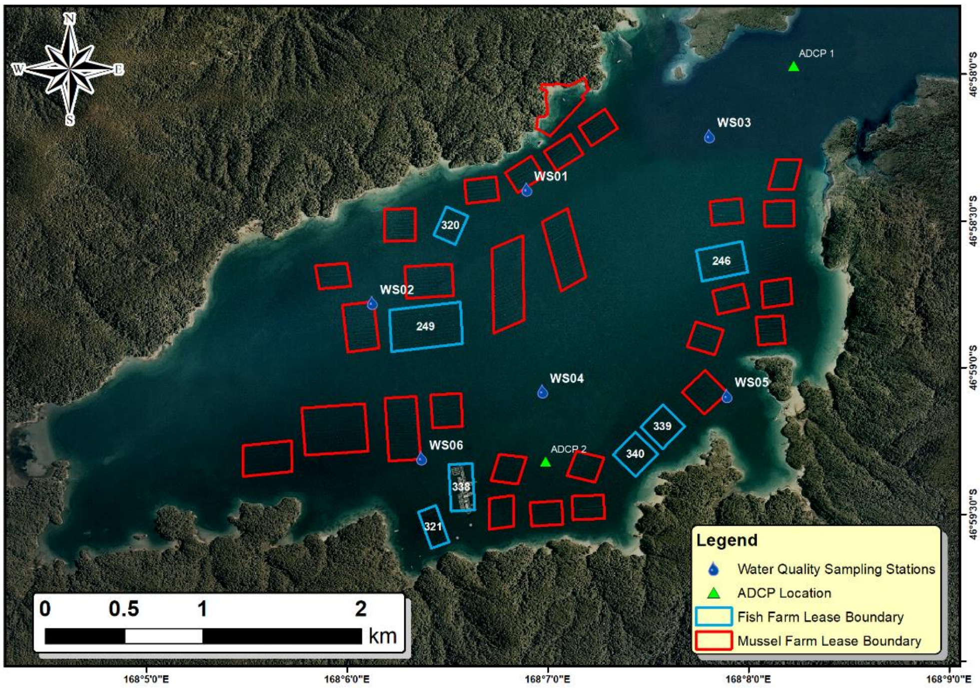


***Figure 5** – Sanford water quality sampling locations.*

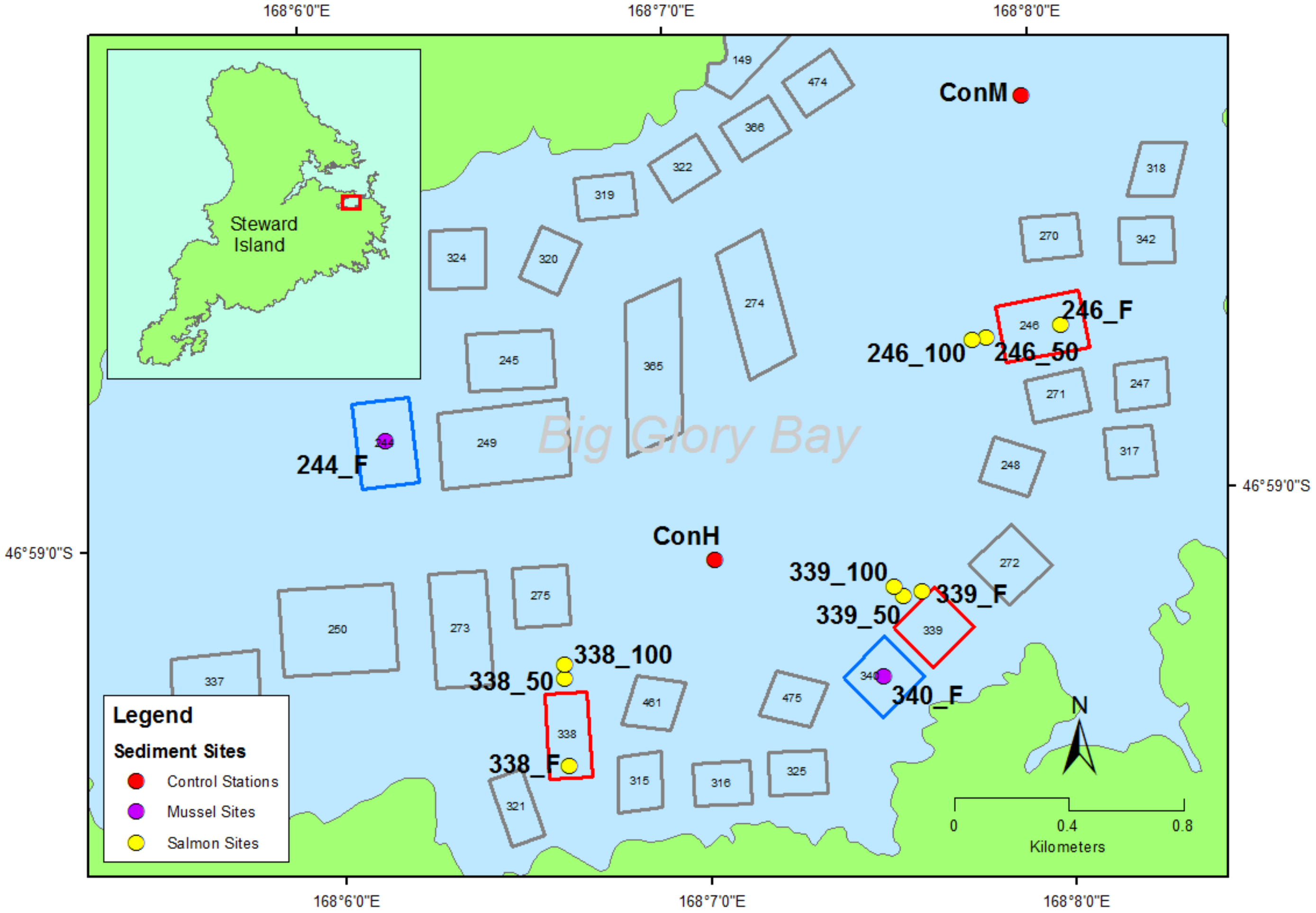


Figure 6. Benthic sites surveyed for Sanford Ltd by ADS in 2017. Red dots are control sites, and around salmon farms in use. Purple dost are sites being fallowed.

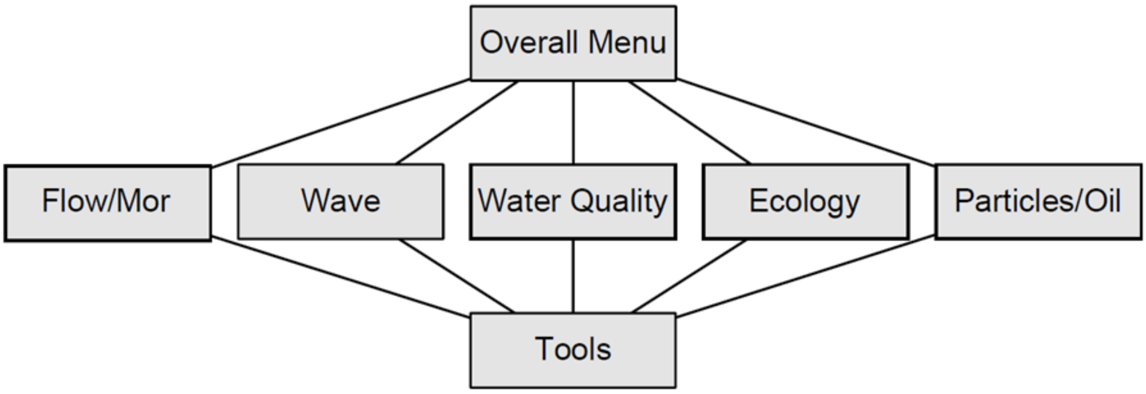


***Figure 7** - DELFT3D modular interface.*

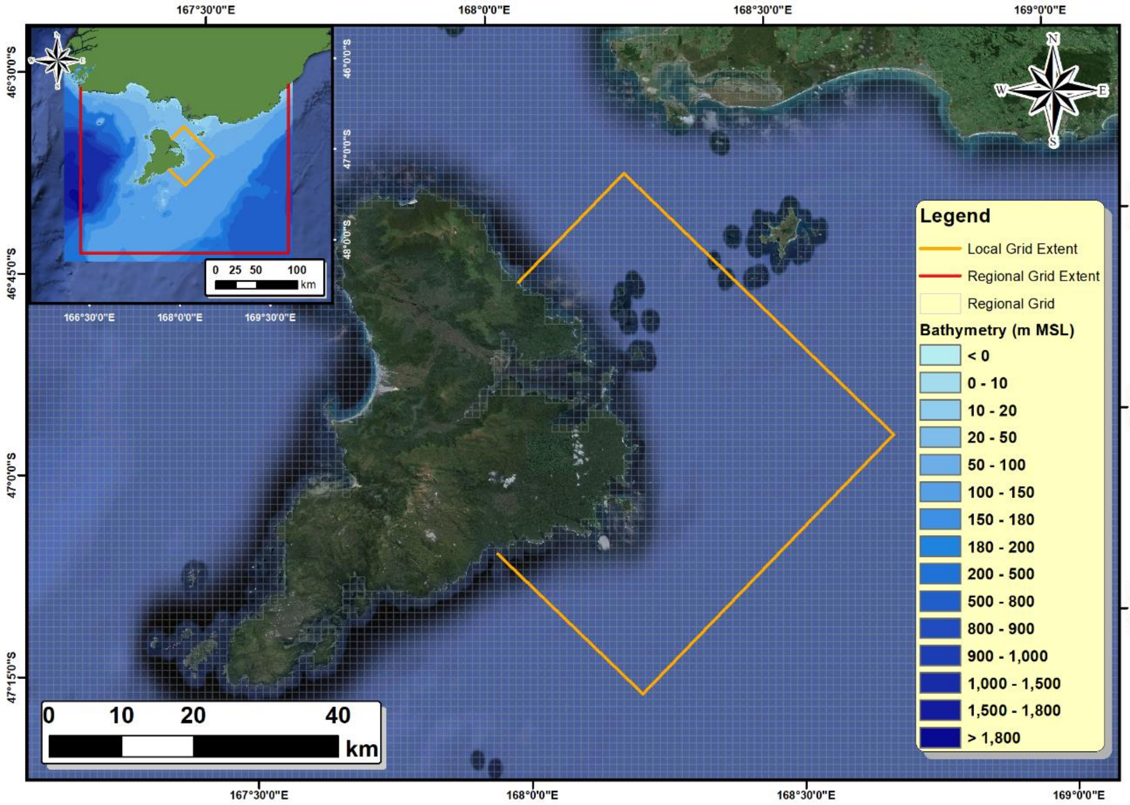


Figure 8 *- Extent of regional and local grids, with regional bathymetry.*

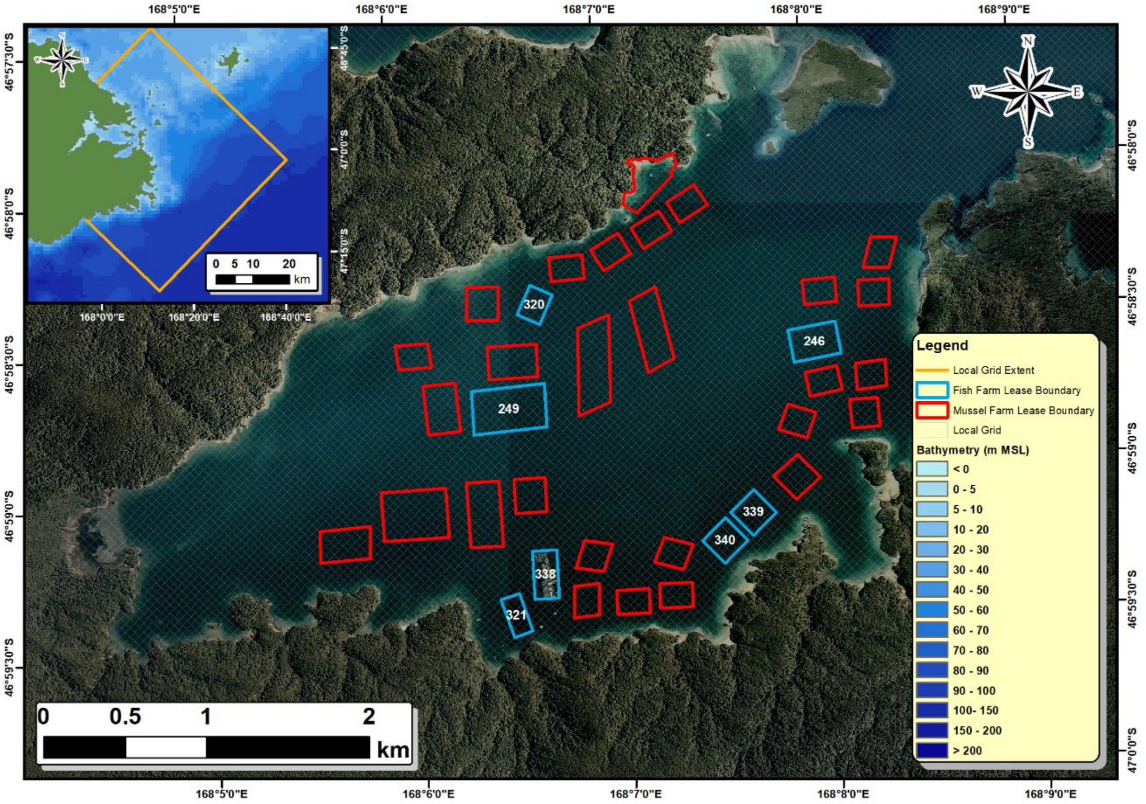


Figure 9 *- Extent of local grid (40m resolution and 10 vertical layers), with bathymetry and farm sites.*

