

Nelson North Wastewater Treatment Plant (NWWTP) dispersion modelling

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1.Introduction

Nelson City Council (NCC) is interested in understanding the dilution and discharge characteristics of contaminant discharged from the Nelson North Wastewater Treatment Plant (NWWTP), and how the dilution characteristics may affect nearby beaches. The wastewater treatment plant is located at the northern end of The Haven (Figure 1-1).

The NWWTP which treats on average approximately 7,200 m³ of wastewater every day (2013-2021, data provided by Nelson City Council); was upgraded in 2007-2009 and is designed to comply with the requirements of the 2004 resource consent. The design of the new plant has allowed for better management of variable inflows and allows adjustments in operation to be made to reduce the negative effects of winter conditions on the pond operation.

The council now require a renewal of the Resource Consent, which will require an understanding of how the wastewater is expected to dilute within the environment by applying a numerical modelling approach.

The NWWTP serves the northern catchment of Nelson City, comprising mainly domestic residences, and a small percentage of industrial discharges from the Port and Vanguard Street industrial areas. Wastewater is collected by a reticulation system that is then pumped from the Neale Park Pump Station to the wastewater treatment plant located at the northern end of the Nelson Haven (Figure 1-1).

The treatment concept for the wastewater treatment plant is based on:

- Removing gross solids through the inlet works
- Pre-treating the wastewater flow to remove organics and solids using a trickling filter and clarifier (as required depending on pond conditions)
- Pond based treatment for the removal of organics, solids, and pathogens
- Natural disinfection using the maturation pond and wetlands

The main components of the NWWTP, includes:

- Flow Buffer (1) attenuates peak flows during periods of high rainfall
- Screening and Grit Removal (2) –removes gross solids and non-organic material, which is disposed off-site
- Clarifier (3) when on-line, removes readily settleable solids (sludge)
- Sludge Tanks (4) sludge from the clarifier is either discharged into the facultative pond or mechanically thickened, stored in tanks and periodically trucked off-site to Bell Island WWTP



- Trickling Filter (5) when on-line, removes organic material via a fixed film growth process
- Oxidation Ponds (6) Two ponds, a facultative pond and a maturation pond, operate in series to collectively remove organics, solids and pathogens
- Wetlands (7) Two wetlands operate in parallel to further treat (or polish) the wastewater
- Bio-Filter (8) Foul air extracted from selected, covered elements of NWWTP is treated by a bark 'biofilter'
- Outfall (9) The outfall pipe goes 350m into Tasman Bay

The relative orientation of the infrastructure listed above are illustrated in Figure 1-2.







Figure 1-1 Location of the NWWTP, including approximate location of the outfall/diffuser and the buoy deployment.



Figure 1-2 NWWTP infrastructure layout.



2.Methodology

2.1. Buoy Data

A buoy deployment was undertaken by Cawthron Institute to assist with the characterisation of the hydrodynamic regime in the vicinity of the treated wastewater discharge point (Figure 1-1). The measurement period extended from 5 August 2020 to 26 November 2020, and included measurement of currents, salinity, temperature, oxygen, chlorophyll, turbidity, and wave parameters. The deployment included a range of instruments as provided in Table 2-1.

The buoy provides current velocity data for the near-field model setup and for the calibration and validation of the hydrodynamic model.

Measurement	Instrument	Instrument name		
Currents	ADCP	RDI Sentinel V50 ADP and		
		RDI Sentinel V20 ADP		
Salinity	CT Sensor	WETLabs WQM		
Temperature	ADCP and CT Sensor	RDI Sentinel V50 ADP,		
		RDI Sentinel V20 ADP, and		
		WETLabs WQM		
Oxygen	DO sensor	WETLabs WQM		
Chlorophyll	Fluorometer	WETLabs WQM		
Turbidity	Turbidity sensor	WETLabs WQM		
Wave	Wave sensor	Seaview SVS-603		

 Table 2-1
 Wakapuaka buoy - Instruments deployed at -41.1986, 173.3215.

2.2. Near-field modelling

Near-field modelling of the initial turbulent mixing was undertaken using CORMIX¹. CORMIX is a USEPA-supported mixing zone model and decision support system for environmental impact assessment of regulatory mixing zones resulting from continuous point source discharges. The system emphasizes the role of boundary interaction to



¹ http://www.cormix.info/

predict steady-state mixing behaviour and plume geometry. CORMIX was used to define the near-field plume characteristics (plume extent, initial dilution) under a range of representative conditions of current velocities and discharge characteristics. The nearfield plume extent and initial dilution was used as input into the far-field model.

The nearfield is the region of a receiving water where the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of a wastewater discharge.

2.2.1. Simulations

Details of the outlet pipe design were provided by NCC and show in Figure 2-1.

The concrete pipe is perpendicular to the shoreline and extends approximately 430 m from the manhole (located at the treatment plant) to the offshore outlet hole. There are a total of 10 outlet holes, 9 of them located on the top half of the pipe and 1 hole located at the end of the pipe.

The holes on the top half of the pipe are equally spaced at 1.93 m along 20 m from the offshore outlet tip. Each hole is 0.3 m by 0.3 m with alternating opening angles. The hole located at the end of the pipe is parallel to the seabed and fitted with a conical reducer with a diameter of 0.3 m.

In CORMIX, it is not possible to simulate the alternating holes together with the conical reducer hole located at the end of the pipe. Therefore, we considered the conical reducer hole to be at the same height and angle as the other 9 alternating holes, totalling 10 alternating holes in our simulations. The pipe is located at the seabed and holes are approximately 1.2 m above the seabed.

The ambient temperature and salinity were assumed to be 14 °C and 34 psu respectively, based on the data measured by sensors attached to the buoy deployment described in the previous section. The wastewater temperature and salinity were calculated as the average of measurements provided by NCC and set to 17.3 °C and 1.2 psu, respectively. The measurements were carried out approximately 1-2 times a month from 13-Aug-2020 to 13-Jan-2021.

Timeseries of wastewater discharge for the past 9 years were provided by NCC. We plotted it to compare the discharge flow between each year (Figure 2-2) and the 2020-2021 period was adopted at the 'current year' scenario for this modelling assessment. Note that 2019-2020 (red line) has a significant peak, but 2020-2021 (black line) have some significant peaks at or above 20,000 m³/day and it is the most recent year. The average flow for the 2020-2021 period is 8,119 m³/day.



The consent flow (year 2059) was calculated based on an expected ratio of population increase (Table 2-2). The population increase ratio from 2021 to 2059 is 1.3. Therefore, we multiplied the 2020-2021 daily flow data by 1.3 to scale up the flows for the year 2059, resulting in an average flow of 10,555 m³/day. We combined flow rates of 2021 and 2059 to bracket all possible flow rates to be simulated, and calculated the 10th, 50th (median) and 90th percentiles of the flow rates (hereafter p10, p50, and p90, respectively).

Note that the calculation of the population increase ratio assumes population growth is uniformly distributed. Also, no allowance for climate change impacts (e.g., change in frequency, intensity and duration of storm events) were considered in the calculation.

Based on the analysis of current velocity timeseries data from Wakapuaka buoy, a range of velocities were selected for the simulations, from near stagnant (0.05 m/s), increasing with intervals of 0.10 m/s, to the maximum velocity of 0.40 m/s (Figure 2-8). While typical spring tide current at the bottom where the pipe is located is in the order of 0.11 m/s, an extreme case of 0.40 m/s was also considered. Wind velocities were kept at 0 m/s to provide a conservative, lower, estimate of the near-field dilution rates.

A total of 15 CORMIX near-field simulation where undertaken, considering p10, p50, and p90 of discharge flow under 5 different ambient current velocities: 0.05, 0.10, 0.20, 0.30, 0.40 m/s (Table 2-3).

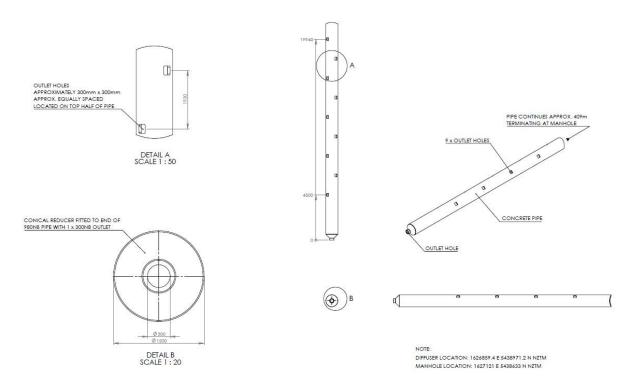


Figure 2-1 Pipe design and dimensions (Source: Nelson City Council).



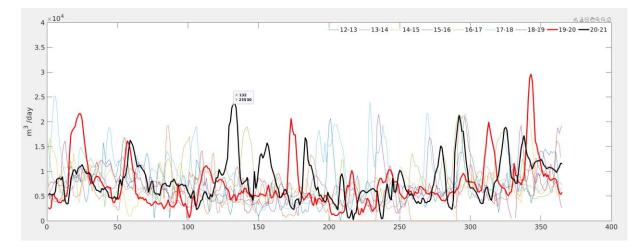


Figure 2-2 Wastewater discharge for the past 9 years provided by NCC. Different years represented by line colours indicated at the top of figure.



Year	NNWWTP Population
2019	26,219
2020	26,641
2021	26,655
2050	32,518
2059	34,897

Table 2-3CORMIX near-field list of simulations.

Scenarios	Ambient (m/s)	current	Flow rate (m ³ /s)			
p10	0.05		0.048			
	0.10					
	0.20					
	0.30					
	0.40					
p50	0.05	0.094				
	0.10					
	0.20					
	0.30					
	0.40					
p90	0.05	0.185				
	0.10					
	0.20					
	0.30					
	0.40					



2.3. Hydrodynamic modelling

The simulation of wastewater far-field dispersion within a complex coastal system requires high resolution hydrodynamic fields. For the present study, high-resolution 3D modelling of the tidal/river/stream discharge hydrodynamics undertaken for other studies within the region would be utilised. These simulations cover a range of climatic conditions (i.e., La Niña/ El Niño complete years) and provide a sound statistical basis to examine the dispersion of contaminants within the receiving environs. The simulations are based on the open-source model SCHISM²³.

Open-source science models allow full transparency of the code, numeric, boundary conditions and outputs. Further, it allows other consultants and researchers to replicate or enhance any previous modelling efforts for a given environment.

SCHISM is a prognostic finite-element unstructured-grid model designed to simulate 3D baroclinic, 3D barotropic or 2D barotropic circulation. The barotropic mode equations employ a semi-implicit finite-element Eulerian-Lagrangian algorithm to solve the shallow water equations, forced by relevant physical processes (atmospheric, oceanic and fluvial forcing). A detailed description of the SCHISM model formulation, governing equations and numerics can be found in Zhang & Baptista (2008).

The finite-element grid structure (i.e., triangles) used by SCHISM has resolution and scale benefits over other regular or curvilinear based hydrodynamic models. SCHISM is computationally efficiently in the way resolves the shape and complex bathymetry associated with estuaries, while the governing equations are similar to other open-source models such as Delft3D. SCHISM has been used extensively within the scientific community⁴, and forms the backbone to operational systems used to predict nowcast and forecast estuarine water levels, currents, water temperature and salinity⁵.

2.3.1. Computational grid

The model resolution has been optimised to ensure the salient hydrodynamic processes are accurately captured, with offshore resolution of the order 10s-100s m, and inside the rivers and estuaries at 5-10 m, depending on the bathymetry gradients. The model domain includes the main river systems which discharge into Tasman Bay (Figure 2-3).



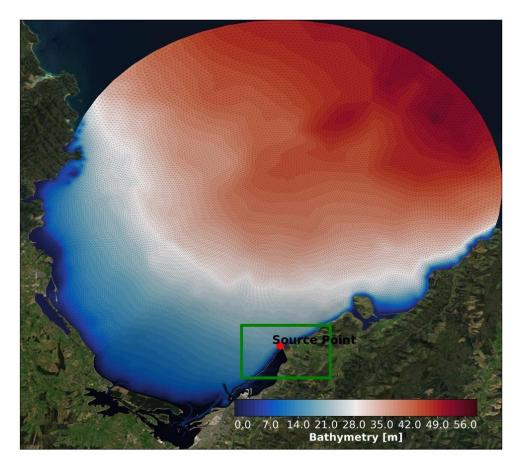
² http://ccrm.vims.edu/schism/

³ http://www.ccrm.vims.edu/w/index.php/Main_Page#SCHISM_WIKI

⁴ http://ccrm.vims.edu/schism/schism_pubs.html

⁵ https://tidesandcurrents.noaa.gov/ofs/creofs/creofs_info.html

The original hydrodynamic model domain was established for the Bell Island WWTP treated wastewater discharge modelling and its grid was extended for the Nelson Port modelling work scopes (MetOcean Solutions Ltd, 2017 and MetOcean Solutions, 2020).



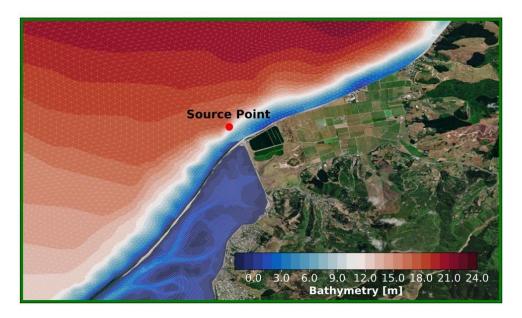


Figure 2-3 Map showing the SCHISM model domain, bathymetry and discharge location from the NWWTP.



2.3.2. Vertical grid

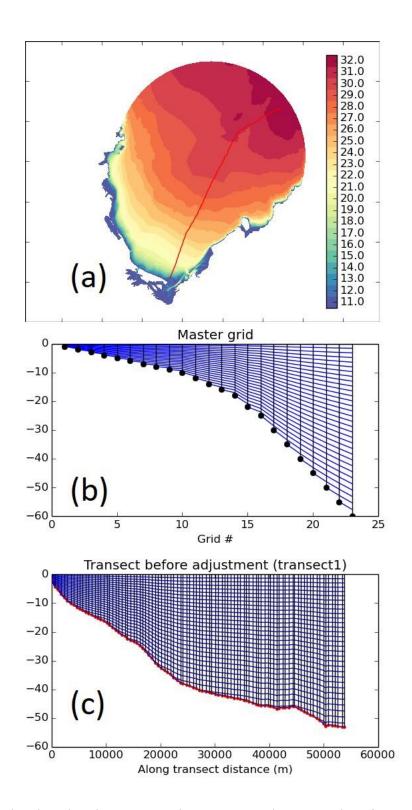


Figure 2-4 Vertical grid used in the present study: (a) - a map showing number of vertical layers across the computational domain with an transect; (b) & (c) – master grid and vertical grid along the transect.



2.3.3. Model forcing and boundary conditions

In this study we applied similar model setup and forcing than the previous work for Bell Island (MetOcean Solutions Ltd, 2017).

2.3.3.1. Tidal forcing

The widely used tidal constituents sourced to force regional and coastal domains in hydrodynamic models - the Oregon State University Tidal Inverse Solution (OTIS, Egbert & Erofeeva, 2002) – was rather coarse for direct use in New Zealand coastal domains. Therefore, tidal constituents from the harmonic analysis of a long term 2D Princeton Ocean Model (POM, Mellor, 1998) tidal simulation with 5 km horizontal resolution were used to derive tidal boundaries.

The NZ-POM domain was forced at the open boundaries by tidal elevation and current harmonic constituents derived from the OTIS Pacific Ocean solution⁶. The SCHISM domain was forced at the open boundary by elevation and current constituents derived from the POM 2D simulation.

2.3.3.2. Offshore residual current forcing

Open boundary non-tidal inflows and outflows were provided by 3-dimensional velocity, temperature and salinity fields and spatially variable sea surface height derived from a nationwide implementation of the Regional Ocean Modelling System (NZ-ROMS) nested within the global Climate Forecast System Reanalysis (Saha et al., 2010).

Velocity boundary conditions were interpolated to each node and sigma level, along the offshore model boundary for each model time-step. Residual elevations were interpolated to each boundary node and each model time-step.

2.3.3.3. Atmospheric forcing

MetOcean Solutions maintains an up-to-date atmospheric hindcast reanalysis from 1979 to 2016 at 12 km resolution for the entire New Zealand and approximately 4 km over central New Zealand (including Nelson). This atmospheric hindcast was produced using the Weather and Research Forecasting (WRF) model forced with boundary conditions from the global CFSR product.

The improvement in resolution from the 35 km of CFSR adds accuracy and variability to the atmospheric fields that force the SCHISM model, especially over coastal margins where topography is known to substantially change the large-scale wind patterns and



⁶ http://volkov.oce.orst.edu/tides/PO.html

local responses. WRF variables such as winds, atmospheric pressure, relative humidity, surface temperature, long and short-wave radiation, and precipitation rate were used at hourly intervals to provide air-sea fluxes to force the Bell Island SCHISM model.

The wind speed from this hindcast has been validated at numerous sites around New Zealand; shown in Figure 2-5 are time series data from Auckland Airport in January 2007 and a quantile-quantile plot from a full year (2007) at Brother's Island in the Cook Strait.

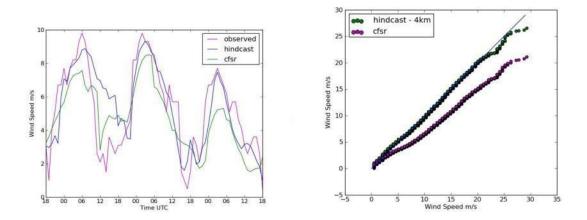


Figure 2-5 Comparison of both CFSR data and a high-resolution WRF hindcast for Auckland Airport during a few days in January 2007 (left) and quantile-quantile plot of both CFSR (magenta) and the WRF hindcast (green) against the observations from Brother's Island in the Cook Strait during 2007.

2.3.3.4. Fluvial discharges

Time-varying open boundary fluvial inputs were prescribed for the Waimea River, Neimann Creek, Jenkins Creek and the Maitai River (Figure 2-6) supplied by both Tasman District Council and Nelson City Council. An example of the measured time-series of discharges for the Waimea River is given in Figure 2-7.



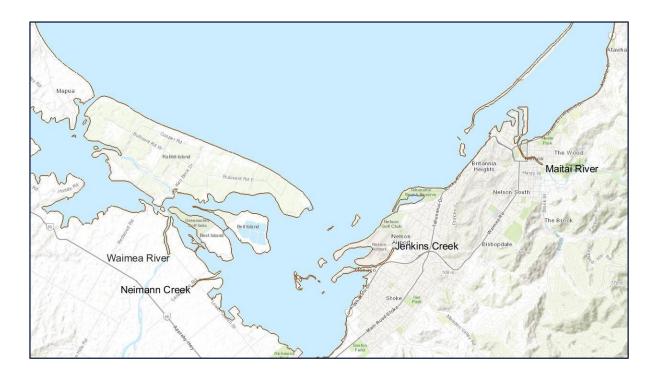


Figure 2-6 Open fluvial boundaries at which time-varying discharges were defined

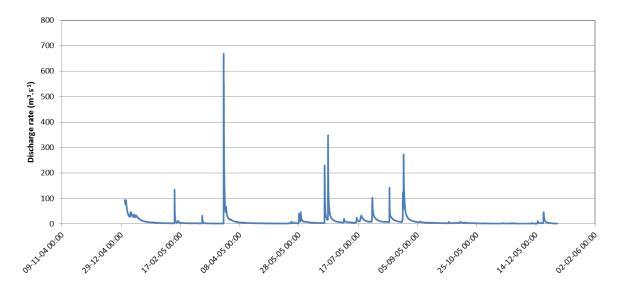


Figure 2-7 Example of the temporal variability in Waimea River discharge rates used at the open boundary of the SCHISM model.

2.3.3.5. Temperature and Salinity

Salinity and temperature boundary conditions were interpolated to each node and sigma level, along the offshore model boundary for each model time-step. Residual elevations were interpolated to each boundary node and each model time-step. Temperature and salinity were treated as passive tracers in the 2D depth averaged baroclinic model.



2.3.4. Model calibration and validation

The governing fluvial and tidal flow dynamics have been calibrated and validated against available measured data collected as part of the Bell Island field data deployment, and data maintained by the Port.

However, further model validation against measured data available was also taken in the present study. The measured data were taken from Wakapuaka buoy located offshore near NWWTP (Figure 1-1).

Comparison of the modelled water elevation against the NIWA predicted tide and the modelled current speed and direction against the field data at middle water depth (~8.68 m below the surface) shows a good agreement between the two datasets (Figure 2-8).

