Appendix E
Numeric Modelling Report (Dilution Study)

Nordic Aquafarms California LLC

Samoa Peninsula Land-based Aquaculture Project

Numerical Modelling Report, Rev. 1

February 2021

Executive Summary

Nordic Aquafarms California LLC (NAFC) proposes a land-based aquaculture facility situated on the Samoa Peninsula near Eureka, California. The Project plans to utilize the existing Redwood Marine Terminal II (RMT II) intake structure, ocean outfall pipe and multiport diffuser to discharge water from the facility to the ocean. The diffuser has 144 ports, each of 2.4-inch diameter. Ports are paired on either side of the pipe at a spacing of 12 ft (3.66 m) between ports. The ports discharge at a 45 degree vertical angle relative to the seabed Currently, the RMT II diffuser is used by DG Fairhaven Power Company for intermittent batch discharges (200-400 GPM) with eight diffuser pairs maintained open (16 open ports) to allow discharge from their facility. A future Samoa sewage treatment plant will also utilize the diffuser (37 GPM average dry weather and 53 GPM peak wet weather effluent design). The proposed NAFC facility will have an average discharge of 8,681 GPM. Source waters to the facility will be a mixture of marine (from Humboldt Bay) and treated freshwater (from the Humboldt Bay Municipal Water District via the Mad River) yielding a salinity of ~26.8 psu. Effluent temperature from the facility will range between 68-72°F. After passing through the facility and prior to discharge through the RMT II outfall infrastructure, the effluent will pass through an advanced wastewater treatment plant (i.e., moving bed biofilm reactor, a membrane bioreactor and UV-C sterilization), thereby attaining low levels of inorganic nutrients and organic suspended solids.

The purpose of this marine modelling investigation is to support the National Pollutant Discharge Elimination System (NPDES) permitting and mixing zone characterization for NAFC's proposed facility, namely through:

1. Establishment of water quality objectives for the coastal waters.
2. Near-field[1] modelling to ascertain if the water quality objectives are achieved in close proximity to the diffuser.
3. Three-dimensional (3D) hydrodynamic modelling to define the spatial extent to meet water quality objectives if not met in close proximity to the diffuser.
4. 3D particle modelling to evaluate whether particulate organic loads pose a risk to the proximal benthic habitat.

The key conclusions from this investigation for the proposed future comingled discharge through the RMT II multiport diffuser include:

- The preliminary concept design of 64 open ports yields a predicted mixing zone (i.e., marine toxicity and physiological stress to biotic receptors) that is met within 5 ft of the diffuser on the basis of the near-field modelling. The port exit velocity of ~10 ft/s also maintains the ports clear of sediment build-up and biofouling, and maintains optimal levels of jet-induced near-field mixing.
- Though there are some differences in the predicted zone of water quality degradation (i.e., elevated nutrients) with the 3D modelling of the two scenarios (i.e., typical summer conditions and a large winter river inflow event):
  - The risk of enhanced pelagic productivity from elevated nutrients in the surface and mid- water column is 'very low'.
  - The risk of enhanced benthic productivity from elevated nutrients in the near-seabed waters is 'very low'.

[1] Near-field modelling predicts the dilution of a plume with the receiving marine waters in close proximity to the diffuser from momentum (jet-induced mixing upon exiting the port) and/or buoyancy (mixing as the plume rises through the water column).

- The predicted organic gross sedimentation rates during both scenarios are very low, and pose a low risk of impacting the benthic community.

This report is subject to, and must be read in conjunction with, the limitations and the assumptions and qualifications contained throughout the Report.

Table of Contents

Table Index

Figure Index

Appendices

Appendix D – Simulated Salinity Transects during the Large Inflow Event Scenario

Acronyms

Acronym	Description
3D	Three-dimensional
ADCP	Acoustic doppler current meter
C_A	Ambient marine water concentration
C_O	Outlet concentration
C_T	Target concentration at mixing zone edge
CCS	California Current System
CFSv2	Climate Forecasting System version 2
D	Dilution
DHI	Danish Hydraulic Institute
DT	Dilution target
DT_{MZ}	Mixing zone dilution target
DT_{NH3}	Mixing zone dilution target for ammonia
DT_{NHX}	Dilution target for zone of water quality degradation for reduced inorganic nitrogen
DT_{NOX}	Dilution target for zone of water quality degradation for oxidized inorganic nitrogen
DT_{PO4}	Dilution target for zone of water quality degradation for orthophosphate
DT_{Sal}	Mixing zone dilution target for salinity
DT_{Temp}	Mixing zone dilution target for temperature
DT_{WQ}	Dilution target for zone of water quality degradation
FM	Flexible mesh
ft	Feet
ft/s	Feet per second
ft^3/s	Cubic eet per second
g/m^2	Grams per square meter
$g/m^2/d$	Grams per square meter per day
GPM	Gallons per minute
HAT	Highest astronomical tide
HYCOM	Hybrid Coordinate Ocean Model
in	Inch
IOA	Index of agreement
kg/day	Kilograms per day
kg/m^3	Kilograms per cubic meter
km	kilometer
LAT	Lowest astronomical tide
m	Meter
m/s	Meters per second
m^3/s	Cubic meters per second
MAE	Mean absolute error
mg/L	Milligrams per liter

Acronym	Description
MGD	Millions of gallons per day
MLLW	Mean lower low water
MHHW	Mean higher high water
MSL	Mean Sea Level
MT	Mud Transport
N/m^2	Newtons per square meter
NAFC	Nordic Aquafarms California LLC
NCEP	National Centers for Environmental Prediction
NH_3	Ammonia
NH_4	Ammonium
NH_X	Reduced inorganic nitrogen
no.	number
NO_3	Nitrate
NO_X	Oxidized inorganic nitrogen
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
PO_4	Orthophosphate
psu	Practical salinity units
Q	Discharge
RMT II	Redwood Marine Terminal II
S	Salinity
SS	Suspended solids
SS_{Settle}	Settleable suspended solids
T	Temperature
ug/L	Micrograms per liter
um	Micrometer
V_A	Volume of ambient marine water
V_E	Volume of effluent water
USGS	United States Geological Survey
WQ	Water quality
WQO	Water quality objective

1. Introduction

1.1 Project Background

Nordic Aquafarms California LLC (NAFC) proposes a land-based aquaculture facility situated on the Samoa Peninsula near Eureka, California, bounded on the west by the dunes adjacent to the Pacific Ocean and on the east by Humboldt Bay. The facility would be located at the site of the former Samoa Pulp Mill in the unincorporated community of Samoa in Humboldt County, California. The Project site is approximately 36 acres and will be utilized for land-based finfish aquaculture. The Project would provide sustainably raised seafood to customers on the West Coast.

The Project plans to utilize the existing Redwood Marine Terminal II (RMT II) intake structure, ocean outfall pipe and multiport diffuser to discharge water from the land-based aquaculture facility to the coastal ocean. CH2M (2016) provides the RMT II outfall pipe and diffuser specifications as:

- 36 inch internal diameter pipe that is ~8,200 ft (2,497 m) long and terminates in an 852 ft (258 m) multiport diffuser in ~82 ft (25 m) maximum depth and ~79 ft (24 m) average depth.
- The diffuser has 144 ports, each of 2.4 in diameter. Each port is paired with 72 ports on either side of the pipe at a spacing of 12 ft (3.66 m) between ports. The ports discharge at a 45 degree vertical angle relative to the seabed.
- The outfall pipe, intake structure and diffuser formerly discharged ~15 million gallons per day (MGD) from the decommissioned pulp mill.

Currently, the RMT II outfall infrastructure is used by DG Fairhaven Power Company (Fairhaven Power) for intermittent batch discharges of 200-400 gallons per minute (GPM). Because of the low Fairhaven Power discharge relative to the outfall infrastructure capacity, much of the diffuser has filled with sediment. Fairhaven Power maintains the openings of eight diffuser pairs to allow discharge from their facility.

A future Samoa waste water treatment plant will also utilize the RMT II outfall infrastructure with anticipated discharges of 37 and 53 GPM for average dry weather and peak wet weather design conditions, respectively.

The proposed NAFC land-based aquaculture facility will have an average discharge of approximately 8,700 GPM through the RMT II outfall infrastructure. Source waters to the facility will be a mixture of marine (from Humboldt Bay) and treated freshwater (from the Humboldt Bay Municipal Water District via the Mad River). After passing through the aquaculture facility and prior to discharge through the RMT II outfall infrastructure, the effluent will pass through an advanced wastewater treatment plant that includes a moving bed biofilm reactor, an ultrafiltration membrane bioreactor, UV-C disinfection.

1.2 Purpose of This Report

The purpose of this marine modelling study is to provide relevant information to support the National Pollutant Discharge Elimination System (NPDES) permitting and mixing zone characterization for NAFC's proposed land-based aquaculture facility and to provide a technical basis for biological evaluations related to marine species.

1.3 Scope

The scope for this marine modelling investigation is to:

1. Establish water quality objectives for the proposed comingled discharge into the coastal waters from the proposed aquaculture facility, future waste water treatment plant and existing power plant to reach environmentally acceptable levels.

2. Undertake near-field[2] modelling to determine if the water quality objectives are achieved in close proximity to the diffuser.
3. Undertake three-dimensional (3D) hydrodynamic[3] modelling to define the spatial extent to meet the water quality objectives if not met within the near-field region.
4. Incorporate particle modelling to evaluate whether particulate organic loads pose a risk to the proximal benthic habitat.

Figure 1 illustrates key locations considered in this modelling investigation including:

- The location of the multiport diffuser (diffuser) and a model transect (simulation transect) used to evaluate the effect of the simulated salinity stratification during large winter river inflow events.
- Sites where water quality (WQ 2012-15), water level (Level 2018), and current speed and direction (ADCP 2004) measurements were collected.
- The confluences of the two proximal major river systems (Eel River, Mad River).

1.4 Assumptions

The following assumptions are adopted in this study:

- Limited data are available to define the ambient water quality in the proximal coastal waters (to characterize ambient water quality). Ambient water quality concentrations were defined on the basis of measurements within Humboldt Bay (near the entrance) as described in Section 3.1.
- The water quality of the future discharge through the multiport diffuser will be a combination of those from the proposed aquaculture facility, existing power plant and future waste water treatment plant. Water quality of these sources and the resultant comingled quality were estimated on the basis of assumptions outlined in Section 3.
- The flow rate from the proposed facility is evaluated assuming a constant discharge over the duration of two simulated periods (summer, winter) for a model duration of ~6 weeks (three spring-neap tidal cycles). As the future waste water treatment plant flow rates are much smaller than the proposed aquaculture facility, average dry weather and peak wet weather variations were not explicitly simulated as they do not have a material effect on the predictions.
- Estimates of potential gross sedimentation (neglecting resuspension) from the organic particles in the combined comingled facility's effluent were evaluated over a range of settling velocities as no information was available on the density or diameter of these particles. Modelling gross sedimentation rates is a conservative measure to ascertain whether organic sediment loading is likely to be an issue for the proximal benthic habitat. Please refer to Section 4 for further justification of this assessment.

1.5 Limitations

This report: has been prepared by GHD for Nordic Aquafarms California LLC and *may only be used and relied on by Nordic Aquafarms California LLC for the purpose agreed between GHD and the Nordic Aquafarms California LLC as set out in this report.*

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[2] Near-field modelling predicts the dilution of a plume with the receiving marine waters in close proximity to the diffuser from momentum (jet-induced mixing upon exiting the port) and/or buoyancy (mixing as the plume rises through the water column).

[3] Three-dimensional hydrodynamic modelling predicts the dilution of the comingled discharge with the receiving marine waters due to naturally occurring mixing mechanisms (e.g. from tides, winds and waves).

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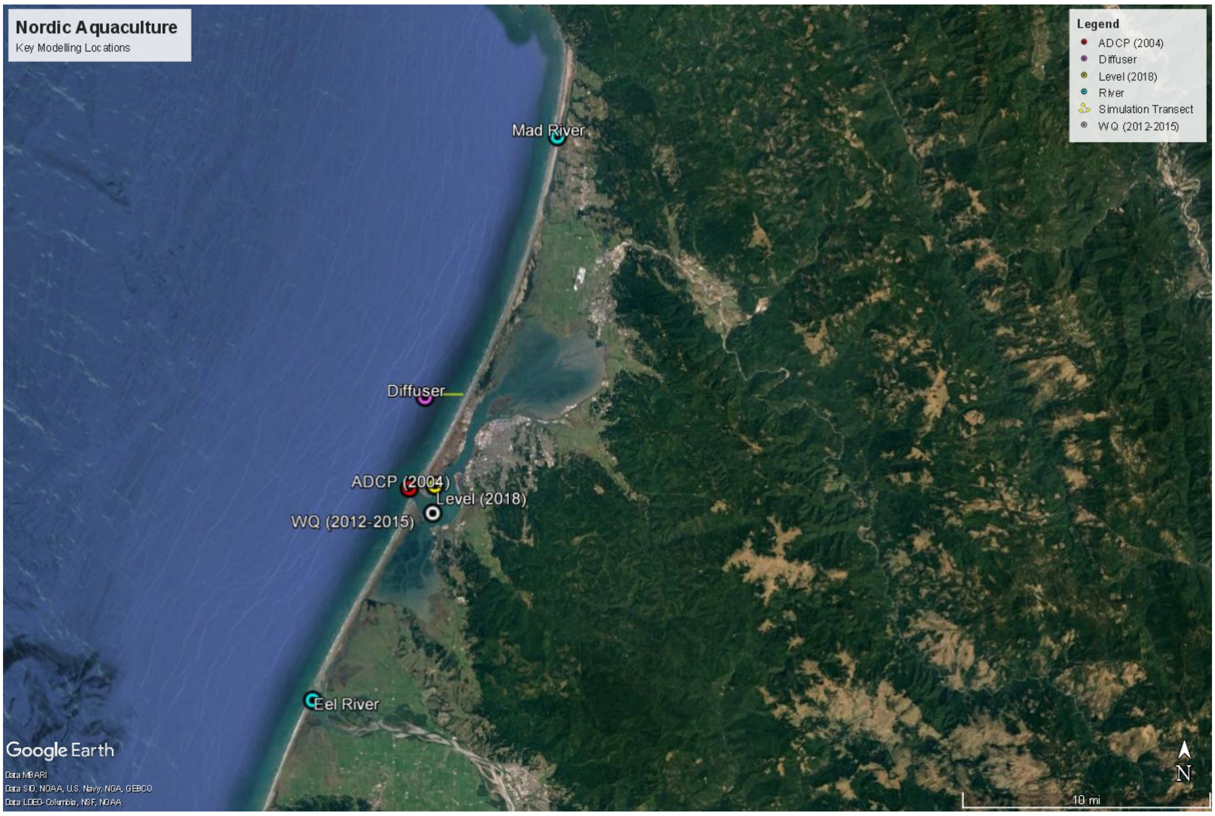


Figure 1 Key locations of monitoring data, diffuser and major river confluences (Eel River, Mad River).

2. Description of the Marine Environment

2.1 Tides

Tidal characteristics for Samoa are presented in Table 1. The greater diurnal range (the difference between MHHW and MLLW) at Samoa is moderate (7.37 ft).

Table 1 Tidal data for Samoa (Humboldt Bay).

Tidal Datum	Tide Level (ft)
Highest Astronomical Tide (HAT)	9.32
Mean Higher High Water (MHHW)	7.37
Mean Sea Level (MSL)	3.99
Mean Lower Low Water (MLLW)	0.00
Lowest Astronomical Tide (LAT)	-2.41

Source: https://tidesandcurrents.noaa.gov/datums.html?id=9418817

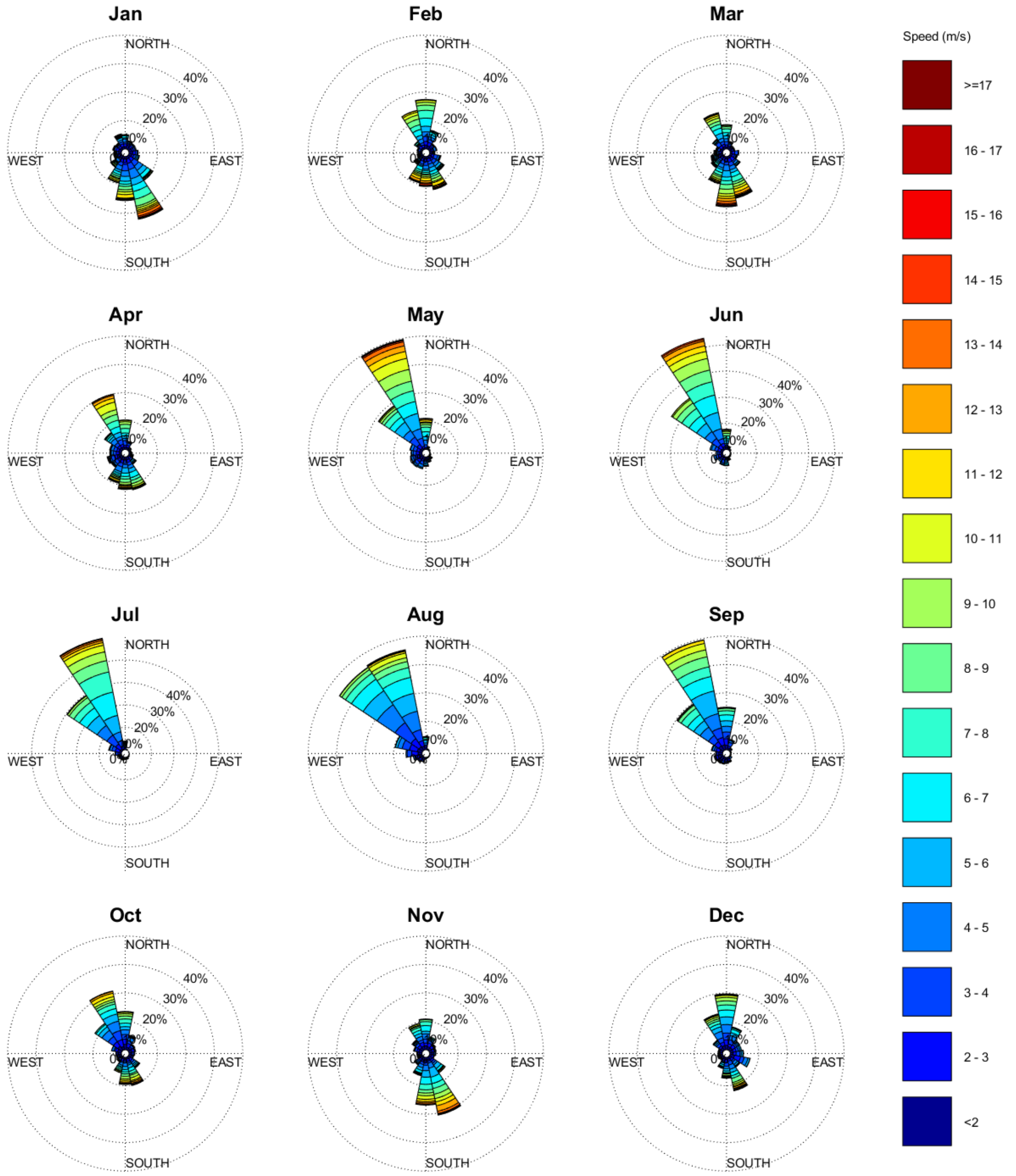
2.2 Oceanographic Currents

The near surface waters off the U.S. West Coast originate in large part from the eastward-flowing North Pacific Current (the northern limb of the North Pacific Gyre), which advects (transports) biota and debris towards the West Coast, and serves as a source of the water properties of the California Current System (CCS). In contrast to the CCS of the upper water column, the California Undercurrent is a poleward-flowing subsurface oceanographic feature of the region.