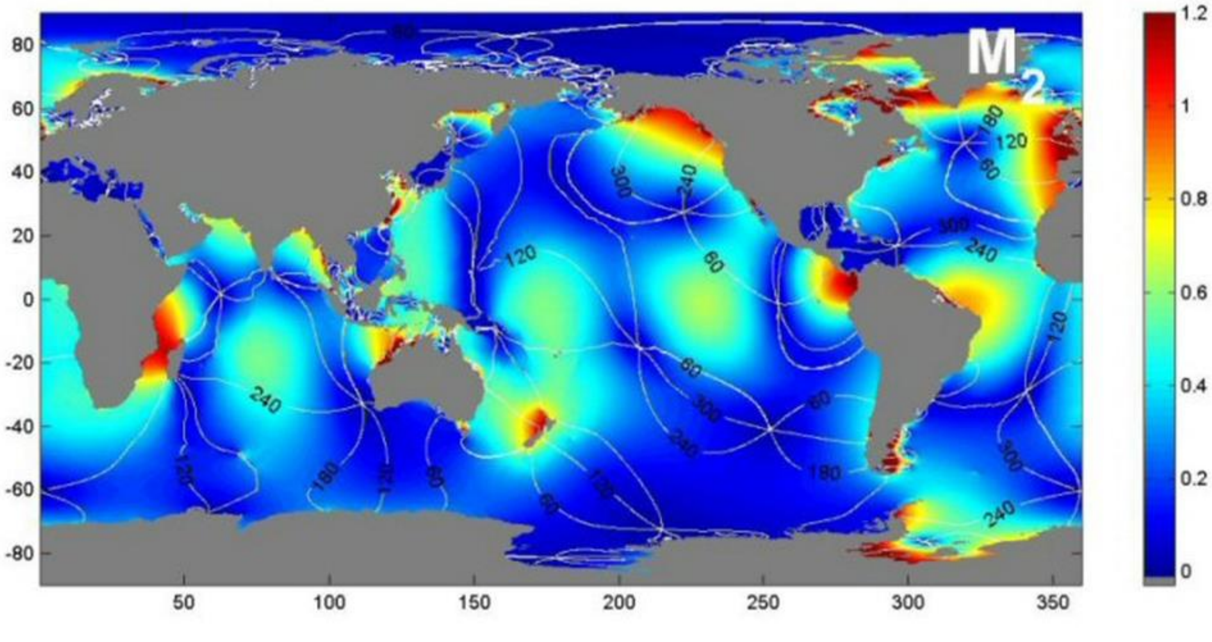


Figure 10 *- Image depicting a sample output from the TPXO model.*

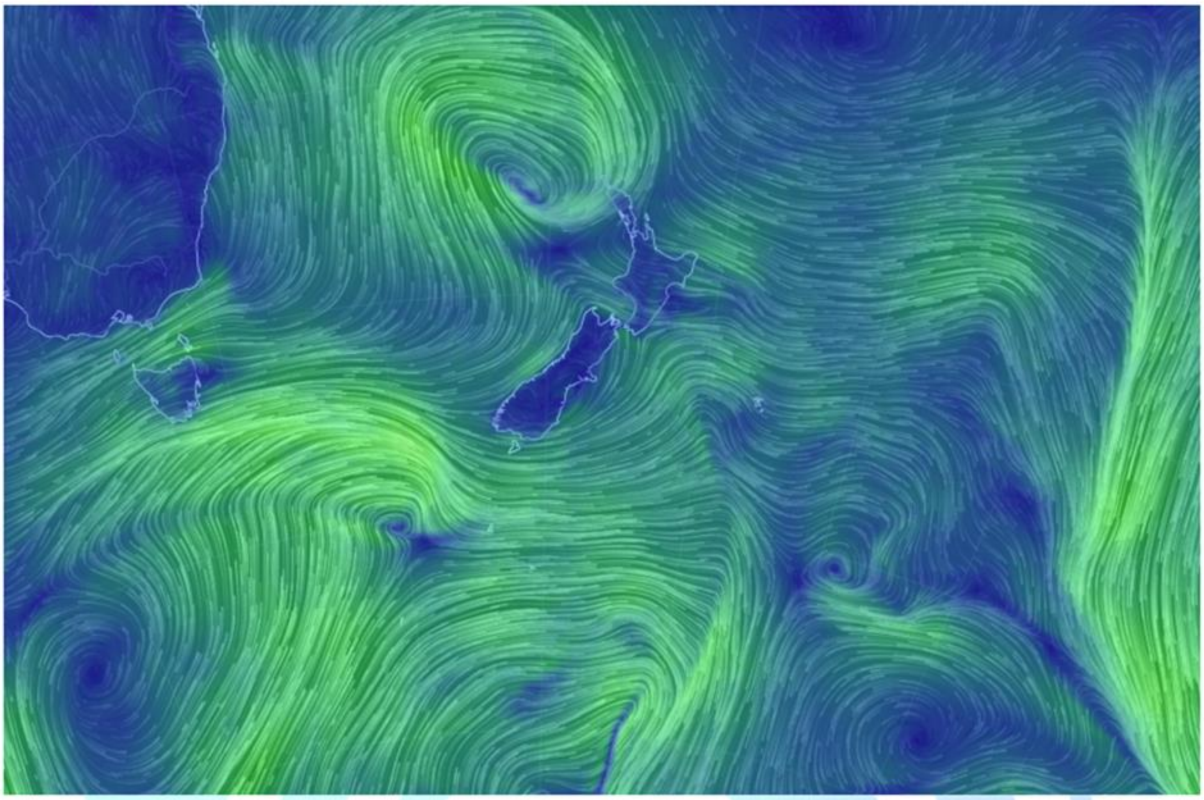


Figure 11 *- Example of GFS wind data centred on New Zealand at 2015-09-04 at 0600 GMT (source: http://earth.nullschool.net/).*

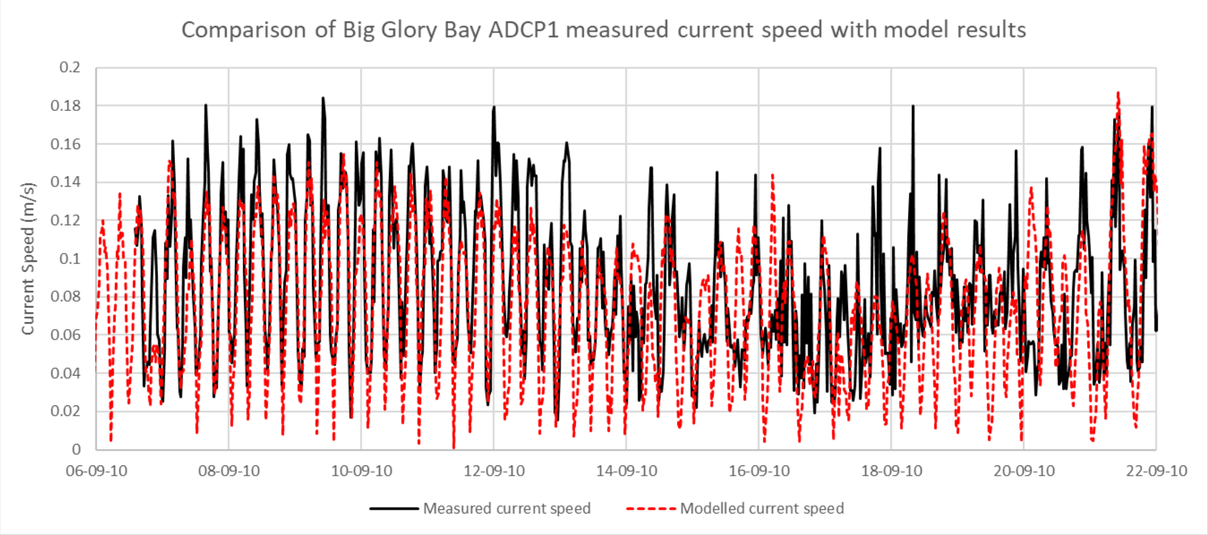


Figure 12 *- Current speed comparison at ADCP1 between measured data and modelled results.*

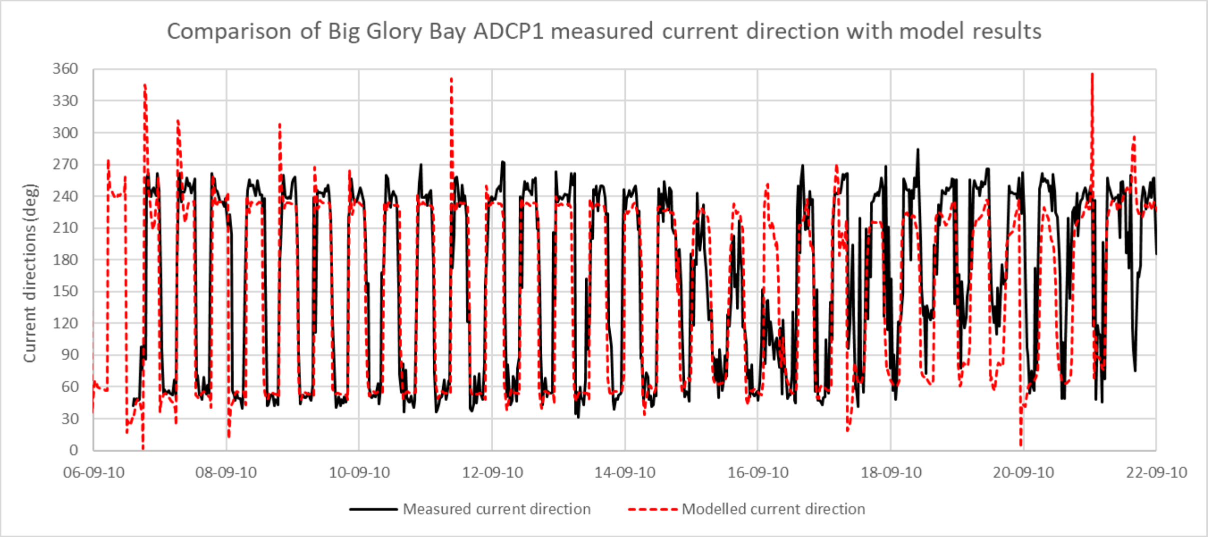


Figure 13 *- Current direction comparison at ADCP1 between measured data and modelled results.*

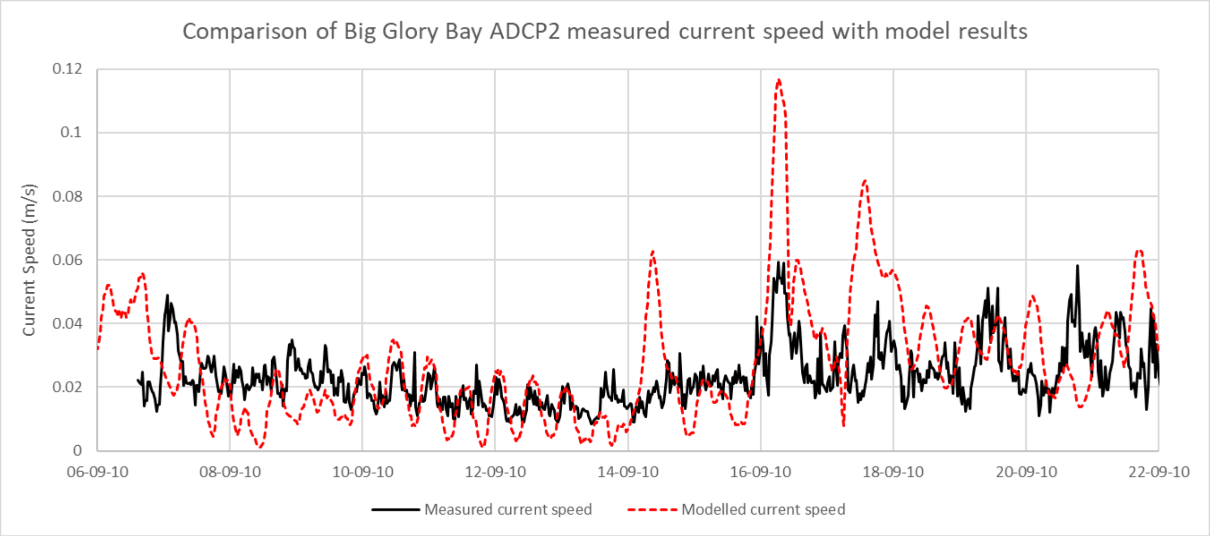


Figure 14 *- Current speed comparison at ADCP2 between measured data and modelled results.*

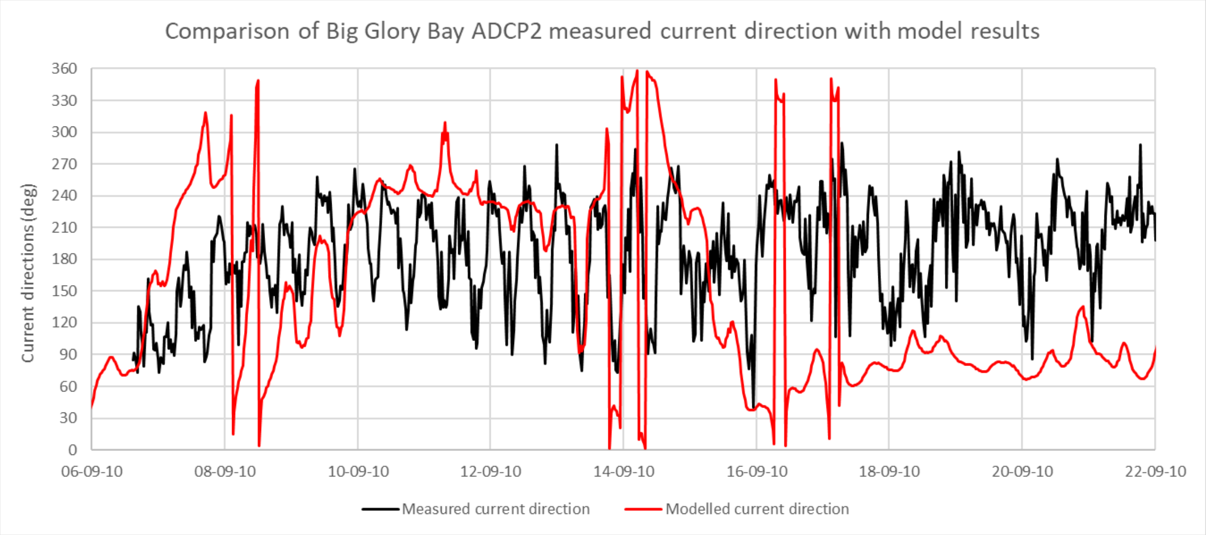


Figure 15 *- Current direction comparison at ADCP2 between measured data and modelled results.*

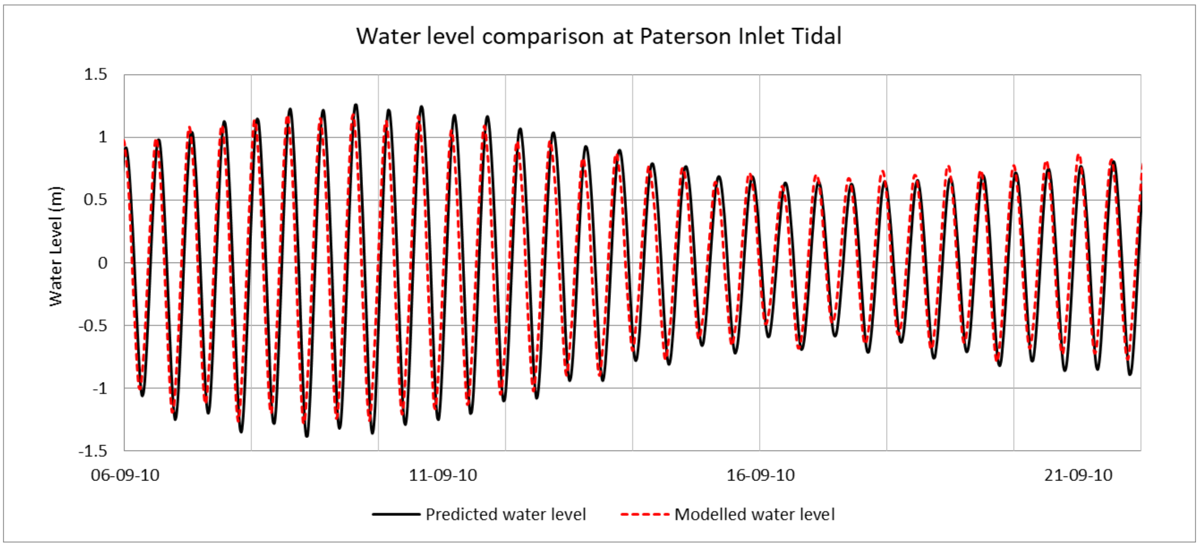


Figure 16 *- Comparison of water level at Paterson Inlet tidal station between predicted tide and modelled results.*