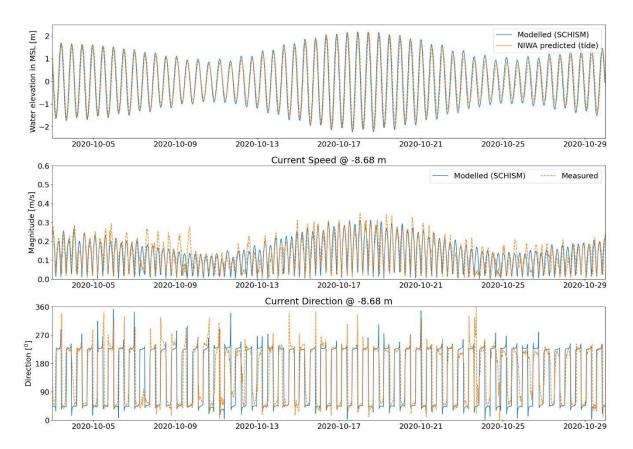


 Figure 2-8
 Model validation: Top panel – modelled surface elevation against NIWA predicted tide; Middle and

 Bottom panels – modelled current speed and direction against field data at buoy provided by the client.



2.4. Far-field modelling

2.4.1. Modelling Approach

The release of pollutants in the oceanic or estuarine environment through an outfall is a process that is generally either continuous over time, or at prescribed times (e.g., specific tidal stage and amplitudes). These discharges are often subject to significant fluctuations in released quantities. The outcome of such releases is inherently non-deterministic and is governed, in part, by random variables such as currents, turbulences, wastewater network use and precipitation, it is therefore difficult to accurately predict.

However, the expected hydrodynamic regime can be assessed from the historical conditions, thereby allowing estimations of the general geographical dispersion. In the present study, the approach consisted of running two year-long simulations within contrasting historical contexts: La Niña and El Niño episodes (April 2010-April 2011, and April 2015-April 2016, respectively).

During El Niño conditions, New Zealand typically experiences stronger or more frequent westerly winds during summer. This leads to a greater risk of drier-than-normal conditions in east coast areas and more rain than normal in the west. In winter, colder southerly winds tend to prevail, while in spring and autumn, south-westerlies tend to be stronger or more frequent, bringing a mix of the summer and winter effects.

During La Niña conditions more north–easterly winds are characteristic, which tend to bring moist, rainy conditions to the north–east of the North Island, and reduced rainfall to the south and south–west of the South Island.

Considering both La Niña /El Niño episodes aims to produce robust probabilistic estimate of the plume dispersion and dilution and thus provide guidance on expected concentration levels associated within the outfall region for existing and proposed consent flow accounting for increasing population.

The general dispersion model employed and considered scenarios are described below.

2.4.2. Opendrift Model description

The dispersion of contaminant discharged in the ocean at the outfall was simulated using the ocean trajectory modelling framework OpenDrift⁷ (Dagestad K.F et al., 2018).



⁷ https://github.com/OpenDrift/opendrift

OpenDrift is an open-source Python-based framework for Lagrangian particle tracking developed by the Norwegian Meteorological Institute, where it is notably used operationally for emergency response for oil spill and search and rescue events. The framework is highly modular and can be used for any type of drift calculations in the ocean or atmosphere. A number of modules have already been developed, including an oil drift module (see Röhrs et al., 2019), a stochastic search-and-rescue module, a pelagic egg module, a plastic drift module.

The contaminant dispersion simulations described in the study were undertaken using the OceanDrift⁸ module that assumes passive particles with no settling velocities, subject to horizontal and vertical advection and mixing.

The dispersion modelling consists of a trajectory tracking scheme applied to discrete particles in time and space-varying 3D oceanic currents.

$$\frac{dx_p}{dt} = \tilde{u}(x, y, z, t) + u_t$$
$$\frac{dy_p}{dt} = \tilde{v}(x, y, z, t) + v_t$$
$$\frac{dz_p}{dt} = w_t + w_s$$

Equation 2-1 (a, b, c)

where (x_p , y_p , z_p) are particle 3D coordinates, $\tilde{u}_{(x,y,z,t)}$, $\tilde{v}_{(x,y,z,t)}$ are horizontal ocean currents, (u_t , v_t , w_t) are the diffusion components representing turbulent motions, and w_s is the sediment settling velocity (here equals to zero).

In the horizontal plane, particles were advected by ocean currents using a 4th order Runge-Kutta tracking scheme, and subject to additional displacement by horizontal diffusion.

In the OpenDrift framework, the horizontal diffusion is included by applying an uncertainty to the horizontal current magnitudes. The magnitude of the current uncertainty was estimated using the general diffusion Equation 2-1.

$$\int_{t}^{t+\Delta t} u_{t} dt = \sqrt{2.K_{u,v} \Delta t} \cdot \theta(-1,1)$$

Equation 2.2



⁸ https://github.com/OpenDrift/opendrift/blob/master/opendrift/models/oceandrift.py

where $\theta(-1,1)$ is a random number from a uniform distribution between -1 and 1, Δt is the time-step of the model in seconds (900 sec. used here) and K_{u,v} is the *horizontal* eddy diffusivity coefficient in m²·s⁻¹.

In the vertical plane, particles are subject to both vertical settling (w_s) (here w_s =0) and diffusive displacement (w_t) due to vertical turbulent motion through the water column. In OpenDrift, the vertical mixing process is parameterised in using a numerical scheme described in Visser (1997) which is similar to equation 2.2 when using a constant vertical diffusion coefficient K_z (as employed here).

The horizontal and vertical diffusion are included in the dispersion modelling account for the mixing and diffusion caused by sub grid scale turbulent processes, such as eddies, that are not explicitly resolved by the hydrodynamic models.

For dispersion at oceanic scales, (Okubo, 1974; Okubo, 1971) proposed that $k_{u,v}$ varies approximately as Equation 2.3, which is close to the general 4/3 power law often considered for atmospheric (Richardson, 1962) and oceanic diffusions (Batchelor, 1952; Stommel, 1949) (Equation 2.4).

$$k_{u,v} = 0.103. L^{1.15}$$

Equation 2.3

Equation 2.4

where *L* is the horizontal scale of the mixing phenomena and α indicates proportionality.

These equations relate the magnitude of the eddy diffusivity $k_{u,v}$ to the length scale of the phenomena and this 4/3 power relationship was found to be relevant over a large range of scale (10m to 1000km) (Okubo, 1974; Okubo, 1971). A similar relationship was found by List et al. (1990) in coastal waters.

In the present study, since high resolution flows are available (Section 2.3), the amount of added diffusion should be limited. A generic horizontal coefficient of 0.025 m²/s was applied which is consistent with a length scale of order 70 m. The spatial scales of the vertical turbulent motions within the water column are one or several orders of magnitude smaller than horizontal ones. The vertical diffusion coefficient was set to a generic value of 5 cm²/s.

In the present model implementation, any particle reaching the shoreline, the seabed or sea surface was re-suspended to continue its dispersion (i.e., non-sticky boundaries).



 $k_{u,v} = \alpha. L^{\frac{4}{3}}$

Particles reaching the edges of the model domain (see Figure 2-3) were removed from the simulations.

2.4.3. Discharge scenarios

The approach employed in the present study consisted in running 1 year-long simulations of wastewater discharges from the outfall location (Figure 2-9, and Table 2-4), within two contrasting historical contexts El Niño / La Niña episodes (April 2015- April 2016, and April 2010- April 2011 respectively).

To reproduce the expected variation of discharge rates over time, an annual time series of daily discharge volumes measured through the calendar years 2020-2021 at the wastewater plant was used as a reference for both El Niño / La Niña scenarios. Simulations were reproduced with projected discharge flow rate increase i.e., consent flow (year 2059). A factor of 1.3 was applied to the current daily discharge flow timeseries (see section 2.2.1).

The nearfield plume dynamics vary over time in response to ambient flow speed and direction and effective outfall discharge rate. This was included in the (far-field) model by releasing particles within time-varying triangular footprints, describing the nearfield range NFR. The dimensions of the release footprints (NFR length, NFR half width, NFR thickness) were defined by interpolation from the look-up table generated from the nearfield modelling results (see section 3.1), accounting for ambient hydrodynamic flow speed at the outfall location, and outfall discharge rate. The triangular release footprints were then aligned with instantaneous flow direction (Figure 2-11). Note the particles were released in the surface layer of the water column within a thickness defined by the NFR thickness as the plume is expected to be buoyant. This will also delay particle interaction with the seabed and thus produce conservative trajectories in terms of how far they could travel.

The number of particles released each day was scaled according to the effective daily discharge rate (i.e., more particles released for large discharge flow rates). Maximum particle age was set to 40 days after which they were removed from the simulation. This was defined from the maximum T90 considered of 32 days Using a maximum particle age prevents saturation of the particle-tracking model with "old" particles and allows keeping a very large number of active particles in the model at all times to correctly represent the plumes.



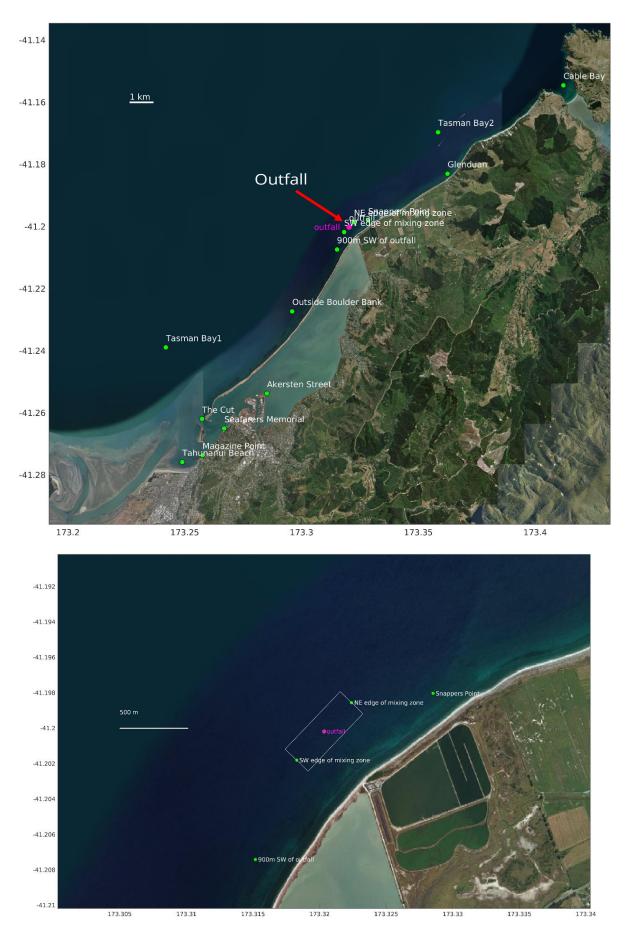


Figure 2-9 Location of outfall (red dot) and extraction sites (white).



Table 2-4 Site locations (see Figure 2-9).

Site Names	Lon	Lat	Depth
'outfall'	173.3203	-41.2002	12.0
'Cable Bay'	173.4121	-41.1545	3.6
'Glenduan'	173.3625	-41.1830	3.8
'Snappers Point'	173.3285	-41.1980	5.0
'900m SW of outfall'	173.3152	-41.2074	5.8
'Outside Boulder Bank'	173.2960	-41.2273	9.8
'Tasman Bay1'	173.2420	-41.2389	11.7
'Akersten Street'	173.2852	-41.2538	1.3
'The Cut'	173.2574	-41.2620	6.5
'Seafarers Memorial '	173.2669	-41.2650	1.7
'Magazine Point '	173.2577	-41.2737	0.6
'Tahunanui Beach'	173.2490	-41.2758	3.3
'Tasman Bay2'	173.3585	-41.1696	22.4
'SW edge of mixing zone'	173.3183	-41.2018	13.0
'NE edge of mixing zone'	173.3224	-41.1986	11.9

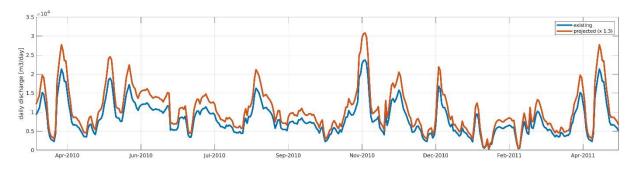


Figure 2-10 Timeseries of daily flow discharge over an annual period for the existing and projected future scenarios.

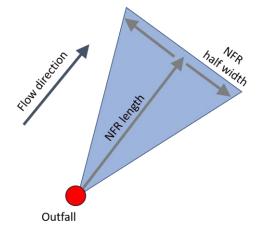


Figure 2-11 Sketch showing the triangular release footprint defined from the nearfield dynamics metrics NFR length and mid width. Particles were released on the surface layer within a thickness defined by the NFR thickness.



2.4.4. Post-processing

2.4.4.1. General approach

The dispersion model outputs a set of particle positions that change over time, thus describing their trajectories. Here, particles can describe any contaminant considered to be passive i.e., freely moved under influence of currents and mixing. Particle trajectories can be useful to assess general transport pathways in a qualitative sense, but it is often needed to reconstruct particle concentration fields, which is a more quantitative metric to assess actual contaminant concentration. The "concentration" of particles at a given point (x,y,z) is related to the particle "density" in the region surrounding this point, which can be estimated by counting particles within each cell of a user-defined grid.

To outline general dispersion pathways, the contaminant concentration fields were reconstructed from the particles clouds on 17 by 14 km frame centred on the outfall location, with a grid resolution of 100 m. Concentrations were computed at three levels in the water column, i.e. surface, mid depth and near bed. Snapshots of particle clouds are shown in Figure 2-12.

Gridded field of contaminant concentrations were reconstructed from the particle clouds using two different techniques, (a) 2D histogram (standard box-counting approach), and (b) kernel density estimator (Silverman, 1986).

For the 2D histogram approach, time-varying contaminant concentration C(t,x,y,z) were obtained by counting the number of particles, each carrying a given contaminant *load*, in each grid cell, for each water column band considered. The total contaminant *load* per cell was then normalized by the cell surface area [m²], and vertical depth band [m] to obtain contaminant concentration in [load/m³].

In the kernel density approach, individual particles are assumed to represent the centre of mass of a "cloud"; the density profile of the cloud is described by the *kernel function*, while the spreading of the particle's equivalent mass is defined by the *bandwidths* associated with a given particle or receptor (Bellasio, et al., 2017; Vitali et al., 2006). These two components are then used to derive a *particle density field*, also referred to as a *probability density function*. Here, the kernel density estimation is undertaken following the approach proposed by Botev, et al. (2010). The proposed method uses an adaptive kernel density estimation method based on the smoothing properties of linear diffusion processes. The key idea is to view the kernel from which the estimator is constructed as the transition density of a diffusion process (Botev, et al., 2010). This method limits the amount of guessing, notably to defining bandwidths, as well as possible excessive smoothing of the density fields (e.g., as obtained with Gaussian kernel density estimators).



Based on a given cloud of particles (X_{part}, Y_{part}), the method yields a *probability density function PDF*(*x*,*y*), derived from the *kernel density estimator* describing the density of particles throughout the domain. The spatial integration of the *probability density function PDF*(*x*,*y*) over the entire domain equals one.

The *PDF(x,y)* values can be converted to <u>particle density</u> when multiplied by the total number of particles in the domain i.e., with units [particles.m⁻²]. The particle density can in turn be converted to <u>load density</u>, or <u>load distribution</u>, based on the equivalent <u>load</u> carried by individual particles i.e., with units [load.m⁻²]. <u>Contaminant load concentration is</u> obtained by dividing the load density by the correct vertical depth band i.e., with units [load.m⁻³].

In order to provide dilution fields (dimensionless), a generic contaminant concentration of Co = $1g/m^3$ (or 1 mg/L) was assumed for the raw wastewater discharged at the outfall.

Dilution was then obtained as D = Co/C(t,x,y,z).

The reconstruction of contaminant concentration fields was undertaken using both the 2D histogram and kernel density approaches to obtain conservative concentration/dilution estimates for both high and low concentrations levels.

This 2D histogram approach is typically more conservative for larger concentration levels at sites near the release and as it will attribute the sum of all particle's load within a given grid cell to that cell. However, for areas with a smaller number of particles (e.g., further from release, or less exposed), concentration may possibly become zero if no particles are within a given cell. In contrast, the kernel density approach spatially smoothes individual particle loads, before doing the box-counting. This typically results in smaller concentrations peaks (e.g., a cell that included 10 particles load in the 2D histogram may now include only 8.5), however this allows better resolving lower concentrations levels at sites less exposed to the contaminants (e.g., a cell that included zero load with the 2D histogram method may now include 0.8 load, from nearby particles). The kernel density approach is similar that occur in Eulerian advection-diffusion models that can also be used to track contaminant dispersion.

Spatial statistics were derived from the obtained time-varying contaminant fields. In addition to the spatial statistics, dilution timeseries were extracted at a range of sites (Table 2-4) for further assessment such as QMRA (Quantitative microbial risk assessment). To ensure conservative estimates of contaminant concentrations at sites of interest, timeseries provided for the Quantitative Microbial Risk Assessment merged the results of both approaches, by taking the maximum of predicted concentrations with the kernel or 2D histogram techniques at each timestep.



2.4.4.2. Inclusion of contaminant inactivation

To account for the decay/inactivation of released contaminant, results were postprocessed accounting for a progressive decay of the contaminant load carried by each particle. Note a conservative scenario with no inactivation was also considered.

The decay rate can be simulated using the relationship below (e.g., Eregno et al., 2018) :

 $C = C_0 e^{-kt}$

Equation 2.5

where t = time [days], Co = concentration at time zero [load/m³], C = concentration [load/m³] at time t, k = inactivation constant [days⁻¹].

Based on Boehm et al. (2019) who carried out a systemic review of virus decay rates in surface waters, two generic inactivation constants were considered to model average and rapid decay (notably for norovirus):

- Average decay K= 0.0708 [days⁻¹], T50 = 10 [days], T90 = 32 [days]
- Rapid decay K= 1.0715 [days⁻¹], T50 = 0.7 [days], T90 = 2 [days]

T50 and T90 are duration after which 50% and 90% of the virus have decayed.



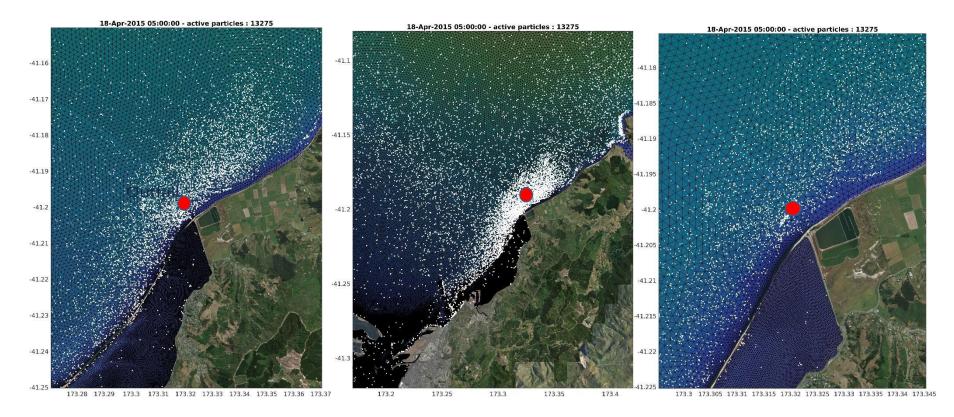


Figure 2-12 Snapshots of particle clouds at several zoom levels. The outfall is shown in red.



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3.Results

3.1. Near field modelling

A range of simulations were undertaken in order to estimate the near field plume characteristics. It is noted that the discharge is occurring via 10 outlets that are holes on the pipe with no diffuser or complex structure. The nearfield plume shape is first represented by 10 point-sources release which are subsequently merged into one positive buoyant plume, represented by the diagram in Figure 3-1.

The nearfield region (NFR) describes the zone of strong initial mixing where the so-called nearfield processes occur (i.e., the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of a wastewater discharge). It is the region of the receiving water where outfall design conditions are most likely to have an impact on in-stream concentrations. Beyond that is the far field region where physical mixing mechanisms are dominating with spreading motions and passive diffusion controlling the trajectory and dilution of the wastewater discharge plume.

A dilution factor of 'n' times at some distance from the discharge indicates a reduction in pollutant level by 'n' times (e.g., with a discharge concentration above background of a nominated value of 1 g/m³ and dilution factor of 5 times, the expected concentration above background will be 1/5=0.2 g/m³).

Results show that the dilution factor at the edge of the near field varies from 220.5 to 2871.4 (Table 3-1). Two examples of dilution along the plume centreline are shown in Figure 3.2 for simulations of p10 of discharge flow and ambient current speed of 0.05 m/s and p90 of discharge flow and ambient current speed of 0.4 m/s. The dilution in the first case (top panel, Figure 3-2) shows an approximately linear increase in dilution and a much higher increase rate further away from the source. The marked changes on the line in the plot are located at distances where CORMIX begins and end specific modules, in accordance with CORMIX hydrodynamic classification (MU1H – description in Appendix A) based on the characteristics of the jet flow and the ambient flow and illustrated in the diagram presented in Figure 3-1.

The second case (bottom panel, Figure 3-2), the hydrodynamic classification is MU8 (description in Appendix A), and different modules are then selected by CORMIX to model this plume, resulting in a different dilution behaviour. The difference is because the crossflowing discharge gets rapidly deflected by the strong ambient current.