Overall biological productivity in the CCS in the locale of Humboldt Bay is generally attributed to seasonal upwelling of nutrient-rich deep waters to the continental shelf, as in other eastern boundary systems (Hill et al., 1998). This upwelling is caused primarily by the stress of winds blowing equatorward on the ocean's surface next to the coastal boundary. When the deeper water with higher nutrient concentration upwells, phytoplankton in the upwelling layers are exposed to light and begin to grow, resulting in a "bloom" (a high concentration of phytoplankton) (MacIsaac et al., 1985).

2.3 Winds

The National Centers for Environmental Prediction (NCEP) Climate Forecasting System version 2 (CFSv2) winds (Kalnay *et al*., 1996; Kistler *et al*., 2001) served as temporally (hourly) and spatially (0.2°) varying inputs for the modelling in this investigation. CFSv2 monthly wind roses at the location that contains both the diffuser and the National Oceanic and Atmospheric Administration (NOAA) Station 9418765 (North Spit California) is shown in Figure 2. The wind regime is characterized primarily by northwesterly winds from May to September and both southerly and northerly winds at other times of year.



Wind roses from 01/01/2016 to 01/01/2019 at 40.98807 , -124.36392

Figure 2 Monthly wind roses from CFSv2 dataset at a location coincident with NOAA Station 9418768 (North Jetty Landing, California) over the period of 2016-2018.

CFSv2 data compares well with the NOAA measurements at the North Jetty Landing (station no. 9418768) (Figure 3). This provides confidence that the spatial variability in wind speeds and directions over the model domain with CFSv2 model inputs accurately represents this important surface forcing mechanism.

Figure 3 Comparison of CFSv2 simulated data and NOAA measurements at the North Spit during October 2018.

3. Water Quality Objectives

There are two types of environmental risks associated with the future comingled discharge through the multiport diffuser into the proximal marine waters, namely:

- **Toxicity risks** to marine organisms in a localized area around the diffuser.
- Nutrient enrichment that may result in **water quality degradation** (e.g. higher nutrient and/or algae levels) over a larger region of the proximal coastal waters.

These two types of risks operate over different spatial scales and are assessed separately in this investigation.

The spatial extent of the 'toxicity mixing zone' and 'zone of potential water quality degradation' for a potential contaminant in this investigation is defined by the distance required to achieve a dilution target (DT) as: $DT = \frac{C_O - C_A}{C_T - C_A}$

Where:

C_O = Outlet concentration

C_A = Ambient marine water concentration

C_T = Target concentration at the edge of the mixing zone (i.e. the water quality objective [WQO]).

The dilution target represents the required dilution of the effluent with ambient seawater to meet the target concentrations (C_T) of the 'toxicity mixing zone' and the zone of 'potential water quality degradation'. The dilution (D) of effluent by seawater is defined volumetrically as:

$$D = \frac{V_A + V_E}{V_E}$$

Where:

V_A = Volume of ambient marine water

V_E = Volume of effluent water.

Dilution (D) of the effluent from the multi-port diffusers is simulated directly by the near-field modelling (Section 5) and indirectly with the application of a numerical conservative tracer with the 3D hydrodynamic modelling (Section 6).

3.1 Ambient Water Quality

The dataset utilized for ambient water quality in this study was collected approximately 3.5 miles south-southeast of the RMT II multiport diffuser. Swanson (2015a) collated data from measurements at Entrance Bay of Humboldt Bay (see Figure 1) from October 2012 to February 2015 that was comprised of:

- Bi-weekly to quarterly measurements from January 2014 to February 2015 by Swanson (2015b).
- Bi-weekly measurements from October 2012 to February 2015 by WTNRD (2015).

A summary of the descriptive statistics of pertinent analytes to this investigation is provided in Table 2.

Table 2 Marine water quality at Entrance Bay of Humboldt Bay.

Analyte	Median	80^{th} Percentile	20^{th} Percentile
PO_4 (ug/L)	45	60	-
NO_3 (ug/L)	150	225	-
NH_4 (ug/L)	42	64	-
S (psu)	33.5	-	32.3
T (°C)	11	13	-

This was the only time series data available to estimate appropriate water quality objectives in Section 3.3. An extensive search for water quality data of the Humboldt coastal waters (e.g. NOAA, USGS and EPA online databases) did not identify any other available existing data sets. Coastal water quality data from local university researchers could not be sourced.

Using a three-dimensional hydrodynamic model, Anderson (2010) estimated the 90% flushing time[4] between Entrance Bay and the ocean to be 1.6 days. Such a high flushing rate supports the assumption of this study that the Entrance Bay water quality is representative of the adjacent coastal waters, including the water quality of the ambient water at the diffuser site.

Hence, given the limited availability of water quality data to characterize the coastal water in proximity to the RMT II outfall, the focus of this study was on the potential impacts from the stimulation of coastal ecosystem productivity by elevated nutrient loads, ammonia toxicity and salinity/thermal stress.

[4] Time to flush 90% of the volume.

3.2 Existing and Future Estimates of Water Quality and Discharge through the RMT II Outfall Infrastructure

Table 3 summarizes the existing NPDES-authorized users that are currently permitted to discharge through the RMT II Outfall (Fairhaven power plant) and anticipated future users (aquaculture, Samoa Waste Water Treatment Plant) flow rates and water quality prior to comingling that will be discharged through the RMT II diffuser. The estimated comingled discharge and water quality through the diffuser is also provided, which serves as the basis to calculate the dilution targets in Section 3.4, and the model inputs for both the near-field modelling (Section 5) and three-dimensional modelling (Section 6).

The Nordic facility's effluent will pass through an advanced wastewater treatment plant that includes a moving bed biofilm reactor, a membrane bioreactor, UV-C sterilization and ultrafiltration (Section 1.1) prior to discharge through the RMIT II outfall prior to exiting the facility. There will be no discharge of free chlorine and ammonia levels will be below ambient levels. SS will be below 0.04 µm due to ultrafiltration, hence particles from the facility will not be settleable. Increased metals/metalloids often associated biofouling reduction measures with in situ coastal aquaculture facilities are not required operationally for this land-based facility, hence these potential contaminant will be at levels similar to those in coastal waters.

The Nordic facility discharge will comprise 95-97% of the comingled discharge through the RMIT II diffuser with the Samoa Waste Water Treatment Plant (<1%) and DG Fairhaven Power Plant (~3-5%) comprising a much smaller proportion. Because of the larger proportion of comingled discharge associated with the Nordic facility, it will provide an environmental benefit in terms of the comingled stream water quality:

- Large reductions in the elevated ammonia (NH_3) and orthophosphate (PO_4) concentrations from the Samoa Waste Water Treatment Plant.
- A large increase in the low salinity (S) of the Samoa Waste Water Treatment Plant.
- Large reductions in the elevated settleable suspended solids (SS) concentrations from both the Samoa Waste Water Treatment Plant and DG Fairhaven Power Plant.

It is clear from Table 3 that the key effluent water quality parameters of concern from the Nordic facility are the high concentrations of reduced inorganic nitrogen (NH_X) and oxidized inorganic nitrogen (NO_X) that pose a potential risk to the receiving coastal waters in terms of increased ecosystem productivity (e.g. higher phytoplankton levels).

Table 3 Characteristic flow rates (Q) and water quality of the existing and proposed future discharges through the diffuser for summer and winter periods.

Discharge Source	Q (GPM)	NH_3 (mg/L)	NH_X (mg/L)	NO_X (mg/L)	PO_4 (mg/L)	T (°F)	S (psu)	SS (mg/L)	SS (mg/L)	Comment
Existing Fairhaven Power Plant Minimum Intermittent Batch Flow (SHN 2020)	200 (minimum intermittent batch flow) 400 (maximum intermittent batch flow)	0.04	0.04	0.15	0.045	68.8	33.5	19	19	- Maximum and minimum intermittent batch discharge (Q) (SHN 2020 - Cooling water temperature (T) 17°F above ambient water temperature (T) (Tingleff, 2006) - Suspended solids (SS) is maximum instantaneous concentration monitored from August 2012-October 2016 of low volume wastewater[5] prior to comingling with cooling tower blowdown well below the maximum daily limit of 100 mg/L from NPDES permit (NCRWQCB 2018)
Future Samoa WWTP – Average Dry Weather Design (NCRWQCB 2020)	37 (average dry weather) 53 (peak wet weather design)	5	5	5	2	55 (summer) 48 (winter)	2	45	45	- Average dry weather design Q and peak wet weather design Q from NPDES permit limit (NCRWQCB 2020) - Assumed nutrients and salinity (S) - T estimated as median summer and winter air T - SS from NPDES permit limit (NCRWQCB 2020)
Future NAFC Aquaculture Facility	8,681	0.004[6]	1.84	15.41	0.12	71.6	26.8	3.9	0	- Nutrients and SS derived from loads, see last row of this table. Note that Nordic Facility discharge undergoes ultra-filtration with the largest particle size e <0.04 µm (i.e. size of clay particles). Hence settleable SS (SS_{Settle}) is 0 mg/L - T at facility's upper operational; design - S as 80% marine waters @ 33.5 psu and 20% freshwater @ 0 psu - Q provided by NAFC
Comingled Discharge through the Diffuser for Winter Case (Summer Case in Parentheses)	9,133 (8,918)	0.03 (0.03)	1.78 (1.82)	14.68 (15.02)	0.13 (0.13)	71.34 (71.47)	26.95 (26.85)	4.81 (4.42)	0.24 (0.22)	- Q on basis of maximum and minimum flow rates for Fairhaven Power Plant intermittent batch flow and SamoaWWTP peak weather design flow rates - Other parameters on basis of mass balance from the three sources - SS_{Settle} is the maximum concentration with particle diameters >0.04 µm after discounting loads from the Nordic facility
Maximum Nordic Facility Loads										
Future Aquaculture Facility Loads (kg/day)	NA	0.2	87.2	729	5.8	NA	NA	185	0	Provided by NAFC

[5] Low volume wastewater comprised of boiler blowdown, demineralizer backflush and reverse osmosis concentration.

[6] Note: The NH_3 effluent concentration (0.004 mg/L) of the future NAFC aquaculture facility will be substantially lower than the numeric water quality objective (0.6 mg/L) in Section 0.

3.3 Water Quality Objectives

Appropriate guidelines/standards for marine water quality served to define the water quality objectives (WQOs).

In this study, the **toxicity mixing zone** is defined as the area in which WQOs for chronic[7] or acute[8] toxicity to marine organisms are likely to be exceeded in the marine waters due to the comingled discharge from the multiport diffuser. The toxicity mixing zone is expected to be limited in spatial extent in immediate proximity to the diffuser.

The **zone of potential water quality degradation** is defined as the area in which WQOs for ambient marine water quality are likely to be exceeded. This latter zone is expected to be substantially larger than the toxicity mixing zone.

The adopted WQOs for toxicity and water quality degradation are summarized in Table 4. The temperature and chronic toxicity mixing zone WQO concentrations are prescribed values in California's Temperature Plan (SWRCB 1998) and Ocean Plan (SWRCP 2019), respectively. There are no applicable local, state or federal numeric guidelines/standards (WQO concentrations) for water quality degradation (i.e., dissolved inorganic nutrients). Hence, the 80th percentile of the ambient marine data (Section 3.1) was adopted, which represents maintenance of a slightly to moderately disturbed ecosystem (ANZECC & ARMCANZ 2000). ANZECC & ARMCANZ (2000) is similar to the US EPA (2001) guidance on the development of nutrient criteria in estuarine and coastal waters with a reference condition approach whereby criteria are developed as two statistical reference points, (1) an average or median condition and (2) an upper percentile condition. By considering both an indicator of central tendency (e.g. median) and a measure of higher concentrations (e.g. 80th percentile), the criteria ensure that future water quality conditions remain similar to present conditions (i.e., the continuation of conditions to support populations of coastal marine flora and fauna). This US EPA (2001) approach is consistent with the ANZECC & ARMCANZ (2000) approach, whereby the zone of water quality degradation from inorganic nutrients is defined as the 80th percentile.

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[7] Chronic toxicity is the development of adverse effects (e.g. inhibited growth) from long term exposure to a toxicant or stressor.

[8] Acute toxicity are adverse effects (e.g. death) from short-term exposure.

Table 4 Adopted WQO threshold values.

Parameter	Units	Mixing Zone WQOs	WQ Degradation WQOs	Source / Basis
Water Temperature Increase (DT)	°F	4	NA	Temperature Plan (SWRCB 1998) defines mixing zone a 4°F increase above ambient.
Salinity Decrease (S)	psu	1	NA	Difference between median and 20th percentile of salinity in Table 2 used as acceptable decrease prior to salinity stress for proximal flora/fauna. No guidance provided in the Ocean Plan (SWRCB 2019), so percentile approach utilised.
Ammonia (NH_3)	mg/L	0.6	NA	Oceans Plan (SWRCB 2019) toxicant value. The adopted ammonia WQO threshold used in this investigation of 0.6 mg/L is the 6-month median limiting concentration in Table 3 of the Ocean Plan (SWRCB 2019), which offers greater protection of marine aquatic life than the daily maximum limiting concentration (2.4 mg/L) and instantaneous maximum limiting concentration (6 mg/L).
Reduced Inorganic Nitrogen (NH_X)	mg/L	NA	0.064	80th percentile of representative background ambient concentrations in Table 2 as per ANZECC & ARMCANZ (2000). This represents the Ocean Plan (SWRCB 2019) stipulation (clause II D 6) that 'Nutrient materials shall not cause objection aquatic growths or degrade indigenous biota'.
Oxidized Inorganic Nitrogen (NO_X)	mg/L	NA	0.225	
Orthophosphate (PO_4)	mg/L	NA	0.060	

3.4 Dilution Targets

Two dilution targets are evaluated in this investigation, namely the mixing zone dilution target (DT_{MZ}) related to marine toxicity (i.e., ammonia) and salinity/temperature stress, and another for the zone of potential water quality degradation (DT_{WQ}) related to nutrient enrichment of the proximal marine environment. There is sufficient information on ambient water quality (Table 2), effluent quality (Table 3) and WQO (Table 4) concentrations to evaluate three parameters for the mixing zone (i.e., T, S, ammonia) and three parameters for potential water quality degradation (i.e., reduced inorganic nitrogen, oxidized inorganic nitrogen, phosphate) as summarized in Table 5. The dilution targets were estimated with the ambient water quality in Section 3.1, the estimated comingled effluent discharge and water quality from Section 3.2 and the WQOs from Section 3.3 with the equation described at the beginning of this section.

The following dilution targets are evaluated in this investigation:

- Dilution targets for the **existing** summer and winter cases are low with values of 4 for the **mixing zone** (on the basis of temperature) and 7 for **water quality degradation** (on the basis of PO_4). The small spatial extent in which these dilution targets are met are readily characterized by the near-field modelling in Section 5, and are not evaluated with the far-field modelling of Section 6.
- Similarly, the **mixing zone** dilution target of 7 (for salinity) for the **future** summer and winter scenarios have a small spatial extent and are readily characterized by the near-field modelling in Section 5, and are not evaluated with the 3D hydrodynamic modelling of Section 6.
- The **water quality degradation** dilution target of ~200 for the **future** summer and winter scenarios is sufficiently large to warrant evaluation with both the near-field modelling in Section 5 and the 3D hydrodynamic modelling of Section 6.

Table 5 Dilution targets to define mixing zone due to marine toxicity and/or salinity/temperature stress (DT_{MZ}), and zone of potential water quality degradation (DT_{WQ}).

Scenario	DT_{MZ}			DT_{WQ}		
	DT_{NH3}	DT_{Temp}	DT_{Sal}	DT_{NHX}	DT_{NOX}	DT_{PO4}
Existing Summer - Fairhaven Power Intermittent Minimum Flow	0	4	0	0	0	7
Existing Winter - Fairhaven Power Intermittent Maximum Flow	0	4	0	0	0	7
Future Summer - Existing Fairhaven Power Intermittent Minimum Flow, Future Dry Weather Samoa WWTP Flow, NAFC Average Flow	0	5	7	80	198	6
Future Winter - Existing Fairhaven Power Intermittent Maximum Flow, Future Peak Wet Weather Samoa WWTP Flow, NAFC Average Flow	0	5	7	79	194	6

4. Sediment Impact Assessment

Another potential risk of the future comingled discharge from the RMT II multiport diffuser is the sedimentation of organic matter onto the proximal benthic habitat. The effluent quality in Table 3 also provides estimates of the organic particles that will be discharged. A range of settling velocities were evaluated with the 3D hydrodynamic modelling as described in Section 6.8.2 to evaluate if gross sedimentation rates of these organic particles will impact benthic habitats. As stated in the assumptions of Section 1.4, gross sedimentation rates provide a conservative measure of the potential area of effect that the deposition of organic particles may have on the proximal benthos to the diffuser. Resuspension of these organic particles is likely, which would greatly diminish the predicted gross sedimentation impacts through subsequent transport and dispersal of these resuspended particles by the near-sediment currents. In other words, the gross sedimentation rate used to assess effect/impact on the benthos yields a larger value than if resuspension was accounted for (i.e. net sedimentation), so if gross sedimentation is well below typical effect/impact thresholds, then this would be more so the case if resuspension was considered.

