Whangārei Harbour Stormwater Dilution Modelling

Prepared for:

Northland REGIONAL COUNCIL
Te Kaunihera ā rohe o Te Taitokerau

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PO Box 151, Raglan 3225, New Zealand
Ph: +64 7 825 0087 | info@ecoast.co.nz | www.ecoast.co.nz

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V1	2 June 2020	Draft	JCB
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Authors

Dougal Greer MSc

Rhys McIntosh MSc

Jose Borrero PhD

Executive Summary

Northland Regional Council (NRC) requires a product that can aid with decision making around consenting of proposed stormwater discharges into the Whangārei Harbour. A hydrodynamic model was developed to provide a yearlong simulation of stormwater release and to assess dilutions over a range of mixing zones. The results were produced with the goal of back calculating acceptable limits for discharge concentrations for a range of contaminants. The tool was developed for three hypothetical stormwater outfalls. These were represented on a flexible, variable resolution grid so that it can be refined for future outfall configurations as required.

The modelling focused on the Hātea River with the three discharges. The model domain also included the Raumanga Stream for future scenarios. The outfalls represented a range of bathymetric settings at up, mid and downstream locations. Each of the outfalls was simulated using two hypothetical catchments: a smaller 'A' catchment with an area of 5,000 m^2 and the larger 'B' catchment with an area of 25,000 m^2. The study considered the 10, 20, 30 and 50 m mixing zones as circular boundaries around each outfall.

The model was compared against available measured sea level data and the model accurately reproduced the predominantly tidal water level signal at the Town Basin even during flood events.

Analysis of the yearlong record of dilution from the modelling shows that the minimum dilutions at the edges of the mixing zones are not simply associated with the largest rain events. Rather they are a complex interaction of tidal conditions and hydrographs. Modelled dilutions were analysed using extreme value analysis to provide 1 and 2 year return interval dilutions at the boundaries of each mixing zone for each scenario.

The Tables of 1 and 2 year return interval dilutions at the edge of each mixing zone are provided and can be used to back calculate outfall concentrations for specific pollutants for similar to those simulated here. The model also provides a general framework that can be used to simulate other outfalls as the need arises.

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1 Background

Northland Regional Council (NRC) requires a product that can aid with decision making around consenting of proposed stormwater discharges into the Whangārei Harbour (Figure 1.1). eCoast was engaged to develop a model that could be used as a general tool to assess the impacts of stormwater outfalls located in waterways draining into the Whangārei Harbour. A hydrodynamic model was developed to provide a yearlong simulation of stormwater release and to assess dilutions over a range of mixing zones. The results were produced with the goal of back calculating acceptable limits for discharge concentrations for a range of contaminants. The tool was developed for three hypothetical stormwater outfalls. These were represented on a flexible, variable resolution grid so that it can be refined for future outfall configurations as required.

The modelling focused on the Hātea River with the three discharges located at upriver ('Upper'), midriver ('Middle') and downriver ('Lower') locations. The model domain also included the Raumanga Stream (see Figure 1.2). The outfalls also represented a range of bathymetric settings with the Middle outfall providing an intertidal setting, the Upper location providing a more rapid drop off into the river channel while the Lower location provided a discharge into deeper water. Each of the three outfalls was simulated using two hypothetical catchments: a smaller 'A' catchment with an area of 5,000 $m^{2-}$and the larger 'B' catchment with an area of 25,000 m^2. These two catchment sizes were used to calculate the stormwater flow rates using the methodology outlined in Section 2.2. The study considered the 10, 20, 30 and 50 m mixing zones as circular boundaries around each outfall.