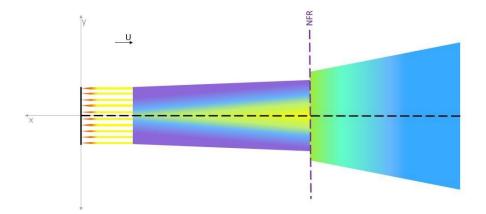


Figure 3-1 Diagram representing the different modules in CORMIX simulations of near-field plume. U = current direction, NFR = Near-field range. From left to right, individual jet/plumes before merging, merging of individual jet/plumes, begin of layer/boundary/terminal layer approach, end of near-field region (NFR). Beyond the NFR is the far-field region which is illustrated here but will be simulated using the particle tracking model (OpenDrift).

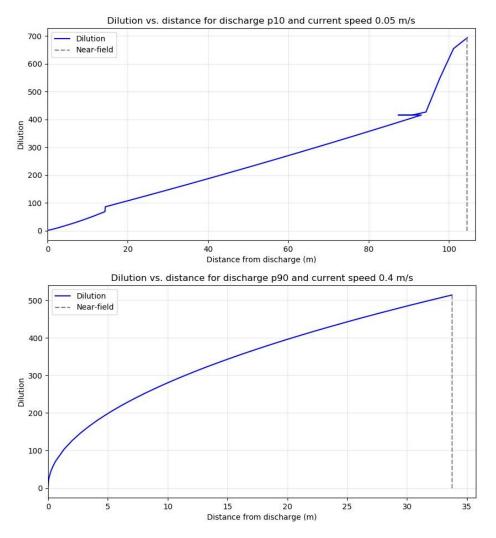


Figure 3-2 Dilution at distance from the discharge for simulations considering p10 of flow and 0.05 m/s ambient current speed (top) and p90 of flow and 0.40 m/s ambient current speed (bottom).



Dilution tends to be higher in faster ambient current velocities although variations to this trend can occur depending on the ambient currents compared to the discharge velocity (i.e., the velocity the discharge exit the pipe).

Results show that plume behave differently in terms of plume shape and length of nearfield zone under different flow rate scenarios (i.e., p10, p50 and p90). For flow rates representing p10 and p50 (0.048 m³/s and 0.094 m³/s) have near-field length increasing with increased ambient current velocity, reaching a distance of up to 1907.3 m from the discharge point. This distance is calculated based on the processes that define what is a near-field zone, as previously described. In terms of dilution, high values are predicted by the model at the edge of the near-field for these scenarios, e.g., for p10 flow rate and ambient velocity of 0.4 m/s dilution is 2871.4 at the edge of near-field which corresponds to 0.035% of the initial concentration (Table 3-1).

In all scenarios, plume is wider in near stagnant water and the plume is extends downstream (x-direction – flow direction) while reducing in extent in the across the flow direction (y-direction) under faster current flow (Table 3-1). The edge of the near field is located before the plume attaches to the shoreline in all simulations (for the conditions simulated in this study). For example, maximum predicted half-width of plume (distance from the centreline to the edge of plume) is 185.9 m while outlets are at least 400 m from the shore, therefore, plume does not contact the shoreline within the near-field zone.

The time when the plume transitions from near-field to far-field ranges from 3 minutes (p90, 0.4 m/s) to 77.8 minutes (1.3 hour, p10, 0.4 m/s). The far-field plume dispersion was modelled using the OpenDrift particle tracking model and results are presented in the next section.



Table 3-1 CORMIX scenarios. NFR = Near-field range.

Scenarios	Ambient current (m/s)	Flow rate (m³/s)	Discharge velocity (m/s)	NFR length (m)	NFR half- width (m)	NFR thickness (m)	Concentration at NFR edge (%)	Dilution at NFR edge	Cumulative travel time (minutes)	CORMIX Hydrodynamic Classification
p10	0.05	0.048	0.07	104.6	24.7	13.5	0.144	693.4	18.5	MU1H
	0.10		0.07	220.1	21.1	11.8	0.096	1037.4	29.3	MU1H
	0.20		0.07	613.7	20.2	10.1	0.059	1702.5	48.7	MU1H
	0.30		0.07	1182.4	19.3	9.6	0.043	2308.5	63.6	MU1H
	0.40		0.07	1907.3	18.7	9.2	0.035	2871.4	77.8	MU1H
p50	0.05	0.094	0.13	121.7	92.4	3.5	0.292	342.6	24.8	MU1V
	0.10	-	0.13	167.5	21.1	12.9	0.173	577.4	20.0	MU1H
	0.20		0.13	433.3	20.6	10.5	0.108	922.6	33.2	MU1H
	0.30		0.13	825.0	19.8	9.9	0.081	1242.3	44.4	MU1H
	0.40		0.13	1333.9	19.1	9.5	0.065	1535.4	54.3	MU1H
p90	0.05	0.185	0.26	154.7	185.9	2.2	0.454	220.5	37.0	MU1V
	0.10		0.26	131.7	22.2	13.5	0.309	324.1	13.8	MU1H
	0.20		0.26	310.6	21.0	11.1	0.199	502.7	22.5	MU1H
	0.30		0.26	33.75	8.9	13.5	0.256	390.2	3.7	MU8
	0.40		0.26	33.75	8.8	13.5	0.194	514.5	2.8	MU8



3.2. Farfield modelling

The time-varying gridded contaminant concentration fields over the two annual El Niña and La Niña periods can be used to derive statistical maps informing on contaminant concentration levels, and dilution, throughout the study site.

General dispersion characteristics of contaminant discharged at the outfall are illustrated in Figure 3-5 to Figure 3-8. The figures show specific dilution contours (1/1000, 1/2000, 1/5000) for different scenarios included *El Niño* versus *La Niña* period, *existing* versus *future* discharge flow rate, and *average* versus *rapid* contaminant inactivation. Results for scenarios with no contaminant inactivation (i.e., worst-case) are provided in Figure 3-9 and Figure 3-10.

The dilution maps were obtained by normalizing the 90th percentile contaminant concentration (i.e., concentration exceeded only 10% of the time), found in top 4 m of the water column, by the initial outfall concentration Co i.e., Dilution = Co / C(t,x,y,z).

The dispersion footprints are clearly elongated in southwest-northeast axis which is driven by the local hydrodynamics (Figure 3-3 and Figure 3-4). Some smaller patches of 1/2000 dilution contour (grey) can be seen closer to the coast, especially in the vicinity of the outfall, and towards the north. We also note some possible small 1/5000 dilution patches on the estuary side of the spit. These are due to some particles entering the estuary by its entrance at the southern end of the spit and moving northwards with tidal flows (e.g., see Figure 2-12). These particles eventually become relatively static once in the inner estuary due to low flows and intermittent wetting drying thus generating some *relatively* higher concentration areas.

Dispersion patterns are very similar for La Niña and El Niño periods (Figure 3-5 and Figure 3-6 left panels), as the hydrodynamic regimes. We can note the 1/5000 dilution contour footprint during La Niña year is slightly wider to the northeast of the outfall, and it also extends further south relative to the El Niño scenario.

The increase of discharge flows (factor 1.3) due to the projected population increase results in similar footprint shapes but with larger spatial excursions, as expected (Figure 3-5 and Figure 3-6 right panels).

The inclusion of contaminant deactivation has a significant impact on the spatial extents of the plume footprints (Figure 3-7 and Figure 3-8). We note maximum excursions of the 1/5000 dilution of order 2-3 km from outfall assuming a virus T90= 2 days (time after which 90% of viral load has decayed), while it is ~ 7-8 km for a longer T90 = 32 days. As



expected, the extents of the plume footprints are the largest when no contaminant inactivation is considered (see Figure 3-9 and Figure 3-10).

Timeseries of contaminant concentration were extracted at several sites (see Figure 2-9) to provide a basis for further assessment such as QMRA (Quantitative microbial risk assessment). Plots of concentration timeseries for La Niña, with no inactivation, are presented in Figure 3-11 and Figure 3-12. El Niño results are shown in Figure 3-13 and Figure 3-14. Note the presented concentrations assume an initial undiluted concentration at the outfall Co = 1g.m⁻³. Dilution factor can be obtained as Co/C(t).

As expected, concentrations are the largest at the outfall and we note a progressive reduction of concentrations levels moving away from its location both northeast-ward (i.e., Snapper's Point, Glenduan), and southwest-ward (i.e., 900m SW of outfall, Outside Boulder Bank).

Concentrations at sites located further south from the outfall, in the vicinity of the estuary entrance, and north (Tasman Bay 2) are further reduced though some peaks are still noticeable at times. It is interesting to note that peaks are not always synchronised with peaks near the outfall, due to local recirculation processes. Inspection of concentration fields suggests these peaks at sites relatively far south from the outfall can be due to contaminant accumulation in some lower current areas or with eddies. This is visible in Figure 3-9 and Figure 3-10 which shows some local patches of the 1/5000th dilution contours south of the domain. It is reminded that the results shown do not included dieoff, which is a worst-case assumption. In reality, it is likely progressive inactivation may reduce the contaminant load in these secondary accumulation zones.



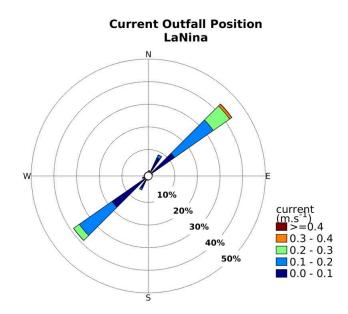


Figure 3-3 Rose of depth-averaged current at the outfall location during La Nina annual period.

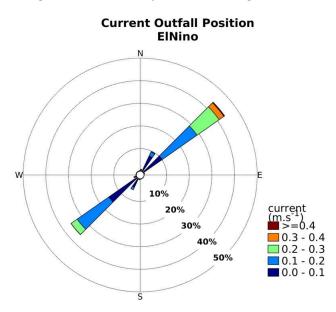


Figure 3-4 Rose of depth-averaged current at the outfall location during El Nino annual period.

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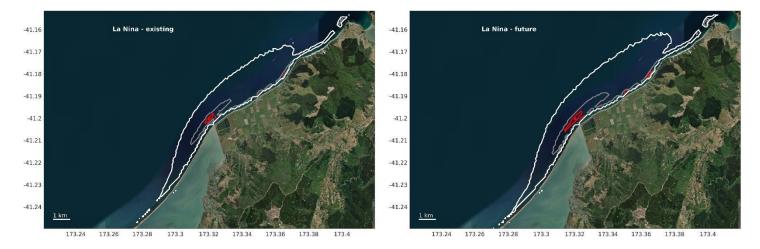


Figure 3-5 Dilution contours 1/1000, 1/2000, 1/5000 (red, grey, white) in surface waters for the La Niña annual period for existing and future discharge flows (T90=32 days). The outfall location is show as a red dot.

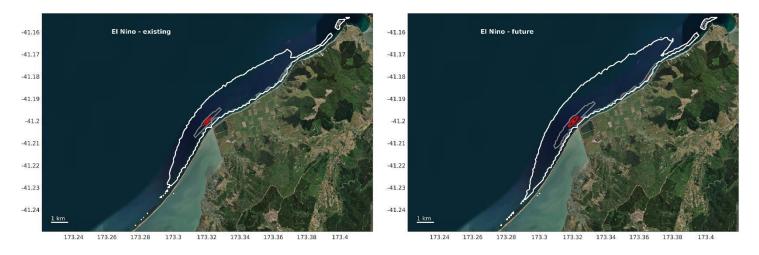


Figure 3-6 Dilution contours 1/1000, 1/2000, 1/5000 (red, grey, white) in surface waters for the **El Niño annual period** for **existing** and **future** discharge flows (T90=32 days). The outfall location is show as a red dot.



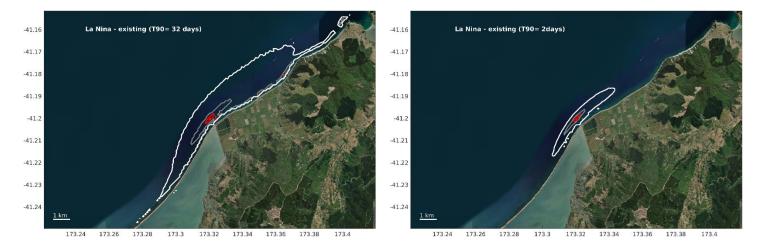


Figure 3-7 Dilution contours 1/1000, 1/2000, 1/5000 (red, grey, white) in surface waters for the La Niña annual period for existing discharge flows for different inactivation coefficients. The outfall location is show as a red dot.

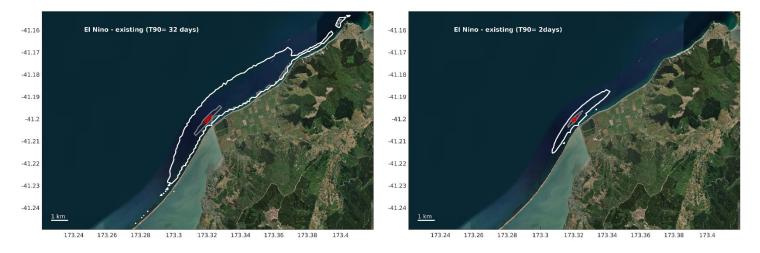
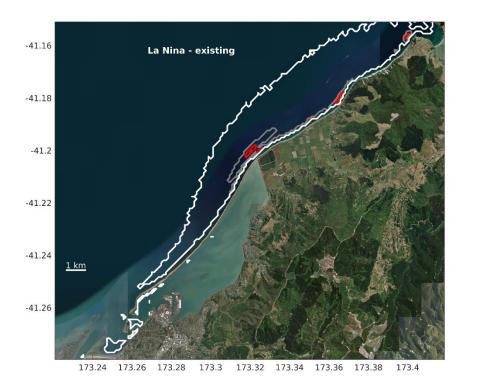


Figure 3-8 Dilution contours 1/1000, 1/2000, 1/5000 (red, grey, white) in surface waters for the **El Niño annual period** for **existing** discharge flows for **different inactivation coefficients**. The outfall location is show as a red dot.





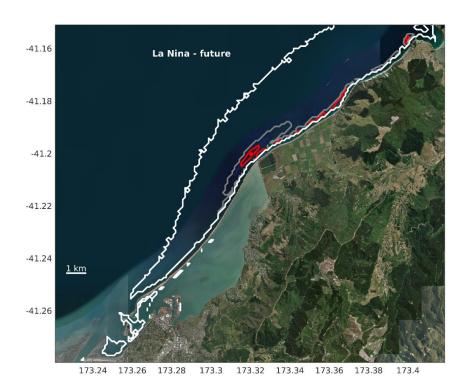
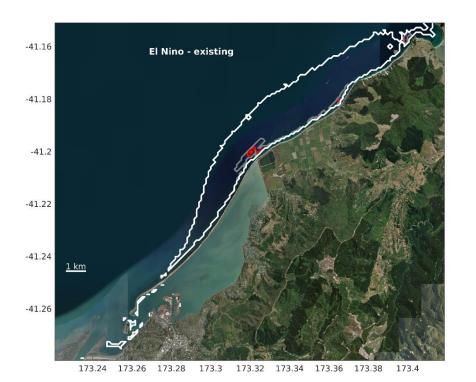


Figure 3-9 Dilution contours 1/1000, 1/2000, 1/5000 (red, grey, white) in surface waters for the La Niña annual period for existing and future discharge flows (no inactivation). The outfall location is show as a red dot.





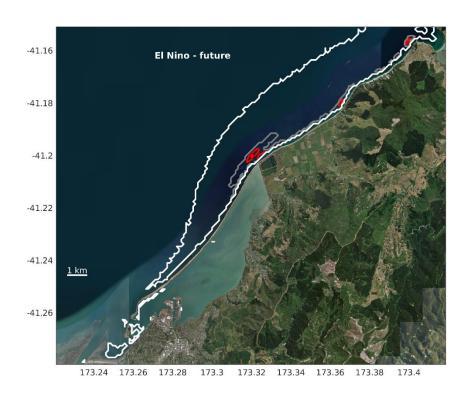
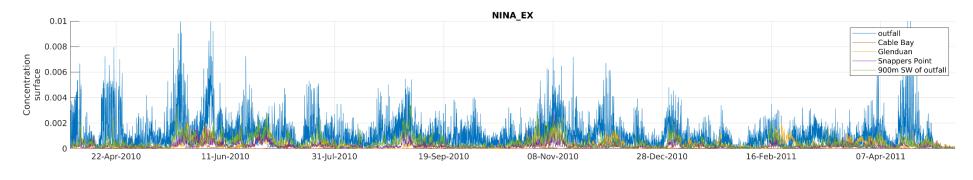
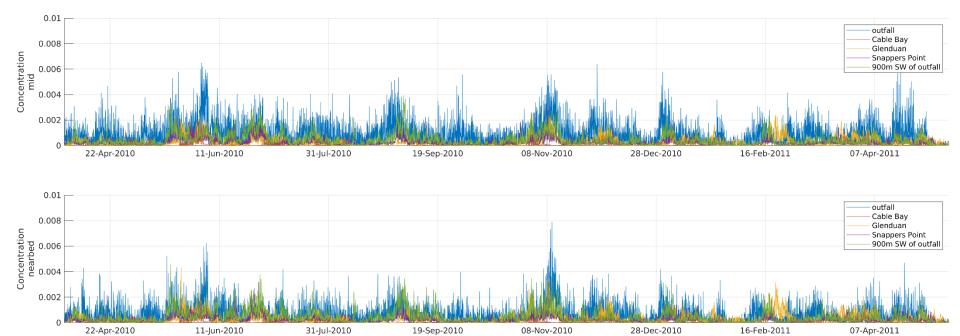


Figure 3-10 Dilution contours 1/1000, 1/2000, 1/5000 (red, grey, white) in surface waters for the El Niño annual period for existing and future discharge flows (no inactivation). The outfall location is show as a red dot.



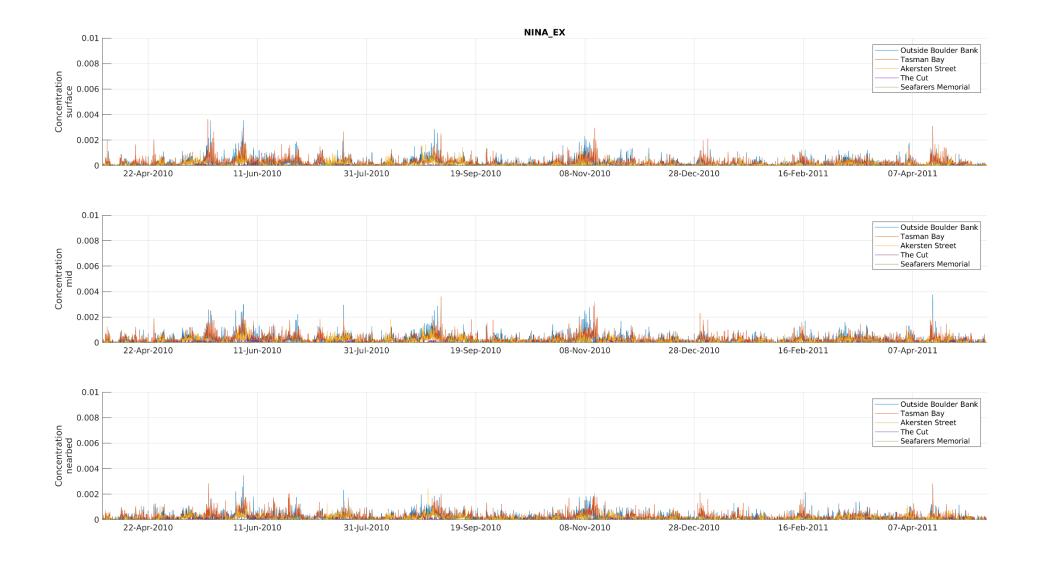








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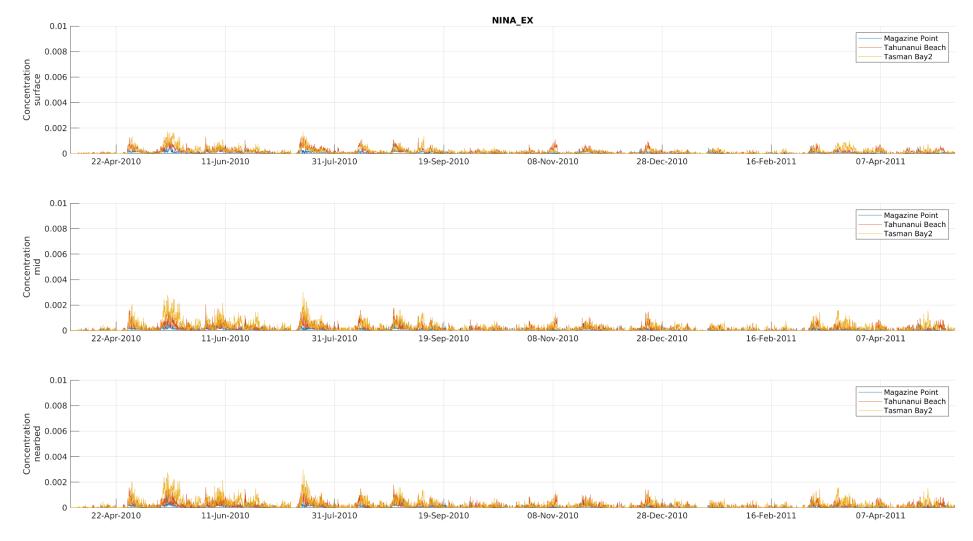
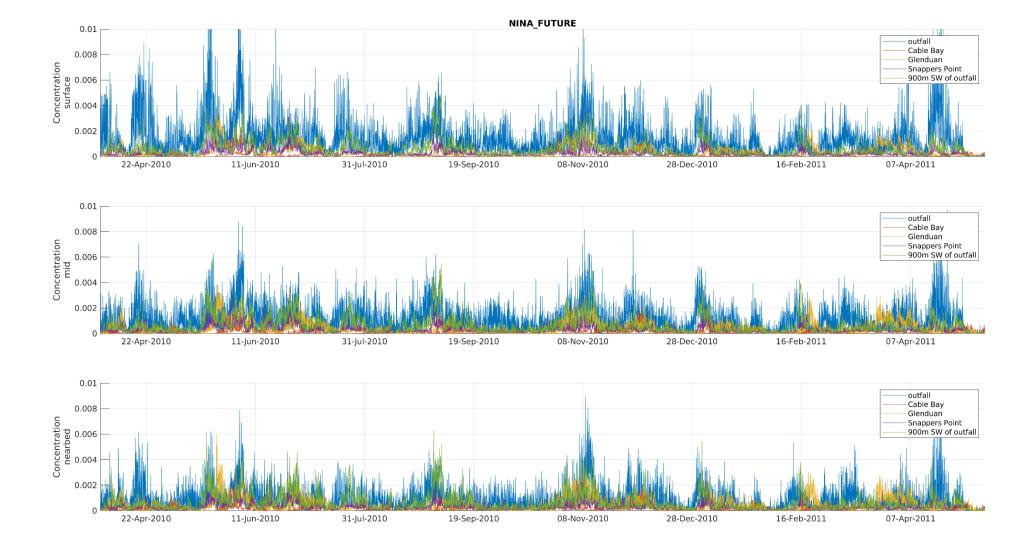