5. Near-Field Modelling

Near-field modelling was used to characterize the dilution of the following three discharge cases with characteristic conditions of the ambient marine waters in the immediate proximity of the RMT II multiport diffuser:

- The existing discharge from the Fairhaven Power plant.
- The comingled discharge from the existing Fairhaven Power plant, the future Samoa Waste Water Treatment Plant, and the proposed NAFC aquaculture facility with:
  - The existing diffuser configuration of 16 open ports (8 diffuser pairs).
  - A diffuser configuration with 64 open ports (32 diffuser pairs).

5.1 Visual Plumes UM3

Near-field modelling of these three discharge cases was carried out with the US Environmental Protection Agency's (USEPA's) Visual Plumes UM3 model (Frick et al. 2001). UM3 simulates the dilution of a discharge with the ambient marine water during the jet (momentum or velocity dominated) and plume (buoyancy dominated) phases that occur in the immediate vicinity of a diffuser. The near-field simulation with UM3 terminates when the plume intersects the sea surface or seabed. At this point, the near-field mixing processes are no longer simulated with UM3. Thereafter, far-field processes (i.e., natural mixing processes) occur, which are simulated with the 3D MIKE 3 Flexible Mesh (FM) model (see Section 6).

5.2 UM3 Inputs

The UM3 (near-field model) inputs for the three cases are shown in Table 6.

Table 6 UM3 inputs for the three cases.

Parameter	Case 1: Existing Discharge	Case 2: Existing Diffuser & Future Discharge	Case 3: 64 port Diffuser & Future Discharge
Diffuser Configuration			
Number of Ports	16		64
Port Diameter (m)	0.06 [2.4 in] (CH2M 2016)		
Port Elevation (m above seabed)	0.1 [0.3 ft] (CH2M 2016)		
Horizontal Port Spacing (m)	3.66 [12 ft] (CH2M 2016)		
Port Depth (m)	24 [79 ft, range 22.9-25 m] (CH2M 2016)		
Horizontal Bearing (°)	45 [northeast] & 135 [southeast] (CH2M 2016)		
Vertical Angle (°)	45 (CH2M 2016)		
Discharge (m^3/s)	0.0126 [200 GPM] (Table 3)	0.564 [8,941 GPM] (Table 3)	
Discharge Salinity (psu)	33.5 (Table 3)	26.8 (Table 3)	
Discharge Temperature (°C)	20.4 [68.8°F] (Table 3)	21.9 [71.4°F]	
Port Exit Velocity (m/s)	0.3 [1 ft/s]	12.5 [41 ft/s]	3.1 [10 ft/s]
Typical Conditions of Ambient Marine Waters			
Marine Water Temperature (°C)	11 [51.8°F] (Table 2)		
Marine Water Salinity (psu)	33.5 (Table 2)		
Marine Water Current Speed (m/s)	0.07 [0.23 ft/s] (CH2M 2016)		
Marine Water Current Direction (°)	180 (CH2M 2016)		

5.3 Near-Field Dilution Results

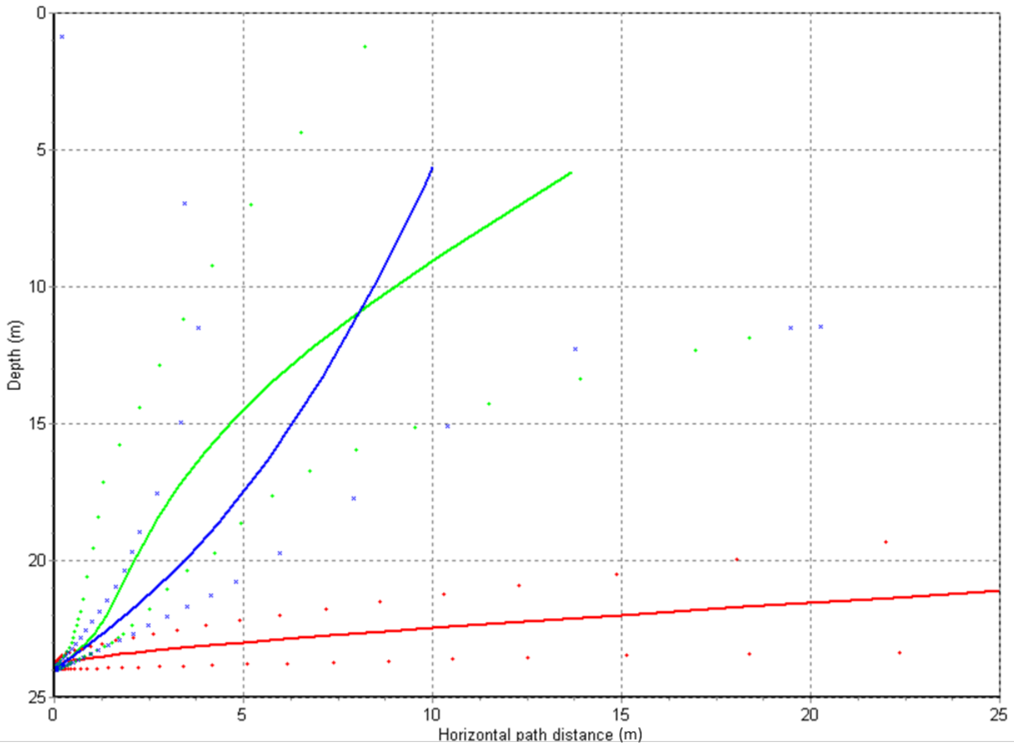
The simulated vertical plume trajectories of the three cases are shown in Figure 4. Because existing case 1 has a small discharge (thus low port exit velocity that does not jet upwards along the 45° vertical port angle) and the same effluent salinity as the ambient marine waters (thereby not generating any buoyancy-driven rise through the water column), the plumes for both the 45° and 135° horizontal port angles are readily transported down-current near the seabed over the 25 m horizontal distance that is illustrated in Figure 4. In contrast, the future cases 2 and 3 with substantially greater discharge (with larger port exit velocities that jet the water upwards) and lower salinity than the ambient marine waters (thereby generating buoyancy-driven rising through the water column) predicts that the outer edges of the plumes breach the water surface (and thereby end the simulation) when the centerline of the plumes are 10-15 m distant from the ports. Similar plume vertical trajectories are simulated for the 135° horizontal port angle, however, as this angle is more aligned with simulated current direction of 180°, the outer edges of the plume breach the water surface (and thereby end the simulation) when the centerline of the plumes are more distant at 22-27 m.

The simulated plume dilution of the three cases are shown in Figure 5. Even though existing case 1 has a small discharge (i.e., low jet-induced mixing) and the same effluent salinity as the ambient marine waters (minimal buoyancy-driven mixing), the simulated plume dilution for both the 45° and 135° horizontal port angles undergo high rates of mixing with the ambient waters due to natural mixing process because of the small volumes released (average and centerline dilutions at 10 m horizontal distance from the port of ~350-375 and ~90-100, respectively [Figure 5]).

In contrast, future cases 2 and 3 with the 45° horizontal port angles are simulated to have much lower dilution (i.e., average dilution at 10 m for low and high number of open ports is ~140 and ~270, respectively, and centerline dilution at 10 m is ~100 and ~150, respectively) than the existing case because much more mixing is required to dilute these larger volumetric flows. Greater dilution is simulated for the higher number of open ports (64) (case 3) than the existing 16 open ports (case 2) because of the greater mixing efficiency associated with smaller than larger plumes, respectively. Similar dilution was simulated for the 135° horizontal port angle, however, as this angle is more aligned with the simulated current direction of 180°, the plumes are transported more rapidly to 10 m from the port and thereby have lower dilution at this distance (average dilution at 10 m for low and high number of open ports is ~120 and ~225, respectively, and centerline dilution at 10 m is ~75 and ~120, respectively [Figure 5]).

In summary, the near-field mixing results indicate the following:

- Near-field mixing readily dilutes the existing plume (Case 1) to meet the dilution targets of 4 and 7 for the mixing zone and the zone of potential water quality degradation, respectively.
- For the future flow rate with the existing 16 existing open ports (Case 2) and preliminary concept design of 64 open ports (case 3), the near-field modelling predicts that the mixing zone dilution target of 7 will be readily achieved within several meters (<5 ft) of the diffuser nozzles. However, the large port exit velocity (41 ft/s) for the existing 16 open ports is well above the optimal value of 15 ft/s; thus this configuration is not considered further.
- The dilution target of 200 for the zone of water quality degradation is predicted to be met within ~20 m (~60 ft) of the diffuser ports. However, UM3 is not a mass balance model and does not check if there is sufficient ambient marine water flowing past the diffusers to satisfy the simulated dilution. Hence, the application of 3D hydrodynamic modelling to predict the spatial extent of the zone of water quality degradation is required for Case 3 (64 open ports) (see Section 6).



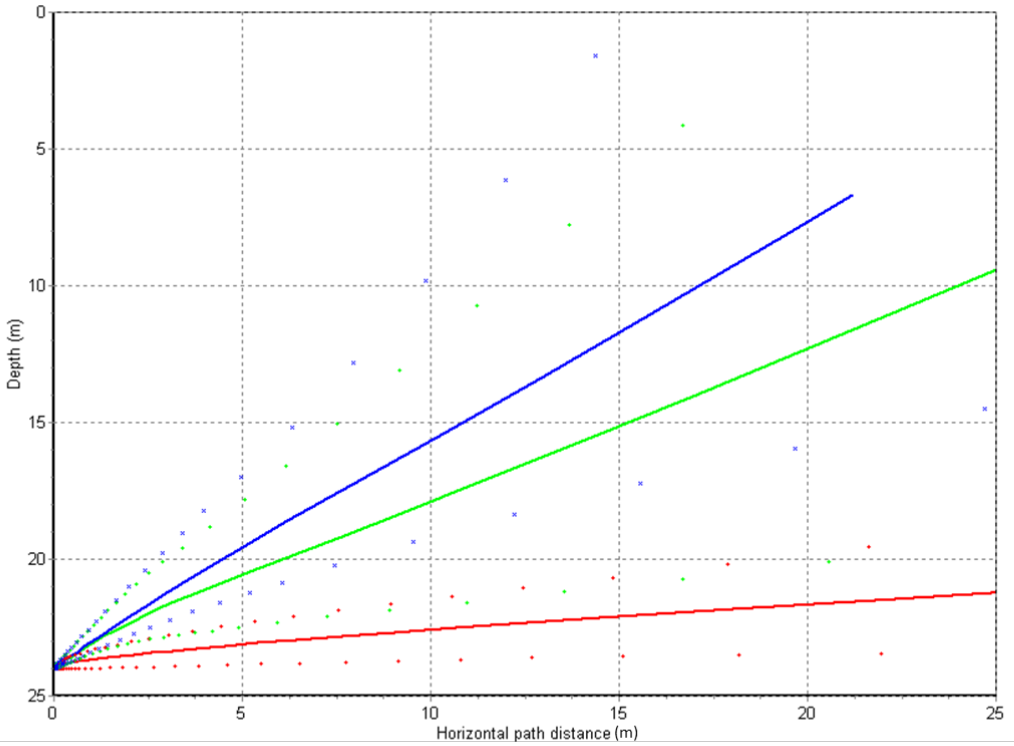
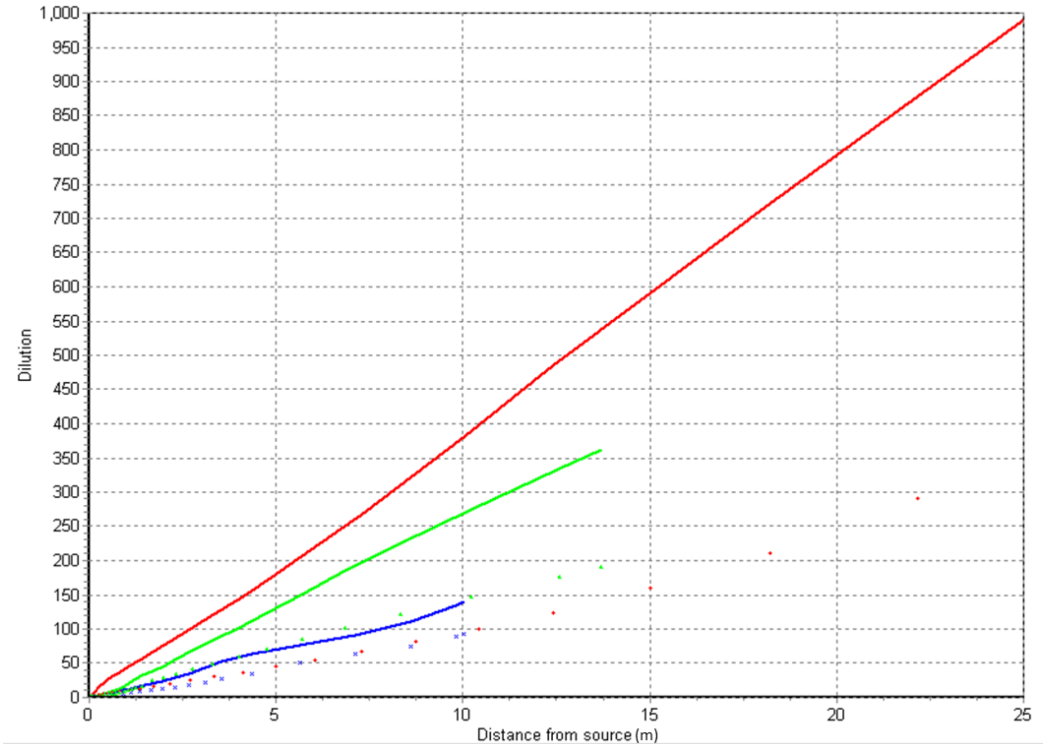


Figure 4 Vertical plume trajectory for existing conditions (Case 1 - red), future comingled discharge with the existing 16 open ports (Case 2 - blue) and with 64 open ports (Case 3 - green) at 45° (top) and 135° (bottom) horizontal angles.[9]

[9] Lines represent the plume centreline and dots represent the plume boundary.



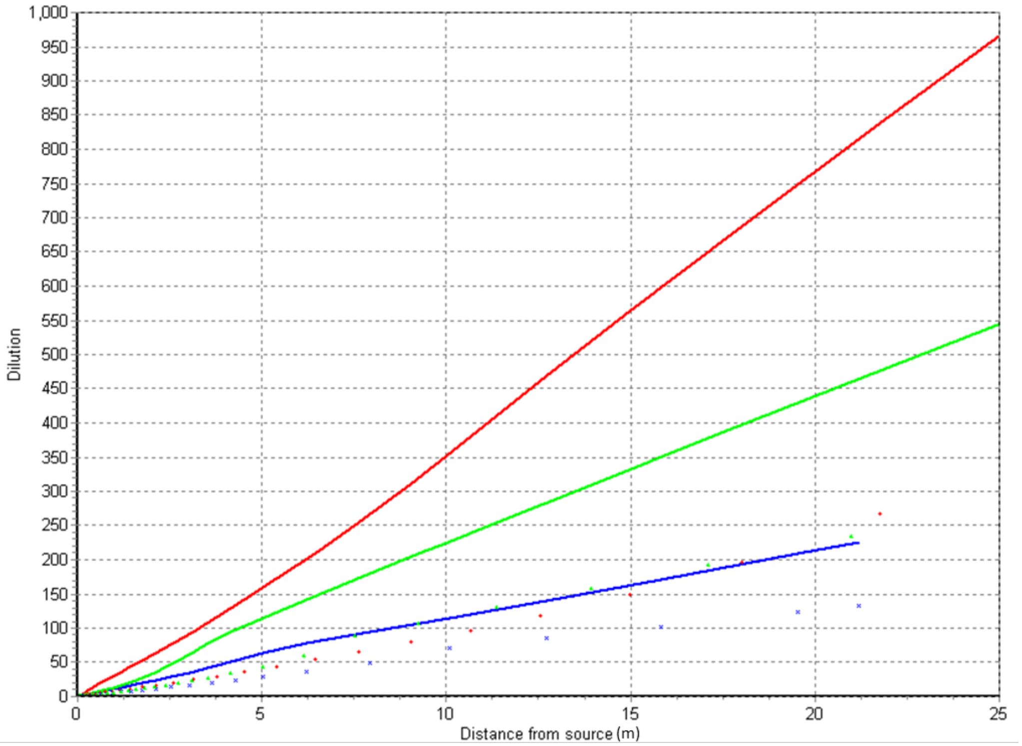


Figure 5 Dilution for existing conditions (Case 1 - red), future comingled discharge with the existing 16 open ports (Case 2 - blue) and with 64 open ports (Case 3 - green) at 45° (top) and 135° (bottom) horizontal angles.[10]

5.4 Comparison to CH2M (2016) Near-Field Modelling

Near-field dilution of the existing (Fairhaven Power) and future (addition of proposed NAFC aquaculture and Samoa Waste Water Treatment Plant) flows through the RMT II multiport diffuser are

[10] Lines represent average plume dilution and dots represent plume centreline dilution.

predicted to be somewhat higher in this investigation than previously by CH2M (2016). However, direct comparisons are not possible as model inputs and the simulated cases differed:

- The existing discharge from the Fairhaven Power plant is ~0.29 MGD through 16 open ports (case 1). CH2M (2016) modelled a 1 MGD discharge through 3-5 open ports with a salinity of 30 psu and temperature of 20°C, and predicted a dilution of ~150. Much higher dilution (>300 at 10 m, Section 5.3) was predicted here with the existing power plant discharge of ~0.6 MGD through 16 open ports with similar temperature (20.4°C) and salinity (33.5 psu).
- The predicted future comingled discharge will likely be ~13 MGD through 64 open ports (case 3). CH2M (2016) modelled a 15 MGD discharge through 61 open ports with a salinity of 30 psu and temperature of 20°C, and predicted a dilution of ~125-150. Higher dilution was predicted with a future comingled discharge of ~13 MGD through 64 open ports, a salinity of 26.8 psu, and temperature of 21.9°C. The predicted future simulated comingled dilution was ~350 by the time the plume breaches the surface (Section 5.3).
- CH2M (2016) also utilized salinity and temperature profiles in the model with ~0.2 psu and 1.3°C changes in salinity and temperature from the bottom to the surface of the water column, whereas for the near-field modelling here isohaline (33.5 psu) and isothermal (11°C) vertically through the ambient marine waters were considered. The isothermal and isohaline conditions adopted in the investigation would also tend to predict a greater degree of dilution than those of CH2M (2016).

In summary, both near-field modelling investigations predict a high degree of dilution of flows that are discharged from the RMT II multiport diffuser. The preliminary design to increase to 64 port openings yields a port exit velocity of ~10 ft/s, which is within the range considered optimal to keep the ports clear of sediment build-up and biofouling and maintain optimal levels of jet-induced near-field mixing (10-15 ft/s).