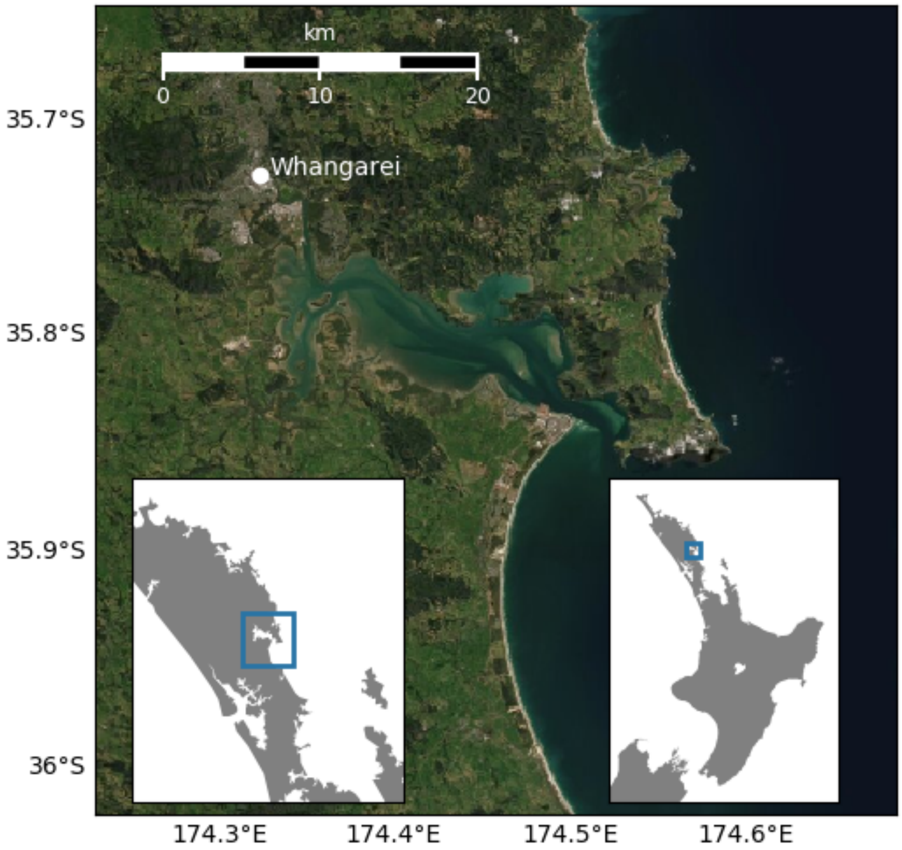

Figure 1.1. Whangārei Harbour located on the northeast coast of Northland.

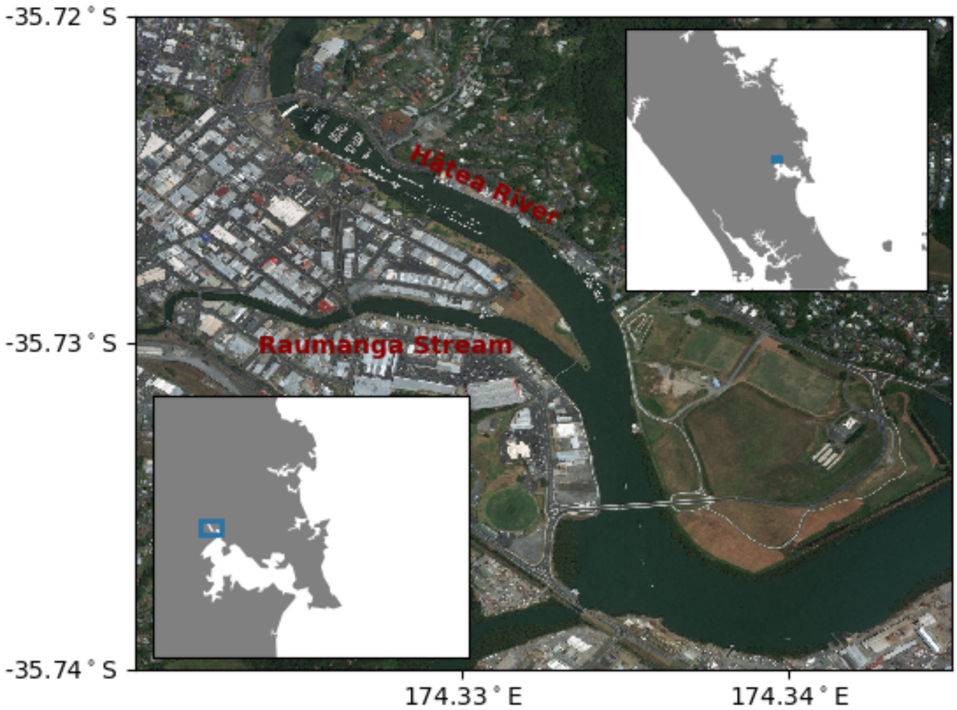

Figure 1.2: The Hātea River and Raumanga Stream which run through Whangārei and drain into the Whangārei Harbour.