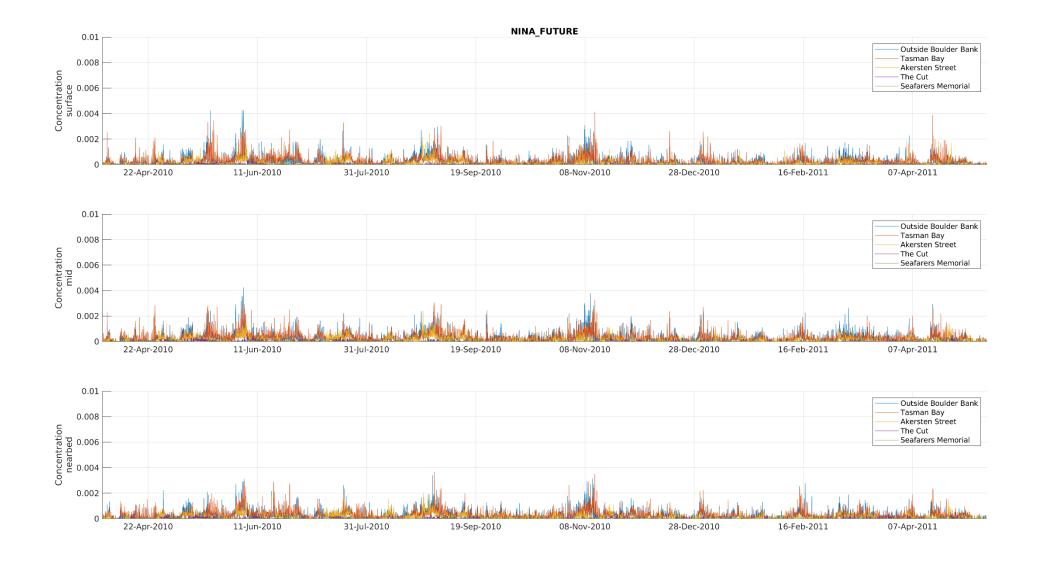
Figure 3-11 Timeseries of contaminant concentration at sites (Figure 2-9), in surface, mid-water and nearbed levels, for **La Niña** annual period and **existing** discharge flows (**no inactivation**). The presented concentrations assume an initial undiluted concentration at the outfall of 1g.m⁻³.







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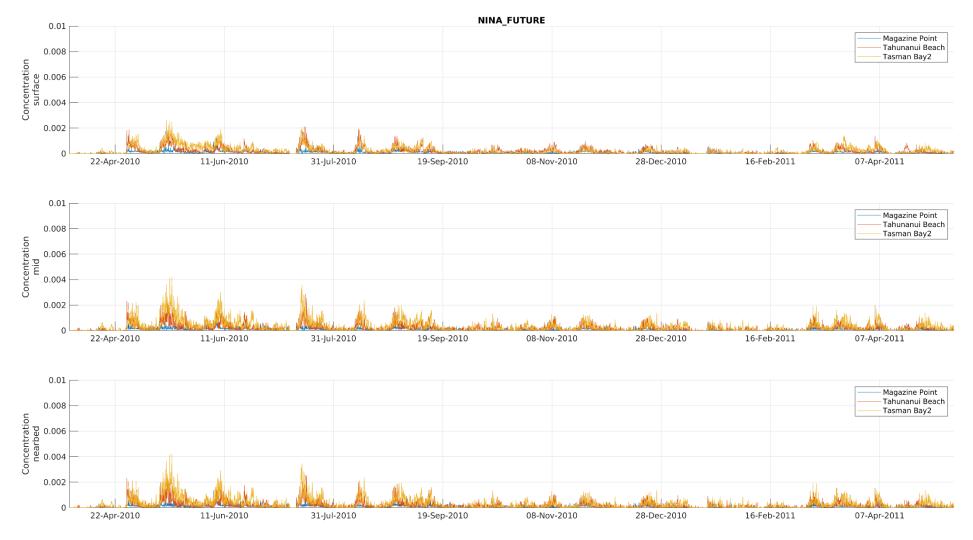
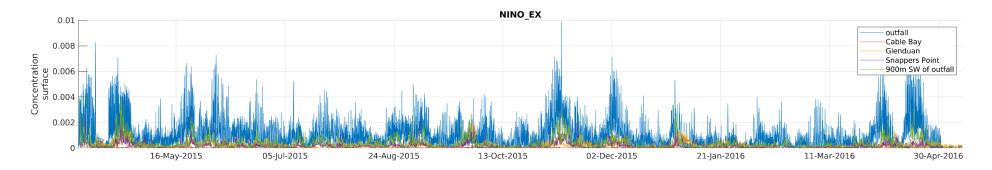
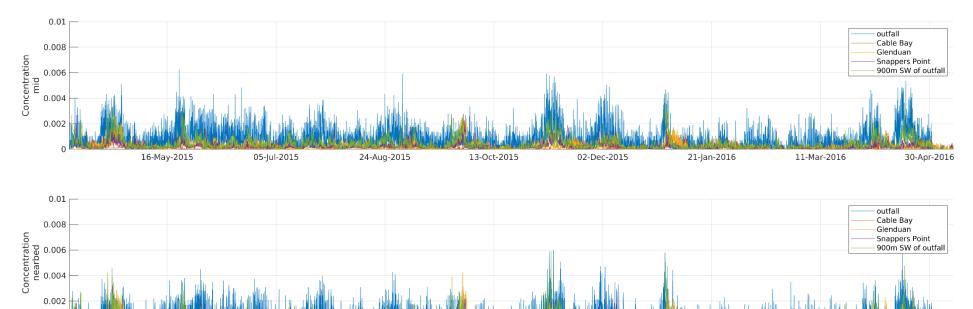


Figure 3-12 Timeseries of contaminant concentration at sites (Figure 2-9), in surface, mid-water and nearbed levels, for **La Niña** *annual period and* **future** *discharge flows (no inactivation). The presented concentrations assume an initial undiluted concentration at the outfall of 1g.m⁻³.*



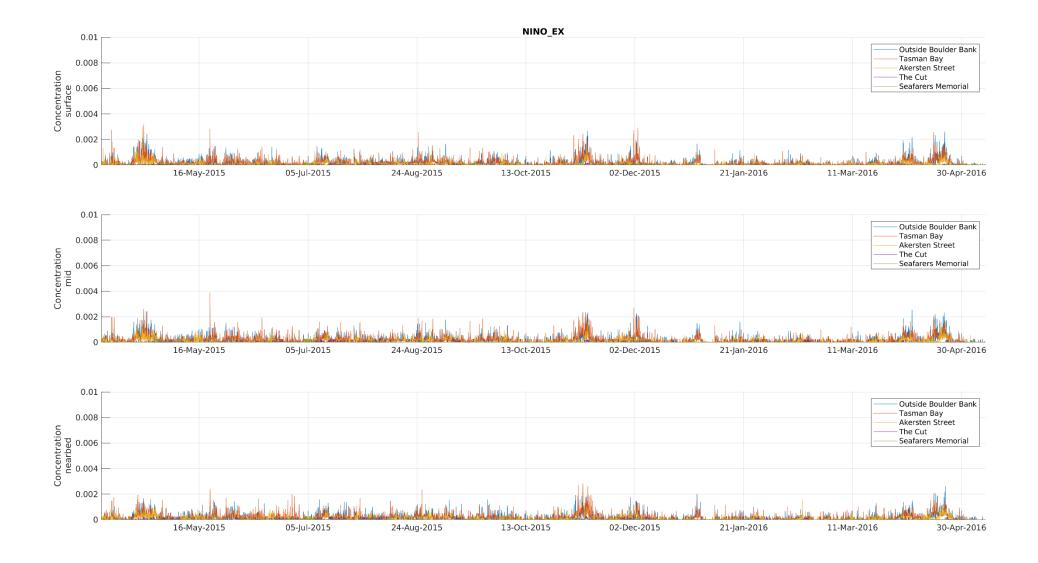




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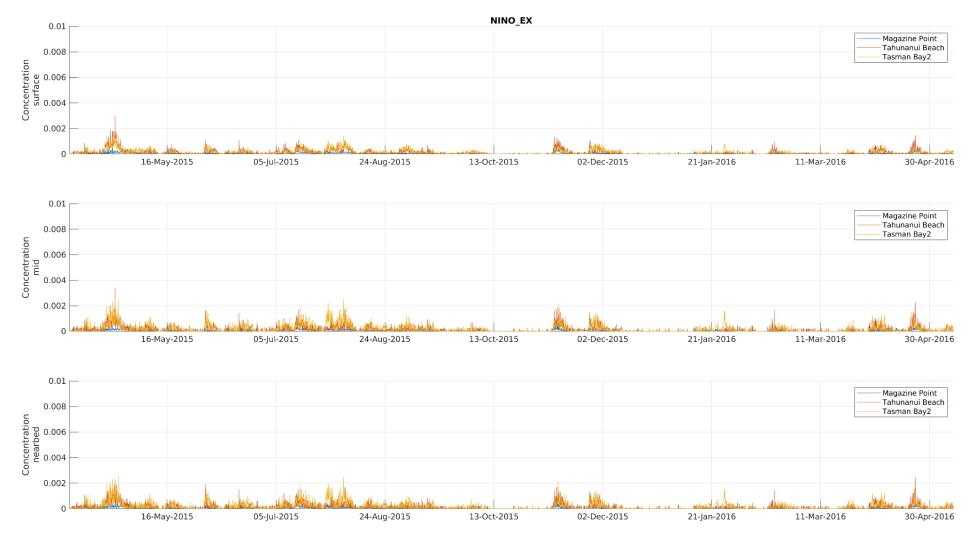
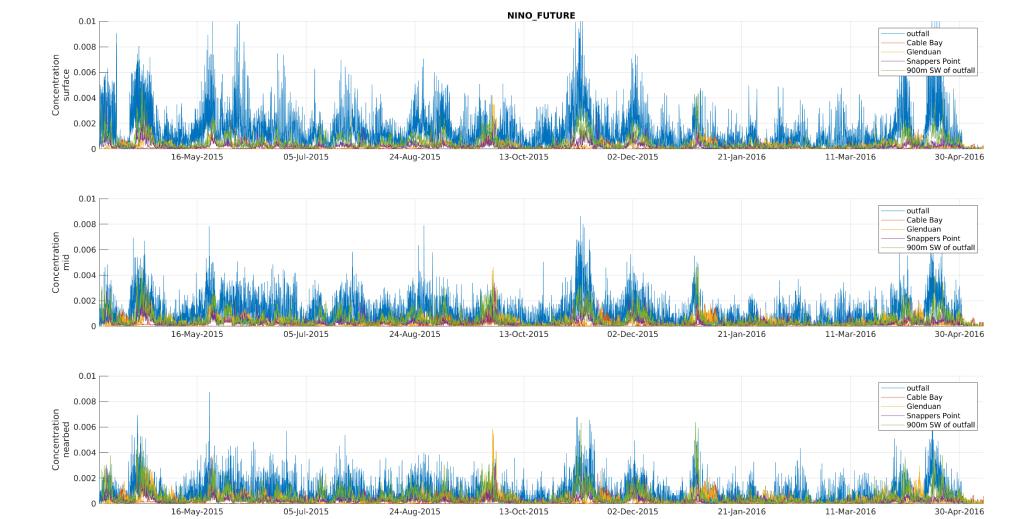


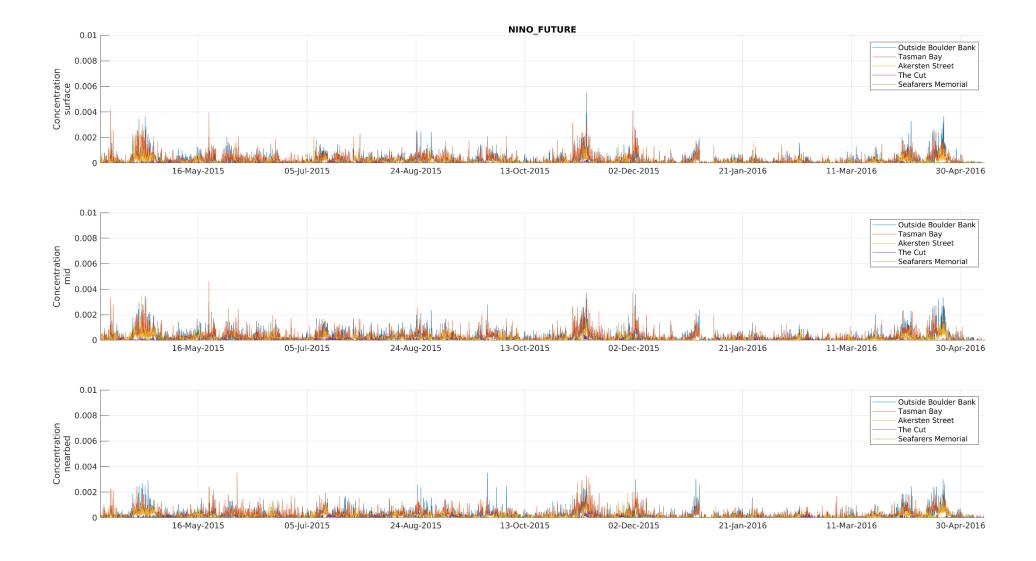
Figure 3-13 Timeseries of contaminant concentration at sites (Figure 2-9), in surface, mid-water and nearbed levels, for **El Niño** annual period and **existing** discharge flows (**no inactivation**). The presented concentrations assume an initial undiluted concentration at the outfall of 1g.m⁻³.













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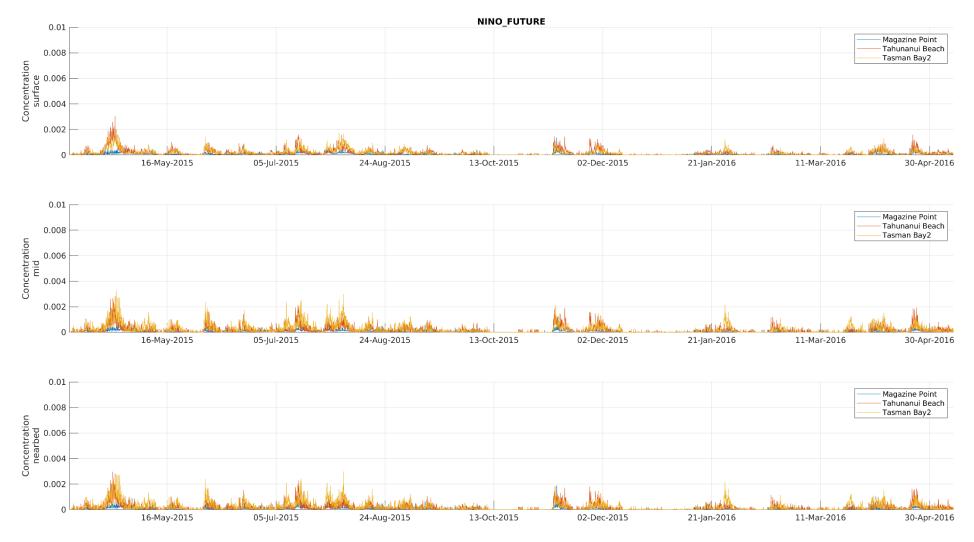


Figure 3-14 Timeseries of contaminant concentration at sites (Figure 2-9), in surface, mid-water and nearbed levels, for **El Niño** annual period and **future** discharge flows (**no inactivation**). The presented concentrations assume an initial undiluted concentration at the outfall of 1g.m⁻³.



3.3. Additional analysis on the worst-case dilution characteristics in the current mixing zone

Additional analysis of model results was undertaken to supplement the original study, notably to quantify the existing dilution characteristics at the edges of the current mixing zone. The results are summarized in a technical note that addresses 3 items :

1) Assess few sites along the main plume axis to get a representative worst-case site (i.e., least dilution at the water surface):

2) 'Worst case' for the edges of current mixing zone and confirmation at what height in the water column that this occurs. The dilutions modelled at the edge of the mixing zone can then be used to determine an end of pipe discharge standard.

3) Assess near-field dilution with a new nominal modern diffuser design.

The technical note is included in Appendix B.



4.Summary

Nelson City Council (NCC) is interested in understanding the dilution and discharge characteristics of contaminant discharged from the Nelson North Wastewater Treatment Plant (NWWTP), and how the dilution characteristics may affect nearby beaches.

In order to quantify the hydrodynamics of the Tasman Bay, a calibrated and validated finite element model of the environs has been used. For this project, the model grid has been extended to cover a larger area around the outlet and resolution has been optimised to ensure the salient hydrodynamic processes are accurately captured. The hydrodynamic model was further validated using measured current velocity and water level data collected near to the discharge location. At the diffuser location the current direction pattern is bi-directional (southwest-northeast) and are aligned with the shoreline with typical velocities of the order 0.1-0.3 m/s.

A range of simulations were undertaken using CORMIX in order to estimate the near field plume characteristics for current year (2021) and predicted (2059) discharges. Results show that the dilution factor at the edge of the near field varies from 220.5 to 2871.4. Dilution tends to be higher in faster ambient current velocities although variations to this trend can occur depending on the ambient currents compared to the discharge velocity (i.e., the velocity the discharge exit the pipe), which depends on the flow rate simulated (i.e., p10, p50 and p90). In all scenarios, plume is wider in near stagnant water and extends downstream (flow direction) while reducing in extent in the across the flow direction under faster current flow. Plume does not contact the shoreline within the near-field zone for the conditions simulated in this study. The time when the plume transitions from near field to far field ranges from 3 minutes (p90, 0.4 m/s) to 77.8 minutes (1.3 hour, p10, 0.4 m/s).

The nearfield plume was included in the far-field model by releasing particles within time varying triangular footprints, describing the nearfield range NFR, and running 1 year-long simulations of wastewater discharges from the outfall location, within two contrasting historical contexts El Niño/La Niña episodes. The far-field dispersion footprints are elongated in the southwest-northeast axis which is driven by the local hydrodynamics. Dispersion patterns are very similar for La Niña and El Niño periods. The 1/5000 dilution contour footprint during La Niña year is slightly wider to the northeast of the outfall, and it also extends further south relative to the El Niño scenario. The increase of discharge flows (factor 1.3) due to the projected population increase results in similar footprint shapes but with larger spatial excursions.



The inclusion of contaminant deactivation has a significant impact on the spatial extents of the plume footprints. Maximum excursions of the 1/5000 dilution are of 2-3 km from outfall assuming a virus T90= 2 days, while it is ~ 7-8 km for a longer T90 = 32 days.

Timeseries of contaminant concentration were extracted at several sites throughout the study area to provide a basis for further assessment such as QMRA (Quantitative Microbial Risk Assessment).



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Appendix A: CORMIX hydrodynamic classification

Flow Class MUIH

The discharge configuration is hydrodynamically "stable", that is the discharge strength (measured by its momentum flux) is weak in relation to the layer depth and in relation to the stabilizing effect of the discharge buoyancy (measured by its buoyancy flux). The buoyancy effect is very strong in the present case.