5.5 Dilution Capacity of Ambient Marine Waters at the Multiport Diffuser Site

The dilution capacity of the ambient waters at the multiport diffuser site for the future comingled discharge was evaluated with a mass balance approach to determine if sufficient ambient marine currents are available to achieve the required dilution target for the zone of potential water quality degradation. The maximum achievable dilution in the near-field is dependent on the following:

- The total discharge rate through the multiport diffuser;
- The effective length of the multiport diffuser, which is:
  - 29.3 m (8 x 3.66 m [port spacing]) for 16 open ports or 8 port pairs;
  - 117.1 m (32 x 3.66 m [port spacing]) for 64 open ports or 32 port pairs;
- The depth of the diffuser (~24 m); and
- The ambient current speeds at the site (a range considered).

The ambient volumetric flow rate past the multiport diffuser was estimated by multiplying the water depth, the effective diffuser length, and a range of ambient current speeds. These ambient water flow rates were divided by the discharge to estimate the maximum near-field dilution capacity. This mass balance approach assumes that the discharge from each port mixes vertically throughout the full water depth and horizontally between each port. As such, it provides an upper limit to the dilution that can be achieved through near-field mixing processes under specific met ocean conditions.

The dilution capacity calculations in Table 7 indicate sufficient ambient flow occurs past the diffuser to achieve the 200 fold dilution target for the zone of water quality degradation for the future comingled discharge if current speeds >0.04 m/s for the 64 open port case, and >0.16 m/s for the 16 open ports case. For lower currents speeds for each of these cases, the dilution efficiency decreases as a proportion of the comingled discharge is re-entrained into the plume.

Table 7 Maximum dilution capacity of the future comingled flow rate for 16 (Case 2) and 64 (Case 3) open ports over a range of current speeds (pink, yellow and green shading represents insufficient, marginal and excess dilution capacity to meet WQOs, respectively).

Case	Ambient Waters Current Speed (m/s)			
	0.04	0.05	0.16	0.17
Case 2 Future 8 Port Pairs (16 ports total)	49	61	195	207
Case 3 Future 32 Port Pairs (64 ports total)	195	244	781	829

6. Three-Dimensional Modelling

Three-dimensional (3D) simulations were carried out with Danish Hydraulic Institute's (DHI's) MIKE 3 FM hydrodynamic model to assess the dispersion and dilution of the comingled discharge from the multiport diffuser into the marine waters. The model was configured with surface winds, river inflows, and tidal-oceanographic currents and water levels at the boundaries. Further details regarding the 3D hydrodynamic modelling setup are described in the following sub-sections.

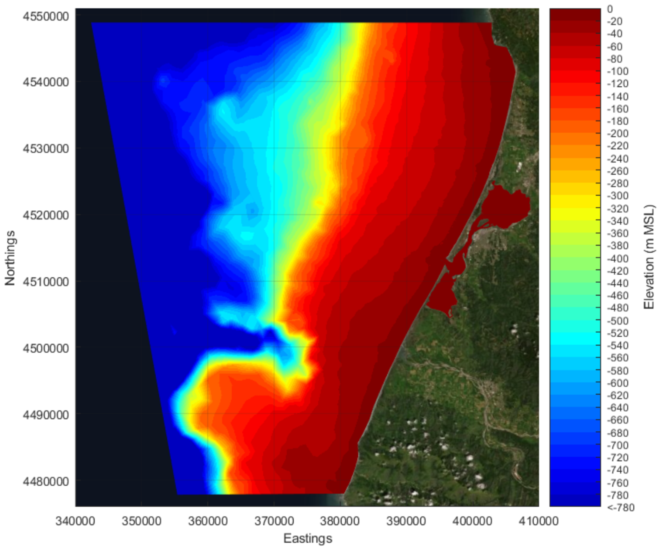
6.1 MIKE 3 Flexible Mesh

The MIKE 3 Flexible Mesh (MIKE 3 FM) was developed by DHI and is an industry standard for three-dimensional (3D) hydrodynamic modelling. The model domain in MIKE 3 FM is defined horizontally by an irregular network of triangles (the model 'cells') that are split into vertical 'layers' by either a z-level (defined layer thicknesses), sigma coordinate (fixed number of vertical layers throughout the model domain), or a combined sigma and z-level configuration. For each model cell, MIKE 3 FM simulates a range of hydrodynamic properties including, but not limited to, current speed, current direction, water level and salinity. MIKE 3 FM is driven by user-defined environmental inputs (e.g., tidal level variations at open boundaries, wind speeds and directions over the surface, and point-source inputs such as diffusers).

6.2 Model Domain

The model domain, mesh triangulation and bathymetry are shown in Figure 6. Mesh element sizes ranged from ~1-2 km at the offshore boundaries (Figure 6) to ~30 m in the vicinity of the diffuser (Figure 7). The model bathymetry was based on DHI's C-Map database of digitized nautical charts. The vertical domain in the 3D model was configured as follows:

- Sigma coordinate system of the 4 layers in the upper 8 m of the water column that expand and contract in response to tidal and non-tidal water level variations.
- Fixed coordinate system of 11 lower layers of 4, 4, 4, 5, 15, 60, 100, 300, 400, 600 and 600 m thicknesses.



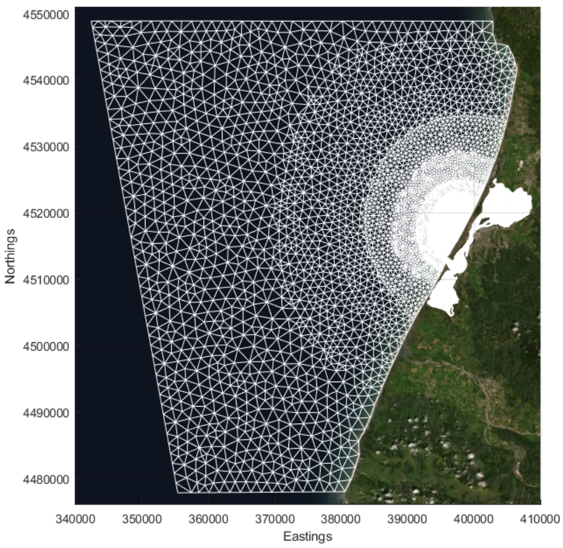


Figure 6 Model bathymetry (left) and mesh (right) of the entire model domain.

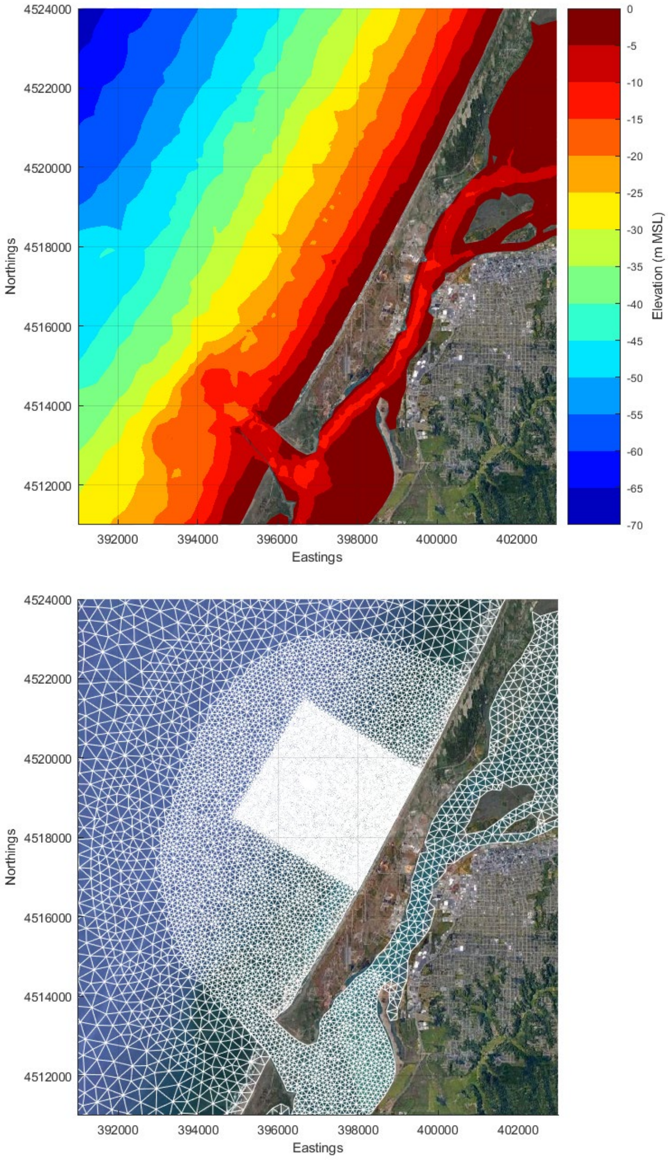


Figure 7 Model bathymetry (left) and mesh (right) in the diffuser locality.

6.3 Open Ocean Boundary Inputs

Water level and water current inputs at the offshore model boundaries were comprised of those from DHI's Global Tide Model astronomical tides (Cheng and Andersen 2010) and oceanographic currents from the Hybrid Coordinate Ocean Model (HYCOM) (Chassignet et al. 2007). The HYCOM dataset also provides water temperatures and salinities along the boundary. Examples of the model inputs at a location in the middle of the northern open boundary from July-September 2018 are illustrated for water levels in Figure 8; and v-currents (north-south), u-currents (east-west currents) water temperatures and salinities in Figure 9.

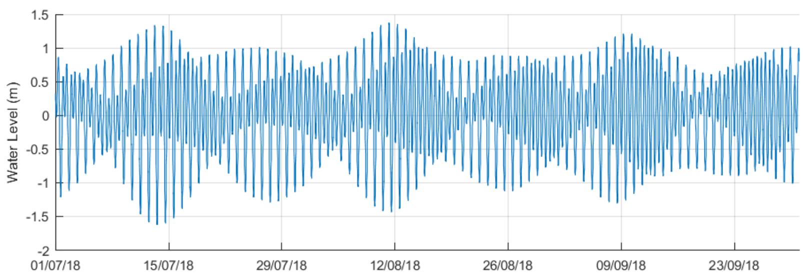


Figure 8 Water levels at a middle location along the northern open ocean boundary from July through September 2018.

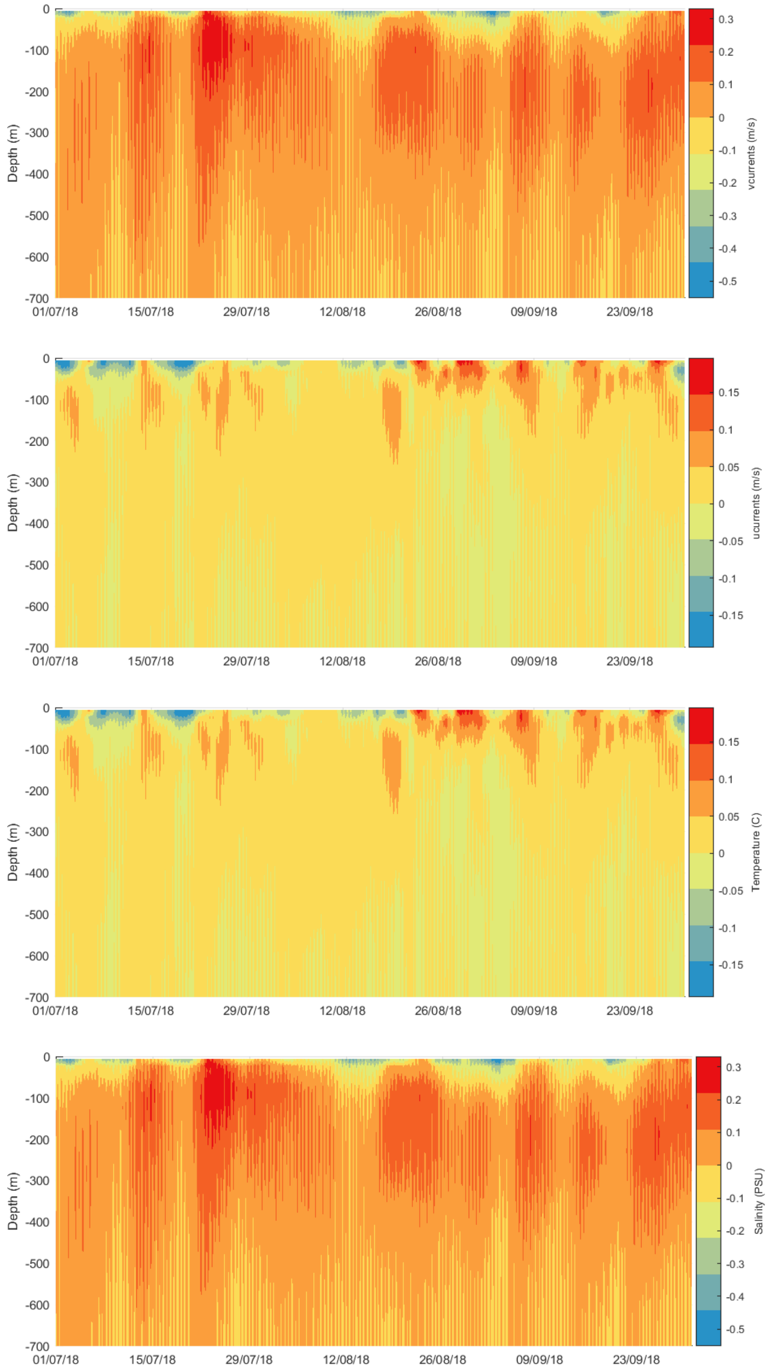


Figure 9 V- (top) and U- (upper middle) currents, temperatures (lower middle) and salinities (bottom) at a middle location along the northern open ocean boundary from July to September 2018.

6.4 Wind Forcing

Seasonal wind patterns were described with monthly wind roses in Section 2.3. Further, Section 2.3 illustrated that CFSv2 winds compare well with measurements from NOAA's North Jetty (station number 9418768). Spatially variable CFSv2 wind forcing was applied in all simulations. Wind speeds and directions from the CFSv2 grid cell that contains the multiport diffuser location for all simulation periods in this investigation are illustrated in Appendix A.

6.5 River Inflows

The purpose of a winter high river flow scenario was to investigate if the dynamics of the plume emanating from the multiport diffuser differ under salinity stratification induced by such events. The combined records of USGS gauging stations at Scotia (Eel River) and Bridgeville (Van Duzen River) were used as inputs for a winter high river flow scenario at the confluence with the Pacific Ocean for a sizeable event in the second week of January 2017 (Figure 10). Locations of these river confluences are shown in Figure 1. Additionally, the USGS gauging station at Arcata for the Mad River served as inputs to this scenario (Figure 10). Appendix B has inflow records at these gauging station from 2004-2018, which demonstrates that the selected event was one of the largest over this recent 15-year period.

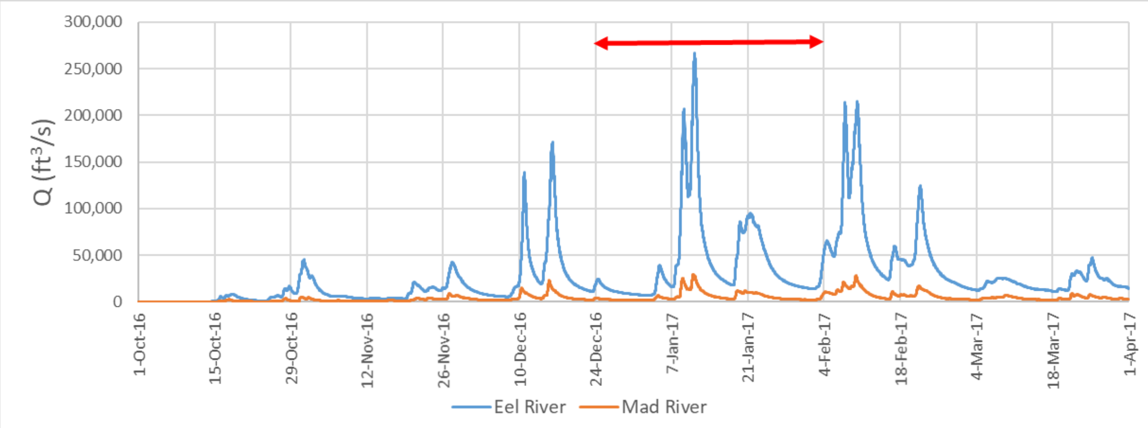


Figure 10 USGS Eel River and Mad River discharge model inputs (15 minute data) from 1 October 2016 to 1 April 2017 with red line demarcating the winter high river flow scenario period.

6.6 Three-Dimensional Model Scenarios

The 3D hydrodynamic model scenarios of this investigation are summarized in Table 8. The hydrodynamic model was initialized with a spatially varying temperature and salinity HYCOM data and water level data from the combined HYCOM and DHI Global Tide model data. To ensure current speeds and directions in the model domain achieved realistic dynamic conditions, a warm-up period of ~1 week was applied for each scenario.

Table 8 Summary of simulation scenarios.