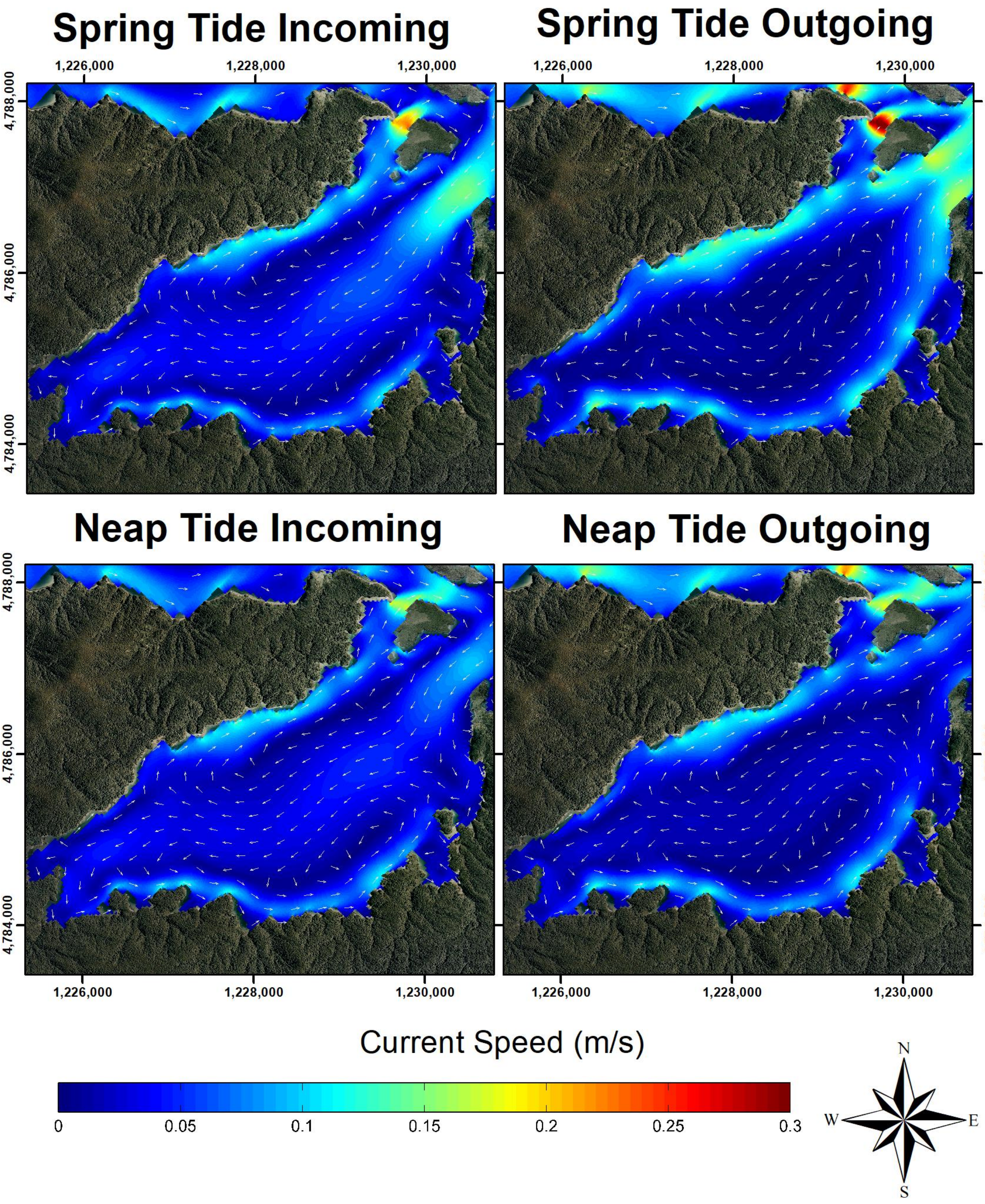


Figure 17 *- Depth averaged local current patterns (during Spring/October conditions) for spring and neap ebb and flood tides (3D hydrodynamic model results).*