The following flow zones exist:

1) Weakly deflected plane jet in crossflow: The flow issuing from the equivalent slot diffuser is initially dominated by the wastewater momentum (jet-like) and is weakly deflected by the ambient current.

2) Strongly deflected plane plume: After some distance the discharge buoyancy becomes the dominating factor (plume-like). The plume is deflected by the effect of the strong ambient current.

3) Surface layer approach: The bent-over submerged jet/plume approaches the terminal level. Within a short distance the concentration distribution becomes relatively uniform across the plume width and thickness. or

3) Density current along diffuser line: The plume develops along the diffuser line due to continuous inflow of mixed buoyant water. The plume spreads laterally along the layer boundary (surface or pycnocline) which it is being advected by the ambient current. The mixing rate is relatively small. This zone extends from beginning to end of the diffuser line.

The zones listed above constitute the NEAR-FIELD REGION in which strong initial mixing takes place. ***

4) Buoyant spreading at layer boundary: The plume spreads laterally along the layer boundary (surface or pycnocline) while it is being advected by the ambient current. The plume thickness may decrease during this phase. The mixing rate is relatively small. The plume may interact with a nearby bank or shoreline.

5) Passive ambient mixing: After some distance the background turbulence in the ambient shear flow becomes the dominating mixing mechanism. The passive plume is growing in depth and in width. The plume may interact with the channel bottom and/or banks.



Flow Class MUIV

The discharge configuration is hydrodynamically "stable", that is the discharge strength (measured by its momentum flux) is weak in relation to the layer depth and in relation to the stabilizing effect of the discharge buoyancy (measured by its buoyancy flux). The buoyancy effect is very strong in the present case.

The following flow zones exist:

1) Weakly deflected plane jet in crossflow: The flow issuing from the equivalent slot diffuser is initially dominated by the wastewater momentum (jet-like) and is weakly deflected by the ambient current.

2) Weakly deflected plane plume: After some distance the discharge buoyancy becomes the dominating factor (plume-like). The plume deflection by the ambient current is still weak.

3) Layer boundary impingement / upstream spreading: The weakly bent jet/plume impinges on the layer boundary (water surface or pycnocline) at a near-vertical angle. After impingement the flow spreads in all directions (more or less radially) along the layer boundary. In particular, the flow spreads some distance upstream against the ambient flow, and laterally across the ambient flow. This spreading is dominated by the strong buoyancy of the discharge.

*** The zones listed above constitute the NEAR-FIELD REGION in which strong initial mixing takes place. ***

4) Buoyant spreading at layer boundary: The plume spreads laterally along the layer boundary (surface or pycnocline) while it is being advected by the ambient current. The plume thickness may decrease during this phase. The mixing rate is relatively small. The plume may interact with a nearby bank or shoreline.

5) Passive ambient mixing: After some distance the background turbulence in the ambient shear flow becomes the dominating mixing mechanism. The passive plume is growing in depth and in width. The plume may interact with the channel bottom and/or banks.

SPECIAL CASE: If the ambient is stagnant, then advection and diffusion by the ambient flow (zones 4 and 5) cannot be considered. the mixing is limited to the near-field region (zones 1 to 3) and the predictions will be terminated at this stage.

Such stagnant water predictions may be a useful initial mixing indicator for a given site and discharge design. For practical final predictions, however, the advection and diffusion of the ambient flow – no matter how small in magnitude - should be considered.



Flow Class MU8

An alternating multiport diffuser with predominantly perpendicular alignment is discharging into an ambient flow. For this diffuser configuration the net horizontal momentum flux is zero so that no significant diffuser-induced currents are produced in the water body. However, the local effect of the discharge momentum flux is strong in relation to the layer depth and in relation to the stabilizing effect of the discharge buoyancy, so that the discharge configuration is hydrodynamically "unstable".

The following flow zones exist:

1) Alternating perpendicular diffuser with unstable near-field zone: The destabilizing effect of the discharge jets produces an unstable nearfield zone. For stagnant or weak cross-flow conditions, a vertical recirculation zone is being produced leading to mixing over the full layer depth: however, the flow tends to re-stratify outside this zone that extends a few layer depths around the diffuser line. For strong cross-flow, additional destratification and mixing are produced.

or, alternatively, a second possibility exists for strongly buoyant discharges :

1) Near-vertical surface impingement, upstream spreading, vertical mixing, and buoyant restratification: The destabilizing effect of the discharge jets produces an unstable nearfield zone. For stagnant or weak cross-flow conditions, a vertical recirculation zone is being produced leading to mixing over the full layer depth: however, the flow tends to restratify outside this zone that extends a few layer depths around the diffuser line. In particular, upstream spreading will occur due to the strong buoyancy of the discharge.

*** The zones listed above constitute the NEAR-FIELD REGION in which strong initial mixing takes place. ***

2) Buoyant spreading at layer boundary: The plume spreads laterally along the layer boundary (surface or pycnocline) while it is being advected by the ambient current. The plume thickness may decrease during this phase. The mixing rate is relatively small. The plume may interact with a nearby bank or shoreline.

3) Passive ambient mixing: After some distance the background turbulence in the ambient shear flow becomes the dominating mixing mechanism. The passive plume is growing in depth and in width. The plume may interact with the channel bottom and/or banks.

SPECIAL CASE: If the ambient is stagnant, then advection and diffusion by the ambient flow (zones 2 and 3) cannot be considered. The mixing is limited to the near-field region (zone 1) and the predictions will be terminated at this stage.



Appendix B: Technical note on dilution near the outfall





Nelson North Wastewater Treatment Plant (NWWTP) dispersion modelling

Technical note on dilution near the outfall

Report prepared for Nelson City Council

March 2023



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1.Introduction

This technical note covers an additional scope following the Nelson North Wastewater Treatment Plant dispersion modelling study (MetOcean Solutions, 2022).

The model results from the previous modelling (MetOcean Solutions, 2022) study were re-analysed with a focus on the nearfield plume footprint to address 3 items:

- 1) Assess few sites along the main plume axis to get a representative worst-case site (i.e. least dilution at the water surface):
- 2) 'Worst case' for the edges of current mixing zone and confirmation at what height in the water column that this occurs. The dilutions modelled at the edge of the mixing zone can then be used to determine an end of pipe discharge standard.
- 3) Assess near field dilution with a new nominal modern diffuser design

Note the results are provided for the existing and future El Niño and La Niña scenarios with no contaminant die-off. The same processing approach as used (MetOcean Solutions, 2022) is following to generate the dilutions timeseries.

Consistent with MetOcean Solutions (2022), conservative estimates of contaminant concentrations at sites of interest was obtained, by taking the maximum of predicted concentrations with the kernel or 2D histogram techniques at each timestep.



2.ltem 1

The objective of the item is to assess surface dilution at a few sites along the main plume axis to get a representative worst-case site (i.e. least dilution at the water surface).

Surface dilutions were extracted at several sites along the primary plume axis, including the outfall location. Extraction sites are shown in Figure 2-1, and locations are provided in Table 2-1. They include the outfall location and sites located on either side along the axis of the plume, first at 50m from the outfall, then every 100m. Some additional sites were added within areas of relatively elevated concentrations following concentration patterns (i.e. smaller dilutions).

Percentile statistics of the dilutions extracted at all sites are shown in Figure 2-2 to Figure 2-13. For the El Nino scenario, with existing discharge, at the surface level, the lowest dilutions are observed at the outfall site and closest sites to the northeast (N50) and southwest (S50). Dilution levels experienced 1% of the time (P1) are 290, 198, 206 at sites N50, outfall, and S50 respectively. Corresponding median (P50) dilutions (i.e. exceeded 50% of the time) levels are 2109, 1667, 2063. Lower dilutions in the close vicinity of the outfall are expected given the importance of oscillating tides (southwest-northeast axis) in the overall hydrodynamic regime. This results in longer residence time around the release location, and therefore larger concentration/ lower dilutions in that area.



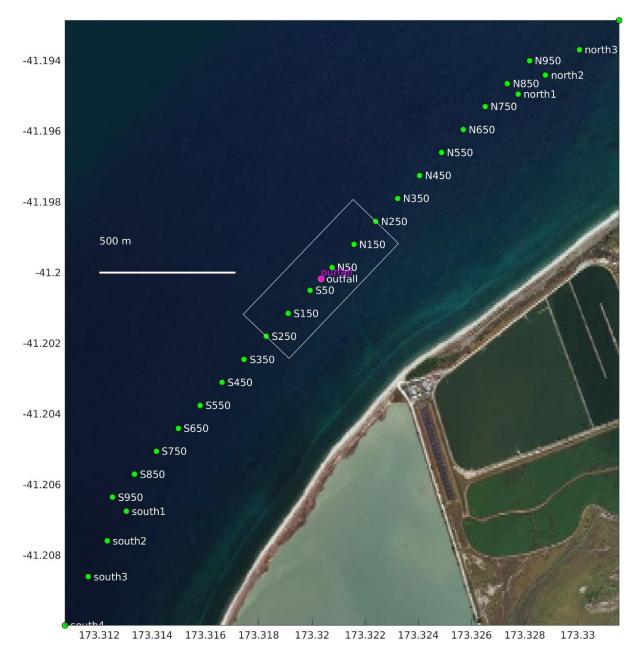


Figure 2-1 Extraction sites along the primary plume axis. They include the outfall location and sites located on either side along the axis of the plume, first at 50m, then every100m.



Table 2-1	Extraction sites along the primary plume axis (WGS84).
-----------	--

Site name	Lon	Lat
'S950'	173.312498	-41.206357
'S850'	173.313323	-41.205707
'S750'	173.314149	-41.205057
'S650'	173.314974	-41.204407
'S550'	173.315800	-41.203756
'S450'	173.316625	-41.203106
'S350'	173.317450	-41.202456
'S250'	173.318276	-41.201806
'S150'	173.319101	-41.201155
'S50'	173.319926	-41.200505
'outfall'	173.320339	-41.200180
'N50'	173.320752	-41.199855
'N150'	173.321577	-41.199205
'N250'	173.322402	-41.198554
'N350'	173.323228	-41.197904
'N450'	173.324053	-41.197254
'N550'	173.324878	-41.196603
'N650'	173.325703	-41.195953
'N750'	173.326528	-41.195303
'N850'	173.327354	-41.194652
'N950'	173.328179	-41.194002
'south1'	173.313013	-41.206758
'south2'	173.312300	-41.207593
'south3'	173.311587	-41.208607
'south4'	173.310715	-41.209979
'north1'	173.327757	-41.194949
'north2'	173.328787	-41.194412
'north3'	173.330056	-41.193697
'north4'	173.331562	-41.192862



		Di	lution at extra	ction sites - NI	NO_EX - surfac	е		106
north4	- 785	1493	2170	9824	60007	114852	360405 -	10-
north3	- 731	1362	2051	8946	61367	107498	343258 -	-
north2	- 660	1266	1899	8852	59046	108038	331396 -	
north1	- 603	1150	1706	8126	54106	98220	317715 -	_
south4	- 517	1114	1743	14343	157909	336703	1946594-	
south3	- 544	1113	1719	13660	141048	286078	1270196-	-
south2	- 541	1110	1725	15055	133138	253074	1011542 -	
south1	- 442	884	1447	14946	123467	223896	806934 -	10 ⁵
N950	- 688	1304	1869	8714	56819	106985	372221 -	
N850	- 627	1231	1780	8281	55267	100240	354992 -	-
N750	- 593	1167	1715	6985	50162	92535	309436 -	-
N650	- 541	1108	1569	7664	48713	90325	287738 -	-
N550	- 568	1067	1541	6819	40311	79609	262879 -	-
N450	- 542	965	1363	6065	37955	76755	239605 -	
N350	- 504	856	1227	5037	32489	64437	218559 -	- 104
N250	- 413	683	966	4273	28064	61497	198510 -	
N150	- 271	492	690	2962	21481	50563	170053 -	-
N50	- 290	458	636	2109	10649	17961	162957 —	-
outfall	- 198	326	455	1667	13351	38322	174024 -	-
S50	- 206	354	487	2063	22825	62477	189895 -	
S150	- 246	452	636	3607	38401	77988	199164 -	
S250	- 434	743	1038	5474	44272	83055	206445 -	-10^{3}
S350	- 481	845	1196	6822	57193	95530	231120 -	-
S450	- 387	776	1158	8009	69905	113235	263794 -	-
S550	- 490	935	1389	8953	77086	128906	310404 -	
S650	- 524	1019	1518	10620	88523	146798	394378 -	-
S750	- 478	962	1525	12665	103121	171638	497339 -	
S850	- 521	1083	1658	14155	116329	198435	643451 -	
S950	- 611	1239	1907	14262	126906	230338	789603 -	
	P1	P5	P10	P50	P90	P95	P99	10 ²

Figure 2-2 Dilution percentile at extraction site shown in Figure 2-1 for the El Niño scenario with existing discharge, at the surface level. Note the colour scale is logarithmic.



			Dilution at extr	action sites - I	NINO_EX - mid			10
north4 –	696	1304	1893	9383	64357	113299	237751 -	10
north3 -	622	1130	1705	9938	59344	105197	237163 -	-
north2 -	551	1030	1504	8905	56069	105297	236808 -	
north1 –	483	929	1386	10383	53107	98551	234799 -	
outh4 -	561	1064	1661	14784	132831	240155	900471 -	
outh3 -	576	1021	1492	13754	120150	221729	626021 -	
outh2 -	596	1026	1486	12342	109333	200630	488679 -	
outh1 -	454	757	1136	13588	102762	184624	407474 -	- 10
N950 -	649	1227	1777	9246	55774	106081	247465 -	
N850 -	600	1106	1652	8560	51835	99951	235987 -	-
N750 -	592	1090	1529	8383	48415	93232	235423 -	-
N650 -	521	996	1357	5984	49357	95434	234585 -	-
N550 -	516	959	1409	7336	43355	85147	232867 -	-
N450 -	473	906	1348	4916	43116	84084	232430 -	
N350 -	476	852	1210	5004	38372	74487	230197 -	- 10
N250 -	411	717	1017	4726	37374	69647	227106 -	
N150 -	338	556	778	3348	36228	70702	222205 -	-
N50 -	369	568	753	2587	23721	55951	220967 -	-
outfall –	274	417	556	2003	32157	73845	226803 -	-
S50 <mark>-</mark>	282	453	583	2873	36139	80336	232425 -	
S150 -	323	527	737	3920	43904	90484	241362 -	
S250 -	509	820	1100	5474	45123	96210	249456 -	- 10
S350 -	517	861	1162	5823	51576	102136	254885 -	- 10
S450 -	393	742	1109	8973	59528	114111	259512 -	-
S550 -	506	913	1340	7650	64564	121472	261309 -	-
S650 -	601	1007	1432	7270	74439	134452	276019 -	-
S750 -	482	898	1277	11329	85153	148398	304347 -	
S850 -	571	1025	1393	12126	92665	163033	334648 -	
S950 -	726	1274	1758	8956	101719	182389	390671 -	
_	P1	P5	P10	P50	P90	P95	P99	10

Figure 2-3 Dilution percentile at extraction site shown in Figure 2-1 for the El Niño scenario with existing discharge, at the mid-depth level. Note the colour scale is logarithmic.



		Dil	ution at extra	tion sites - NI	NO_EX - nearbe	ed		
north4	- 943	1664	2371	12049	72978	134127	274463 -	-
north3	- 817	1444	2118	13488	69738	126005	270821 -	_
north2	- 752	1463	2112	12643	67304	124957	267628 -	-
north1	- 688	1238	2012	11658	63849	122811	270663 -	
south4	- 693	1227	1802	14543	126723	249248	796384 -	
south3	- 622	1200	1614	13523	116608	222335	608814 -	-
south2	- 749	1351	2000	12700	105963	200293	500127 -	
south1	- 568	1064	1789	13339	96893	183523	438250 -	-
N950	- 874	1546	2197	13067	67157	128131	274081 -	-
N850	- 826	1427	2070	12157	62605	123302	274215 -	-
N750	- 736	1354	1951	10637	57326	113449	270312 -	
N650	- 585	1276	1923	9707	58151	116258	272948 -	-
N550	- 579	1063	1532	9392	50672	108539	264602 -	-
N450	- 590	1047	1435	6889	46422	100511	264858 -	
N350	- 596	1037	1493	5961	43337	94470	263265 –	-
N250	- 516	884	1273	6840	43692	95377	262692 -	-
N150	- 366	625	860	4290	42447	95487	259353 -	_
N50	- 448	694	936	3560	28807	69549	255702 -	-
outfall	- 339	513	691	2861	36651	87413	260856 -	-
S50	- 354	543	743	3256	38786	88463	260466 -	_
S150	- 357	614	851	4769	44742	102225	265178 -	
S250	- 595	966	1325	5573	43999	103525	274634 -	_
S350	- 579	954	1337	6253	48523	113591	285378 -	-
S450	- 381	740	1108	9074	57186	127223	294097 –	-
S550	- 539	946	1307	7650	58478	132690	301346 -	-
S650	- 682	1113	1530	6835	64871	143739	318254 -	-
S750	- 650	1152	1632	11123	76308	153306	345647 -	
S850	- 686	1180	1717	12015	85148	162819	391008 -	
S950	- 848	1428	2000	8225	94174	180785	438676 -	
	P1	P5	P10	P50	P90	P95	P99	

Figure 2-4 Dilution percentile at extraction site shown in Figure 2-1 for the El Niño scenario with existing discharge, at the nearbed level. Note the colour scale is logarithmic.



	C17	1110	1045	7405	42227	00007	400000
orth4	617	1116	1645	7495	42337	82687	422908
orth3	567	1051	1580	7744	43918	77855	396662
orth2 –	501	955	1464	6017	42268	76436	355894 -
orth1 -	468	888	1322	5543	39099	72008	334180
outh4 –	421	866	1338	9816	141529	309687	3957187
outh3 -	457	877	1326	11544	130429	272623	1633428
outh2 -	440	843	1286	11190	120018	244002	1060889
outh1 –	332	694	1112	10512	108263	223316	818339
N950 -	532	991	1478	7342	43775	75050	351863
N850 -	513	936	1380	7038	40356	71455	340490
N750 -	467	897	1324	6176	36210	68453	287397
N650 -	438	831	1285	5826	34658	65668	271707 -
N550 -	444	832	1231	5072	28647	57210	227313 -
N450 -	456	783	1103	4426	26595	53610	202843
N350 -	430	700	948	3877	22058	43068	184021
N250 -	324	529	735	3087	17800	38735	171097
N150 -	210	360	506	2168	13508	31736	147781
N50 -	218	349	473	1507	8816	17633	106149
utfall –	159	249	334	1143	8002	20109	122093
S50 -	165	268	366	1386	12176	37782	138416
S150 -	191	350	488	2555	25996	53723	154355
S250 -	329	577	793	4010	31549	59521	164569
S350 -	391	666	921	5170	43705	76840	201238
S450 -	321	621	930	4865	57674	99949	262698
S550 -	381	722	1073	7448	64837	118811	315529 -
S650 -	418	790	1169	8067	75081	143507	398604
S750 -	377	752	1171	8833	88347	172544	566140
S850 -	414	828	1264	10172	100629	206442	730349
S950 -	481	929	1433	11816	111927	231641	931578
	P1	P5	P10	P50	P90	P95	P99

Figure 2-5 Dilution percentile at extraction sites shown in Figure 2-1 for the El Niño scenario with future discharge at the surface level. Note the colour scale is logarithmic.



		Dil	ution at extrac	tion sites - NII	NO_FUTURE - m	id	
orth4	- 575	1028	1527	7495	43250	81355	203062 -
orth3	- 481	970	1382	6049	40502	74649	207088 -
orth2	- 442	864	1241	7046	40119	72539	194532 -
orth1	- 384	765	1148	7163	37328	69869	195986 -
outh4	- 467	858	1291	9975	109429	199544	767328 -
outh3	- 481	848	1238	8933	100590	179336	611756 -
outh2	- 482	824	1203	7781	90188	163268	460526 -
outh1	- 370	724	1064	9055	82292	150285	368848 -
N950	- 511	990	1442	5678	39467	73739	196707 -
N850	- 476	879	1307	5366	36634	68377	194519 -
N750	- 480	865	1218	5987	35549	64591	188825 -
N650	- 408	791	1044	4221	33955	64548	184124 -
N550	- 420	766	1103	5020	29537	53780	176137 -
N450	- 422	765	1061	4253	29306	53595	172284 -
N350	- 418	720	987	4106	25878	49189	166990 -
N250	- 345	575	800	3096	26241	49043	164984 -
N150	- 261	433	596	2701	23861	48265	156166 -
N50	- 290	445	599	1986	14398	37869	156855 -
outfall	- 222	339	426	1539	19828	47402	161234 -
S50	- 232	356	457	1923	24046	51800	162141 -
S150	- 255	419	588	2648	29884	63440	170849 -
S250	- 416	669	897	3969	30941	66644	175290 -
S350	- 429	700	961	4406	36112	77434	180275 -
S450	- 325	579	812	6002	43139	87406	191666 -
S550	- 408	717	1008	5827	47343	94836	203713 -
S650	- 468	784	1114	6333	54681	105587	224006 -
S750	- 403	735	1093	7756	64786	118140	255847 -
S850	- 483	838	1180	8521	73873	134663	296224 -
S950	- 594	1014	1431	7958	81337	149384	357771 -
-	P1	P5	P10	P50	P90	P95	P99

Figure 2-6 Dilution percentile at extraction sites shown in Figure 2-1 for the El Niño scenario with future discharge at the mid-depth level. Note the colour scale is logarithmic.