Scenario	Diffuser Discharge	Simulation Warm-Up	Simulation Analysis
Water Level Verification	No Discharge	1–2 January 2018	3 January–21 January 2018
Water Currents Verification	No Discharge	14 July-20 July 2004	21 July-18 August 2004
Summer Scenario	0.564 m^3/s (Q) 21.9°C (T) 26.8 psu (S) 5 mg/L (SS)	1–7 July 2018	8 July–22 August 2018
Winter Scenario		24–31 December 2016	1 January–15 February 2017

6.7 Model Verification

Quantitative indices of model performance were used to compare the simulations with measurements that included:

- **Percentile distributions** of simulated and measured data. This is a graphical comparison of the statistical spread of the data of a parameter at a specific location. This comparison quantifies the percentage of time the model is under- or over-predicting measurements.
- **Mean Absolute Error (MAE).** This is the average difference between the simulation and measurements at a particular location. Low MAE represents good model performance. Wilmott (1982) proposes this metric as an easily interpretable and more natural index than the commonly used root-mean-squared error, as it is less influenced by extreme values (i.e., outliers or 'noise' in the measured data). The **MAE** is calculated as follows:

$$\boldsymbol{MAE} = \frac{\sum_{i=1}^{n} |P_i - O_i|}{n}$$

Where:

- P_i = Predicted value at comparison time i;
- O_i = Observed value at comparison time i; and
- n = number of comparison measurements.
- **Index of Agreement (IOA).** The IOA (Wilmott 1982) is the average difference between simulation and measurements relative to the range of observations in the data. IOA is between 0 and 1, with values near 0 having large relative differences (i.e., poor validation) and values near 1 having small relative differences (i.e., good validation). Willmot et al. (1985) suggest that IOA values meaningfully greater than 0.5 represent good model performance, with values near 1 representative of excellent model performance. The **IOA** is calculated as follows:

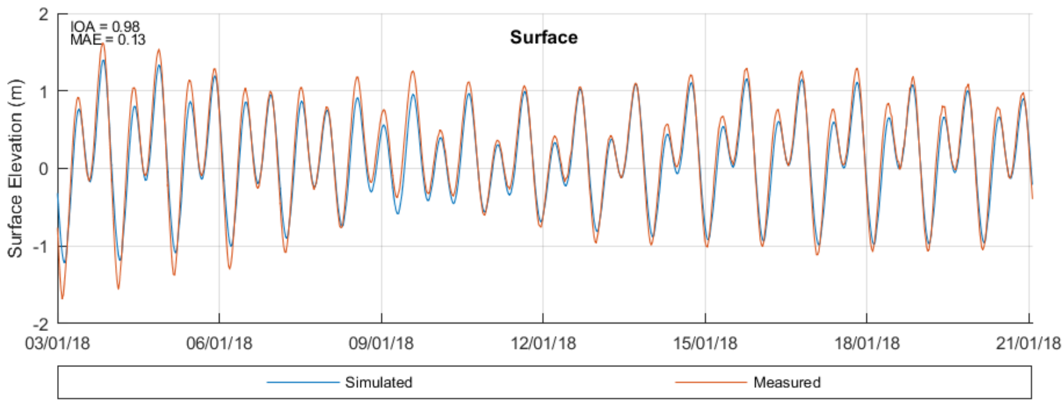
$$\boldsymbol{IOA} = 1 - \frac{\sum_{i=1}^{n} (P_i - O_i)^2}{\sum_{i=1}^{n} (|P_i - \bar{O}| + |O_i - \bar{O}|)^2}$$

Where, further to the definitions for MAE:

$\bar{O}$ = The mean of the observations during the comparison period.

6.7.1 Water Levels

The location of water level measurements at the NOAA Station 9418767 North Spit California from 1-21 January 2018 in Humboldt Bay near the entrance is shown in Figure 1. The model performance in regards to water level over a representative period is illustrated in Figure 11, which was considered good in that the model captured the water levels very well with an IOA of 0.98, MAE of 0.16 m (0.5 ft) and an excellent match between the measured and simulated percentile distributions.



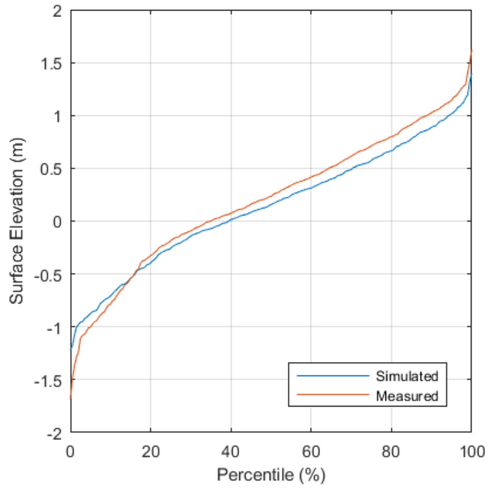


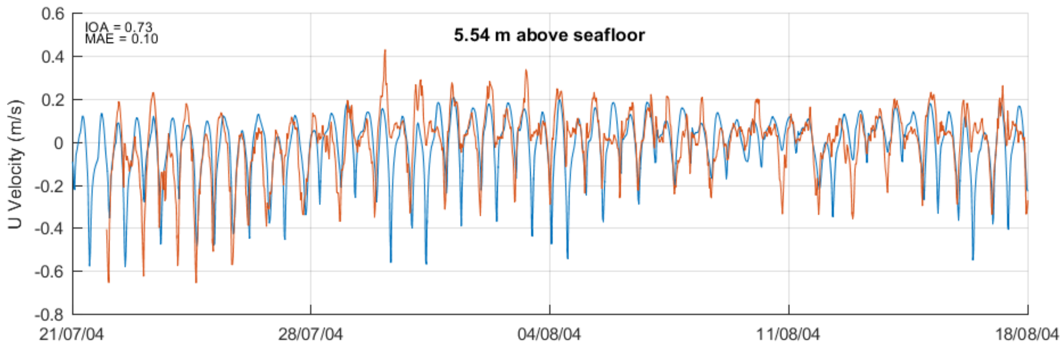
Figure 11 Comparison of simulated and measured water levels at NOAA station 9418767 (North Spit) from 3-21 January 2018.

6.7.2 Water Currents

The deployment location of a Workhorse acoustic doppler current profiler (ADCP) by NOAA from 22 July-18 August 2004 at the entrance to Humboldt Bay is illustrated in Figure 1. The model performance in regards to current speeds over the ADCP deployment period is illustrated in Figure 12, which was considered good on the following basis:

- The model captured the U-velocities (east-west component of the currents) very well with an IOA of 0.73, MAE of 0.10 m/s and an excellent match between the measured and simulated percentile distributions.
- The model captured the V-velocities (north-south component of the currents) well with an IOA of 0.58, MAE of 0.11 m/s and a reasonable match between the measured and simulated percentile distributions.

Overall, the model's good performance to reproduce the currents in the Humboldt Bay entrance in relative proximity to the diffuser location provides high confidence in the simulated predictions in this investigation.



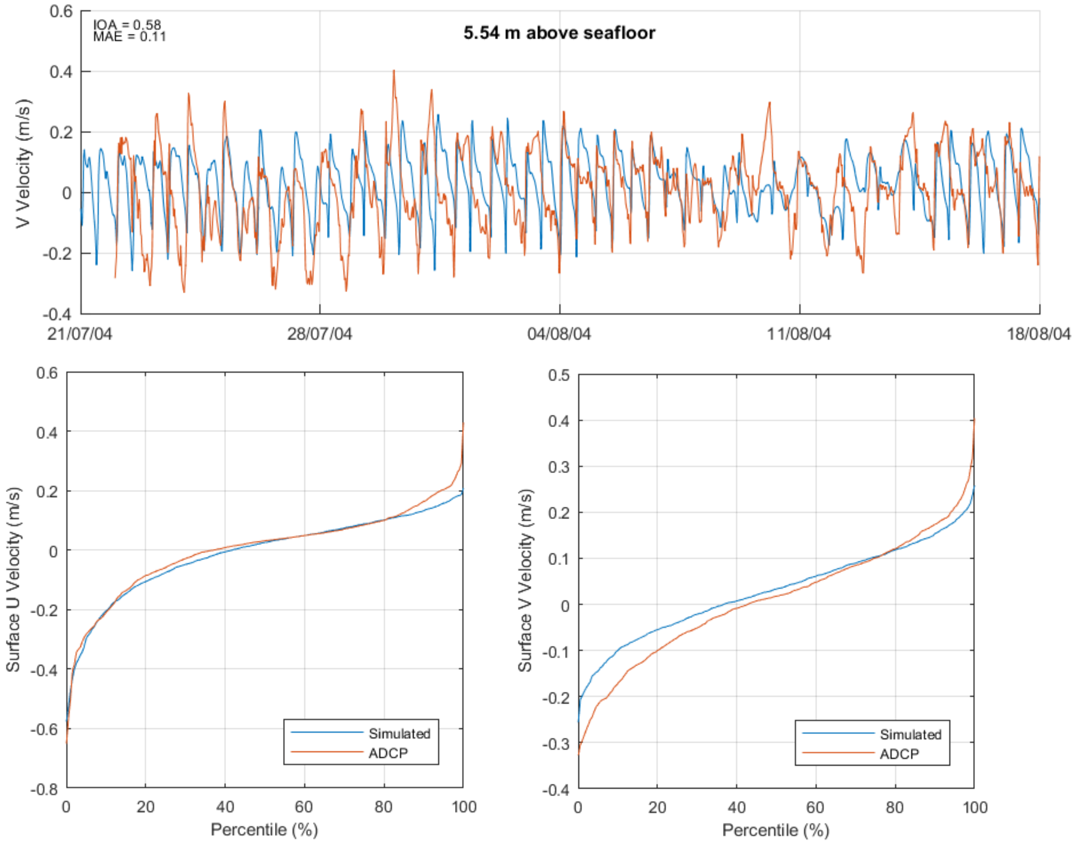


Figure 12 Simulated and measured mid-depth U-velocity (east positive, west negative) and V-velocity (north positive, south negative) components of the currents at the ADCP deployment location in the Humboldt Bay entrance from 22 July-18 August 2004.

6.7.3 Qualitative Comparison of 6 June 2007 and 8 October 2007 Field Profiles of Temperature and Salinity with the Summer Simulation

CH2M (2016) reports on the collection of previous temperature and salinity profiles at 5 ft depth intervals in the immediate vicinity of the RMT II diffuser on two occasions (6 June 2007 and 8 October 2007) and current speeds via drogue tracking (6 June 2007). Temperature and salinity differences between the surface and bottom of the 70 ft water column were in the range of 0.2-1°C and <0.1 psu, respectively, and the average current speed (presumably at the surface as drogue measurements) was 0.07 m/s. It is likely that these temperature and salinity field profiles on these two dates were collected during calm conditions (low winds and waves). The 95^{th} percentile [11] difference between the simulated top and bottom temperatures over the summer simulation (Table 8, 8 July – 22 August 2018) was 0.5°C, which is within the range of the measured 2007 summer and autumn profiles. Similarly, simulated salinity differences during the summer simulation were <0.1 psu in agreement with the measurements on the two 2007 field dates. The temperature range for the summer simulation of 10-11.5°C was in good agreement with the range of the June 2007 and October 2007 field profiles of 10-12°C. Though the salinity range of 33.45-33.75 psu over the summer simulation was similar to June 2007 (33.9-34.1 psu) and October 2007 (32-32.5), confidence in the accuracy of the salinity measurements reported in CH2M (2016) cannot be determined. Current speeds are largely dependent on tidal state and surface winds, which are unknown at the time of collection of the 2007 field profiles. However, the median surface current speed for the summer simulation was 0.08 m/s, which compares favorably with the average value of 0.07 m/s from drogue measurement during June 2007. In short,

[11] 95^{th} percentile temperature difference representative of relatively calm conditions when thermal stratification can develop due to less wind- and wave-induced mixing.

the simulated patterns of temperature and salinity during the summer are comparable to the only available field data from 6 June 2007 and 8 October 2007, providing confidence that the 3D hydrodynamic model accurately represents the oceanographic conditions in the locale of the RMT II outfall.

6.8 Environmental Assessment Methodology

6.8.1 Defining the Zone of Potential Water Quality Degradation

The 64 open port (32 port pairs) multiport diffuser configuration (Section 5.2) was incorporated into the 3D hydrodynamic model and run over a representative summer period and the high river inflow event with the comingled discharge model inputs through the multiport diffuser (i.e., flow rate, temperature, salinity) as described in Section 6.6. DHI's MIKE Mud Transport (MT) model[12] was configured to simulate a conservative tracer of the comingled discharge with a value of 1.0. All other inputs (i.e., open boundaries of model domain, river inflows) had a conservative tracer value of 0.0 and the entire model domain was initialized with value of 0.0. Hence, the concentration of tracer throughout the model domain represents the proportion of comingled discharge from the multiport diffuser in each grid cell, and the dilution is calculated as the inverse of the tracer concentration.

Statistical maps of the simulated dilution were generated in the following manner:

- Dilution was calculated with the inverse of the tracer concentration, which is equivalent to the proportion of effluent in each model grid cell for each simulation time step;
- Percentiles of dilution for each grid cell in the model domain were calculated between the start and end simulation analysis dates in Table 8 for the winter and summer scenarios. Plots with spatial statistical contours of the dilution target of **200** are presented as:
  - The 1st percentile dilution contour represents the spatial extent in which the target dilution occurs 'within' for 99% of the time over the simulation period. Alternatively, it represents the spatial extent that the dilution target of 200 is 'outside' of the contour for 1% of the time;
  - Similarly, the 5th, 10th, 20th and 50th percentile dilution contours are also presented; and
  - These statistical contours are based on the dilution of the 3D model layers at the surface (0-2 m) and the mid-water column (2-16 m) to evaluate potential zone of enhanced pelagic productivity, and near the seabed (>16 m) to evaluate the potential zone of enhanced benthic productivity.

The SS concentration of the future comingled discharge from the three sources (Samoa Waste Water Treatment Plant, DG Fairhaven power plant, proposed Nordic aquaculture facility) was estimated on the basis of a mass balance approach as 4.4-4.8 mg/L (Table 3). As a conservative measure, a SS concentration of 5 mg/L was used for the comingled discharge.

6.8.2 Defining the Zone of Potential Sediment Impacts

Discharges from the Nordic facility will undergo ultra-filtration (among other treatment processes) to provide a maximum organic particle diameter of 0.04 µm. However, there is uncertainty in the properties of particles that are discharged from the Samoa Waste Water Treatment Plant and DG Fairhaven Power Plant. As noted in Section 3.2, the maximum intermittent batch discharge of the DG Fairhaven Power Plant (400 GPM, Table 3) and peak wet weather design flow of the Samoa Waste Water Treatment Plant (53 GPM, Table 3) only represent ~5% of the total future comingled discharge. DHI's MIKE MT was configured to simulate four settling velocities that are representative of four potential organic particle sizes from the Samoa STP or four inorganic particle types from the DG

[12] Hydrodynamic simulation output from MIKE 3 FM is also used as inputs to MIKE MT.

Fairhaven Power Plant as summarized in Table 9. The 0.04 µm particle diameter filtration from the Nordic facility is smaller than clay (1-4 µm), thus the effluent from the diffuser will not undergo any material settling in proximity to the diffuser. As a conservative measure (maximum batch discharge for the Fairhaven power plant and peak wet weather flow for the Samoa Waste Water Treatment Plant) were used in the assessment of potential sedimentation effects as this provides the largest SS loads.

Table 9 Summary of particle settling velocities used as 3D model inputs.

Representative Organic Particle Diameter (µm)	Representative Organic Particle Density (kg/m^3)	Stokes Settling Velocity (m/s)	Model Input Velocity (m/s)	Equivalent Inorganic Particle Type
100	1050	0.0001	0.0001	Fine Silt
333	1050	0.0015	0.001	Coarse Silt
1000	1050	0.01	0.01	Very Fine Sand
3333	1050	0.1	0.1	Coarse Sand

Additionally, the MIKE MT model was configured with the following:

- The SS_{Settle} concentration used to predict the sedimentation impacts is does not include the SS loads from the Nordic facility, as ultrafiltration of the effluent yield particle diameters <0.04 µm. Hence, rather than the SS value of 5 mg/L utilized for assessment of turbidity (i.e., SS in the water column) a value of 0.25 mg/L representative of the comingled SS_{Settle} concentration is used (refer to Table 3).
- A depositional critical shear stress of 0.1 N/m^2 was used, which is at the upper end of recommended values by DHI.
- No resuspension was simulated, hence gross sedimentation when below the depositional critical shear stress is simulated . Refer to Section 1.4 and 4 for the rationale that gross sedimentation is a conservative assessment of the potential impacts to the benthos.

Gross sedimentation expressed as mass per unit area was calculated for each seabed cell between the start and end simulation analysis dates in Table 8 for the high inflow event and representative summer scenarios. Spatial contour plots of a range of gross sedimentation rates were generated to evaluate the potential risk to benthic habitat from organic particle deposition for each of the four particle settling velocities simulated (Table 9).

Organic sedimentation rates of 0.22 g/m^2/d (San-Jazaro et al. 2011) and 1.9 g/m^2/day (Cromey et al. 1998, Gellbrand et al. 2002) were used to define thresholds for 'potential seabed effect' and 'degraded seabed impacts', respectively.

6.9 Summer Scenario

6.9.1 Typical Summer Ambient Salinity Climate

The key factor that influences the vertical extent of the water column that is influenced by the comingled plume that emanates from the multiport diffuser is the vertical salinity structure. During the summer simulation at the start (8 July 2018), middle (30 July 2018) and end (22 August 2018) of the analysis period, salinity stratification was weak with vertical variations of ~0.1 psu along the simulated 4 km east-west transect just offshore of the multiport diffuser to the nearshore waters (Appendix C, see Figure 1 for transect location). The relatively homogeneous vertical salinity structure does not greatly impede the rise of the buoyant plumes to the water surface. Hence, a strong surface expression of the plume is anticipated under such conditions. Plots of salinity profiles collected on 6 June 2007 (summer) and 8 October 2007 (autumn) near the RMT II diffuser were vertically homogeneous (CH2M 2016).

6.9.2 Zone of Potential Water Quality Degradation

The statistical contours for the dilution target of 200 (zone of potential water quality degradation) at the surface (0-2 m), mid-water column (2-16 m) and near-seabed (>16 m) for the representative summer scenario are illustrated in Figure 13. Because the comingled discharge (~27 psu) is less saline than the ambient seawater (~33.5 psu) and the ambient salinity stratification is weak (Appendix C), the plume has a greater tendency to rise to the surface as it undergoes dilution than detraining in the middle of the water column. Further, the zone of potential water quality degradation (i.e., elevated nutrients) near the seabed is much smaller than the areal extent of the surface and mid-water column, so that the risk of enhanced benthic productivity is low.

The zone of potential water quality degradation in the surface waters (upper 2 m) for 1%, 5%, 10% and 20% of the time extends up to ~1 km, ~500 m, ~400 m and ~300 m from the diffuser, respectively. However, the 50th percentile contour only occurs in the immediate locale of the diffuser, which is in line with the near-field modelling results of Section 5.3. The spatial extent of the zone of potential water quality degradation in the mid-water column (2-16 m) is similar, but smaller in spatial extent. Because the currents are constantly transporting surface and mid-depth waters through this area, the duration that pelagic (in water) organisms experience elevated nutrients is limited (minutes). Hence, a ‘negligible’ material increase in pelagic ecosystem productivity under such conditions is predicted, and the risk of deleterious water quality impacts to the surface and mid-water column waters are ‘very low’.

The zone of potential water quality degradation in the lower portion of the water column (>16 m) for 1% and 5% of the time extends up to ~50 m and ~25 m from the diffuser, respectively. Dilution of the comingled discharge with the ambient marine waters in the lower water column was always greater than the dilution target of 200 for at least 90% of the time (i.e., no 10% contour in the plot). The combination of the limited spatial extent and relatively brief duration that the proximal benthic habitat would experience elevated nutrients indicates a ‘very low’ risk of increased benthic ecosystem productivity.