2 Model Development and Calibration

The hydrodynamic modelling software used for this project is D-Flow Flexible Mesh (D-Flow FM) by Deltares, part of the Delft3D FM Suite (Deltares, 2019). It was developed as a 3D model including salinity but not temperature as it was not required for this model. Wind was also not included in the model as the riverine currents are much more strongly affected by river flow and tidal effects. The model domain was extended to include Whangārei Harbour in its entirety so that the tidal signal from the open ocean was propagated accurately to the outfall location. Salinity was included from the open ocean, the upstream river and from the stormwater outfalls while numerical tracers were used to track the freshwater from each stormwater in isolation from other freshwater sources.

The model was developed with seven layers with higher resolutions in the upper layers to better represent the buoyant plume. The layers thicknesses were 50%, 25%, 22.5%, 6.5%, 3.5%, 2.4% and 0.1% (from seabed to surface). The model was developed and run for the 2014 calendar year to provide a representative description of the outfall behaviour throughout the different seasons. This year was also chosen as it included several large rain events including a 2-year RI flood event in July 2014.

The modelling approach presented here has been prepared to provide estimates for a set of generalised outfall configurations and catchments. The outfalls are represented in the model as discharges in the upper layer of the water column, but without consideration to particular outfall structures or the velocity of discharged water into the marine environment.

2.1 Bathymetry Grid

D-Flow FM works with unstructured grids, meaning model cells can be from 3-sided up to 6-sided and irregularly shaped. This grid format allows model cell shape and size to be manipulated based on the morphology of areas of interest, removing the need for multiple model domains and making simulations more accurate and efficient.

Bathymetry for the model grid was derived from multiple sources. This included digitised LINZ hydrographic chart data within the Whangārei Harbour, two surveys of the Hātea River and numerous cross-sections of the Hātea River and Raumanga Stream. The model cells were designed to be coarse and regular in the open harbour (approximately 200 m by 200 m) for model efficiency, as essentially their function was only to propagate the tidal boundary condition from Marsden Point to the Hātea River (Figure 2.1 to Figure 2.5). At the Upper outfall location, the discharge is into shallow water but next to the deeper water of the narrow river channel. The Middle outfall is located further downstream, on a partially intertidal shallow flat which is approximately 60 m from the river channel. The Lower outfall is located at the river mouth also onto a shallow (but not intertidal) flat some 100 m from the main channel.