10 ⁶		rbed	_FUTURE - nea	on sites - NINO	on at extraction	Diluti		
10-	239958 -	97925	52275	9293	2000	1371	- 761	north4
-	224037 -	88374	47803	9123	1872	1237	- 668	north3
	220135 -	87127	46767	8730	1677	1213	- 664	north2
-	213259 -	84944	43363	9405	1518	1094	- 583	north1
	882892 -	198595	103450	9889	1443	1008	- 554	south4
-	655347 -	176920	93796	8718	1456	1002	- 551	south3
	558664 -	161569	84615	8500	1486	1064	- 611	south2
- 10 ⁵	482122 -	148373	77041	9285	1136	945	- 532	south1
-	225575 -	88089	46578	9372	2000	1367	- 741	N950
-	215423 -	83276	43205	8421	1744	1180	- 683	N850
-	210490 -	76019	41167	8383	1567	1119	- 612	N750
-	208561 -	76520	39382	5968	1325	979	- 518	N650
-	200654 -	63793	34455	6268	1225	845	- 464	N550
s	202357 -	60565	33342	4916	1167	824	- 476	N450
104	202019 -	58207	28681	4872	1192	850	- 469	N350
- 2	201173 -	54750	27474	4280	994	717	- 417	N250
-	191598 -	50216	26867	3348	680	483	- 294	N150
	191520 -	36835	18037	2939	723	545	- 333	N50
-	194165 -	46155	24033	2655	541	408	- 260	outfall
	193351 -	48064	24832	2841	572	441	- 279	S50
	200239 -	59903	28423	2913	662	477	- 289	S150
-10^{3}	202097 -	58345	29107	4434	1047	776	- 492	S250
	206071 -	70646	33565	4562	1044	769	- 463	S350
-	226003 -	92466	42454	6074	784	569	- 320	S450
_	236297 -	95829	44335	5304	1066	737	- 433	S550
-	279386 -	111011	51396	6333	1230	878	- 535	S650
	337559 -	124388	58631	7769	1218	867	- 519	S750
	393305 -	135571	65442	8121	1329	986	- 574	S850
	469526 -	148254	73813	7958	1590	1136	- 691	S950
10 ²	P99	P95	P90	P50	P10	P5	P1	

Dilution at extraction sites - NINO_FUTURE - nearbed

Figure 2-7 Dilution percentile at extraction sites shown in Figure 2-1 for the El Niño scenario with future discharge at the nearbed level. Note the colour scale is logarithmic.

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		Dil	ution at extra	tion sites - NI	NA EX - surfac	е	
north4	- 616	1206	1725	6936	48363	86996	303078 -
north3	- 567	1108	1600	7013	48646	82780	268861 -
north2	- 486	989	1437	6017	44157	81676	236912 -
north1	- 487	928	1376	5543	41322	76965	224385 -
south4	- 473	931	1422	9735	76679	158550	3054963-
south3	- 470	937	1430	10294	76445	148848	2525123-
south2	- 479	944	1395	9420	72989	139401	1773714-
south1	- 392	819	1136	8812	70391	123113	1640897-
N950	- 554	1022	1488	6805	46650	84124	269753 -
N850	- 528	1007	1449	6452	43733	77921	236981 -
N750	- 499	989	1377	5894	38440	73392	198119 -
N650	- 489	916	1325	5641	35989	69654	168464 -
N550	- 462	937	1331	5072	29501	61755	142863 -
N450	- 445	837	1188	4443	27849	55525	121559 -
N350	- 436	754	1045	3997	23690	45030	109177 -
N250	- 369	621	854	3200	20263	40453	99703 -
N150	- 280	459	616	2271	15654	32585	90439 -
N50	- 260	435	590	1790	8980	17633	77971 –
outfall	- 188	308	426	1335	7261	16857	81531 -
S50	- 191	329	462	1628	10901	26489	83978 -
S150	- 236	431	602	2648	19959	37897	89485 —
S250	- 355	688	944	4010	25824	42794	99401 -
S350	- 386	754	1071	5014	33001	55459	133565 —
S450	- 343	672	1040	4701	42368	66702	300726 -
S550	- 397	802	1162	6659	47483	74295	481951 -
S650	- 454	897	1277	7589	53247	83774	583824 -
S750	- 445	843	1216	6907	62974	98066	935018 -
S850	- 531	960	1434	9017	69168	111238	1633110 -
S950	- 604	1137	1629	9818	71613	130001	1973549 -
	P1	P5	P10	P50	P90	P95	P99

Figure 2-8 Dilution percentile at extraction sites shown in Figure 2-1 for the La Niña scenario with existing discharge at the surface level. Note the colour scale is logarithmic.



			Dilution at extr	action sites -	NINA_EX - mid			10
north4 –	624	1128	1604	7135	56162	97336	217998 -	10
north3 -	566	1030	1437	5626	50130	93403	203378 -	-
north2 -	504	879	1251	6713	49545	90712	163917 —	
north1 -	445	848	1208	6515	45179	85927	150991 -	_
outh4	520	958	1421	8872	74238	120327	988968 —	
outh3	471	925	1370	8082	70000	112630	744168 —	
south2 -	512	942	1333	7527	67053	103258	562288 -	
south1 -	439	756	1132	8837	63314	96417	482764 -	- 10
N950 -	605	1044	1452	5380	47264	90170	165180 -	3
N850 -	533	1002	1380	5366	44118	84809	151958 -	-
N750 -	531	966	1356	5987	41307	78634	136684 -	-
N650 -	457	843	1314	4221	40303	76075	129148 -	-
N550 -	449	868	1195	4893	35120	67857	123567 -	-
N450 -	481	835	1130	4334	34476	60769	120345 -	
N350 -	449	772	1051	4106	28358	54079	115761 -	- 10
N250 -	374	649	884	3206	26719	50306	112779 —	-
N150 -	308	504	675	3213	25056	46818	109906 -	-
N50 -	354	545	695	2245	13867	34451	105885 -	-
outfall	260	404	527	1879	18183	40509	106820 -	-
S50 -	275	438	569	2038	21158	41787	105118 -	-
S150 -	317	514	714	2648	25537	45792	107031 -	
S250 -	484	784	1034	3984	26112	46395	108070 -	- 10
S350 -	513	811	1075	4406	30837	54492	116164 -	-
S450 -	358	702	1029	5717	38090	64897	145065 -	
S550 -	449	816	1157	5644	39790	70560	208011 -	_
S650 -	529	914	1304	6333	45312	77159	243069 -	-
S750 -	475	828	1205	7521	51530	83691	334409 -	
S850 -	548	966	1335	8037	56303	89473	378245 -	
S950 -	699	1203	1647	7849	61666	94179	471923 -	
	P1	P5	P10	P50	P90	P95	P99	10

Figure 2-9 Dilution percentile at extraction sites shown in Figure 2-1 for the La Niña scenario with existing discharge at the middepth level. Note the colour scale is logarithmic.



		Dil	ution at extra	ction sites - NI	NA_EX - nearbo	ed		10 ⁶
north4	- 825	1447	2012	8473	64958	105106	213856 -	10-
north3	- 706	1330	1945	8777	60243	98821	185970 -	-
north2	- 690	1241	1772	8147	58542	94877	173541 -	
north1	- 600	1119	1589	8893	55183	91961	164997 —	_
south4	- 639	1157	1743	9696	73972	123912	3905586-	
south3	- 607	1057	1531	9140	68531	115443	2154039-	
south2	- 687	1225	1675	8509	63717	106660	1227923-	
south1	- 549	1064	1478	9135	60424	100919	1145104-	- 10 ⁵
N950	- 845	1452	2154	8515	58971	94838	174378 -	-
N850	- 758	1323	1909	7917	53843	91013	168031 -	-
N750	- 685	1257	1682	8100	50569	85811	154315 -	-
N650	- 586	1025	1383	6188	48922	85025	150484 -	-
N550	- 543	955	1403	6507	42475	77401	145740 -	
N450	- 533	963	1358	4916	39810	72423	143062 -	
N350	- 560	993	1388	5389	34045	67667	135942 -	104
N250	- 466	820	1131	5060	32971	64901	134327 -	- 6
N150	- 340	596	822	3348	31245	60983	133200 -	
N50	- 416	685	901	3026	21172	50359	129485 -	
outfall	- 318	507	690	2857	26403	54858	129399 -	
S50	- 348	540	715	3058	26803	53365	127444 -	-
S150	- 352	609	808	3778	30344	58563	131127 -	
S250	- 596	936	1262	5031	29664	58003	141014 -	-10^{3}
S350	- 563	937	1259	5061	33636	65840	166049 -	-
S450	- 378	716	1055	6567	41481	74268	198918 -	-
S550	- 516	875	1210	5884	40512	73813	225114 -	_
S650	- 645	1072	1432	6333	43928	80540	352232 -	-
S750	- 593	1102	1359	8081	50019	85895	647097 -	
S850	- 637	1164	1645	8406	53847	91566	1315288-	
S950	- 824	1418	1932	7958	57684	97825	1525876	
	P1	P5	P10	P50	P90	P95	P99	10 ²

Figure 2-10 Dilution percentile at extraction sites shown in Figure 2-1 for the La Niña scenario with existing discharge at the nearbed level. Note the colour scale is logarithmic.



horth4	466	938	1333	5347	38388	71583	297313
horth3 -	440	850	1220	4695	36820	67639	247564
north2 -	410	790	1148	4879	35254	65642	199178
north1 -	372	746	1073	4566	32833	62161	172652
outh4	367	733	1102	7208	59712	140472	6627473
outh3	374	739	1102	6424	59577	130908	4008352
outh2 -	368	736	1076	6525	59937	121806	1906725
outh1 -	309	624	908	5116	58493	109259	2089476
N950 -	443	816	1178	4747	37986	67303	247983
N850 -	398	774	1142	4674	34350	63036	188608
N750 -	382	759	1084	4647	31148	59039	158624
N650 -	380	732	1028	4033	27674	54640	136673
N550 -	368	744	1033	3994	23518	45467	112376
N450 -	350	686	959	3670	20187	40727	101376
N350 -	356	618	852	3107	16955	33028	92337
N250 -	299	494	674	2474	14360	26663	86653
N150 -	209	349	469	1716	10801	22075	79683
N50 -	207	332	443	1287	5987	11796	71198
outfall <mark>-</mark>	153	234	331	977	5714	13333	75028
S50 <mark>-</mark>	157	254	357	1178	6512	15272	77024
S150 -	176	336	464	2044	13945	24063	79257
S250 -	280	545	739	3004	18037	29267	81858
S350 <mark>-</mark>	300	604	834	3745	23877	41672	118489
S450 -	258	533	796	4222	32903	53425	247727
S550 <mark>-</mark>	302	616	885	5052	37137	60440	277759
S650 -	346	676	980	5722	43093	69578	368668
S750 -	336	641	960	5436	50619	83707	826208
S850 -	390	748	1080	5574	55463	99961	1103490
S950 -	460	860	1225	7652	58887	115113	1787355
_	P1	P5	P10	P50	P90	P95	P99

Figure 2-11 Dilution percentile at extraction sites shown in Figure 2-1 for the La Niña scenario with future discharge at the surface level. Note the colour scale is logarithmic.



		Dil	ution at extrac	tion sites - NI	NA_FUTURE - m	nid		106
north4	- 494	918	1273	5444	42300	72689	182441 -	10-
north3	- 438	820	1126	4473	37068	68610	133897 -	-
north2	- 389	711	1012	4506	35846	65895	123435 -	
north1	- 362	653	940	4318	32360	61978	116653 -	_
south4	- 432	755	1125	5584	55560	92283	3121563-	
south3	- 388	756	1037	6412	53641	84980	1954431-	
south2	- 422	760	1048	6074	50230	78872	1007777-	
south1	- 347	642	946	5834	47256	74250	586290 -	- 10 ⁵
N950	- 465	841	1144	4357	34294	66535	130100 -	-
N850	- 419	774	1091	4140	31838	61910	118810 -	-
N750	- 400	764	1054	4136	29978	56088	109626 -	-
N650	- 371	687	998	3861	28299	55149	105870 -	-
N550	- 367	694	980	3474	23833	45740	99695 —	
N450	- 377	676	953	3649	22788	43732	96007 -	
N350	- 374	628	868	3251	19538	37204	93177 –	104
N250	- 328	536	724	2772	18553	34239	89693 -	_
N150	- 243	402	534	2067	16271	32840	89259 -	-
N50	- 276	427	540	1630	8980	21412	85642 -	-
outfall	- 208	323	409	1427	11140	26864	85529 -	-
S50	- 226	345	453	1574	12892	28457	84739 –	
S150	- 260	416	570	2408	16541	31611	85208 -	
S250	- 405	628	828	3040	16673	31983	84602 -	-10^{3}
S350	- 414	666	882	3444	21385	38967	91592 -	-
S450	- 286	541	753	3556	26838	46190	108287 -	-
S550	- 353	654	910	3771	29081	51121	116302 -	-
S650	- 417	729	1030	4280	32176	57297	150466 -	-
S750	- 386	677	972	5082	37689	64764	215646 -	
S850	- 461	806	1116	5601	41720	69964	290038 -	
S950	- 566	974	1321	5787	44902	73220	581662 -	in a second
	P1	P5	P10	P50	P90	P95	P99	10 ²

Figure 2-12 Dilution percentile at extraction sites shown in Figure 2-1 for the La Niña scenario with future discharge at the mid-depth level. Note the colour scale is logarithmic.



north4	644	1178	1649	6198	50033	81155	179035 -	
north3 -	563	1060	1491	5668	45213	74722	147805 -	
north2 -	556	1000	12/14/25/25			100000 AL 10	1	
-			1463	6375	43239	71306	141696 -	
north1 -	491	873	1291	6220	39382	66654	128790 -	
south4	540	915	1304	6018	56789	97133	6387357-	
south3	487	883	1262	6830	52438	89001	3646725 -	
south2	572	996	1395	6746	47676	84592	1541898-	
south1 -	454	757	1133	6383	45950	79710	1065943 -	
N950	686	1187	1631	5643	42724	72092	141436 -	
N850 -	606	1061	1478	5366	39256	66165	130217 -	
N750 -	553	976	1399	5595	36510	62078	124324 -	
N650 -	493	823	1287	4221	33740	59114	119169 -	
N550 -	410	749	1083	4470	29715	53224	114012 -	
N450 -	429	756	1061	4052	28329	50491	110711 -	
N350 -	432	785	1077	4106	24542	46620	107336 -	
N250 -	369	640	902	3176	23813	45306	106129 -	
N150 -	276	456	627	3152	21132	43519	104194 -	
N50 -	314	510	688	2256	12789	33614	99658 -	
outfall -	238	385	513	2001	15822	37491	100410 -	
S50 -	257	421	540	2043	16307	36770	97884 -	
S150 -	285	470	633	2648	19564	39487	99070 -	
S250	451	721	971	3661	19820	40192	105043 -	
S350 -	436	709	981	4108	23540	46635	122331 -	
S450 -	312	549	755	4226	28762	53263	189075 -	
S550 -	408	700	971	3771	29640	53842	193384 -	
S650 -	512	831	1118	4395	33218	62494	204516 -	
5750 -	496	848	1165	5515	37865	69856	356087 -	
S850 -	542	921	1268	5953	40963	73626	589679 -	
S950 -	699	1124	1535	6405	44218	77991	895571 -	
	P1	P5	P10	P50	P90	P95	P99	

Figure 2-13 Dilution percentile at extraction sites shown in Figure 2-1 for the La Niña scenario with future discharge at the nearbed level. Note the colour scale is logarithmic.



3.ltem 2

The nearfield dynamics are incorporated in the far-field model using nearfield length, width, and thickness at each time step (see Figure 3-1). These metrics are interpolated from the look-up table produced by the CORMIX ¹ model, according to ambient hydrodynamic flow velocity, and wastewater discharge flow (see MetOcean Solutions, 2022). The orientation of the release cone is adjusted at each release time according to ambient hydrodynamic flow direction.

General statistics on the nearfield plume metrics are provided in Table 3-1 to inform on general plume dimensions. Median nearfield length, half width, and surface thickness are 248.0 m , 21.0 m and 11.1 m respectively. Note some values are identical for some different percentiles (e.g. P1, P5, P10 for the nearfield length. This is because we use nearest neighbour extrapolation for the hydrodynamic and discharge flow conditions that fall outside of the range covered by the lookup table events.

Successive release footprints over the duration of the particle-tracking simulations were combined to map the possible extents of the plume after the initial nearfield dynamics, and before it gets advected by ambient current in the far-field model. The nearfield plume map is shown in Figure 3-2. The colour indicates the probability of wastewater to end up in a given area after the nearfield dynamics, over the annual period considered. Yellow zones are zones where the wastewater ends up more regularly after the nearfield dynamics, whereas blue areas are areas where the wastewater can end up at time, but less frequently. The extraction sites considered in item 1 can be used to inform on dilution along the nearfield plume main axis.

A 3D view of the nearfield plume is shown in Figure 3-3. We see that the plume has larger extents in the shallower levels and becomes more compact near its deeper extremity (at ~14 m below surface) (see also Table 3-1). Vertical slices are shown in Figure 3-4. As in previous plots, the colour informs on the probability for the wastewater to end up in a particular area. On the horizontal, largest probabilities are typically found within 200m of the outfall with two hotspots on either side of the outfall (to the northeast and southwest). On the vertical, most frequent depth range is [0-4m] below surface. The plume footprint then goes down the water column to ~ 10-12m below the surface, within 200-



¹ www.cormix.info

500m of the outfall, but with reduced probability. Deeper excursions (~14m) are possible though less frequent, and typically only up to ~125 m either side of the outfall.

Timeseries of dilutions were extracted around the edge of the current mixing zone, which is a rectangular box centred on the outfall with its main axis along the nearfield plume footprint (NCC, pers. comm., 2023) (Figure 3-5).

Dilution percentiles are presented in Figure 3-6 to Figure 3-17 for the different scenarios. Minimum dilution percentiles (i.e. worst-case) experienced around the mixing zone are tabulated in Table 3-2. For example, the minimum P1 dilution for El Nino scenario under the current discharge, at the surface, is 413. Corresponding dilution level for La Nina scenario is 355. Minimum dilutions are generally observed at the sites mix17-N250, or mix3-S250 which are aligned with the nearfield plume footprint.

Minimum dilution levels are consistently smaller for La Nina scenario compared to El Nino, though they general remain within a similar order of magnitude. The lower La Nina dilutions can be attributed to weaker hydrodynamic flows in the vicinity of the outfall during La Nina scenario, which are therefore less efficient in dispersing the released contaminant, relative to El Nino scenario (see current roses at outfall location in Figure 3-18 and Figure 3-19 reproduced from MetOcean Solutions, 2022).



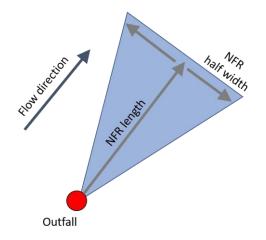


Figure 3-1 Sketch showing the triangular release footprint defined from the nearfield dynamics metrics NFR length and mid width. Particles were released on the surface layer within a thickness defined by the NFR thickness.

	P1	Р5	P10	P25	P50	P75	P90	P95	P99
NFR length	104.6	104.6	104.6	139.3	248.0	460.4	738.0	938.0	1466.7
NFR half- width	18.7	19.6	19.9	20.5	21.0	24.7	90.0	92.4	185.9
NFR thickness	2.2	3.5	5.7	10.0	11.1	12.2	13.5	13.5	13.5

 Table 3-1
 Nearfield plume length, half-width, and thickness percentiles.



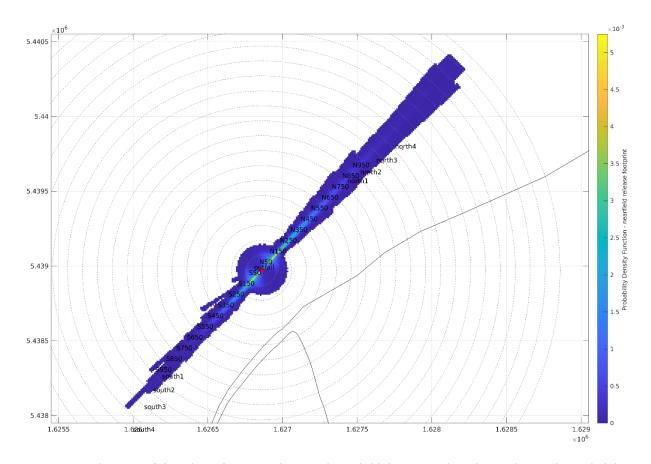


Figure 3-2 Plan view of the release footprint after initial nearfield dynamics. The colour indicates the probability of wastewater to end up in a given area after the nearfield dynamics, over the annual period considered. Sum of all probabilities is 1. Yellow zones are zones where the wastewater ends up more regularly after the nearfield dynamics, whereas blue areas are areas where the wastewater can end up at time, but with a lower probability. The outfall location and extraction sites are shown as red dots. Concentric circles are added every 100m from the outfall for scale.