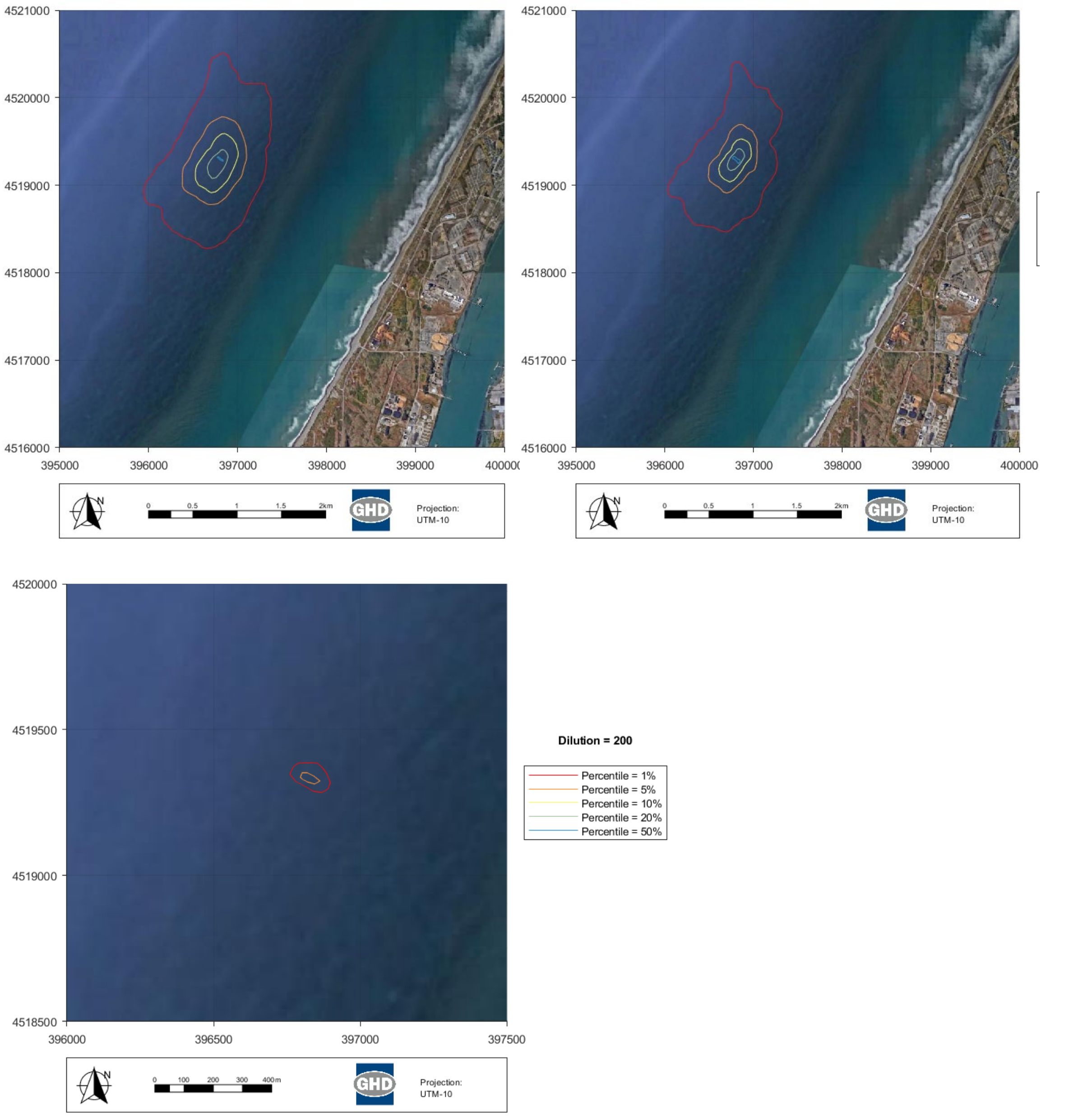


Figure 13 Statistical spatial contours of a plume dilution of 200 at the surface (top left, upper 2 m), mid-water (top right, 2-16 m) and near-seabed (bottom, >16 m) for the summer scenario.

6.9.3 Zone of Potential Benthic Impacts

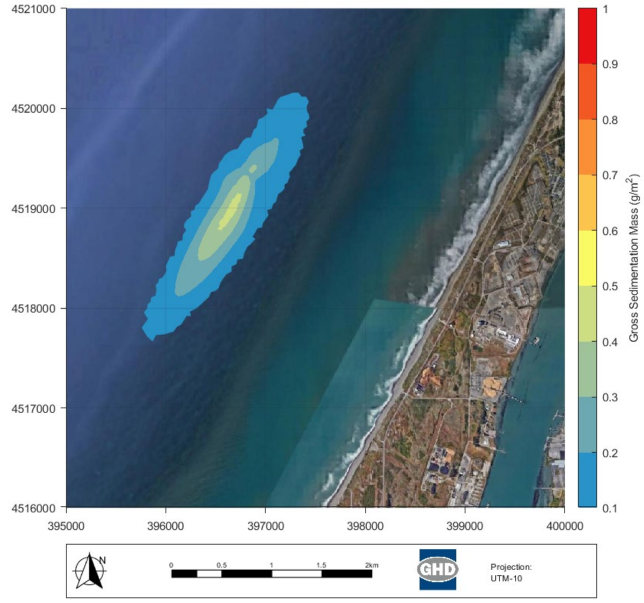
The simulated gross sedimentation rates over the 45 days of the representative summer scenario for three of the four settling velocities are illustrated in Figure 14. There was no material gross sedimentation (<0.1 g/m^2) simulated over the 45 day analysis period for a particle settling velocity of 0.0001 m/s. A summary of the predictions include:

- A particle settling velocity of 0.001 m/s yielded a sizeable spatial area of gross sedimentation >0.1 g/m^2 over the 45 days that was up to ~1.5 km from the diffuser with a maximum gross sedimentation <0.5 g/m^2. A 0.5 g/m^2 gross sedimentation over the 45 days of the analysis period is equivalent to 0.01 g/m^2/day, which is well below the indicative sedimentation threshold that some benthic 'effects' from organic loading may occur (0.22 g/m^2/day, Section 6.8.2).
- A particle settling velocity of 0.01 m/s yields a small spatial area with gross sedimentation of >0.1 g/m^2 over the 45 days limited to within ~10-20 m of the diffuser. The maximum gross

sedimentation of 0.7 g/m^2 (0.015 g/m^2/day) is well below the indicative sedimentation threshold that some benthic 'effects' from organic loading may occur (0.22 g/m^2/day, Section 6.8.2).

- A particle settling velocity of 0.1 m/s yields a similar spatial area of gross sedimentation of >0.1 g/m^2 as that for a 0.01 m/s settling velocity. However, the maximum gross sedimentation of 1 g/m^2 (0.02 g/m^2/day) is well below the indicative sedimentation threshold for some 'benthic effects' form organic loading (0.22 g/m^2/day, Section 6.8.2).

In short, negligible effects on the benthos from sedimentation are predicted, in large part due to the pre-dilution of setteable particles from the Samoa Waste Water Treatment Plant and DG Fairhaven power plant by the Nordic facility (see Table 3).



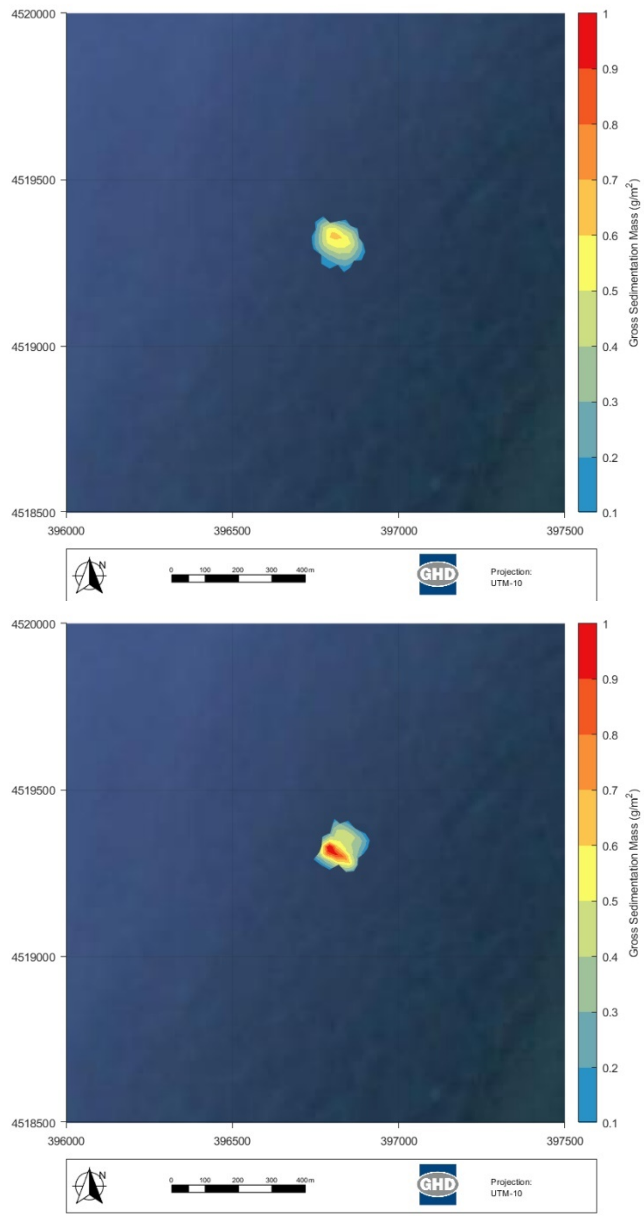


Figure 14 Spatial extent of gross sedimentation over the summer scenario for particle settling velocities of 0.001 (top), 0.01 (bottom left) and 0.1 (bottom right) m/s.

6.10 Winter High River Flow Scenario

6.10.1 High River Flow Effects on Ambient Salinity Climate

During the high flow event at the start (1 January 2017), middle (23 January 2017) and end (15 February 2017) of the simulation analysis period, salinity stratification was relatively strong with vertical variations of ~0.3, 4.6 and 3 psu, respectively, at the diffuser as illustrated along the simulated 4 km east-west transect (Appendix D, see Figure 1 for transect location). Hence, salinity stratification is effective at 'trapping' the rising plume prior to reaching the surface. As the plume entrains the higher salinity deeper waters, the average plume salinity increases in excess of the lower salinity surface waters (and thereby the plume is no longer positively buoyant and does not rise further). Hence, a stronger mid-water column expression of the plume is anticipated under such conditions.

6.10.2 Zone of Potential Water Quality Degradation

The statistical contours for the dilution target of 200 (zone of potential water quality degradation) at the surface (0-2 m), mid-water column (2-16 m) and near-seabed (>16 m) for the high river flow scenario are illustrated in Figure 15. Because of strong salinity stratification over most of this simulation's analysis period (Appendix D), as the plume rises through the water column and entrains ambient seawater in the lower to mid-portions of the water column (~33 psu), the plume attains a salinity (through entrainment of ambient waters) that is greater than the surface waters (26-32 psu). At this point the plume is no longer positively buoyant, no longer rises in the water column, and it detrains into the mid-water column below reaching the surface. Hence, dilution in the surface waters (0-2 m) is greater than 200 for at least 99% of the time (i.e., no contours in the top left plot of Figure 15).

In contrast, the detrainment of the plume into the mid-water column (2-16 m) yields a zone of potential water quality degradation for 1%, 5%, 10% and 20% of the time that extends up to ~1 km, ~200 m, ~100 m and ~50 m from the diffuser, respectively. However, the 50th percentile contour only occurs in the immediate locale of the diffuser, which is in line with the near-field modelling results of section 5.3.

The spatial extent of the zone of potential water quality degradation in the near-seabed waters (>16 m) yields a zone of potential water quality degradation for 1%, 5%, 10% and 20% of the time that extends up to ~450 m, ~200 m, ~150 m and ~100 m from the diffuser, respectively. Hence, salinity stratification increases the spatial extent and duration that the proximal benthic habitat would experience elevated nutrients and thereby the potential for some increased benthic ecosystem productivity.

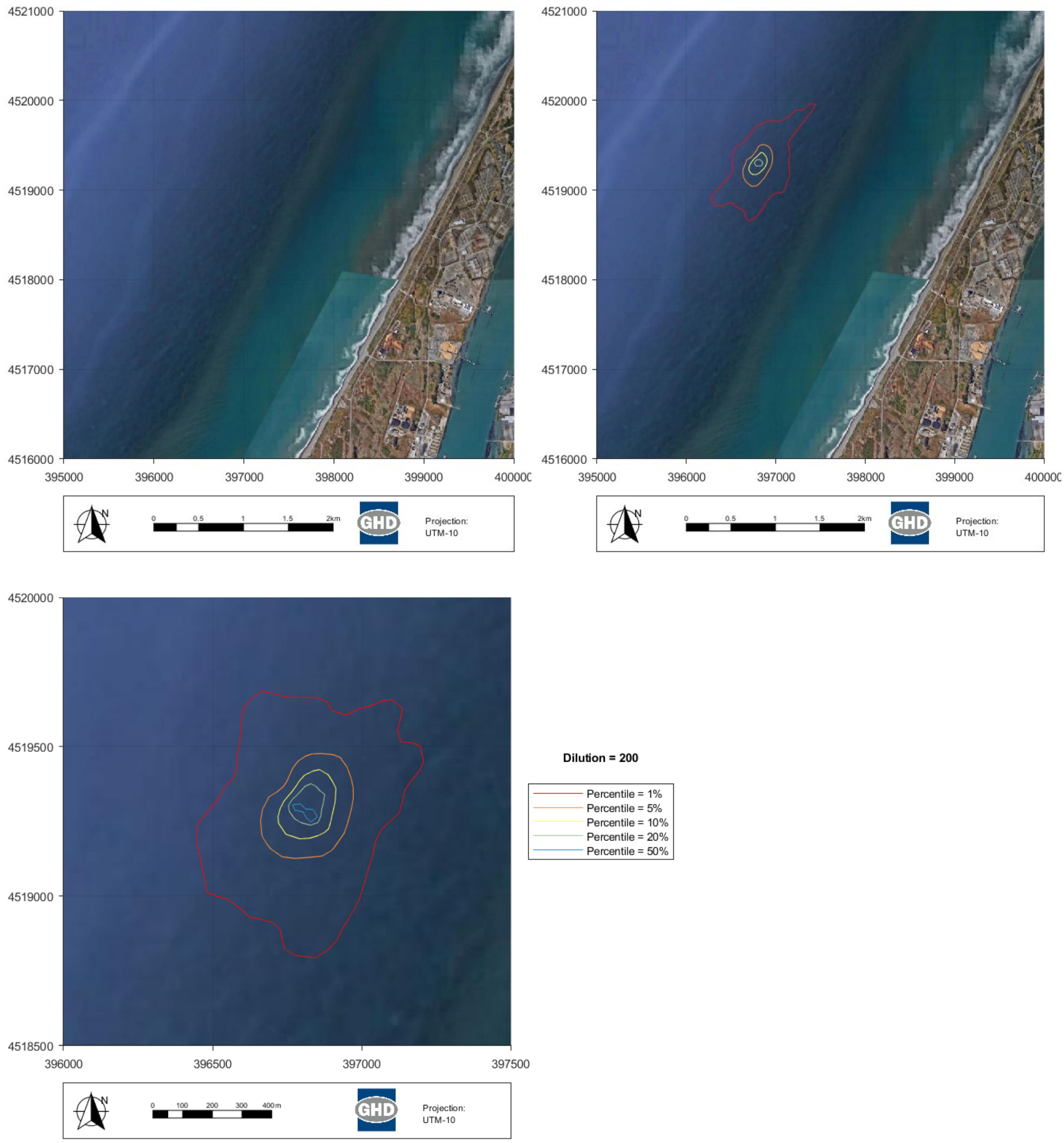


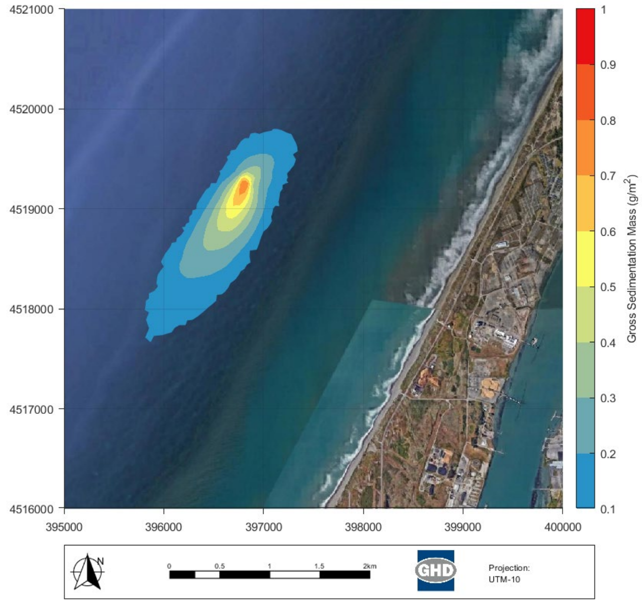
Figure 15 Statistical spatial contours for a plume dilution of 200 at the surface (top left, upper 2 m), mid-water (top right, 2-16 m) and near-seabed (bottom, >16 m) for the winter scenario.

6.10.3 Zone of Potential Benthic Impacts

The simulated gross sedimentation rates over the 45 days of the analysis period of the high river flow scenario for three of the four settling velocities are illustrated in Figure 14. There was no material gross sedimentation (<0.1 g/m^2) simulated over the 45 day analysis period for a particle settling velocity of 0.0001 m/s. A summary of the predictions include:

- As with the representative summer period, a particle settling velocity of 0.001 m/s yielded a sizeable spatial area of gross sedimentation >0.1 g/m^2 over the 45 days that was up to ~1.5-2 km to the south of the diffuser with a maximum gross sedimentation ~0.8 g/m^2 in the immediate vicinity of the diffuser. The 0.8 g/m^2 maximum gross sedimentation over the 45 days of the analysis period was within ~100 m of the diffuser and is equivalent to 0.018 g/m^2/day, which is well below the indicative sedimentation threshold in which some benthic effects from organic loading may occur (0.22 g/m^2/day, Section 6.8.2).