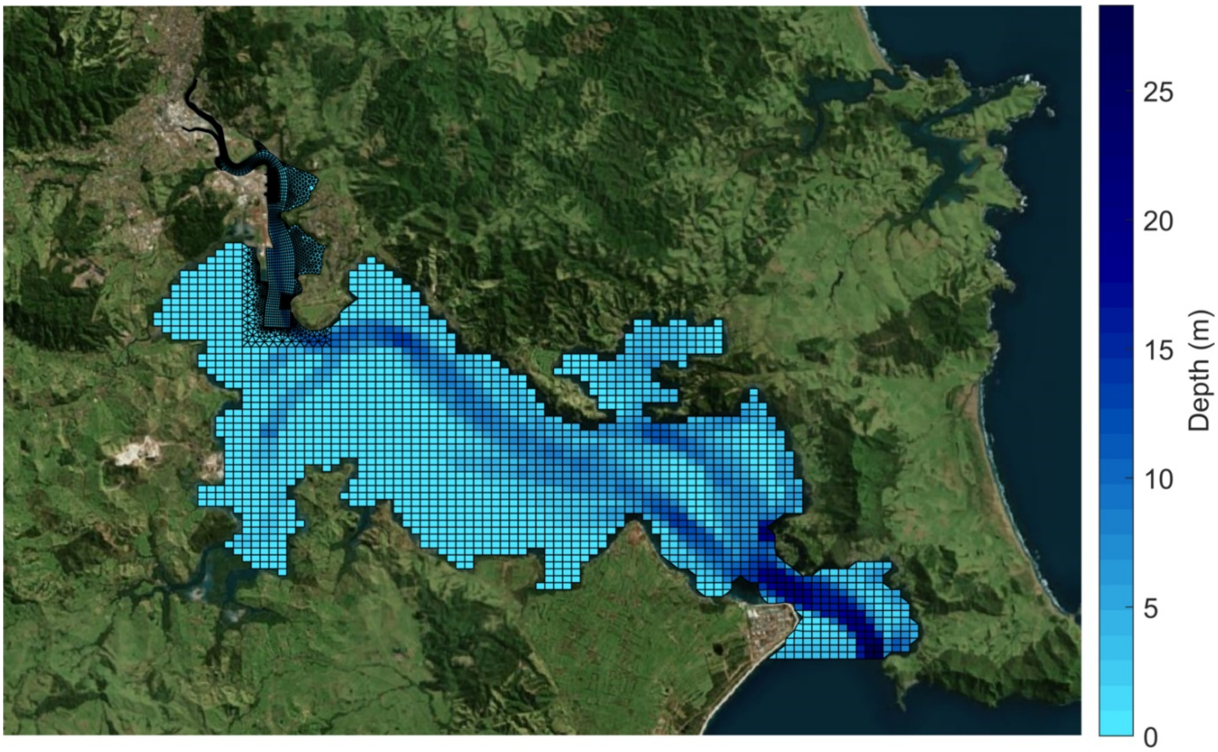

Figure 2.1 Model grid of the Whangārei Harbour showing model cells and interpolated bathymetry.

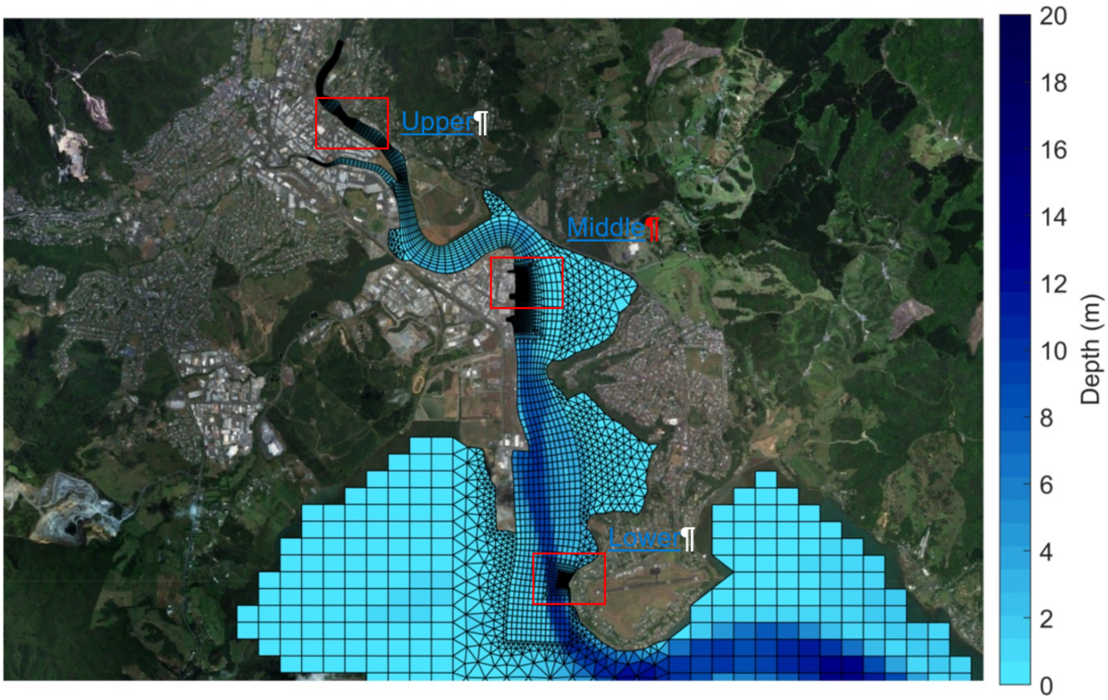

Figure 2.2 Magnified view of the model grid and its bathymetry, showing the unstructured mesh used for the Hātea River and its surroundings. Red boxes indicate the surrounding areas of theoretical outfalls 'Upper', 'Middle' and 'Lower'.