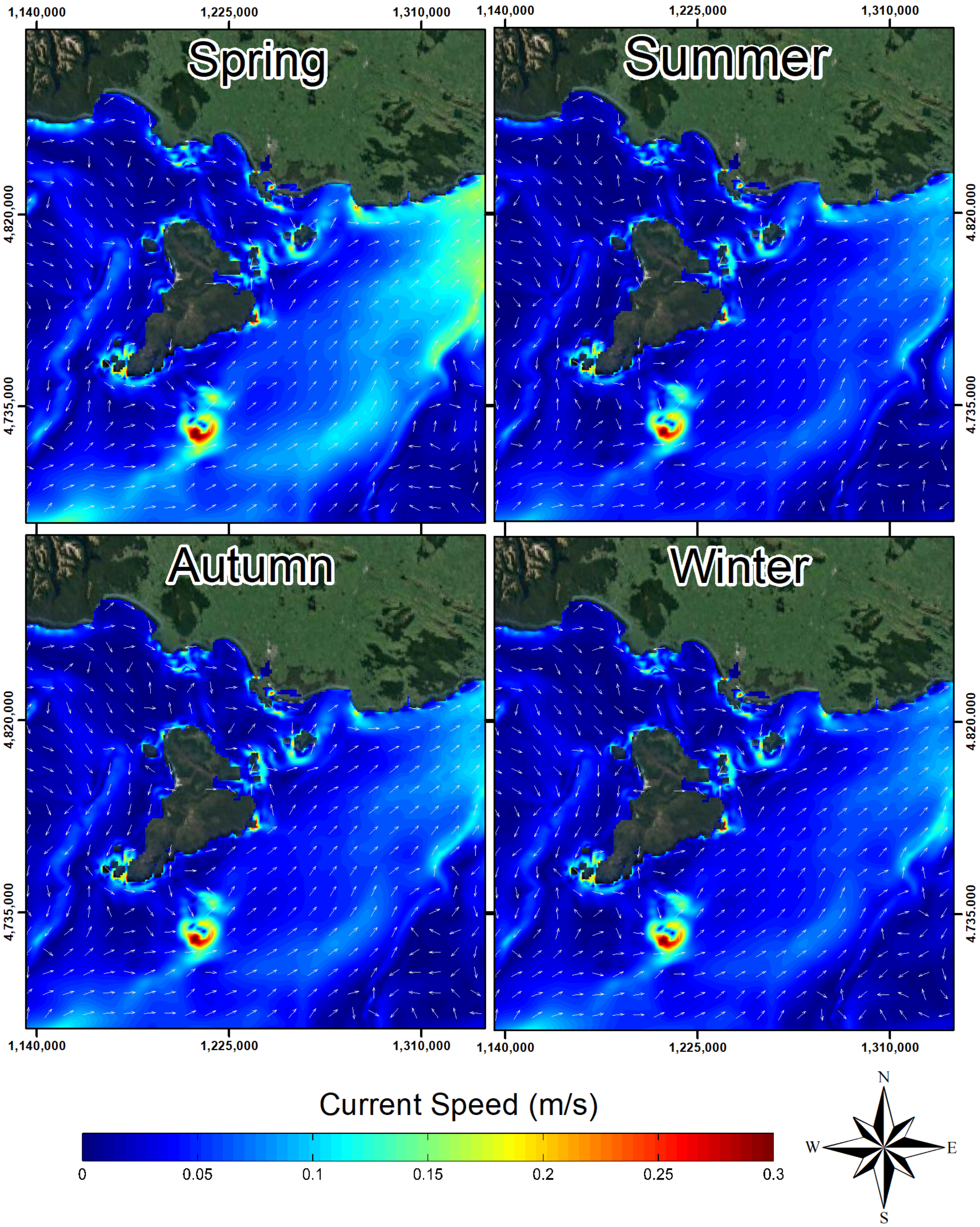


***Figure 18** - Seasonal regional flow patterns around Stewart Island and the southern portion of South Island.*

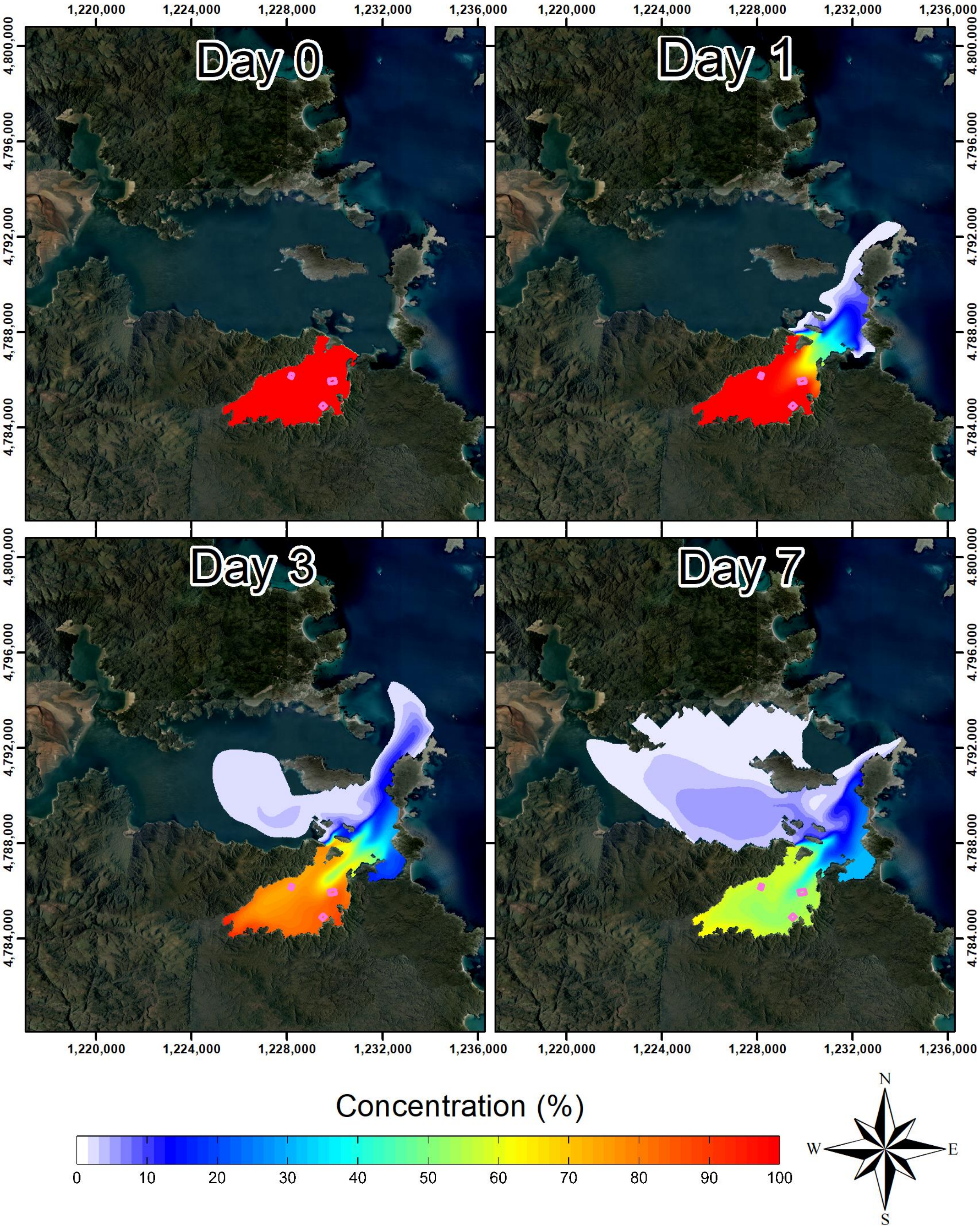


Figure 19 *- Full bay flushing results for spring, day 0 to day 7.*

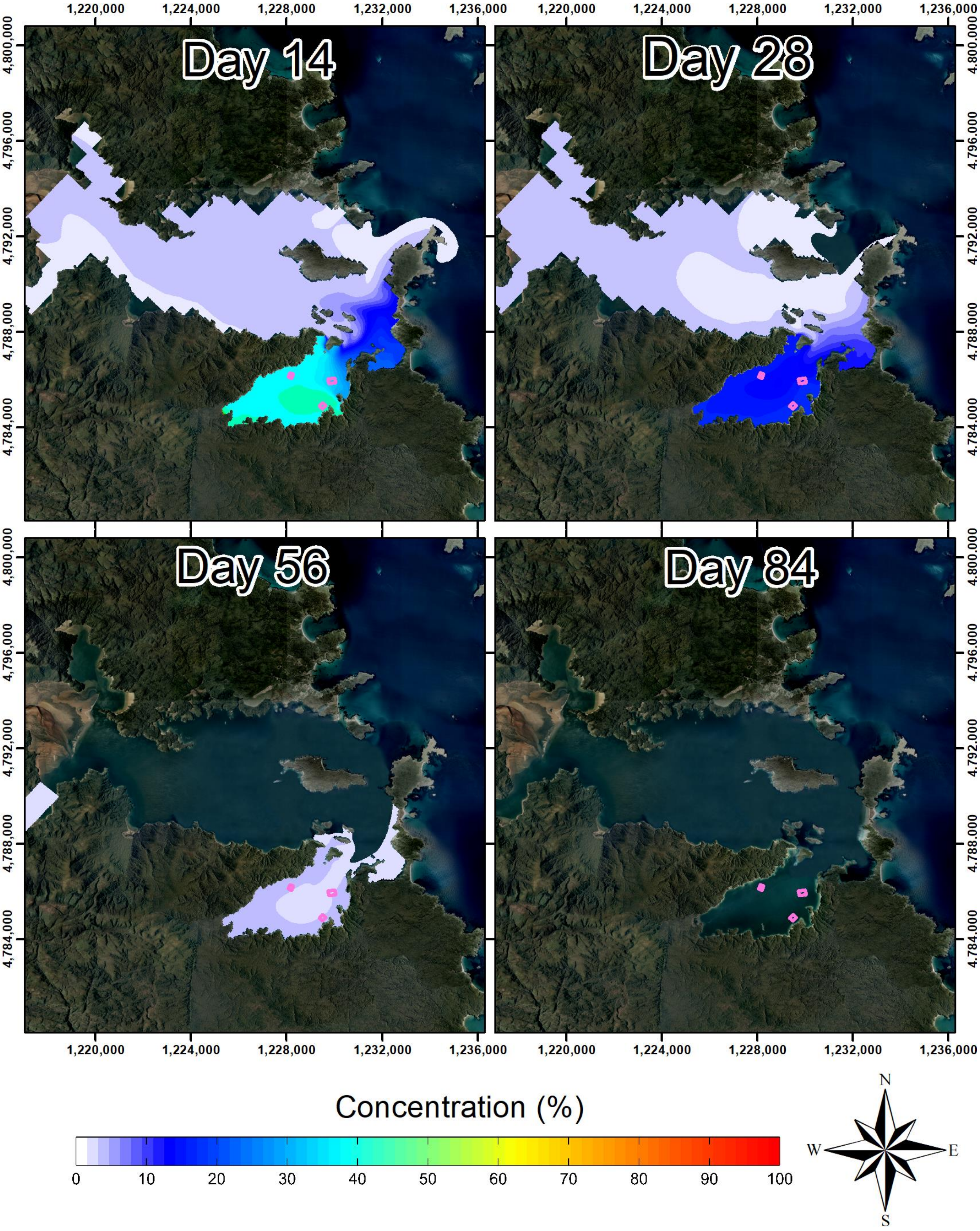


Figure 20 *- Full bay flushing results for spring, day 14 to day 84.*

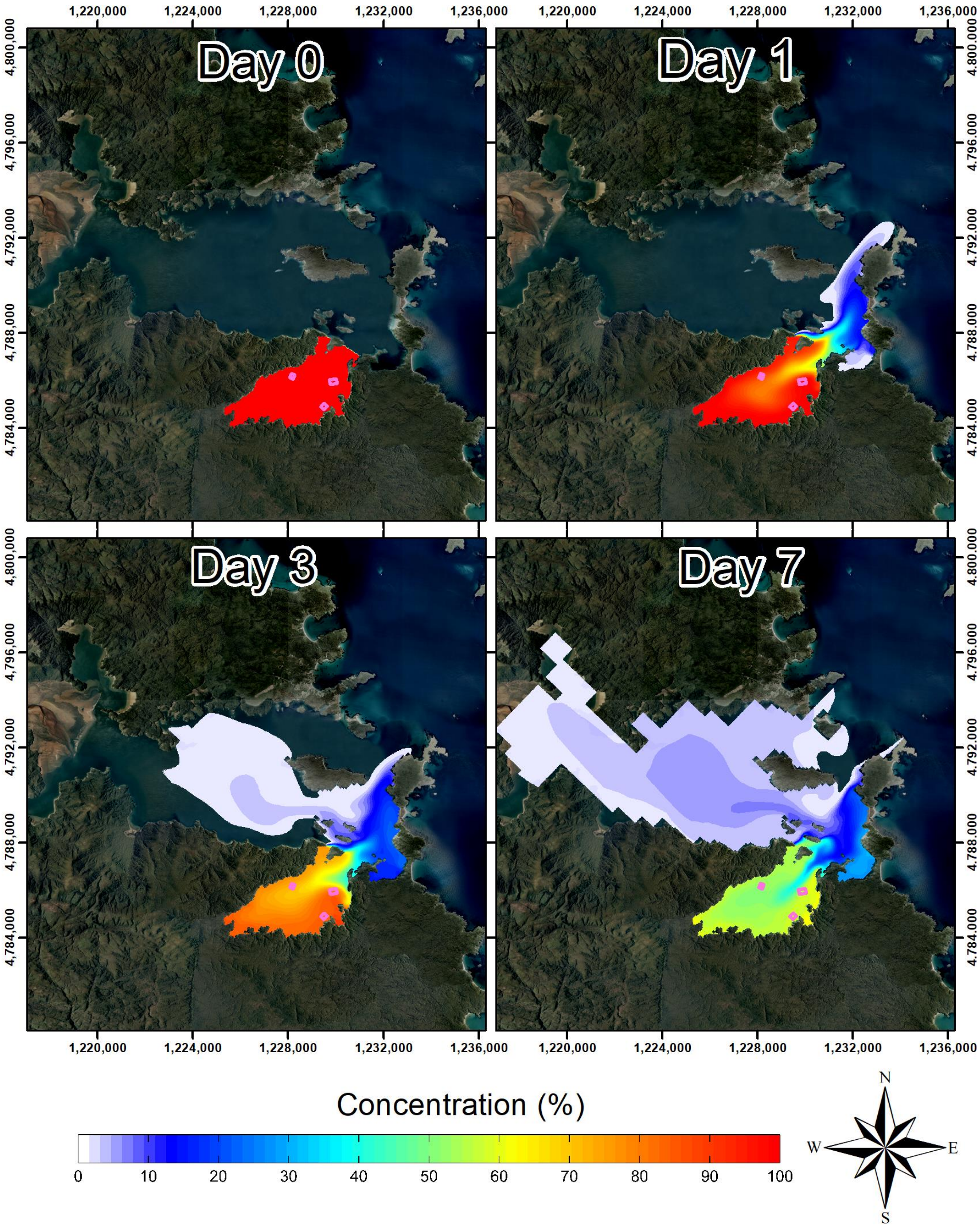


Figure 21 *- Full bay flushing results for summer, day 0 to day 7.*

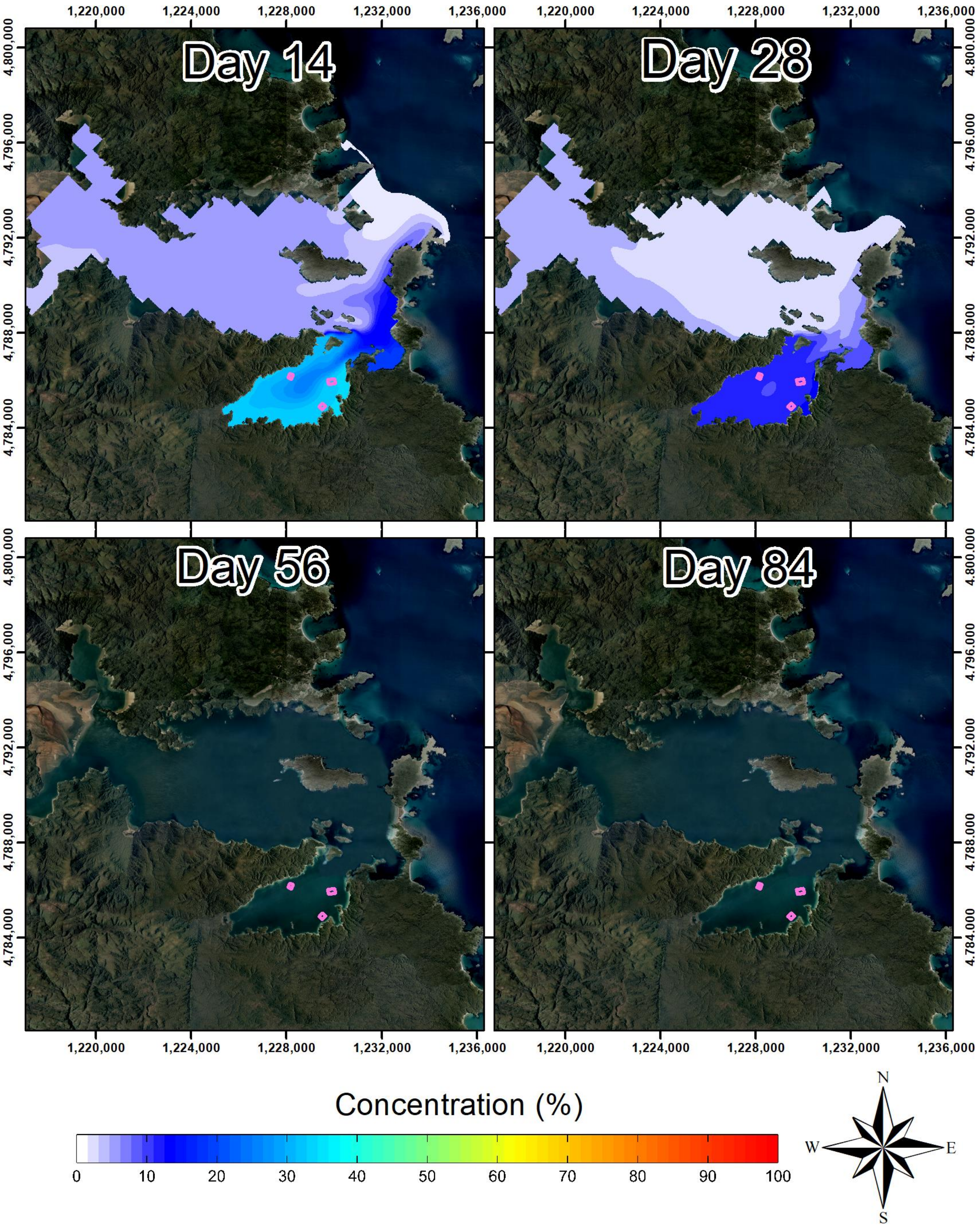


Figure 22 - Full bay flushing results for summer, day 14 to day 84.