- A particle settling velocity of 0.01 m/s yields a small spatial area with gross sedimentation of 0.4-0.5 g/m^2 over the 45 days up to ~100 m from the diffuser. The maximum gross sedimentation of 0.5 g/m^2 (0.01 g/m^2/day) is well below the indicative sedimentation threshold in which some benthic effects from organic loading may occur (0.22 g/m^2/day, Section 6.8.2).
- A particle settling velocity of 0.1 m/s yields a smaller spatial area for gross sedimentation >0.1 g/m^2 as the 0.01 m/s settling velocity. However, the maximum gross sedimentation of 1 g/m^2 (0.02 g/m^2/day) is well below the indicative sedimentation threshold in which some benthic effects from organic loading may occur (0.22 g/m^2/day, Section 6.8.2). Thus, only minor effects on the benthos would be expected in the immediate vicinity (~25 m) of the diffuser with this particle settling rate as well.



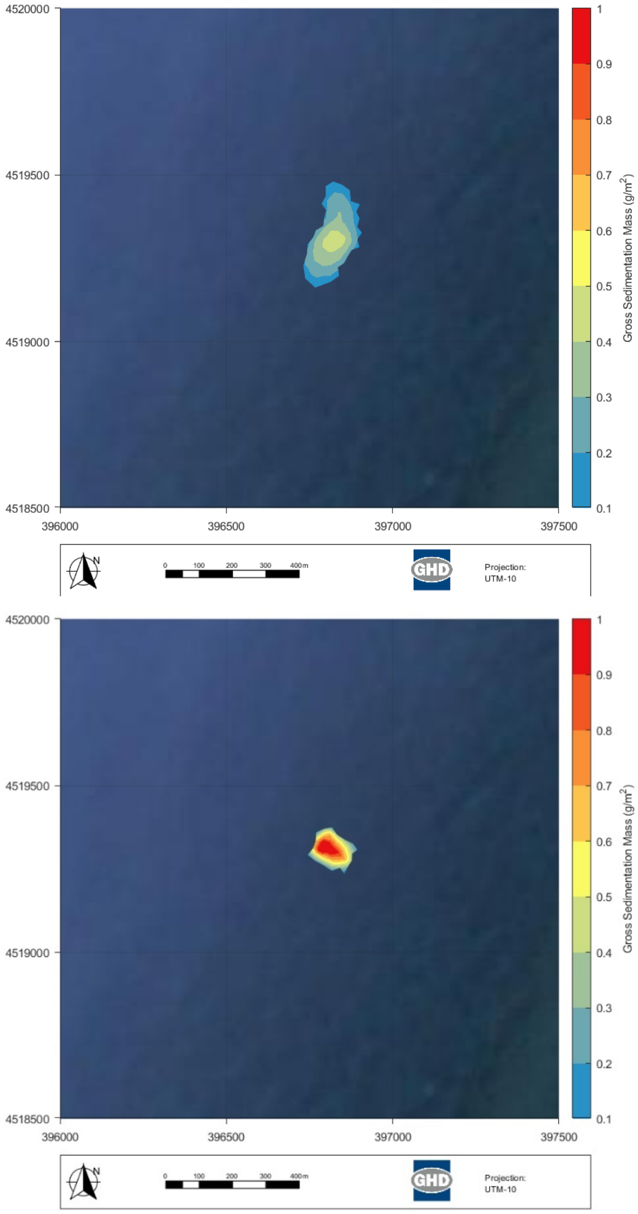


Figure 16 Spatial extent of gross sedimentation over the winter scenario for particle settling velocities of 0.001 (top), 0.01 (bottom left) and 0.1 (bottom right) m/s.

7. Conclusions

The key conclusions from this investigation of the proposed future comingled discharge through the RMT II multiport diffuser include:

- The preliminary concept design of 64 open ports for the proposed comingled discharge yields a predicted mixing zone (i.e., related to marine toxicity and physiological stress to biotic receptors) that is readily met within <5 ft of the diffuser on the basis of the near-field modelling. This preliminary concept design of 64 port openings also yields a port exit velocity of ~10 ft/s, which will keep the ports clear of sediment build-up and biofouling, and maintain optimal levels of jet-induced near-field mixing.
- The predicted zone of water quality degradation is dependent on the salinity stratification of the ambient marine waters, where:
  - For the scenario of representative summer conditions with no or weak stratification:

    The surface waters (0-2 m) were predicted to not achieve the water quality dilution target of 200 beyond ~1 km from the diffuser for 1% of the time and ~300 m from the diffuser for 20% of time, but always met the dilution target everywhere for at least 50% of the time. Similar spatial patterns of the zone of potential water quality degradation, albeit somewhat smaller in extent, were also predicted through the mid-water column (2-16 m). Estimates of the transport time of plume waters ~1 km from the outfall on the basis of simulated summer current speeds range from ~1 day for low current speeds (1st percentile) to ~1 hour for high current speeds (99th percentile). Hence, the risk of deleterious water quality impacts to the surface and mid-depth waters is 'very low' as the transport time scales of the plume waters with elevated inorganic nutrients are dispersed and transported rapidly, limiting nutrient-stimulated increase in phytoplankton levels.

    The zone of potential water quality degradation in the near-seabed waters (>16 m) was predicted to exceed the water quality dilution target for 1% of time beyond ~50 m and 5% of the time beyond ~25 m from the diffuser. This poses a 'very low' risk of a nutrient-stimulated increase in benthic ecosystem productivity.
  - For the winter high river flow scenario that led to strong salinity stratification of the ambient waters:

    The surface waters (0-2 m) were predicted to not exceed the adopted threshold at any time. Because of salinity stratification as the plume rises through the water column and entrains ambient seawater, the plume attains a higher salinity than the surface waters and detrains in the mid-waters before reaching the surface. This plume detrainment in the mid-water column (2-16 m) is predicted to exceed the water quality dilution target beyond ~1 km for 1% of the time and ~50 m for 20% of the time, but always met the dilution target everywhere for at least 50% of the time. Estimates of the transport time of these elevated inorganic nutrient plume ~1 km on the basis of simulated winter current speeds in proximity to the diffuser range from <1 day for the slowest current speeds (1st percentile) to <1 hour for higher current speeds (99th percentile). Hence, the risk of deleterious water quality impacts to the surface and mid-depth waters is 'very low', as the transport time scales of the plume in the coastal waters are dispersed and transported rapidly, thereby limiting nutrient-stimulated increase in phytoplankton levels.

    The zone of potential water quality degradation in the near-seabed waters (>16 m) was predicted to exceed the water quality dilution target for 1% of time beyond ~450 m and 5% of the time beyond ~100 m from the diffuser. This poses a greater risk than the representative summer conditions, but is still considered a 'very low' risk of increased benthic ecosystem productivity.

- Across three orders of magnitude in particle settling velocities, the predicted zone of potential benthic impacts via sedimentation from the settleable particles in the future comingled discharge over the representative summer and winter large river inflow event scenarios was well below the thresholds for potential benthic ‘effects’ (~0.2 $g/m^2/day$) and potential benthic ‘impacts’ (~2 $g/m^2/day$). In short, the predicted gross sedimentation rate is very low and poses a low risk of impact to the benthic community in the locale of the RMT II multiport diffuser.

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Appendices

Appendix A – Wind Speed and Direction Inputs

Figure 17 CFSv2 simulated wind data at the North Spit from January to March 2018 (water level verification period).

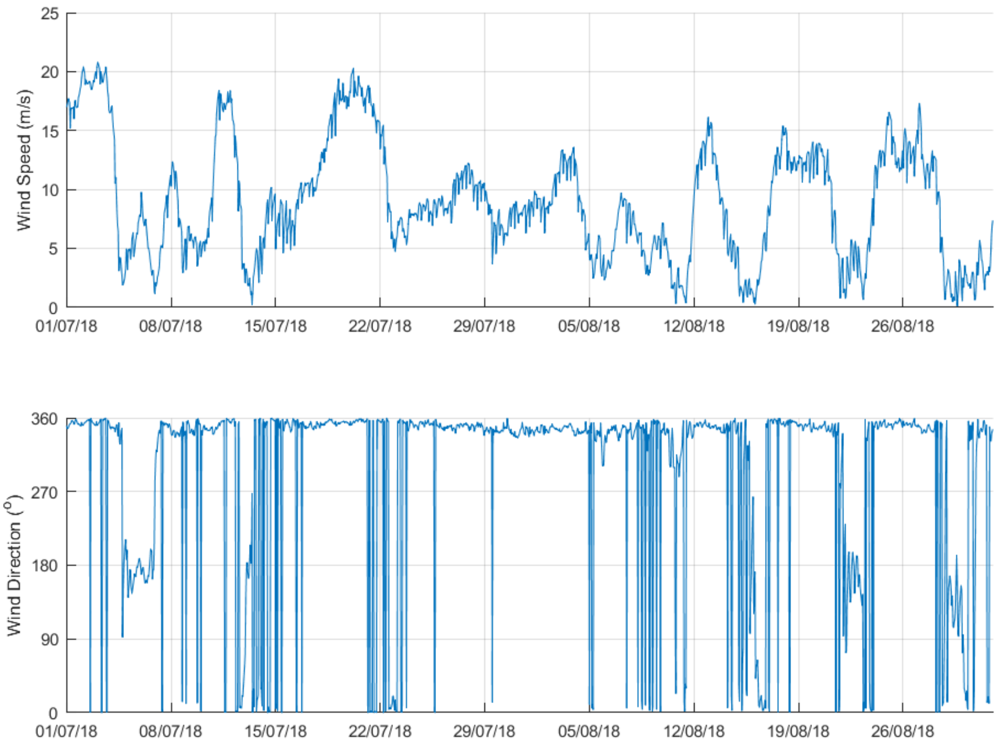

Figure 18 CFSv2 simulated wind data at the North Spit from July to September 2018 (summer scenario period).

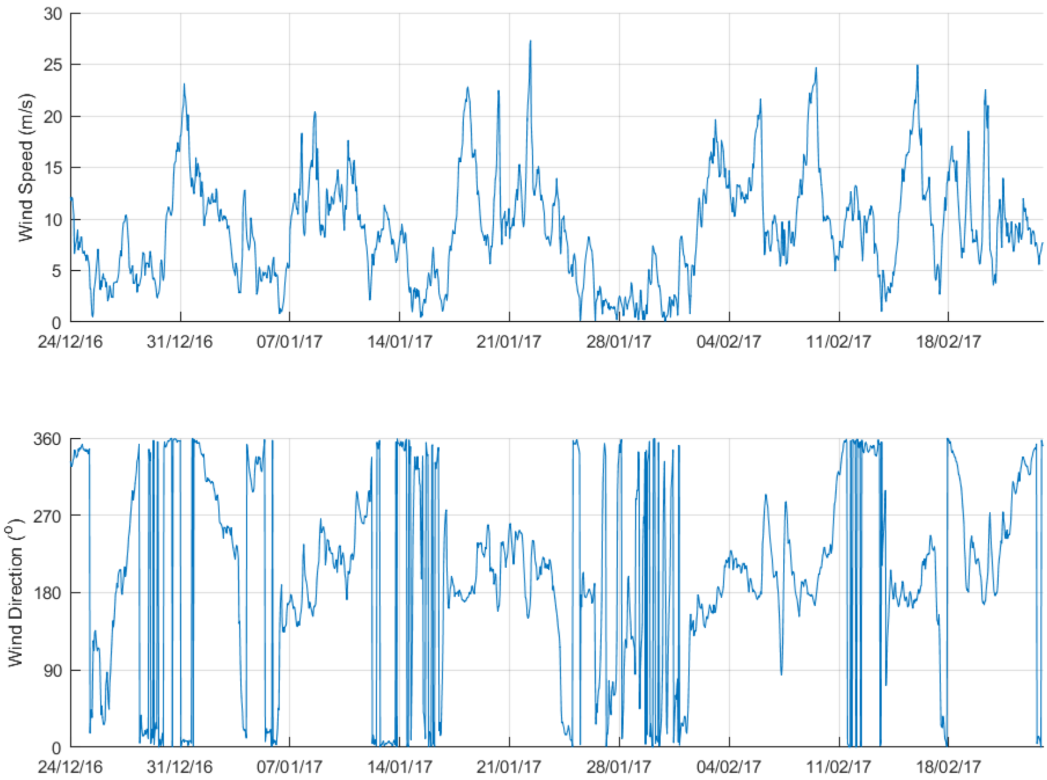

Figure 19 CFSv2 simulated wind data at the North Spit from December 2016 to February 2017 (winter scenario period).

Appendix B – River Inflows

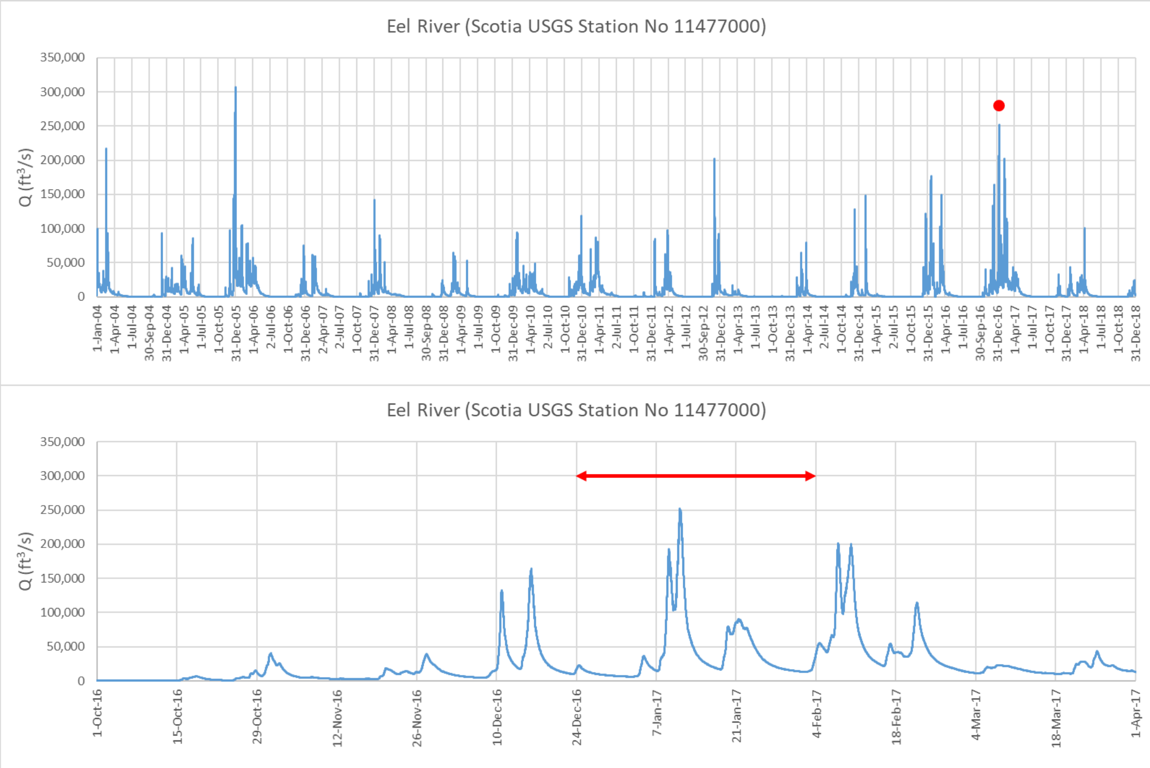

Figure 20 Eel River 15 minute discharge measurements at Scotia (USGS Station No 11477000).

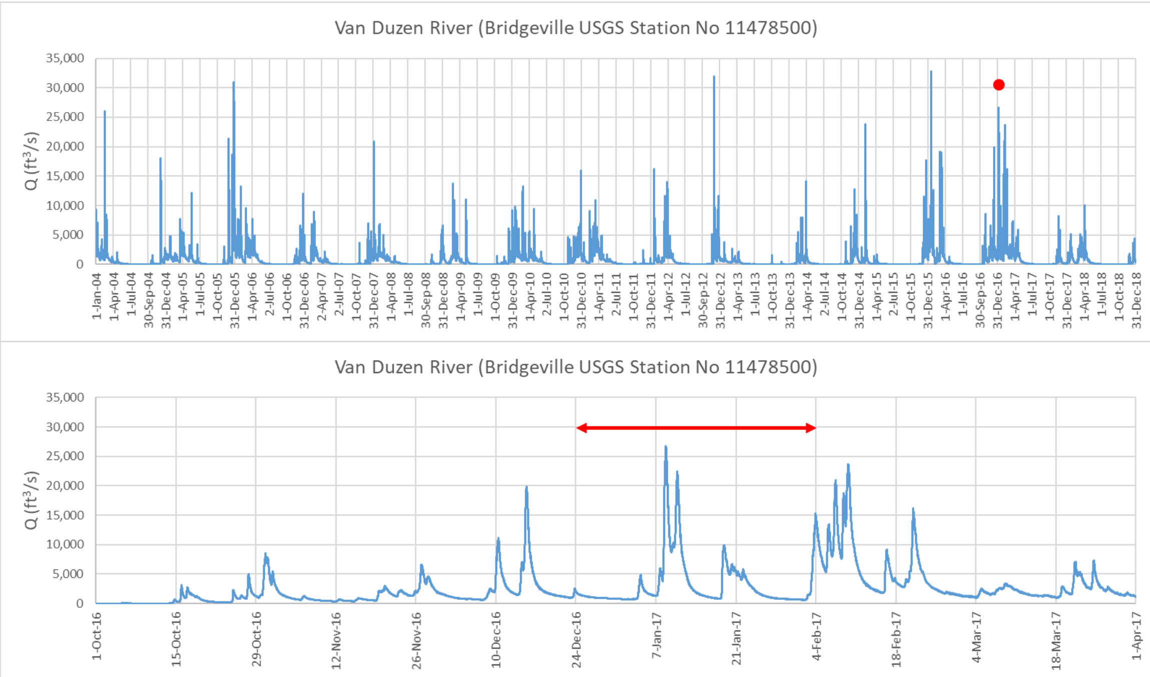

Figure 21 Van Duzen River 15 minute discharge measurements at Bridgeville (USGS Station No 11478500).