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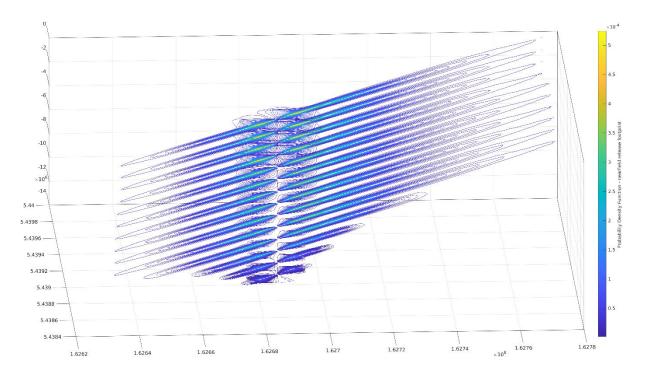


Figure 3-3 3D view of the release footprint after initial nearfield dynamics. The colour indicates the probability of wastewater to end up in a given area after the nearfield dynamics, over the annual period considered. The vertical axis is the water column height where 0 is the sea surface; sum of all probabilities is 1. Yellow zones are zones where the wastewater ends up more regularly after the nearfield dynamics, whereas blue areas are areas where the wastewater can end up at time, but with a lower probability.



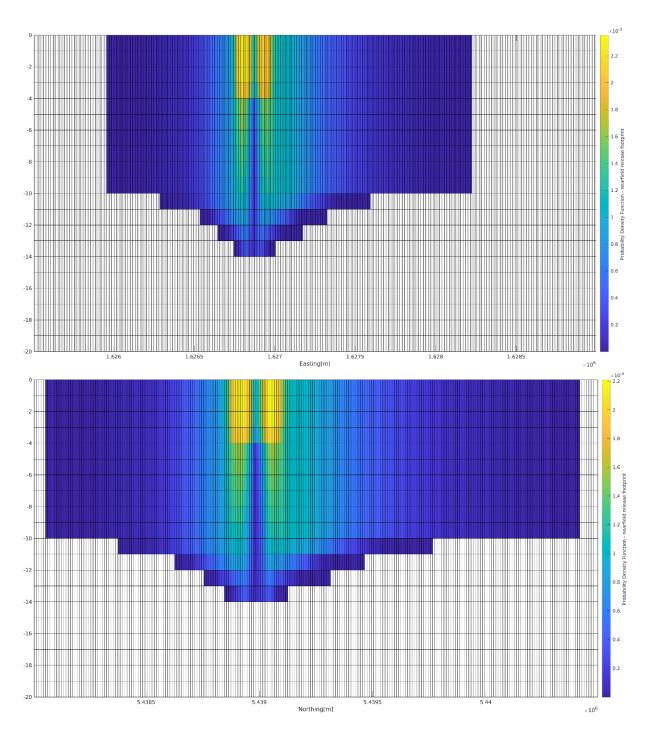


Figure 3-4 Vertical slices of the 3D nearfield release footprint, along the x and y axes. The colour indicates the probability of wastewater to end up in a given area after the nearfield dynamics, over the annual period considered. Sum of all probabilities is 1. Yellow zones are zones where the wastewater ends up more regularly after the nearfield dynamics, whereas blue areas are areas where the wastewater can end up at time, but with a lower probability.

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175.510 175.517 175.510 175.515 175.52 175.521 175.522 175.525 175.524

Figure 3-5 Extraction sites around the edges of the mixing zone.



_		Dilution at e	extraction sites	s around mixin	g zone - NINO_I	EX - surface		10⁶
mix28 –	547	968	1415	6563	42413	79486	199761 -	10-
mix27 -	537	918	1318	5785	37596	76282	198121 —	-
mix26 –	472	823	1194	5042	42316	79438	199670 —	
mix25 –	451	794	1120	4441	25810	59432	186598 —	-
mix24 –	473	779	1102	4204	23291	58435	184840 —	
mix23 -	471	867	1304	4823	42528	77649	202201 -	
mix22 -	518	929	1290	5031	20833	50036	173647 —	5
mix21 -	539	979	1362	5223	23278	52008	180644 —	10 ⁵
mix20 -	565	1036	1427	5432	39830	74376	193488 —	
mix19 -	653	1124	1522	5729	25838	60495	197791 —	
mix18	465	773	1091	4956	31519	66598	200381 -	-
mix17-N250	413	683	966	4273	28064	61497	198510 —	
mix16	520	849	1187	4628	24528	60052	204928 -	
mix15	590	1054	1543	6483	35436	75091	227214 -	
mix14 -	598	1001	1432	5384	31477	70402	213249 —	104
mix13 -	561	1002	1413	5879	33120	70970	205122 -	-
mix12 -	464	833	1154	4807	27468	62469	191365 —	
mix11 -	439	757	1037	4252	25300	57283	189914 —	-
mix10	492	819	1119	4720	26306	60773	190414 —	
mix9 –	497	827	1145	5420	39688	79181	201307 -	
mix8 –	489	806	1152	4921	39039	79105	201840 -	
mix7 -	535	890	1296	5835	42435	80576	199024 -	- 10 ³
mix6 –	571	993	1471	7465	50516	88034	210678 -	1
mix5 -	597	1029	1518	7791	52201	90733	212604 -	
mix4 –	442	801	1158	5507	51815	88469	213259 -	-
mix3-S250 -	434	743	1038	5474	44272	83055	206445 -	
mix2 -	452	853	1182	5886	45611	82491	203133 -	
mix1 -	540	1005	1473	6727	50876	86844	210181 -	
_	P1	P5	P10	P50	P90	P95	P99	10 ²

Figure 3-6 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the El Niño scenario with existing discharge at the surface level. Note the colour scale is logarithmic.



		Dilution at	extraction sit	es around mix	ing zone - NINO	_EX - mid	
mix28 –	621	1063	1514	7055	45157	97032	246452 –
mix27 –	656	1072	1463	6021	43802	94293	244745 -
mix26 –	542	974	1161	8418	48833	100688	241101 –
mix25 –	579	922	1260	4973	36272	81930	234957 –
mix24 –	591	942	1268	4823	36439	80040	232959 –
mix23 –	540	1016	1199	8579	47716	93612	236173 –
mix22 –	615	994	1428	5109	37167	71633	225751 -
mix21 -	602	1016	1448	5820	37483	72047	226775 –
mix20 –	545	1029	1507	8682	42772	82014	236017 –
mix19 -	635	1126	1583	6084	40770	78857	236813 -
mix18	444	785	1165	5687	41862	81989	233944 –
nix17-N250 -	411	717	1017	4726	37374	69647	227106 -
mix16 -	538	877	1248	5525	35928	69548	224136 -
mix15 –	621	1002	1422	8130	43119	84834	227462 -
mix14 –	627	1060	1428	5384	40605	79797	226173 –
mix13 –	596	1026	1424	6871	41499	81627	223841 -
mix12 –	554	903	1225	6328	40919	84586	223742 -
mix11 -	545	870	1182	4950	38173	82941	223618 -
mix10 -	542	919	1195	5770	39933	85723	223961 -
mix9 –	585	962	1291	5796	43803	89515	231035 -
mix8 –	588	938	1298	4639	42602	92236	235333 -
mix7 –	631	1045	1429	6845	44013	91707	240310 -
mix6 –	681	1130	1528	5947	48524	99058	242867 –
mix5 –	692	1156	1566	6387	50211	102595	246767 -
mix4 –	502	860	1176	6898	48814	99776	246582 -
mix3-S250 -	509	820	1100	5474	45123	96210	249456 -
mix2 –	540	877	1215	5600	45542	96729	250817 –
mix1 -	556	1017	1312	9278	53123	106242	254056 -
	P1	P5	P10	P50	P90	P95	P99

Figure 3-7 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the El Niño scenario with existing discharge at the mid-depth level. Note the colour scale is logarithmic.



		Dilution at e	xtraction sites	around mixing	g zone - NINO_E	X - nearbed		10 ⁶
mix28 –	592	1065	1510	7244	44634	102401	271968 -	101
mix27 –	632	1074	1500	6162	43241	99434	269388 -	-
mix26 -	525	962	1161	8899	49004	110216	269226 –	-
mix25 –	566	983	1359	6038	37981	87065	262795 –	-
mix24 –	601	1009	1391	5823	37360	84356	261050 -	
mix23 –	532	1030	1202	9182	48330	106435	267501 -	
mix22 -	627	1032	1447	6062	40247	89889	263143 –	5
mix21 -	616	1095	1507	6307	40180	88953	263587 –	10 ⁵
mix20 -	568	1077	1687	9541	43974	95591	266993 —	-
mix19	743	1265	1733	7465	42233	92372	264619 -	-
mix18	519	929	1356	7373	44606	95405	261801 -	_
mix17-N250	516	884	1273	6840	43692	95377	262692 -	
mix16	653	1142	1596	6057	42957	95886	262072 -	
mix15	767	1257	1964	9751	48004	111445	263606 -	e e
mix14 -	782	1322	1795	6979	44643	102446	261153 —	- 10 ⁴
mix13 -	728	1281	1724	6895	45544	102813	263407 –	-
mix12 -	720	1202	1605	7210	44249	96633	263356 -	_
mix11 -	736	1178	1639	5669	42030	95973	263637 –	-
mix10	823	1276	1743	7148	45016	103092	265217 -	
mix9 –	769	1289	1694	5796	46625	105929	264515 -	
mix8 –	726	1171	1573	6512	44372	106650	265068 -	
mix7 –	706	1228	1667	8043	45064	101586	263832 -	- 10 ³
mix6 –	778	1330	1840	7595	47721	115065	270164 -	-
mix5 -	775	1305	1777	7513	48942	116246	275880 -	
mix4 –	605	1053	1342	8426	48413	115083	278645 –	
mix3-S250 -	595	966	1325	5573	43999	103525	274634 -	
mix2 -	574	943	1298	6448	44157	104278	275277 –	
mix1 -	527	1005	1251	9673	52602	115105	281441 -	
	P1	P5	P10	P50	P90	P95	P99	10 ²

Figure 3-8 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the El Niño scenario with existing discharge at the nearbed level. Note the colour scale is logarithmic.



		Dilution at ext	raction sites a	round mixing z	one - NINO_FU	TURE - surface		106
mix28	- 422	750	1055	4601	30482	54321	153229 –	10*
mix27	- 421	700	972	4000	25720	50493	148886 -	-
mix26	- 372	643	902	4117	28609	52195	152979 –	
mix25	- 350	603	816	3208	18607	36116	136655 -	-
mix24	- 352	591	806	2934	17473	34657	136116 –	
mix23	- 365	680	945	4060	27231	53222	159324 –	
mix22	- 401	698	965	3406	17910	29923	141973 —	5
mix21	- 417	741	1020	3658	18811	32730	148499 -	10 ⁵
mix20	- 435	802	1093	4206	27199	49105	169505 —	
mix19	- 500	842	1165	4114	17322	38058	178356 -	
mix18	- 374	608	842	3391	21118	44583	185242 –	-
mix17-N250	- 324	529	735	3087	17800	38735	171097 —	
mix16	- 401	666	914	3451	18631	36146	171894 –	
mix15	- 466	835	1177	4891	22371	50114	204511 -	u li
mix14	- 480	782	1098	4029	20721	44530	182631 –	10 ⁴ Intio
mix13	- 463	773	1079	4112	20558	45692	170679 —	-
mix12	- 374	632	884	3548	17243	39784	143052 -	-
mix11	- 345	571	794	3070	16453	34054	137675 —	
mix10	- 377	615	868	3299	15045	36419	138638 -	
mix9	- 380	632	871	3753	24840	53359	155222 –	
mix8	- 373	626	876	3692	25141	53920	157561 —	
mix7	- 412	681	1001	4301	29040	57851	160327 –	- 10 ³
mix6	- 446	764	1106	4912	34885	65037	179241 –	-
mix5	- 462	800	1170	5502	38323	68766	186254 -	
mix4	- 337	622	883	4524	37503	65734	178516 —	
mix3-S250	- 329	577	793	4010	31549	59521	164569 —	
mix2	- 375	653	908	4231	33824	60191	166753 —	
mix1	- 406	768	1108	4978	35528	62885	175066 -	1.02
	P1	P5	P10	P50	P90	P95	P99	10 ²

Figure 3-9 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the El Niño scenario with future discharge at the surface level. Note the colour scale is logarithmic.



mix28 –	489	828	1154	4943	31247	64874	173131 –	1
mix27 –	505	816	1105	4148	29052	62398	170196 -	
mix26 –	432	736	1061	5059	32567	68450	169854 -	
mix25 –	456	729	982	3590	22754	51818	164298 —	
mix24 –	456	736	976	3556	22438	50346	161931 –	
mix23 –	423	717	1048	4954	32843	63779	164559 —	
mix22 -	467	782	1077	3961	24183	49290	157498 —	- 1
mix21 -	476	815	1098	3880	25321	49341	161384 -	- 1
mix20 –	454	764	1079	5453	29759	53535	168420 -	-
mix19 –	503	883	1201	4330	25304	51411	168969 -	
mix18 –	370	631	879	3202	28541	54606	166410 -	-
.7-N250 -	345	575	800	3096	26241	49043	164984 -	
mix16 –	430	723	987	3809	23533	47468	163916 -	
mix15 –	479	838	1184	4925	29252	59126	167237 -	- 1
mix14 –	513	841	1148	4655	26793	55241	165378 -	
mix13 –	483	822	1083	4426	28343	56104	163816 -	-
mix12 –	436	722	962	3605	26623	54432	161896 -	
mix11 –	435	692	919	3727	24673	50395	162219 –	-
mix10 -	444	719	982	3589	26717	55639	162290 -	
mix9 –	478	769	1030	3821	30537	63517	166269 -	
mix8 –	475	757	1003	4364	29957	64898	169007 –	- 1
mix7 –	499	811	1103	4469	31370	64848	171461 -	-
mix6 –	541	883	1188	4912	34189	69163	172607 –	-
mix5 –	554	917	1238	4420	33842	72763	175670 -	
mix4 –	423	706	970	4590	33213	71531	175137 –	-
<3-S250 -	416	669	897	3969	30941	66644	175290 -	
mix2 –	433	711	968	3998	32003	66987	175444 -	
mix1 -	452	822	1115	5824	36162	75166	178153 -	

Figure 3-10 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the El Niño scenario with future discharge at the mid-depth level. Note the colour scale is logarithmic.



		Dilution at ext	raction sites ar	ound mixing z	one - NINO_FUT	URE - nearbed	
mix28 –	478	807	1133	5227	30186	58076	202527 -
mix27 –	514	846	1153	4922	28063	55994	200606 -
mix26 –	421	742	1075	5770	31541	62848	202513 –
mix25 –	465	770	1049	4237	23910	46575	197133 —
mix24 –	470	775	1051	3979	23413	46098	196718 —
mix23 –	425	717	1064	5671	32185	63874	200092 –
mix22 –	481	800	1091	4541	25036	48213	197528 —
mix21 –	491	843	1169	4305	26004	49227	197923 —
mix20 –	490	838	1129	5948	30562	55421	198227 —
mix19 -	603	969	1324	4847	27449	54396	197312 –
mix18 –	444	732	1024	4575	29925	57856	196225 —
17-N250 <mark>-</mark>	417	717	994	4280	27474	54750	201173 –
mix16 -	569	910	1240	5129	26720	54272	200155 –
mix15 –	628	1100	1424	6631	31694	63865	201599 -
mix14 –	658	1055	1413	5384	28688	60003	200565 -
mix13 –	626	1022	1373	5869	30290	60856	200191 –
mix12 –	596	956	1306	5504	28904	58969	196770 -
mix11 -	588	936	1248	4950	27482	56850	194988 —
mix10 -	645	1001	1349	5579	29085	58153	194541 —
mix9 –	643	1021	1366	5411	30142	59183	195398 —
mix8 –	602	972	1279	4639	28729	58949	196998 —
mix7 –	624	984	1339	5568	29867	59832	200010 -
mix6 –	661	1057	1431	4912	33996	69656	205629 -
mix5 -	635	1045	1456	5555	33343	74867	209933 —
mix4 –	509	833	1174	5688	32234	68737	203690 -
x3-S250 -	492	776	1047	4434	29107	58345	202097 -
mix2 –	459	740	1007	4516	30329	58301	202512 -
mix1 -	431	769	1112	6284	34465	71635	206228 -
	P1	P5	P10	P50	P90	P95	P99

Figure 3-11 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the El Niño scenario with future discharge at the nearbed level. Note the colour scale is logarithmic.



		Dilution at e	extraction site	s around mixin	g zone - NINA_I	X - surface		10 ⁶
mix28 –	497	933	1299	4776	24164	40773	90957 -	10
mix27 -	491	886	1227	4149	21362	35996	87294 -	-
mix26 –	434	789	1124	4250	23356	41460	89983 –	
mix25 –	422	753	1048	3398	16095	25810	82155 –	-
mix24 –	435	760	1037	3327	14974	25268	82410 –	
mix23 –	462	857	1127	4129	23608	43127	94574 –	
mix22 –	491	889	1184	3667	17711	27500	85239 –	5
mix21 -	473	939	1242	3854	18836	29474	86065 –	105
mix20 –	516	959	1319	4206	25305	43878	94272 –	-
mix19 –	570	1015	1352	4132	17322	32934	96235 –	
mix18 -	412	706	955	3511	21785	42612	98050 –	-
mix17-N250	369	621	854	3200	20263	40453	99703 –	
mix16 –	436	746	1026	3639	20107	37623	102738 -	
mix15 -	500	911	1265	4872	24321	47976	116918 -	
mix14 -	516	896	1221	4235	21648	40557	105330 -	- 10 ⁴
mix13 -	507	862	1192	4316	21895	41100	99548 –	-
mix12 -	427	735	1031	3605	17234	36566	93136 -	
mix11 -	402	687	940	3299	16453	31489	89744 –	-
mix10 -	433	731	995	3556	15326	32598	90529 -	
mix9 –	454	767	1030	3864	20489	38953	93337 –	
mix8 –	444	755	1021	3915	21492	37379	93186 -	, I
mix7 –	461	819	1125	4399	23241	41151	92934 –	10 ³
mix6 –	490	895	1236	4924	27844	48460	102160 -	
mix5 –	521	944	1289	5413	29827	49657	108624 -	
mix4 –	390	706	995	4397	28087	50055	107080 -	
mix3-S250 -	355	688	944	4010	25824	42794	99401 -	
mix2 -	398	781	1088	4382	25853	44122	99823 -	
mix1 -	488	933	1328	4978	27969	49474	104822 -	
	P1	P5	P10	P50	P90	P95	P99	10 ²

Figure 3-12 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the La Niña scenario with existing discharge at the surface level. Note the colour scale is logarithmic.



		Dilution a	t extraction sit	es around mix	ing zone - NINA	_EX - mid		10
mix28 –	588	1019	1399	5100	26809	46633	107136 -	10
mix27 -	626	1010	1367	4542	24972	45537	106060 -	-
mix26 –	511	774	1156	5515	30337	51860	108197 –	
mix25 –	536	875	1184	4237	21507	40699	105660 -	-
mix24 –	538	894	1175	3882	19234	40208	106231 -	
mix23 –	516	876	1100	5199	30636	53025	110487 –	
mix22 -	570	942	1272	4271	23451	44619	110054 -	
mix21 -	568	955	1287	4020	25139	46185	110439 -	- 10
mix20 –	537	975	1163	5319	29328	50850	112093 —	-
mix19 -	618	1030	1395	4330	26079	51216	112579 –	
mix18 -	400	710	947	3541	29743	52862	112363 —	-
nix17-N250 -	374	649	884	3206	26719	50306	112779 –	
mix16 -	505	836	1119	3894	25407	49470	112477 –	
mix15 -	554	998	1259	5106	30205	53653	114909 -	
mix14 –	582	990	1346	4890	26867	49980	111037 –	- 10
mix13 -	576	966	1285	4681	28351	49809	109991 -	-
mix12 -	533	869	1189	3605	25539	48732	108628 -	
mix11 -	515	825	1089	3967	23797	47118	108102 -	-
mix10 -	527	875	1172	3673	25447	48341	108461 -	
mix9 –	550	932	1230	4520	27286	48114	108615 -	
mix8 –	561	928	1220	4639	25291	45941	108641 -	
mix7 –	566	979	1321	4737	26986	46324	107575 -	- 10
mix6 –	640	1058	1433	4912	30456	50353	109324 -	1
mix5 –	678	1105	1473	4744	30123	52348	109602 -	
mix4 –	482	805	1096	4995	29283	51313	109645 -	-
mix3-S250 -	484	784	1034	3984	26112	46395	108070 -	
mix2 –	504	851	1130	4125	27152	46620	107854 -	
mix1 -	528	989	1248	5946	32585	55921	110331 -	
	P1	Р5	P10	P50	P90	P95	P99	10

Figure 3-13 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the La Niña scenario with existing discharge at the mid-depth level. Note the colour scale is logarithmic.