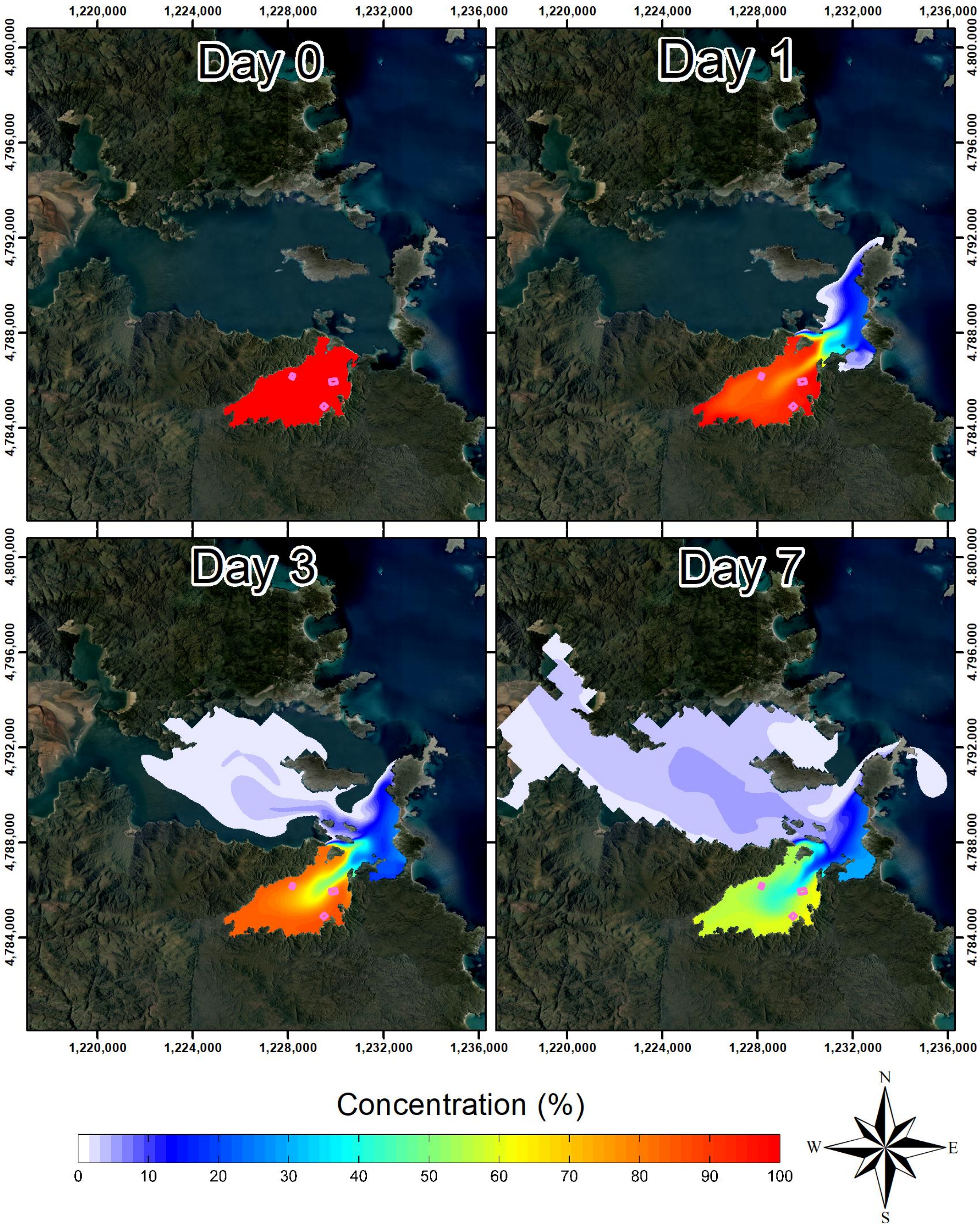


Figure 23 *- Full bay flushing results for autumn, day 0 to day 7.*

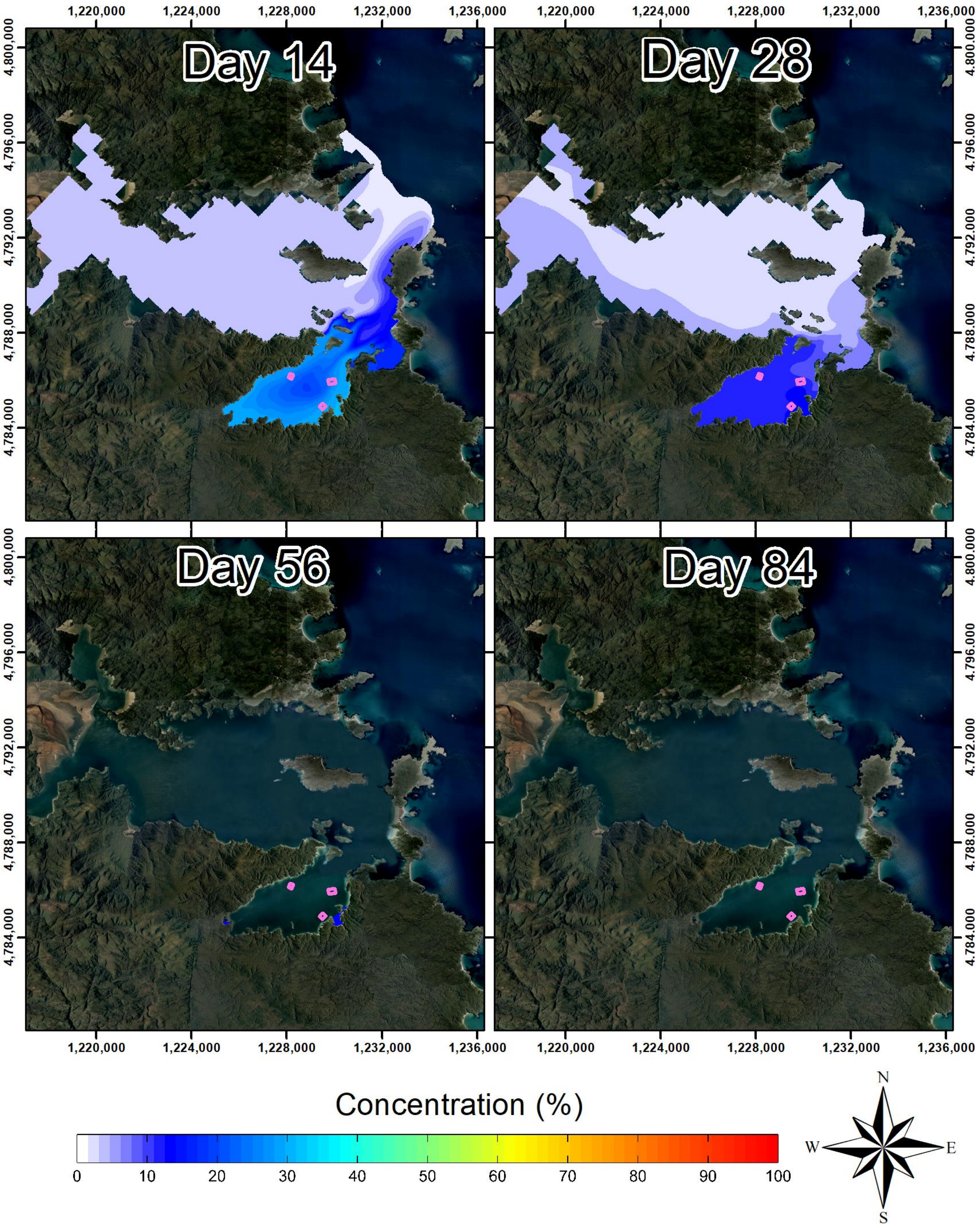


Figure 24 *- Full bay flushing results for autumn, day 14 to day 84.*

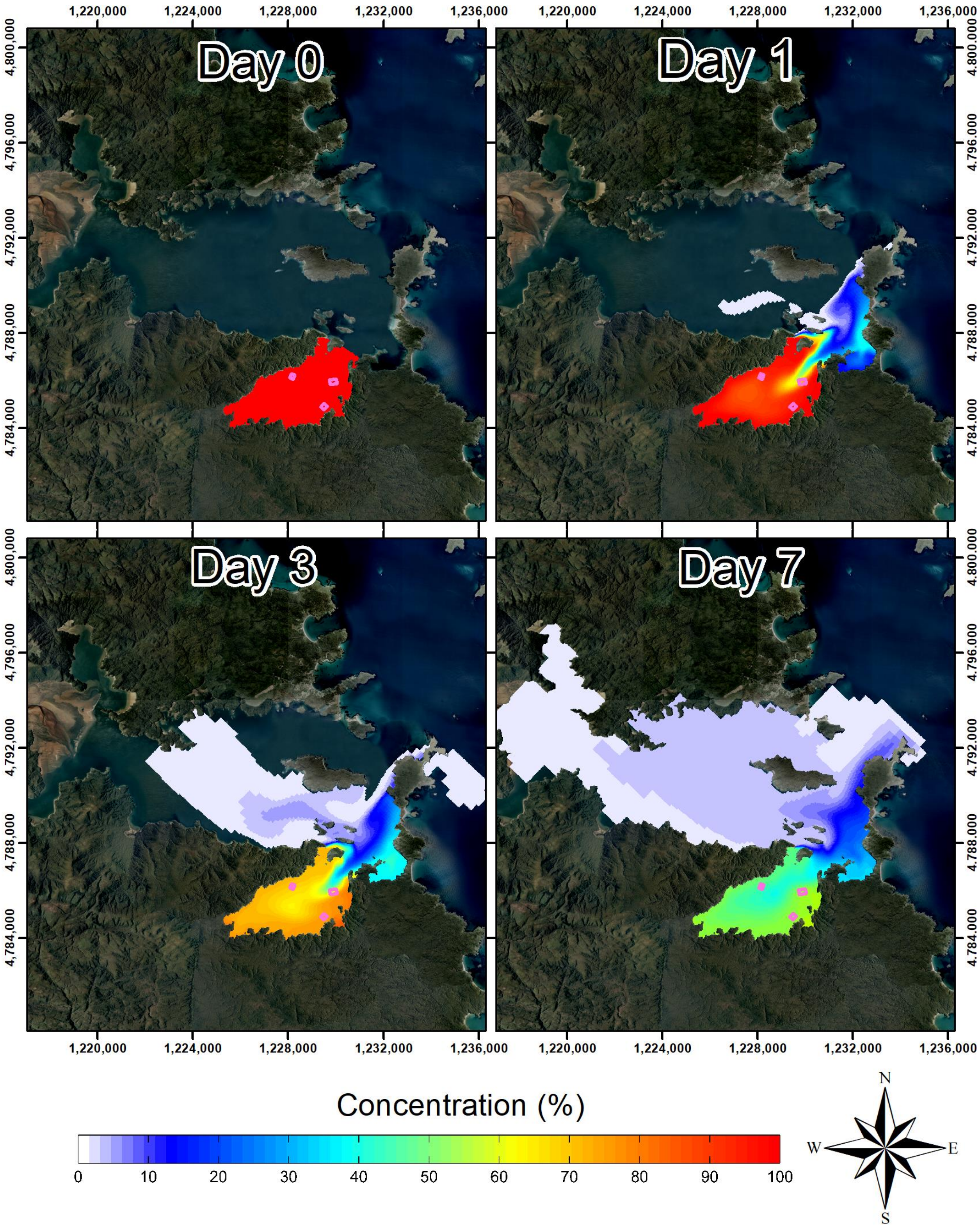


Figure 25 *- Full bay flushing results for winter, day 0 to day 7.*

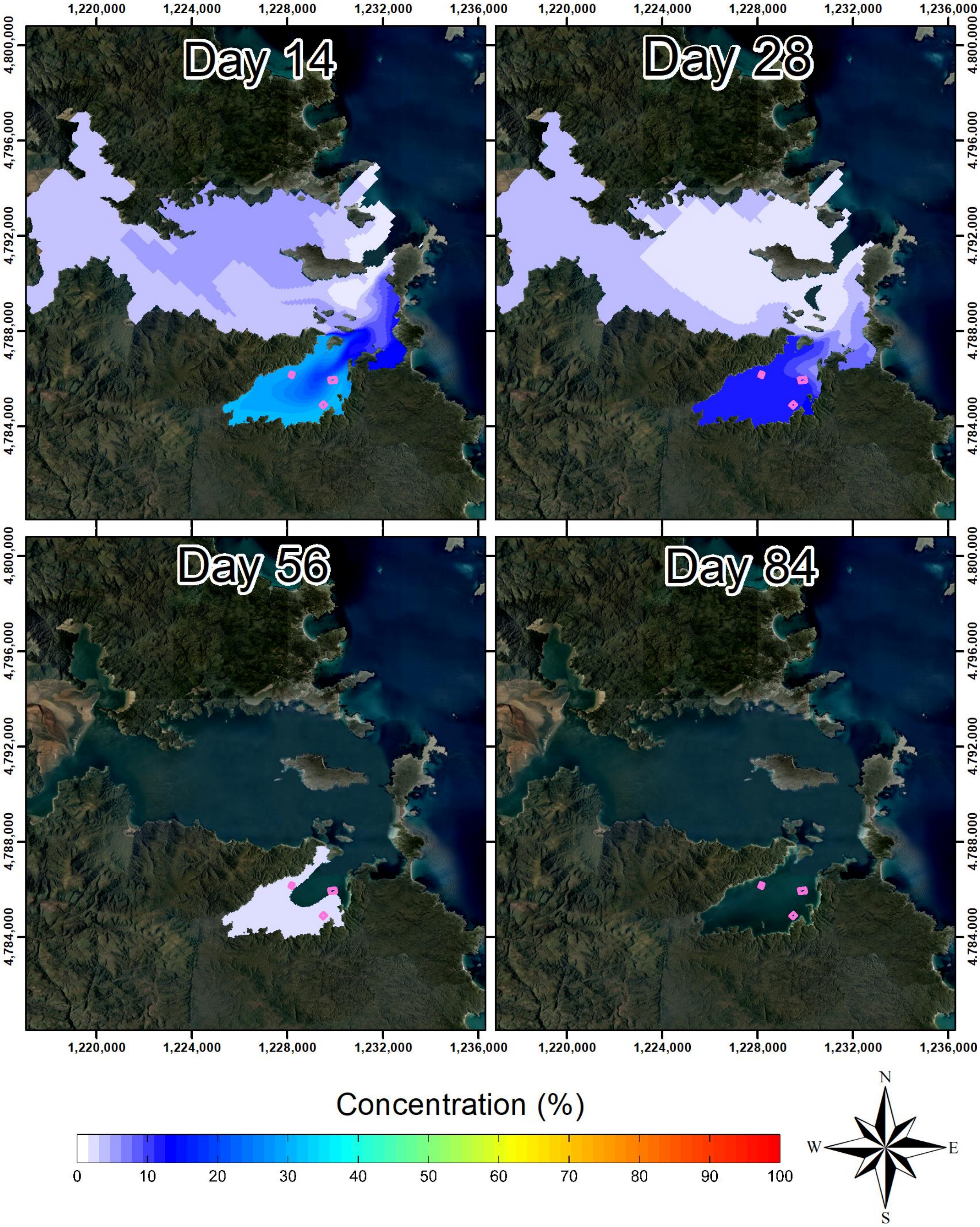


Figure 26 *- Full bay flushing results for winter, day 14 to day 84.*

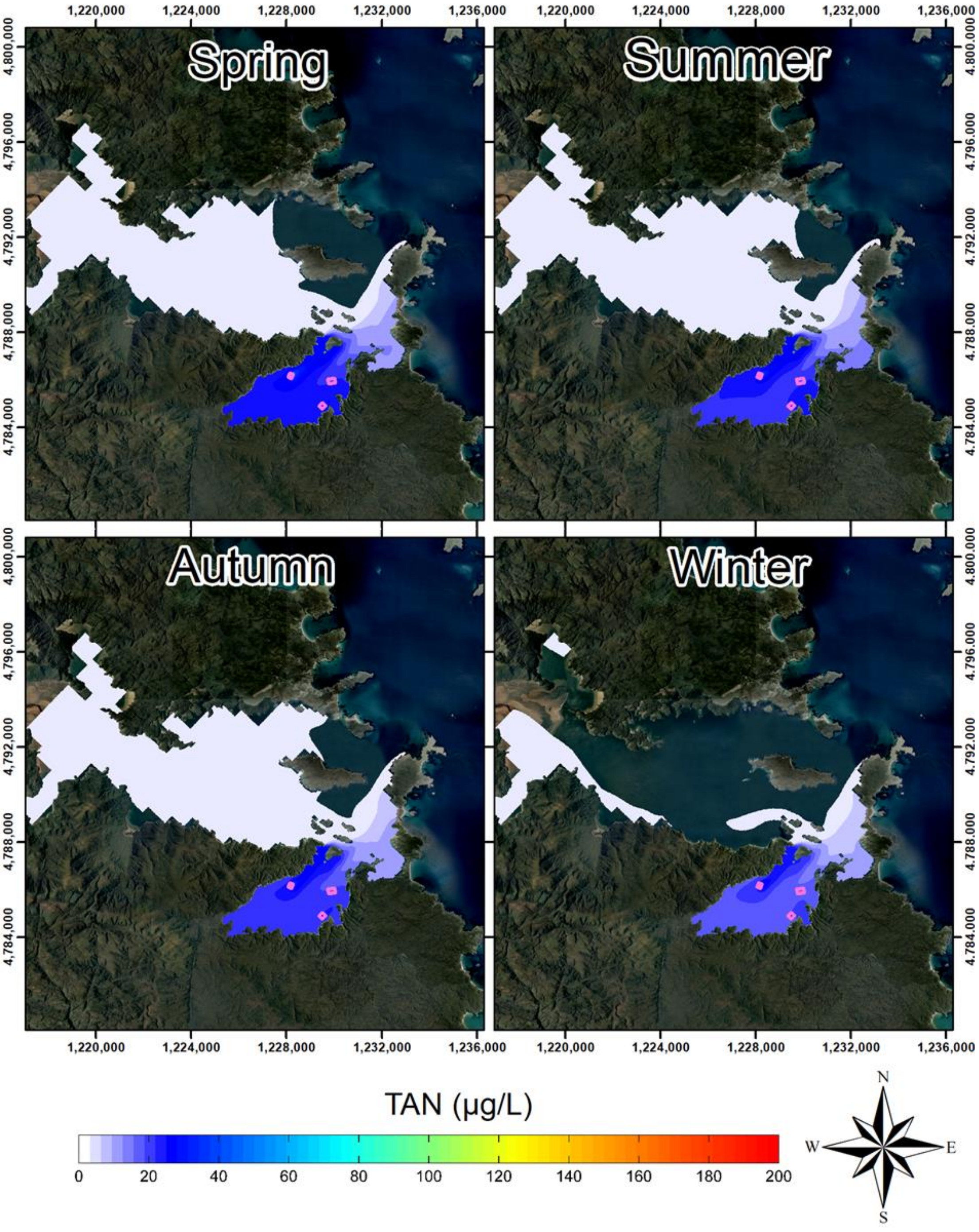


***Figure 27 -** Seasonal average excess concentrations of TAN for the higher level scenario (maximum minus baseline) at the surface.*

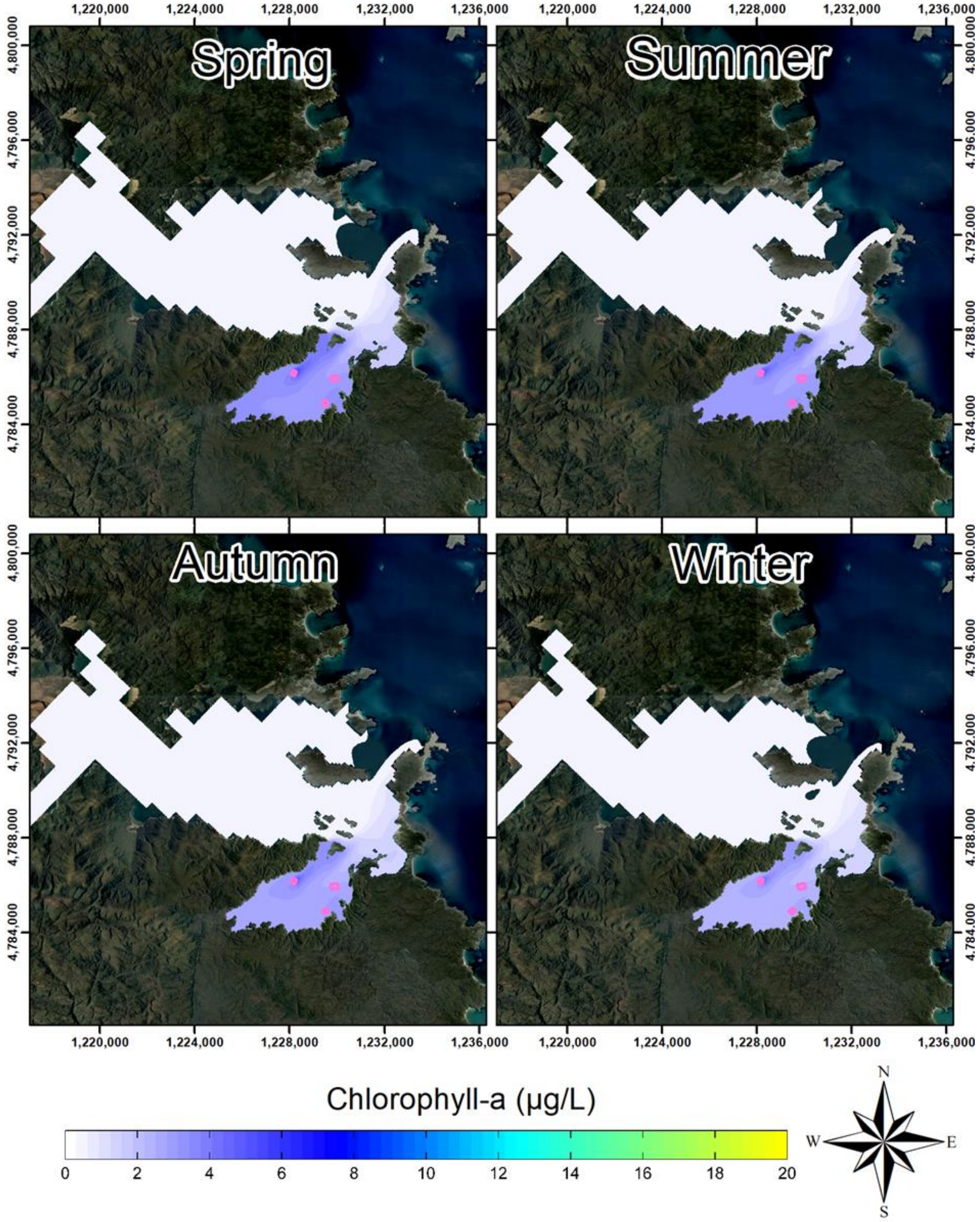


Figure 28 - *Seasonal average excess concentration of chlorophyll-a for the higher level scenario at the surface.*