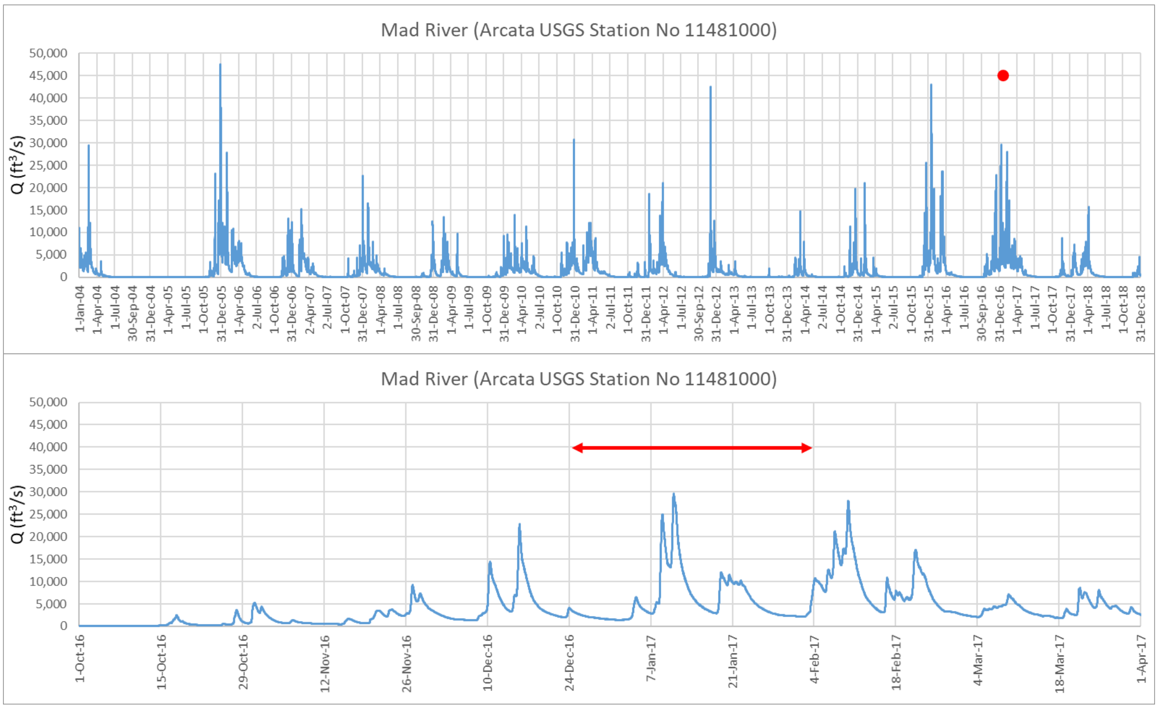

Figure 22 Van Duzen River 15 minute discharge measurements at Arcata (USGS Station No 11481000).

Appendix C – Simulated Salinity Transects during the Representative Summer Scenario

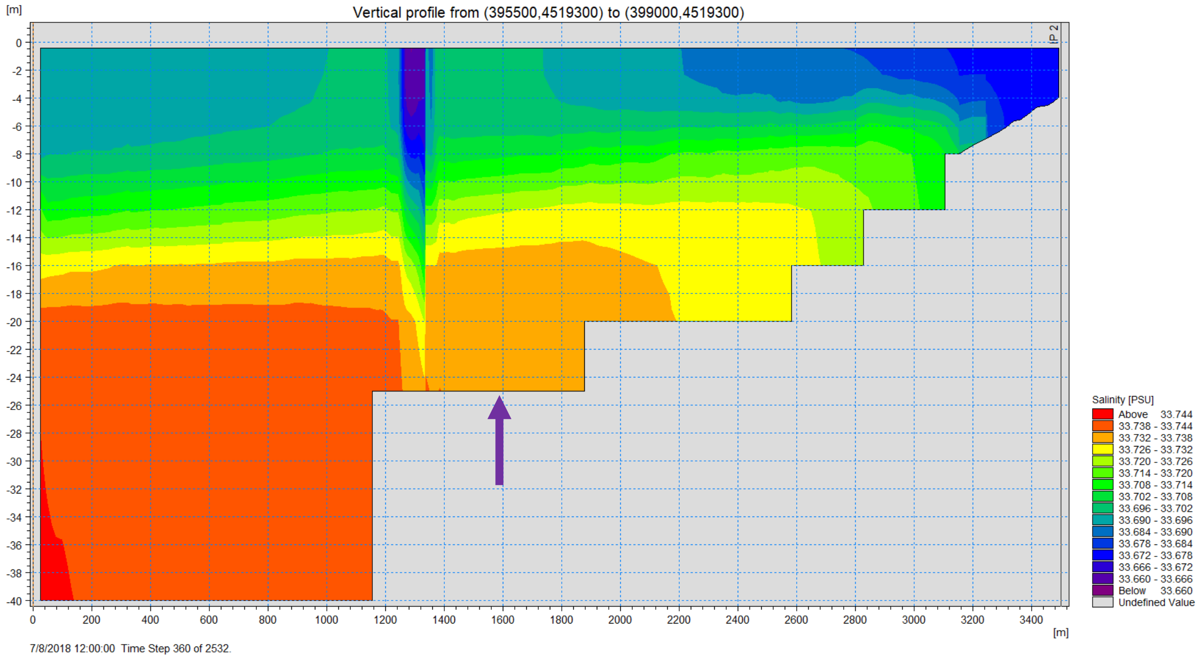

Figure 23 Salinity with depth (y-axis) along the east-west transect (x-axis) just offshore of the diffuser towards the shoreline (refer to Figure 1 for transect location) at the start of the summer analysis period on 8 July 2018. Purple arrow demarcates the horizontal location of the diffuser on the seabed.

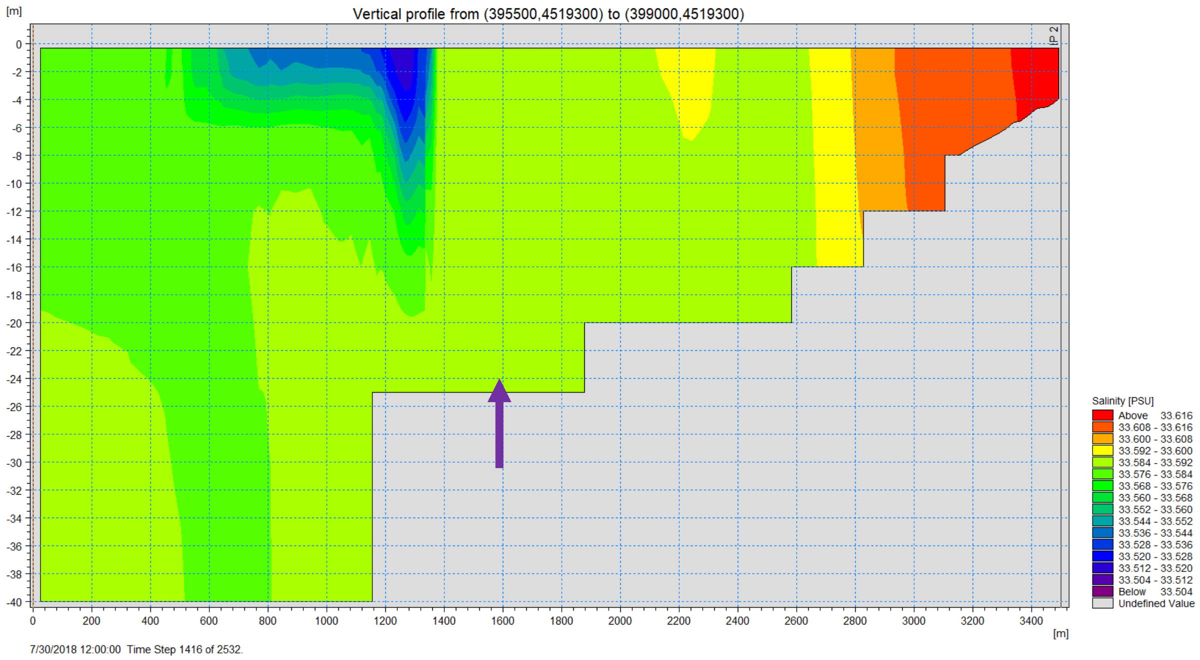

Figure 24 As Figure 23 at the middle of the summer analysis period on 30 July 2018.

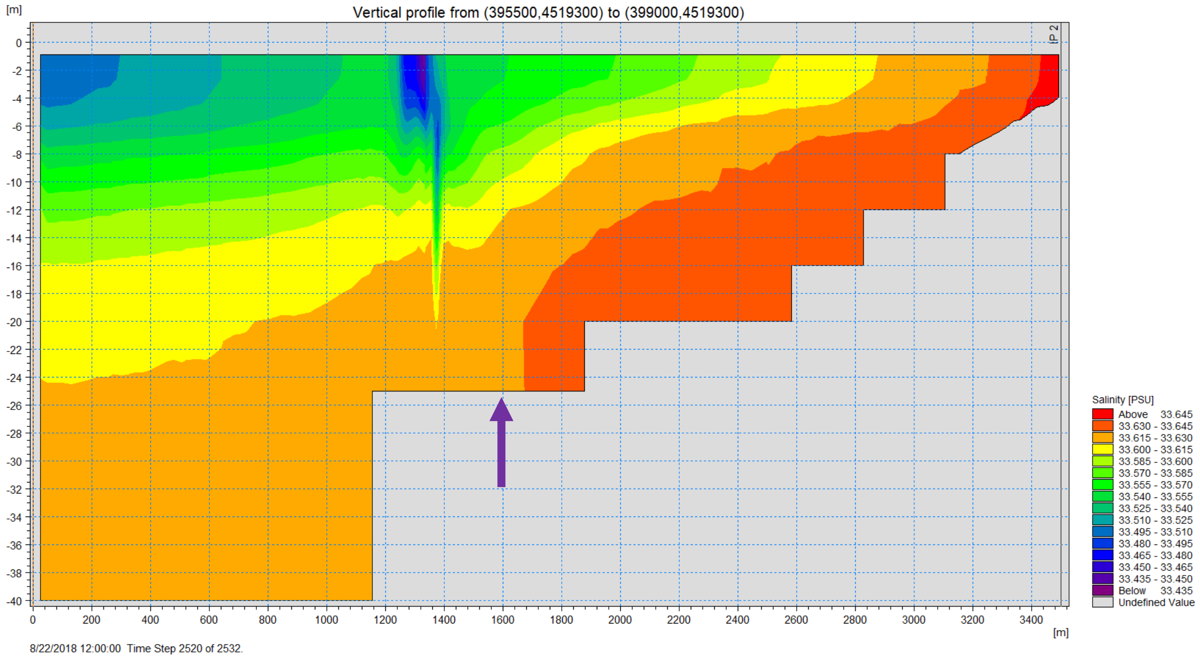

Figure 25 As Figure 23 at the end of the summer analysis period on 22 August 2018.

Appendix D – Simulated Salinity Transects during the Large Inflow Event Scenario

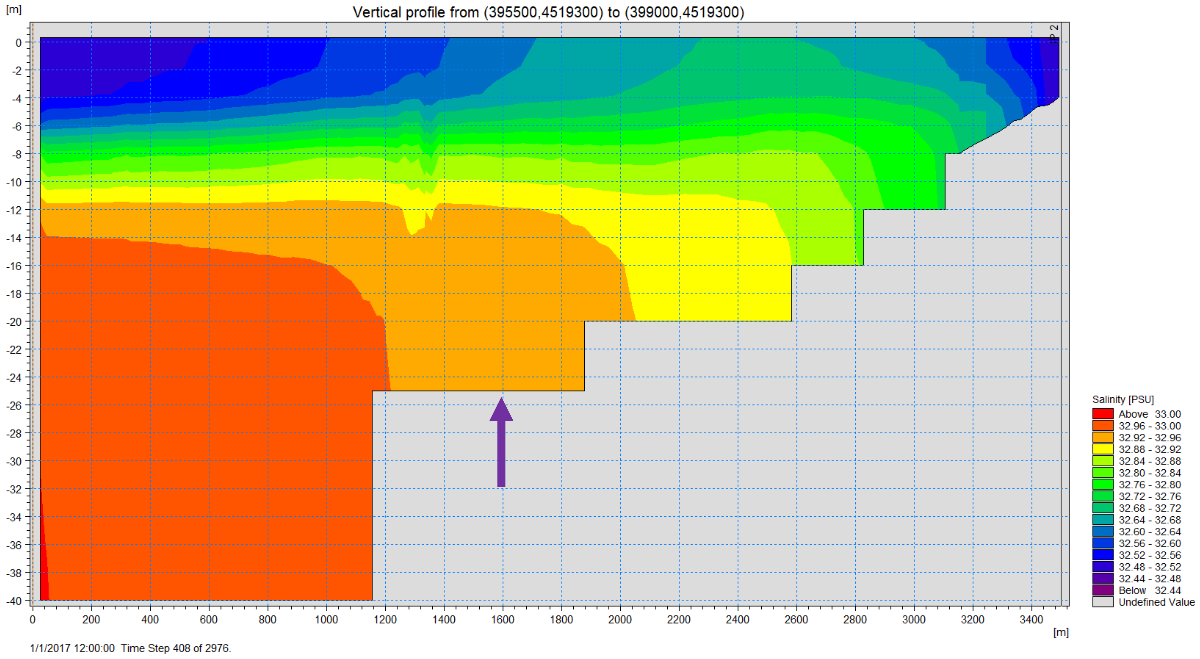

Figure 26 As Figure 23 at the start of the winter analysis period on 1 January 2017.

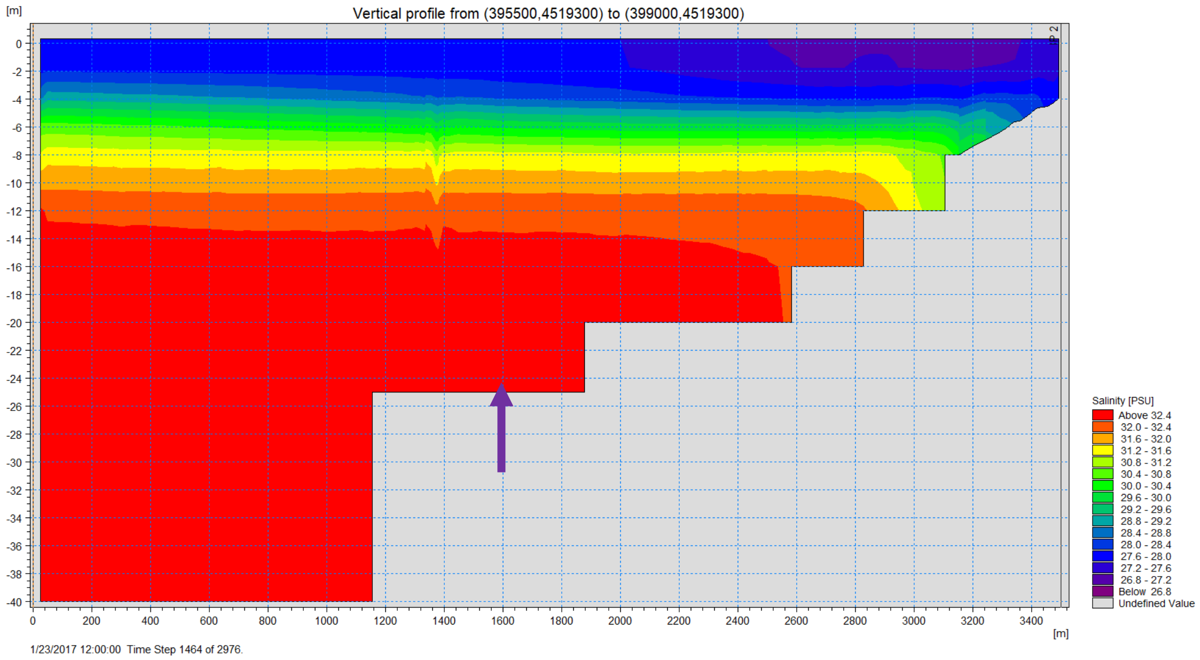

Figure 27 As Figure 23 at the middle of the winter analysis period on 23 January 2017.

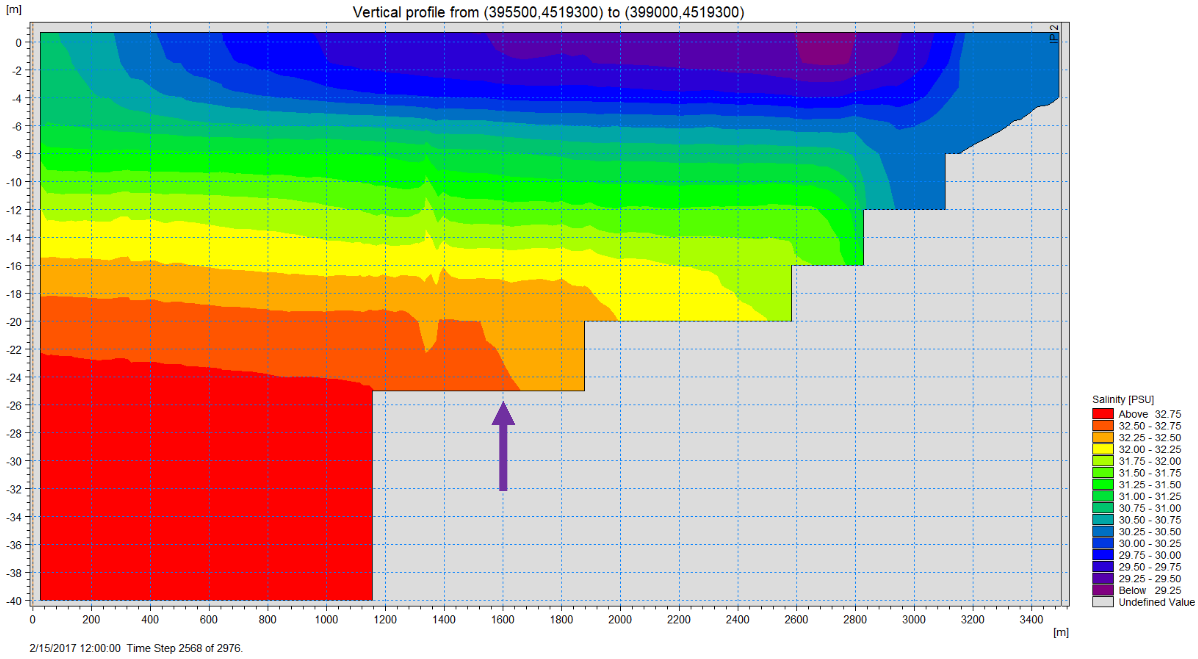

Figure 28 As Figure 23 at the end of the winter analysis period on 15 February 2017.

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Level 10
999 Hay Street
T: 61 8 6222 8222   F: 61 8 9463 6012   E: permail@ghd.com

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		Name	Signature	Name	Signature	Date
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