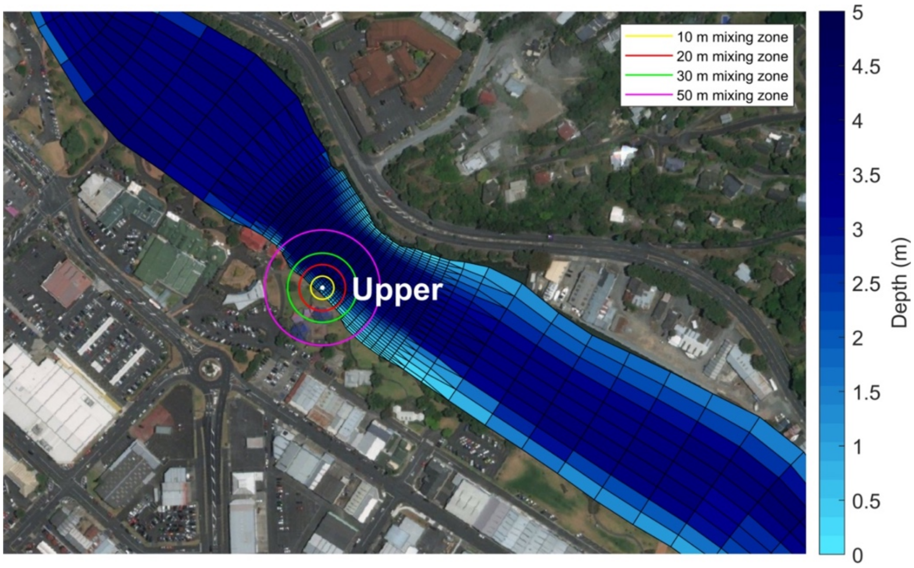

Figure 2.3: Bathymetry grid around the Upper outfall.

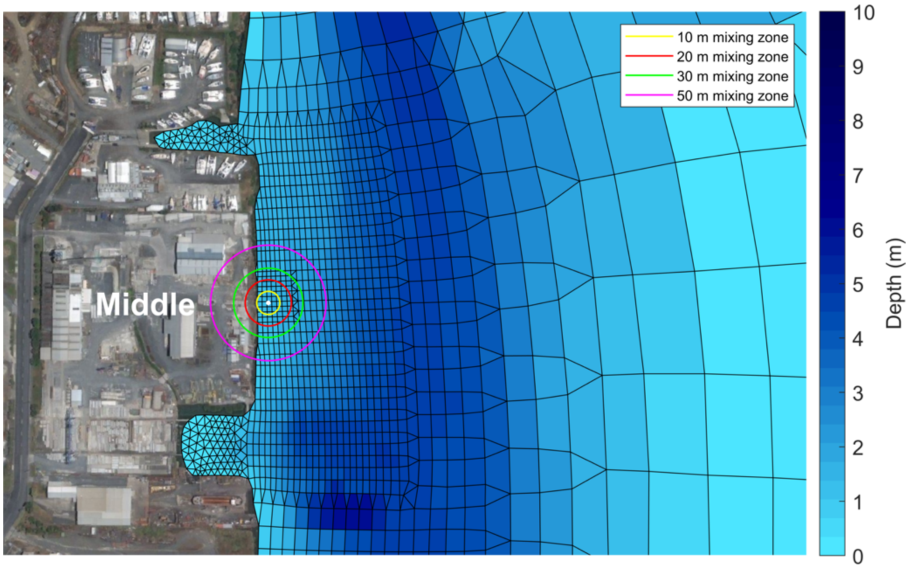

Figure 2.4: Bathymetry grid around the Middle outfall.