		Dilution at e	extraction sites	around mixing	g zone - NINA_E	X - nearbed		10 ⁶
mix28	- 565	974	1385	5784	30869	57996	136825 -	101
mix27	- 592	1007	1413	5566	29079	56383	133271 –	-
mix26	- 450	774	1159	6293	34059	64126	133145 —	
mix25	- 544	928	1285	4589	25087	52669	130085 -	-
mix24	- 572	947	1319	4583	24565	53041	128880 -	
mix23	- 440	813	1100	6215	33771	63859	130516 -	
mix22	- 571	973	1319	5031	28242	58930	134054 -	5
mix21	- 597	1020	1390	4949	28939	59967	134666 -	- 10 ⁵
mix20	- 566	1029	1166	6258	34238	65201	135325 —	-
mix19	- 728	1174	1578	5410	31542	64465	136103 -	
mix18	- 475	857	1223	5251	33706	65698	135364 —	
mix17-N250	- 466	820	1131	5060	32971	64901	134327 –	
mix16	- 693	1111	1509	5636	32695	63292	133487 –	
mix15	- 772	1258	1928	7052	36607	67792	135102 -	u li hu
mix14	- 822	1325	1795	5384	33760	64000	132643 —	Dilution
mix13	- 807	1281	1645	6265	34199	63767	131795 —	-
mix12	- 754	1192	1582	6099	32589	61708	131550 —	
mix11	- 733	1208	1602	4950	30884	60284	131017 –	
mix10	- 785	1204	1575	6179	32300	61216	130661 -	
mix9	- 800	1271	1664	5775	32471	60870	130701 -	
mix8	- 770	1235	1573	4639	31232	59701	130570 -	
mix7	- 784	1253	1698	6014	31796	59843	130932 -	- 10 ³
mix6	- 838	1350	1903	5115	36450	65738	140024 -	
mix5	- 823	1368	1831	5555	35635	67755	149394 -	
mix4	- 593	1044	1297	6369	34445	65855	149844 -	
mix3-S250	- 596	936	1262	5031	29664	58003	141014 -	
mix2	- 527	892	1219	4936	31306	58723	140569 -	
mix1	- 499	834	1247	6703	36414	67089	148002 -	
	P1	P5	P10	P50	P90	P95	P99	10 ²

Figure 3-14 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the La Niña scenario with existing discharge at the nearbed level. Note the colour scale is logarithmic.



		Dilution at ext	raction sites a	round mixing z	one - NINA_FU	TURE - surface		10⁶
mix28	- 380	711	990	3449	16606	28501	77339 -	10-
mix27	- 380	673	932	3064	13504	24084	76307 –	-
mix26	- 342	619	867	3060	15620	27798	77450 –	
mix25	- 332	572	790	2533	11500	20229	75175 —	-
mix24	- 332	569	785	2415	11059	19316	75012 –	
mix23	- 354	628	874	2934	15441	28546	81520 —	
mix22	- 384	682	889	2648	10971	20436	76035 —	5
mix21	- 381	710	930	2783	11866	22447	75577 —	- 10 ⁵
mix20	- 403	725	987	3182	16529	28572	81979 —	1
mix19	- 437	790	1027	3044	14125	22014	78262 –	
mix18	- 331	559	766	2711	14678	27670	85929 –	-
mix17-N250	- 299	494	674	2474	14360	26663	86653 —	
mix16	- 363	594	809	2757	13918	24713	87767 –	
mix15	- 408	712	996	3555	19068	32177	99888 -	Lion Hi
mix14	- 418	698	953	3142	14461	27516	89441 –	Dilution
mix13	- 407	695	941	3106	13849	28703	86991 –	-
mix12	- 344	585	792	2608	13924	23449	81321 –	_
mix11	- 329	544	727	2356	10032	20543	78700 -	-
mix10	- 342	585	784	2546	12678	20850	79815 –	
mix9	- 338	593	794	2847	12612	25802	82173 –	
mix8	- 340	588	789	2807	13388	25070	80343 -	
mix7	- 364	641	871	3245	16254	27053	80040 -	- 10 ³
mix6	- 389	709	950	3836	19213	34039	86406 –	-
mix5	- 419	729	990	4048	21359	37266	97257 –	
mix4	- 308	563	776	3435	21170	35509	91726 –	-
mix3-S250	- 280	545	739	3004	18037	29267	81858 -	
mix2	- 311	609	842	3237	18195	31484	80944 –	
mix1	- 377	715	1029	3957	19905	33655	82964 -	102
	P1	P5	P10	P50	P90	P95	P99	10_

Figure 3-15 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the La Niña scenario with future discharge at the surface level. Note the colour scale is logarithmic.



		Dilution at e	xtraction sites	around mixing	zone - NINA_F	UTURE - mid		10 ⁶
mix28	- 468	797	1083	3623	18403	32716	84885 -	10
mix27	- 484	804	1075	3360	15561	30556	85099 —	-
mix26	- 383	713	998	3238	19681	35433	86444 –	
mix25	- 439	710	925	2904	12905	27928	84406 –	-
mix24	- 445	700	923	2787	12414	27440	85022 –	
mix23	- 421	703	1014	3110	20058	35536	87239 –	
mix22	- 435	731	990	3020	14907	30292	87580 -	5
mix21	- 438	749	1001	3143	15915	30975	89227 –	10 ⁵
mix20	- 429	724	1021	3315	21024	37648	89900 -	-
mix19	- 494	789	1055	3382	15793	34558	90658 -	
mix18	- 354	574	792	2869	19347	37227	90530 –	-
mix17-N250	- 328	536	724	2772	18553	34239	89693 —	
mix16	- 416	667	884	2955	16340	33806	90003 –	
mix15	- 455	773	1102	3563	20558	38989	91381 -	tion .
mix14	- 486	792	1063	3454	18085	35390	89646 –	Dilution
mix13	- 456	779	1039	3148	18916	36164	89532 -	-
mix12	- 424	698	903	2892	17788	34701	89190 -	
mix11	- 406	673	882	2742	15236	31456	87935 -	-
mix10	- 422	708	941	2791	16776	33006	87489 -	
mix9	- 452	746	972	3169	17573	33147	86072 –	
mix8	- 456	734	940	3319	16766	30940	85909 —	
mix7	- 481	777	1023	3328	18018	31575	85850 -	- 10 ³
mix6	- 507	851	1109	4031	20665	35951	86116 –	
mix5	- 520	875	1161	4110	21041	36105	86376 –	-
mix4	- 401	645	860	3070	20253	35161	85397 –	
mix3-S250	- 405	628	828	3040	16673	31983	84602 -	
mix2	- 409	681	913	3224	19158	33006	84678 –	
mix1	- 445	765	1102	3934	21937	38032	87014 -	10 ²
	P1	P5	P10	P50	P90	P95	P99	

Figure 3-16 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the La Niña scenario with future discharge at the mid-depth level. Note the colour scale is logarithmic.



		Dilution at extr	action sites ar	ound mixing z	one - NINA_FUT	URE - nearbed	
mix28 –	449	766	1066	3681	20594	40220	99656 -
mix27 –	450	799	1077	3807	17773	38059	98990 -
mix26 –	360	698	992	3801	22262	42315	100859 -
mix25 –	416	719	968	3385	16157	34966	98870 -
mix24 -	434	728	964	3246	15976	34987	99059
mix23 –	367	695	1003	3570	23837	44007	102092 -
mix22 -	430	740	1004	3406	16627	38505	102871 -
mix21 -	452	775	1053	3504	18812	39360	103972 -
mix20 –	441	740	1071	3660	22014	42772	105398 -
mix19 -	555	887	1195	3801	19454	42239	106327 -
mix18 -	376	668	930	3195	23604	45189	105699 -
(17-N250 -	369	640	902	3176	23813	45306	106129 -
mix16 -	524	864	1176	3894	21922	44932	105541 -
mix15 -	626	1002	1401	4707	25741	47937	106808 -
mix14 -	642	1028	1373	4330	23068	45011	105197 -
mix13 -	615	1024	1328	4107	23756	44340	104103 -
mix12 -	576	933	1279	3605	21909	44096	102794 -
mix11 -	575	911	1237	3879	19956	41343	101627 -
mix10 -	636	1001	1287	3670	21628	43105	100716 -
mix9 –	639	1003	1309	3933	21530	42496	100623 -
mix8 –	620	953	1240	3999	19906	40783	100704
mix7 -	617	979	1289	4116	22031	41374	99920 -
mix6 –	646	1057	1394	4337	25375	44859	107073 -
mix5 -	629	1049	1393	4420	24641	45372	113494
mix4 –	475	787	1091	4009	24189	45490	113217 -
ix3-S250 -	451	721	971	3661	19820	40192	105043
mix2 –	413	699	937	3702	21051	40628	104576 -
mix1 –	400	716	1075	4270	25191	46802	108231 -
	P1	P5	P10	P50	P90	P95	P99

Figure 3-17 Dilution percentile at extraction sites around the mixing zone edges (Figure 3-5) for the La Niña scenario with future discharge at the nearbed level. Note the colour scale is logarithmic.



NINO_EXISTING	P1	P5	P10	P50	P90	P95	P99
surface	413	683	966	4204	20833	50036	173647
mid	411	717	1017	4639	35928	69548	223618
nearbed	516	884	1161	5573	37360	84356	261050
NINO_FUTURE							
surface	324	529	735	2934	15045	29923	136116
mid	345	575	800	3096	22438	47468	157498
nearbed	417	717	994	3979	23413	46098	194541
NINA_EXISTING							
surface	355	621	854	3200	14974	25268	82155
mid	374	649	884	3206	19234	40208	105660
nearbed	440	774	1100	4583	24565	52669	128880
NINA_FUTURE							
surface	280	494	674	2356	10032	19316	75012
mid	328	536	724	2742	12414	27440	84406
nearbed	360	640	902	3176	15976	34966	98870

Table 3-2Minimum dilutions around the edges of the mixing zone for the different scenarios.



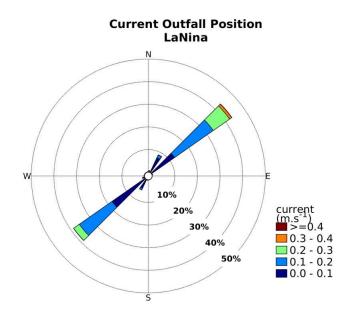


Figure 3-18 Rose of depth-averaged current at the outfall location during La Nina annual period.

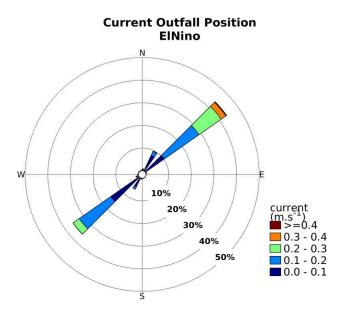


Figure 3-19 Rose of depth-averaged current at the outfall location during El Nino annual period.



4.ltem 3

Nelson City Council considered an upgrade of the current outfall diffuser to improve mixing of the wastewater at the outfall. The current diffuser design is considerably different from the proposed upgrade (Figure 4-1 and Figure 4-2, respectively) and therefore a rerun of the near-field model was necessary to assess changes in the near field. Near-field modelling of the initial turbulent mixing was undertaken using CORMIX (see section 2.2 in MetOcean Solutions, 2022).

The proposed upgrade design is a 2-arm diffuser, extending 100 m each at an angle of 30 degrees to the centreline, 60 degrees between the two arms (Figure 4-2). The pipe that connects the diffusers to the treatment plant is perpendicular to the shoreline and is approximately 430 m long. There are a total of 40 ports in each arm, with openings approximately 2.5 m apart and on alternate sides. The ports are fitted with a duckbill valve. The initial height of the diffuser port centreline is at 0.5 m above seabed.

Due to limitations in the model setup, the following factors have to be considered in order to represent the proposed design:

- The model setup did not include the duckbill fitted on the ports. We used a port opening diameter of 75 mm (informed by Nelson City Council).
- The model can only have one arm per simulation. Therefore, we simulated each arm separately, and half of the discharge flow in each arm.

The model output provided the geometry of the nearfield (length and width) as well as the dilution at the edge of the nearfield that can be used as input in far-field particle tracking modelling (not carried out at this stage for the proposed design). In this subsequent stage (far-field modelling), the nearfield results for both arms can be combined, accounting for the distance between the arms (see the "V" shape design) and assess the different dilutions for the QMRA analysis.

Simulations

Ambient and wastewater characteristics (temperature and salinity) were setup as previously for the current diffuser simulations (see MetOcean Solutions, 2022). Wastewater is buoyant (has a lower density) in relation to the ambient (receiving) water. A total of 15 CORMIX near-field simulations where undertaken. We used half of the flow that have been previously simulated to account for a single arm, and simulated the discharge flow under 5 different ambient current velocities: 0.05, 0.10, 0.20, 0.30, 0.40 m/s (Table 4-1)



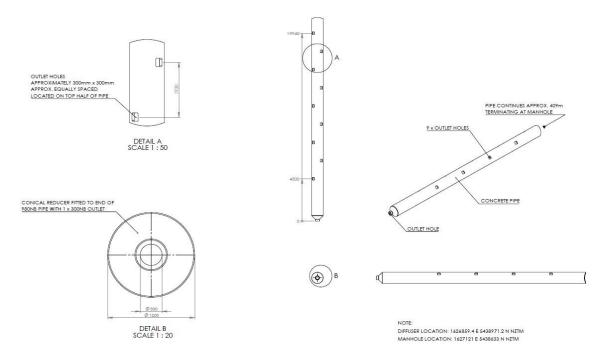


Figure 4-1 Current diffuser design and dimensions (Source: Nelson City Council).

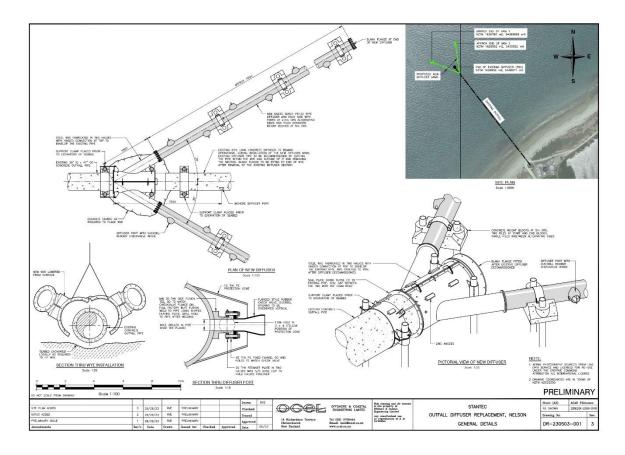


Figure 4-2 Proposed diffuser upgrade design and dimensions (Source: Nelson City Council).



Table 4-1CORMIX near-field list of simulations.

Scenarios	Ambient current (m/s)	Total Flow rate (m³/s)	Flow rate – EACH ARM (m³/s)		
	0.05				
	0.10				
p10	0.20	0.048	0.024		
	0.30	_			
	0.40				
	0.05				
	0.10				
p50	0.20	0.094	0.047		
	0.30				
	0.40				
	0.05	_			
p90	0.10	_			
	0.20	0.185	0.0925		
	0.30	_			
	0.40				

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Results

A range of simulations were undertaken in order to estimate the nearfield plume characteristics. It is noted that the proposed design is a 2-arm diffuser and, due to model setup limitations, the simulations considered one arm only and half of the flow, so results should be interpreted accordingly. The intention was to use these nearfield results at each arm for the particle release in the far-field modelling (which was finally not undertaken).

The nearfield region (NFR) describes the zone of strong initial mixing where the so-called nearfield processes occur (i.e., the initial jet characteristic of momentum flux, buoyancy flux and outfall geometry influence the jet trajectory and mixing of a wastewater discharge). It is the region of the receiving water where outfall design conditions are most likely to have an impact on in-stream concentrations. Beyond that is the far field region where physical mixing mechanisms are dominating with spreading motions and passive diffusion controlling the trajectory and dilution of the wastewater discharge plume.

Results show that in general, the dilution at the edge of the nearfield region (for one-arm) is significantly higher for the proposed upgrade (Table 4-2 vs Table 4-3). Dilution with the proposed design varies from 913.3 to 21,205.2 (Table 4-3). We note that, in reality, there would be a superimposition of the modelled plume with the plume released from the other arm. However, the large dilution difference predicted for the existing vs proposed design suggest that the mixing would still be improved for the 2-arm setup. Dilution tends to be higher in faster ambient current velocities (for the same flow rate). Variations to this trend across different flow rates can occur depending on the ambient currents compared to the discharge velocity (i.e., the velocity the discharge flow exits the pipe).

In all scenarios, the nearfield region is expected to be shorter (NFR length) and wider (NFR width) in near stagnant water while, under faster current flow, this region lengthens in the flow direction (Table 4-3).

The transition between nearfield and far-field dynamics (the edge of the nearfield) occurred between 4.2 minutes to 35.1 minutes, for the different conditions simulated and does not reach the shoreline.

Scenarios	Ambient current (m/s)	Flow rate (m³/s)	Discharge velocity (m/s)	NFR length (m)	NFR half- width (m)	NFR thickness (m)	Concentration at NFR edge (%)	Dilution at NFR edge	Cumulative travel time (minutes)	CORMIX Hydrodynamic Classification
p10	0.05	0.048	0.07	104.6	24.7	13.5	0.144	693.4	18.5	MU1H
	0.10		0.07	220.1	21.1	11.8	0.096	1037.4	29.3	MU1H
	0.20	-	0.07	613.7	20.2	10.1	0.059	1702.5	48.7	MU1H
	0.30		0.07	1182.4	19.3	9.6	0.043	2308.5	63.6	MU1H
	0.40		0.07	1907.3	18.7	9.2	0.035	2871.4	77.8	MU1H
p50	0.05	0.094	0.13	121.7	92.4	3.5	0.292	342.6	24.8	MU1V
	0.10		0.13	167.5	21.1	12.9	0.173	577.4	20.0	MU1H
	0.20		0.13	433.3	20.6	10.5	0.108	922.6	33.2	MU1H
	0.30		0.13	825.0	19.8	9.9	0.081	1242.3	44.4	MU1H
	0.40		0.13	1333.9	19.1	9.5	0.065	1535.4	54.3	MU1H
p90	0.05	0.185	0.26	154.7	185.9	2.2	0.454	220.5	37.0	MU1V
	0.10		0.26	131.7	22.2	13.5	0.309	324.1	13.8	MU1H
	0.20		0.26	310.6	21.0	11.1	0.199	502.7	22.5	MU1H
	0.30		0.26	33.75	8.9	13.5	0.256	390.2	3.7	MU8
	0.40		0.26	33.75	8.8	13.5	0.194	514.5	2.8	MU8

Table 4-2Results for near-field simulations for the **EXISTING** diffuser. NFR = Near-field region.



Scenarios	Ambient current (m/s)	Flow rate – ONE ARM (m ³ /s)	Discharge velocity (m/s)	NFR length (m)	NFR half- width (m)	NFR thickness (m)	Concentration at NFR edge (%)	Dilution at NFR edge	Cumulative travel time (minutes)	CORMIX Hydrodynamic Classification
p10	0.05	0.024	0.14	47.63	56.81	13.50	0.0313	3195.3	12.0	MU1H
	0.10		0.14	114.04	52.43	13.50	0.0170	5898.3	17.7	MU1H
	0.20		0.14	305.41	51.19	12.91	0.0091	11015.4	25.2	MU1H
	0.30		0.14	555.34	51.00	12.61	0.0062	16079.8	30.6	MU1H
	0.40		0.14	853.67	50.93	12.49	0.0047	21205.2	35.1	MU1H
p50	0.05	0.047	0.27	37.53	59.31	13.50	0.0587	1703.7	8.5	MU1H
	0.10		0.27	84.72	53.87	13.50	0.0323	3094.7	12.5	MU1H
	0.20		0.27	58.75	43.72	13.50	0.0199	5022.8	11.2	MU8
	0.30		0.27	58.75	43.49	13.50	0.0133	7494.5	7.5	MU8
	0.40		0.27	58.75	43.41	13.50	0.0100	9974.1	5.6	MU8
p90	0.05	0.0925	0.52	29.89	62.58	13.50	0.1095	913.3	6.1	MU1H
	0.10	-	0.52	26.18	50.54	12.55	0.0729	1371.5	4.2	MU8
	0.20		0.52	58.75	43.95	13.50	0.0390	2565.9	11.1	MU8
	0.30		0.52	58.75	43.59	13.50	0.0262	3817.3	7.5	MU8
	0.40		0.52	58.75	43.47	13.50	0.0197	5074.9	5.6	MU8

Table 4-3Results for near-field simulations for the **PROPOSED** upgrade diffuser. NFR = Near-field region.



5.References

MetOcean Solutions. (2022). *Nelson North Wastewater Treatment Plant (NWWTP) dispersion modelling* (No. P0526; p. 117). MetOcean Solutions.