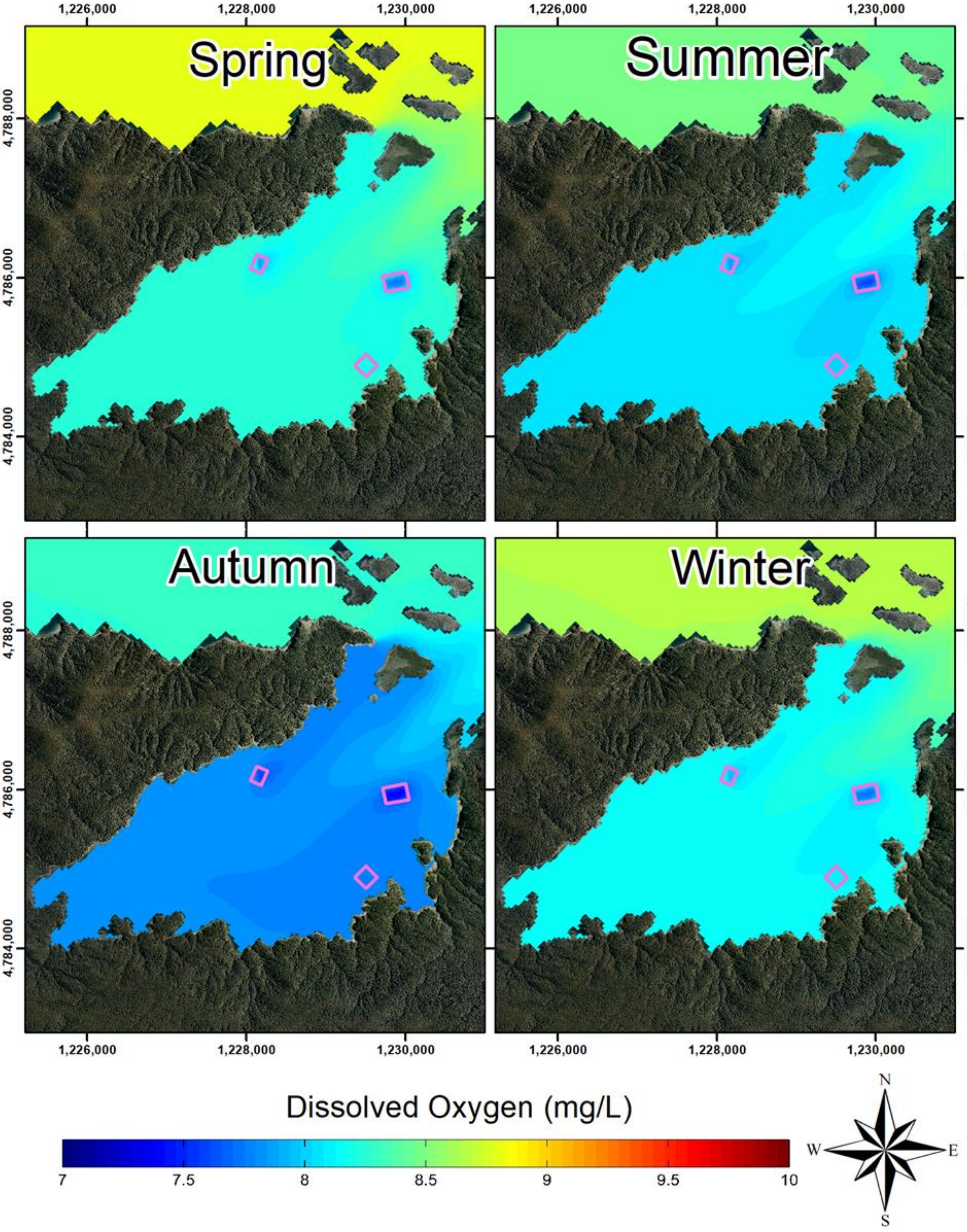


Figure 29 *- Seasonal average dissolved oxygen concentration for the higher level scenario at the surface.*

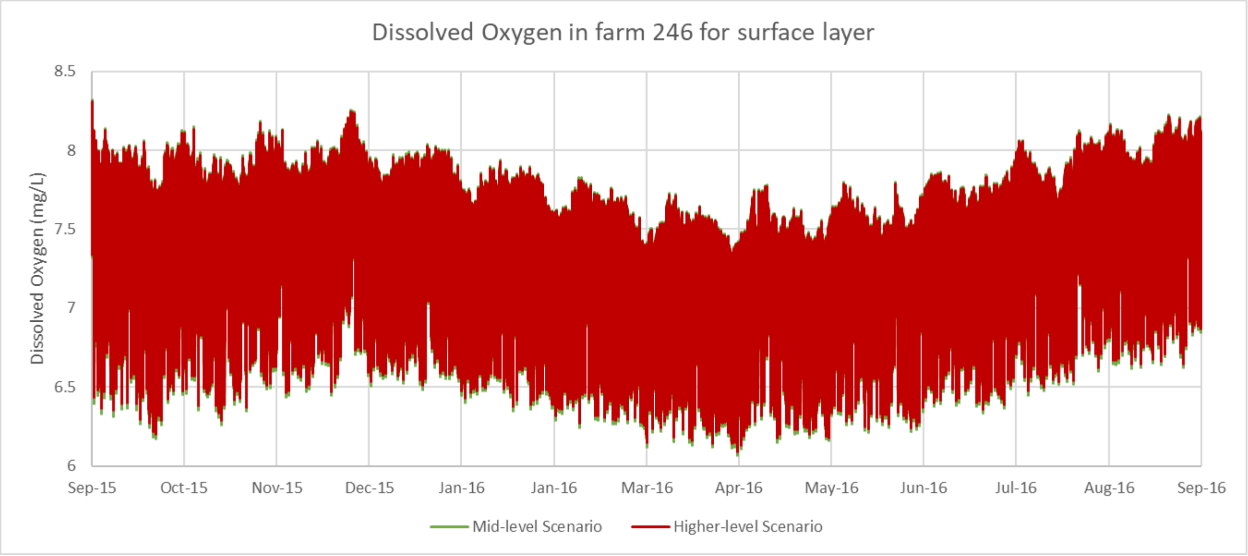


Figure 30 *- Comparison of dissolved oxygen in farm 246 at the surface for the 2 proposed scenarios.*

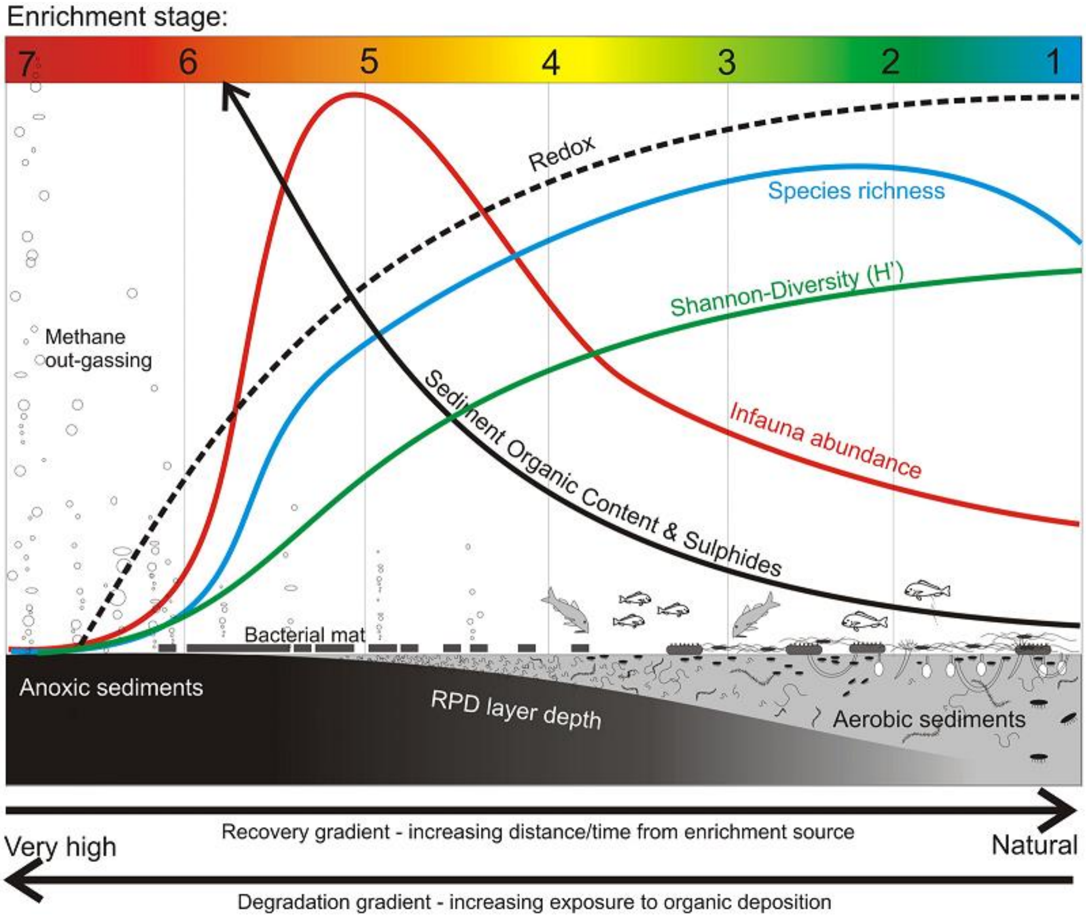
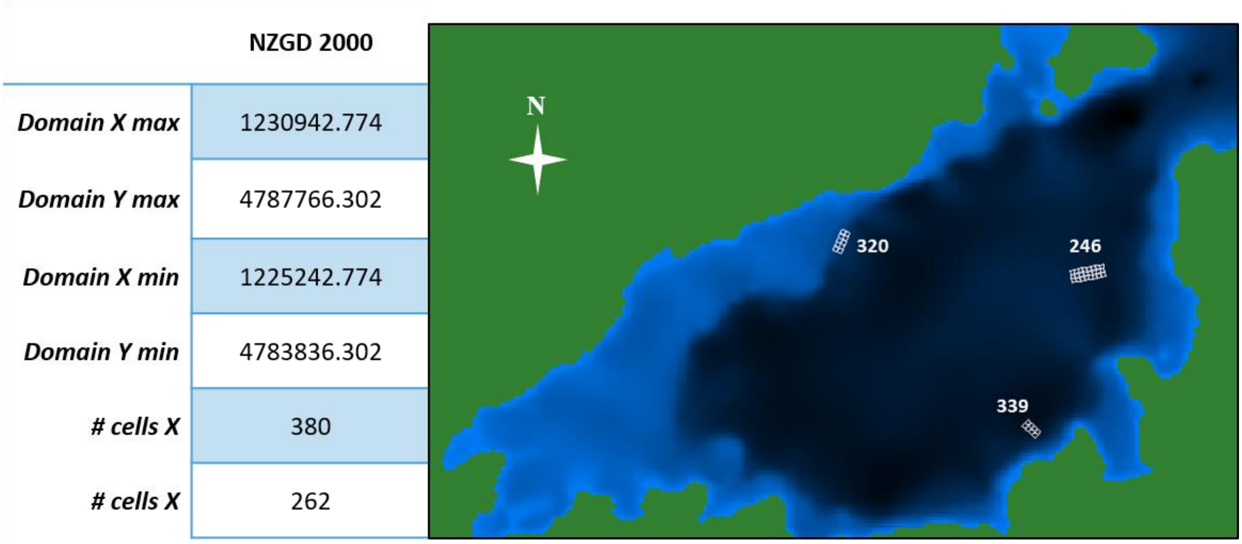


***Figure* 31** *– Seabed effects with increasing organic enrichment. Modified from Pearson and Rosenberg 1978*



	NZGD 2000
Domain X max	1230942.774
Domain Y max	4787766.302
Domain X min	1225242.774
Domain Y min	4783836.302
# cells X	380
# cells X	262

Figure 32 **-** *Domain bounds used in this depositional mode along with pen positions and groups referenced by permit number. All coordinates expressed in NZGD 2000.*

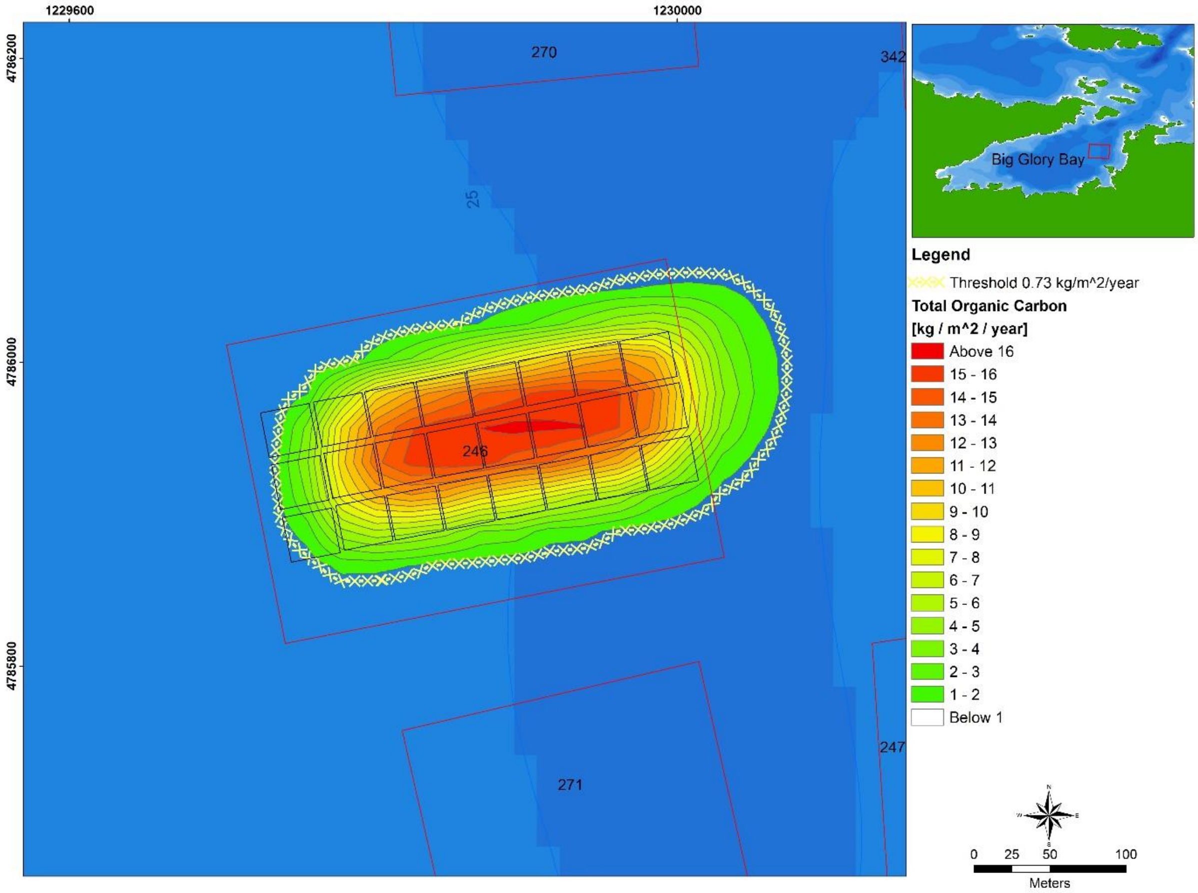


***Figure 33** – MF246 total carbon deposition with a 12.0 kg m^{-3} stocking density. A binding agent is assumed to be in the feed. This scenario assumes an annual feed mass of 6,798 tons. Yellow hatched lines highlight the extent of the 2g C m^{-2} day depositional footprint.*