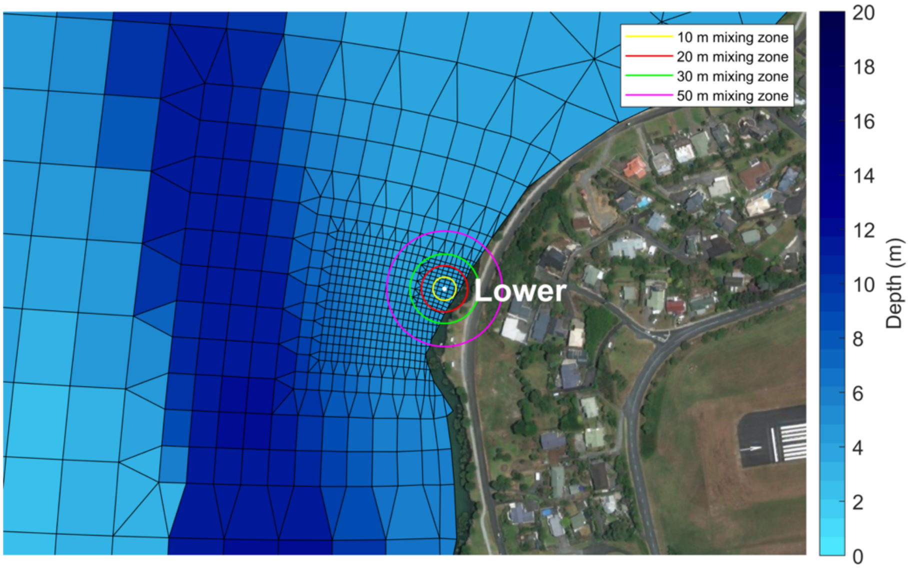

Figure 2.5: Bathymetry grid around the Lower outfall.

2.2 Boundary Conditions

The hydrodynamic model was driven by a water level boundary at the harbour entrance and discharge boundaries at the Hātea River and Raumanga Stream, all from long term records provided by NRC. Harbour entrance water level was sourced from the Marsden Point tide gauge, while discharge data was sourced from the Whareora Road and Bernard Street flow gauges for the Hātea River and Raumanga Stream respectively (see Figure 2.6 and Figure 2.7 for locations). All boundary data was extracted for the period 30 December 2013 to 1 January 2015 in order to model the entire year of 2014, including two days model spin-up time.

When the exact configuration of an outfall is known, nearfield modelling can be undertaken to consider ‘near-field’ plume dynamics which account for turbulence and the velocity of the outfall discharge water. Here the precise configuration is not known so near field modelling was not undertaken and stormwater was discharged into the top layer presenting a conservative approach without any vertical mixing. The stormwater was discharged as freshwater (0 psu) in to receiving water with a background salinity of 35 psu. In the model, the freshwater from each outfall was tracked separately so that freshwater from the river upstream and the other outfalls did not distort results. Note that the dilution values in the discharge cell do not take into account the complexities of mixing in the near field.

Discharge boundaries for the outfalls were generated by converting 2014 rainfall data from the Waiarohia at NRC Water St rain gauge (Figure 2.7) to peak discharge using the Rational Method (Kuichling, 1889):

$$Q = CiA$$

Where $Q$is peak discharge, C is the rational coefficient (0.95 for impervious surfaces), i is rainfall intensity and A is the catchment area.

Rainfall intensity will vary depending on the time of concentration Tc, which is defined as the time taken for rainfall to travel from the furthest part of the catchment to the point of discharge. For small catchments like the theoretical ones used in this study, Tc was estimated to be less than 10 minutes. However, both Auckland Regional Council and Hamilton City Council recommend that 10 minutes should be the lowest value used for Tc (Beca Carter Hollings & Ferner Ltd, 1999 and Hamilton City Council, 2010), so rainfall values were summed over a 10 minute period before being converted to intensity. Overall, there were two outfall flow time series applied to all three outfalls in a scenario, one time series for the 5000 m^2 catchment (Catchment A) and one for the 25,000 m^2 catchment (Catchment B).

Figure 2.6 Locations of available flow and stage data, used for boundary conditions and calibration.

Figure 2.7 Magnified view of the Hātea river, showing locations of available flow and stage data.

2.3 Model Output

Model output was produced as hourly spatial maps of modelled quantities and with a higher temporal resolution (10 minutes) as timeseries at specified observation points. For this project, observation points were placed at regularly spaced intervals along the mixing zone boundaries of each outfall (Figure 2.8). The timeseries from these observation points formed the basis of subsequent analysis of dilutions associated with each mixing zone.

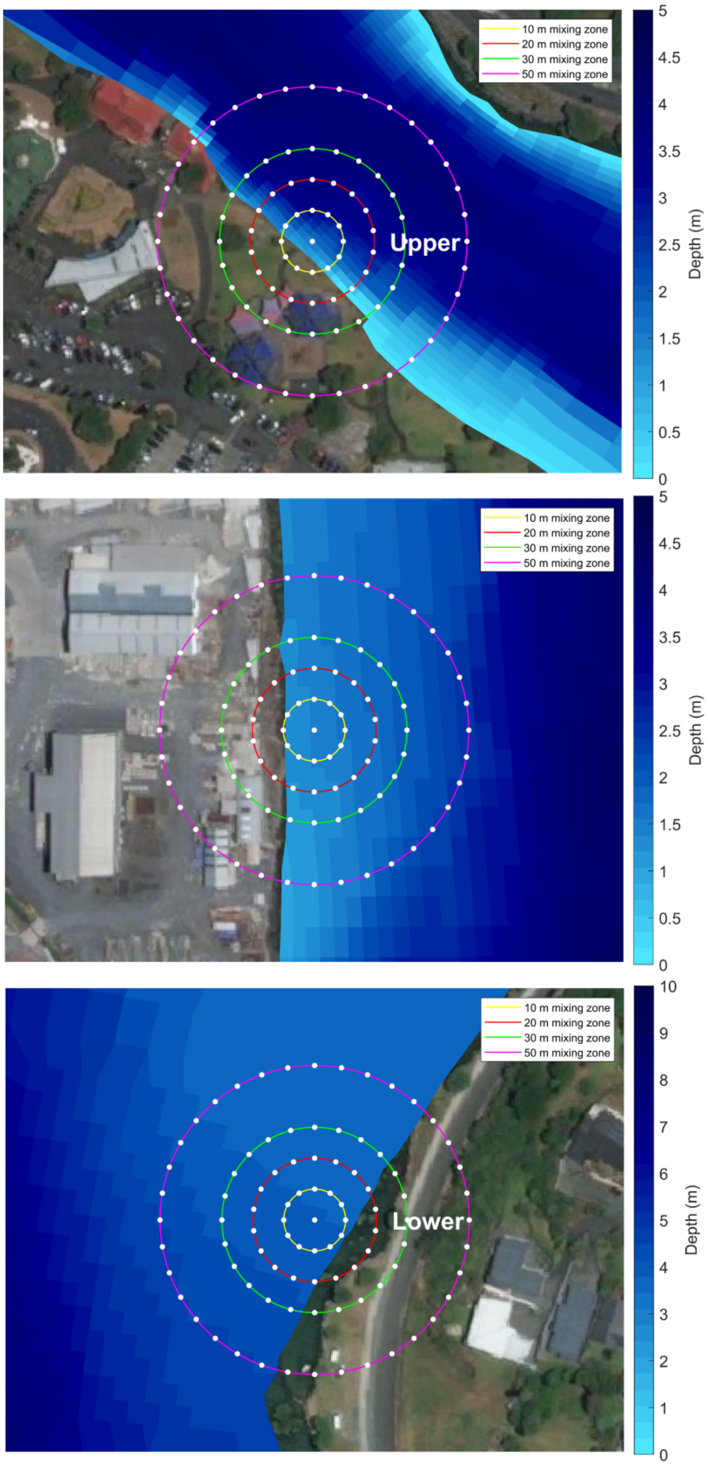

Figure 2.8: Model observation points for each mixing zone for each outfall.

2.4 Model Calibration

To assess the performance of the model, it was compared against available measured data. While no current speed data was available, sea level data from the Town Basin stage gauge (Figure 2.7) was used to provide measured water levels for comparison. Figure 2.9 shows the model accurately reproduced the predominantly tidal water level signal at the Town Basin. To assess the model, a separate calibration simulation was run taking in the largest flow event in the Hātea River at Whareora Road gauge record, (28 - 29 January 2011, maximum flow reached 478 m³/s). Figure 2.10 shows the model was able to reproduce water levels to a satisfactory level, even during flood events.