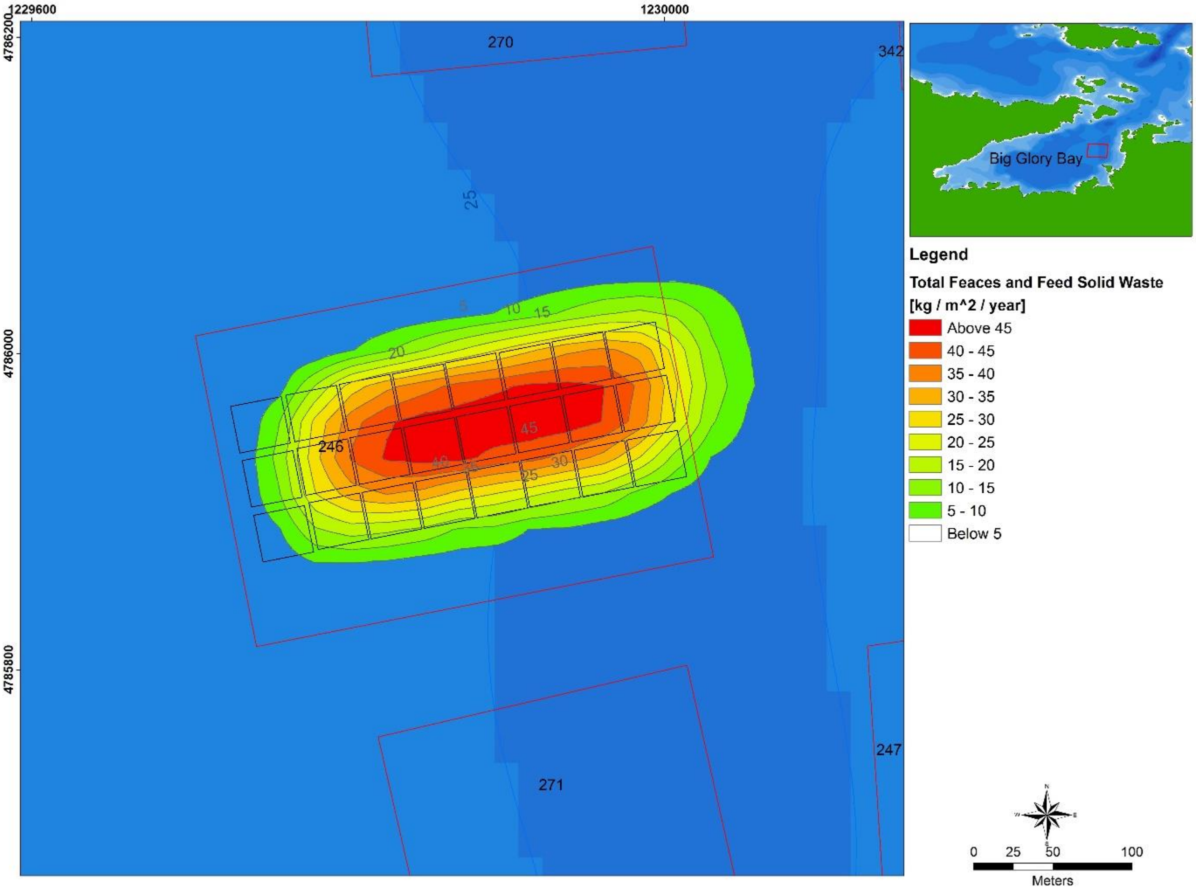


***Figure 34** – MF246 total faeces and solids deposition with a 12.0 kg m^{-3} stocking density. A binding agent is assumed to be in the feed. This scenario assumes an annual feed mass of 6,798 tons.*

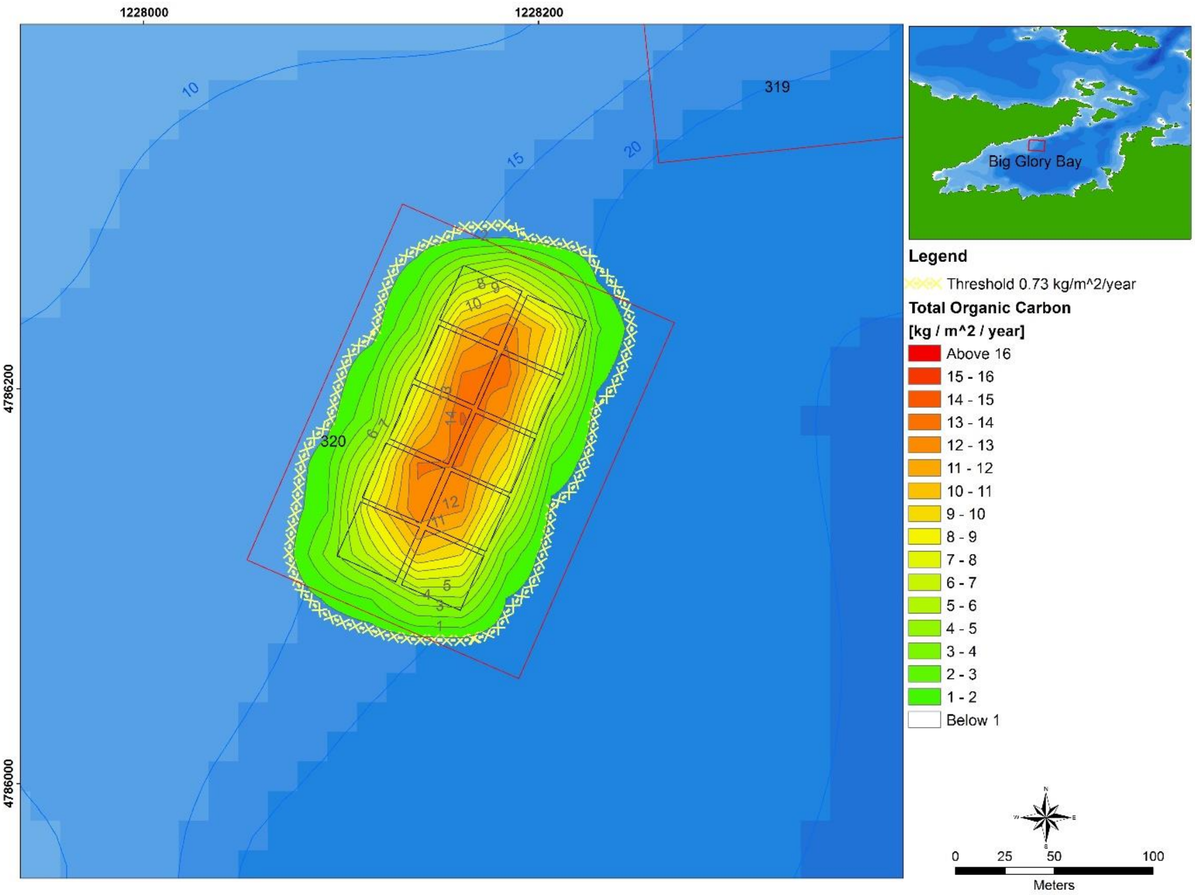


Figure 35 *- Li320 total carbon deposition with a 12.0 kg* m^{-3} *stocking density. This scenario assumes an annual feed mass of 2,832 tons. Yellow hatched lines highlight the extent of the 2g C* m^{-2} day^{-1} *depositional footprint.*

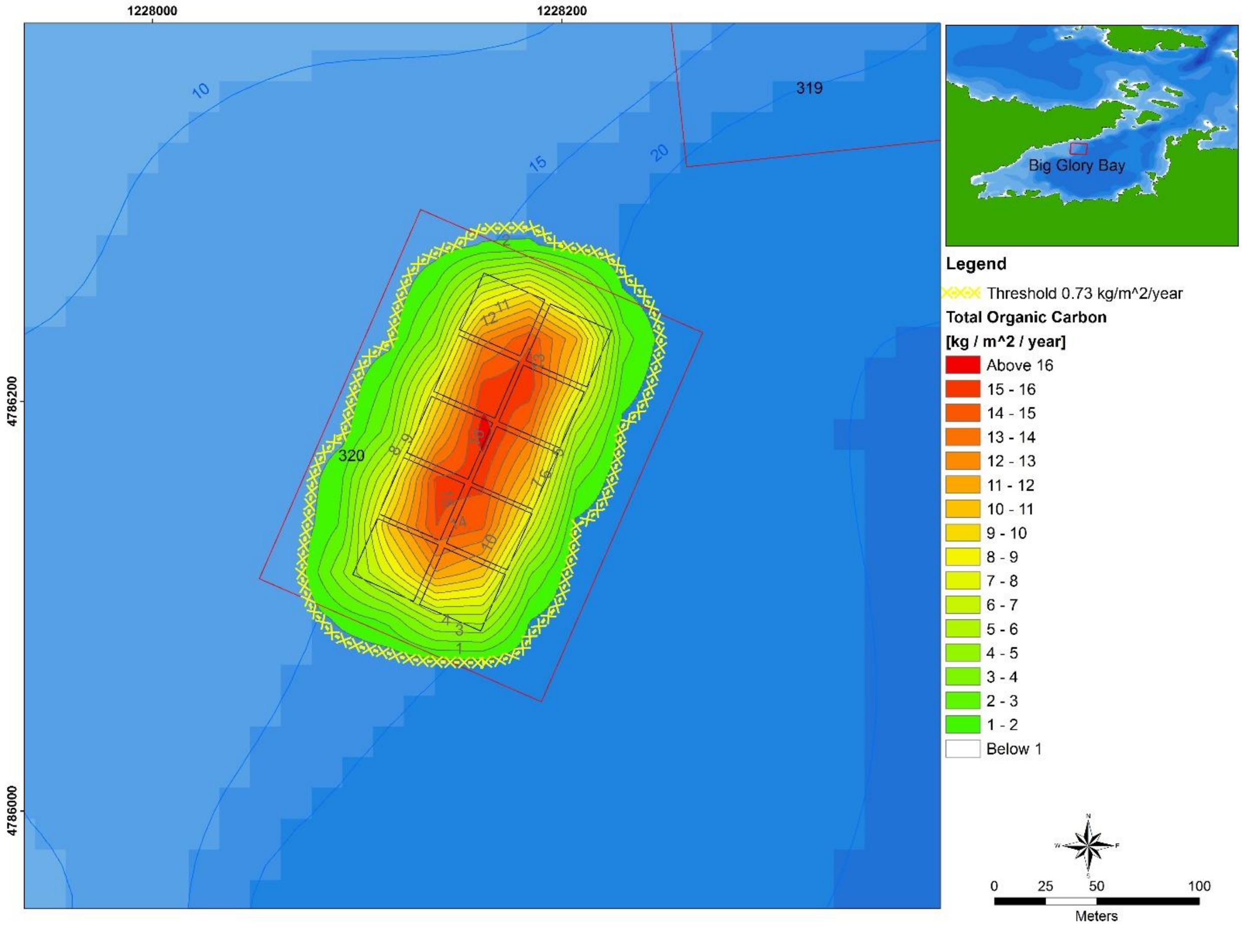


Figure 36 *- Li320 total carbon deposition with a 14.0 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 3,303 tons. Yellow hatched lines highlight the extent of the 2g C m^{-2} day^{-} depositional footprint.*

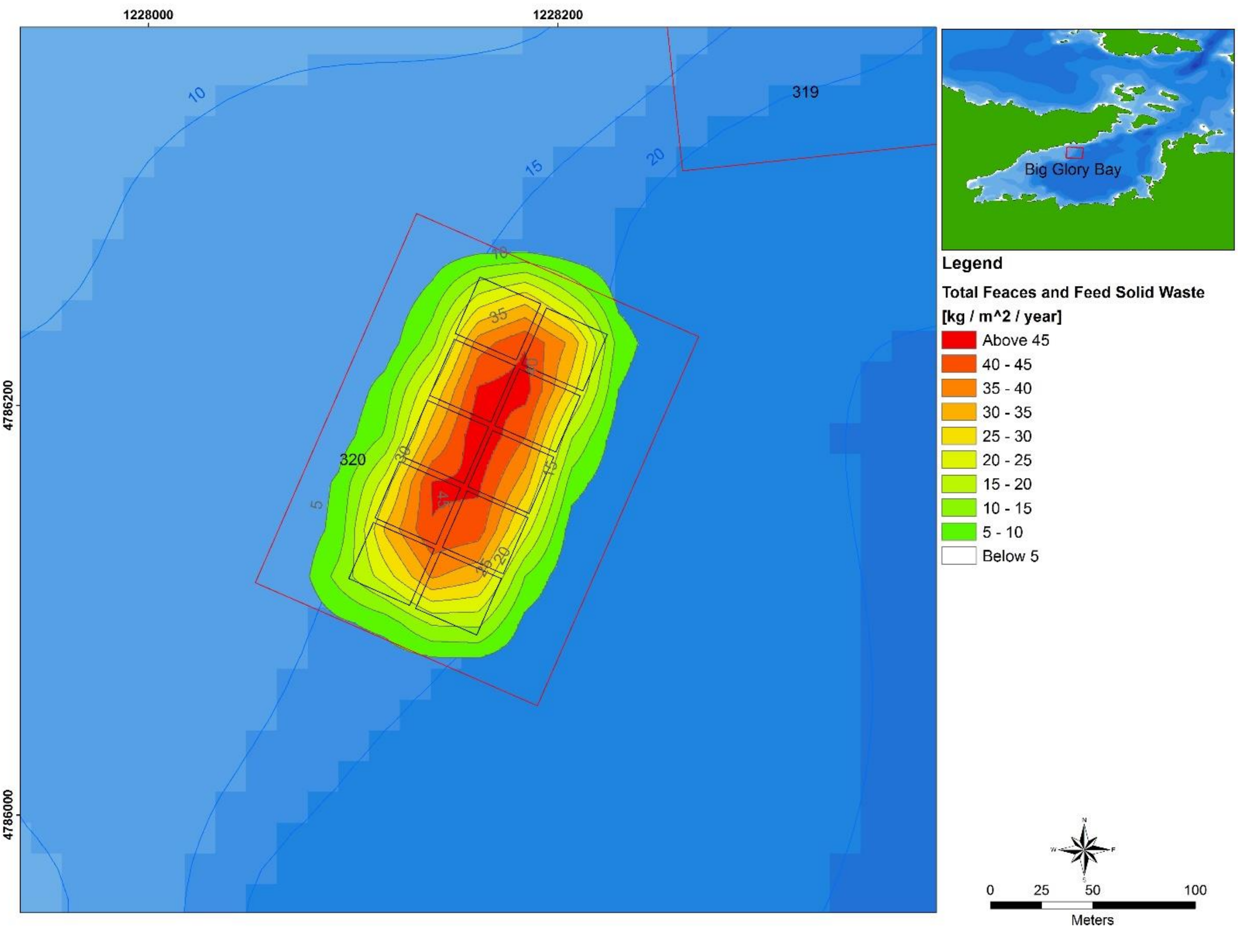


Figure 37 *- Li320 total faeces and solids deposition with a 14.0 kg m-3 stocking density. This scenario assumes an annual feed mass of 3,303 tons.*

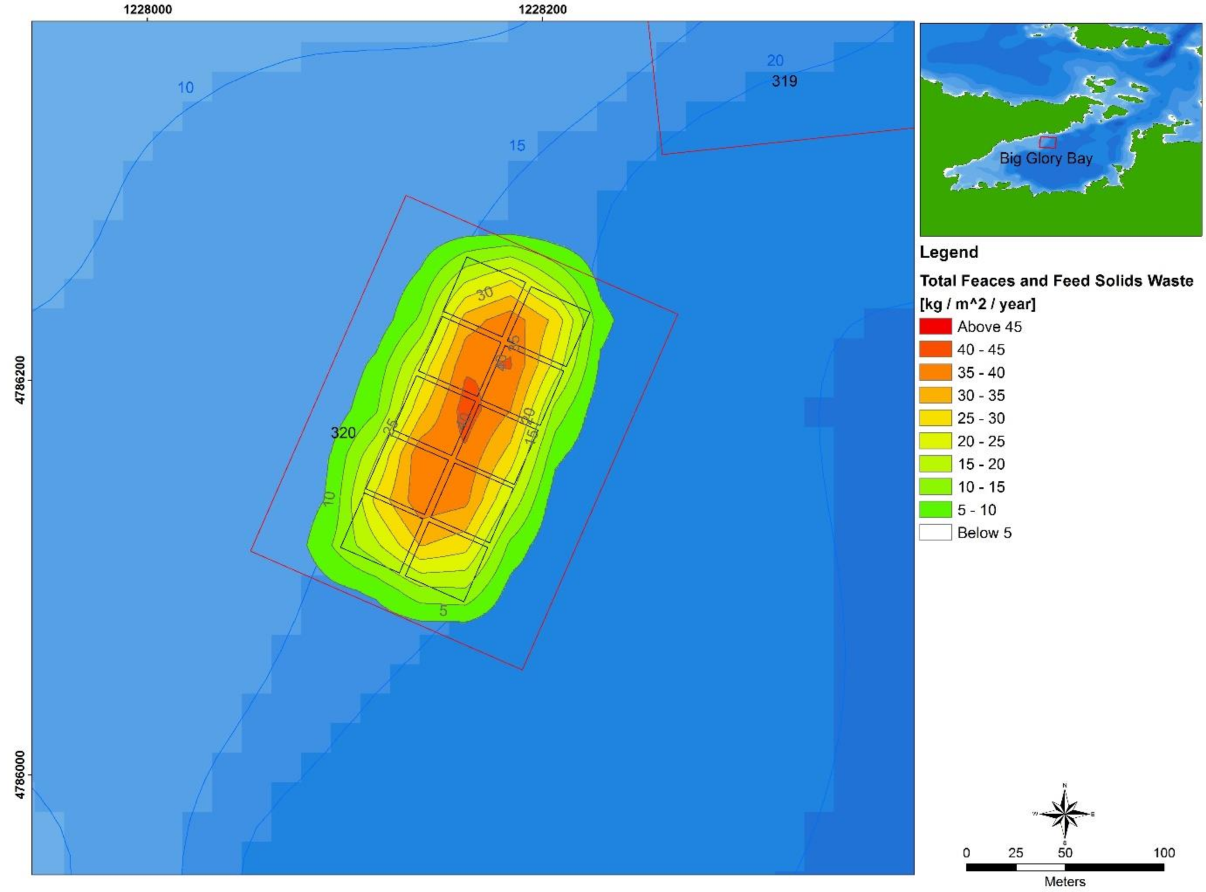


Figure 38 *- Li320 total faeces and solids deposition with a 12.0 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 2,832 tons.*

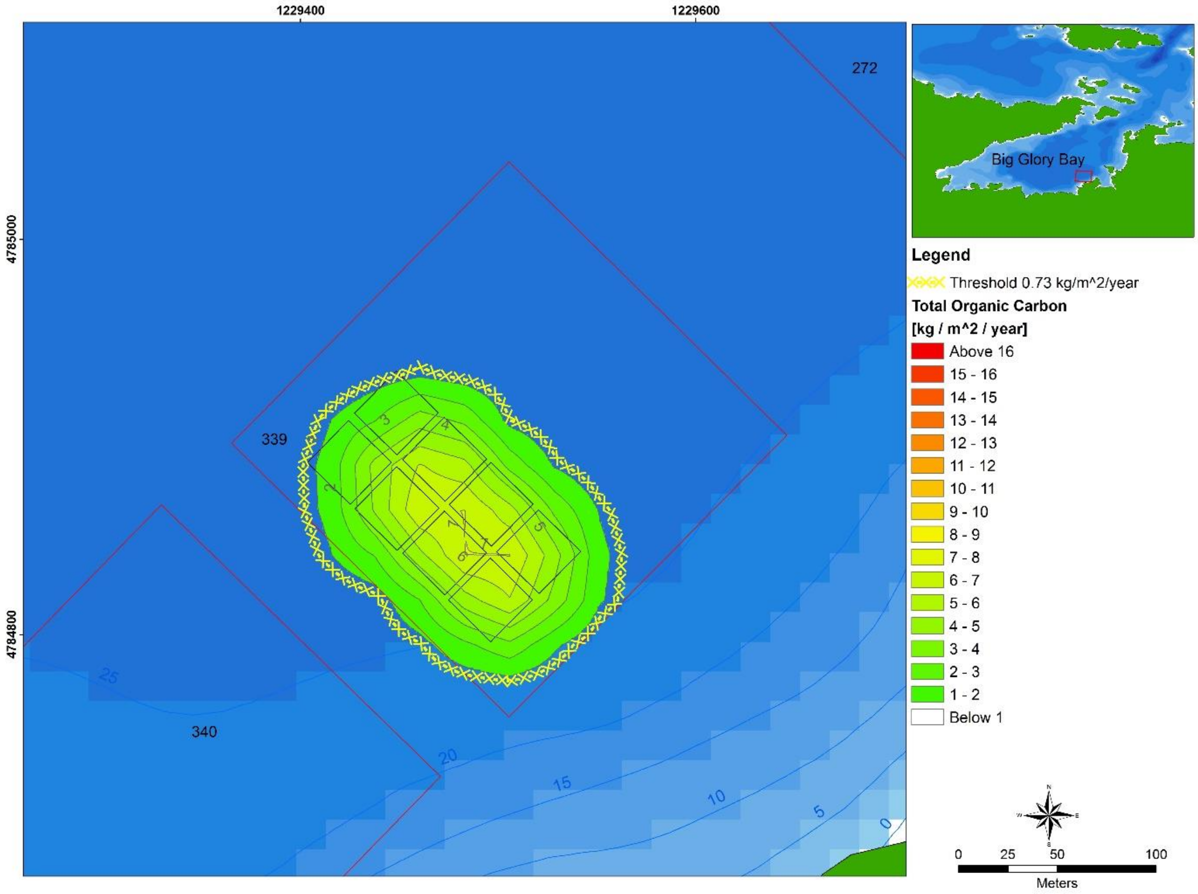


Figure 39 *- Li339 total carbon deposition with a 4.3 kg* m^{-3} *stocking density. This scenario assumes an annual feed mass of 567 tons. Yellow hatched lines highlight the extent of the 2g C* m^{-2} *day*$^{-}$ *depositional footprint.*

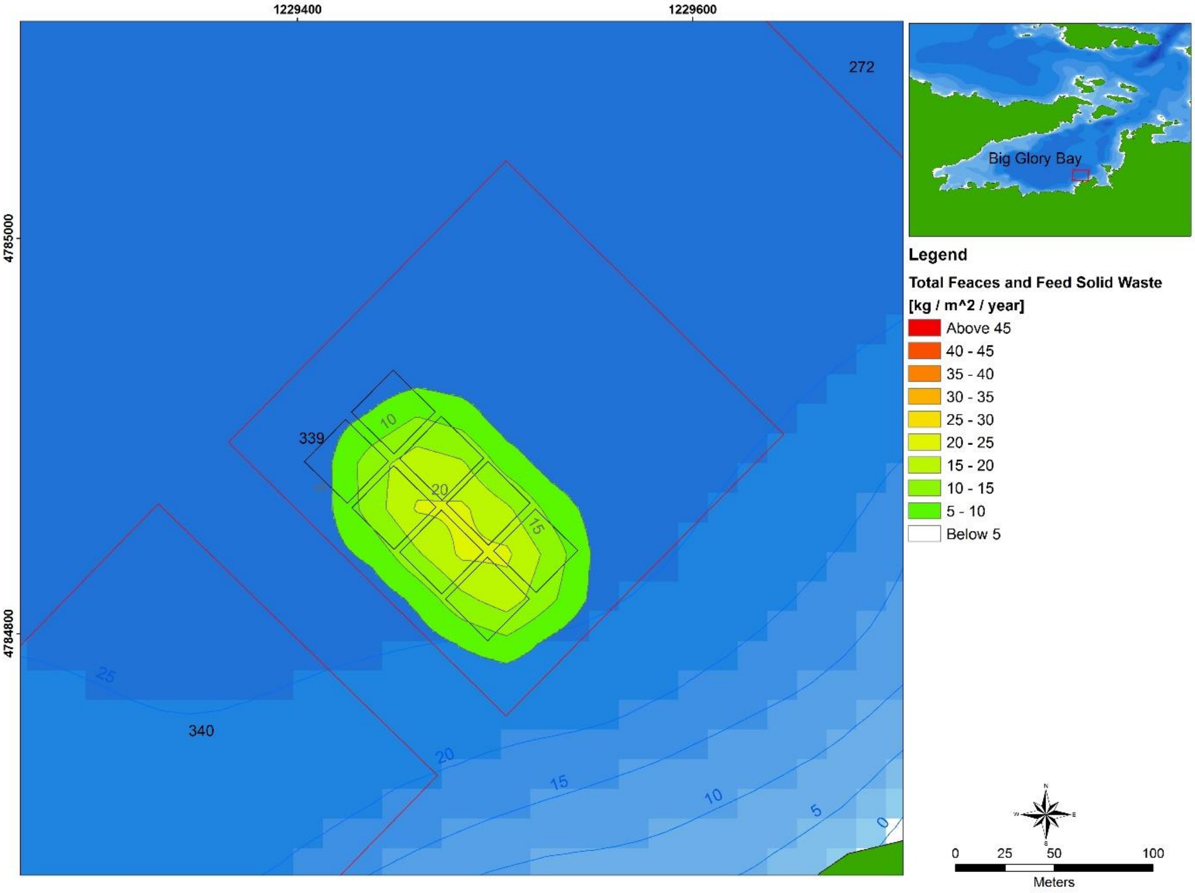


Figure 40 *- Li339 total faeces and solids deposition with a 4.3 kg m^{-3} stocking density. This scenario assumes an annual feed mass of 567 tons.*

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TABLE 1 SUMMARY OF MAIN DATA SOURCES USED TO BUILD THE HYDRODYNAMIC MODEL

Data Type	Sources
Predicted Tidal Elevation	TPXO Global Tidal Solution and WX tidal data

Current (ADCP)	ADCP1: 168.140293, -46.965581 ADCP2: 168.117658, -46.987192
Wind	Global Forecast System by National Oceanic and Atmospheric Administration (GFS)
Regional Current data	HYCOM
Bathymetry	Chart data from Land Information New Zealand

TABLE 3 – BIG GLORY BAY MODEL TAN LOAD INPUTS

	Mid-level	**Higher-level**
January	32.18	34.03
February	31.05	32.68
March	29.61	32.33
April	30.21	32.80
May	31.49	33.36
June	29.16	30.69
July	27.50	29.05
August	26.03	27.45
September	26.13	27.55
October	27.66	28.21
November	32.86	35.69
December	34.40	37.42
TOTAL TAN	358.28	381.2
TOTAL N in FEED	621.4	659

TABLE 4 – BIG GLORY BAY MODEL OXYGEN DRAWDOWN INPUTS

Big Glory Bay Oxygen Drawdown Inputs (tons day^{-1})

	Mid-level	**Higher-level**
	8.85	9.315

TABLE 4 - PEN DESIGNS, LOCATIONS, LAYOUTS, AND VOLUMES USED FOR THIS DEPOSITIONAL MODEL. PENS LOCATIONS ARE REPORTED AS THEY ARE ENTERED INTO DEPOMOD (I.E. REFERENCING THE CENTER OF THE TOP LEFT PEN BEFORE ADJUSTING THE BEARING OF THE PEN SET). COORDINATES ARE GIVEN IN NZGD2000.

	Lease 246 Pens	Lease 320 Pens	Lease 339
X Position	1229774.23	1228119.06	1229441.56
Y Position	4785964.45	4786123.51	4784879.658
Layout (row x column)	3 x 8	2 x 5	2 x 4
Pen Dimensions (m)	30 x 30	30 x 30	30 x 30
Pen Depth (m)	15	15	15
Bearing (°N)	79.15	23.35	44.38
Total Volume (m^3)	324,000	135,000	108,000

TABLE 5 - DEPOSITIONAL MODEL LOADING INPUT PARAMETERS. STOCK TO FEED RATIO IS DEFINED AS THE AVERAGE DAILY FEED RATE (TONS DAY^{-1}) DIVIDED BY THE ANNUAL PRODUCTION (TONS YR^{-1}).

	Lease 246 all scenarios	Lease 320 Mid-level scenario	Lease 320 Higher-level scenario	Lease 339 Mid-level scenario	Lease 339 Higher-level scenario
Stocking Density/Biomass in the cage (kg m^{-3})	12.0	12.0	14.0	3.0	4.3
Stock: Feed	0.479	0.479	0.479	0.479	0.479
Feed Mass (tons day^{-1})	18.6	7.76	9.05	1.55	4.1
% Feed Wastage	3	3	3	3	3
% Feed Digested	85	85	85	85	85
% Water Content	9	9	9	9	9
Feed % C	49	49	49	49	49
Faeces % C	30	30	30	30	30
Feed % N	6.1	6.1	6.1	6.1	6.1

Faeces % N	17.3	17.3	17.3	17.3	17.3
Bay Salinity (ppt)	35	35	35	35	35
Bay Temperature	10	10	10	10	10