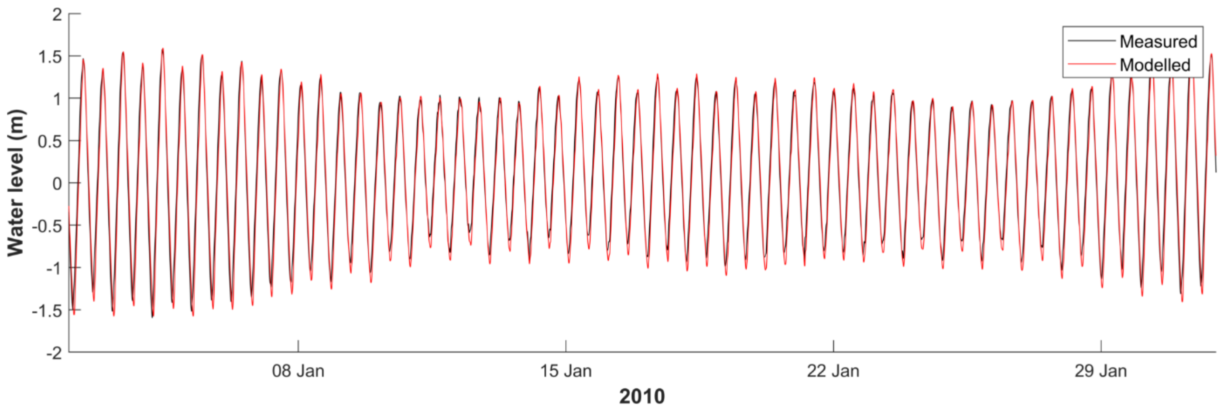

Figure 2.9 Measured and modelled water levels at the Whangārei Town Basin for the month of January 2010.

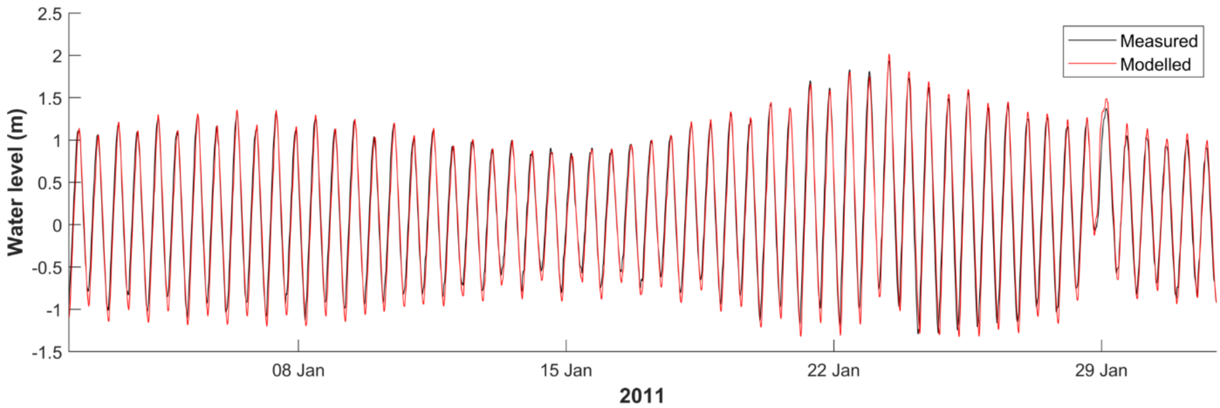

Figure 2.10 Measured and modelled water levels at the Whangārei Town Basin for the month of January 2011. Note the flood event beginning on 28 January.

3 Model Results

The model output was largely interpreted in terms of dilution at observation points along the boundary of each mixing zone, although for the purposes of understanding the hydrodynamic setting of each outfall, we also consider the spatial variability in the dilution and current velocity climate at each outfall location. Percentile results for dilution and current speed presented in this section only take into account the time when the outfall was flowing. This is because, the outfall only flows for 7% of the time (based on a 10 m rain record).

3.1 Velocity

Current speed percentiles from the yearlong model run of the B catchment scenario are shown in Figure 3.1 to Figure 3.3 for each outfall individually. The current speeds are dominated by river flow and tides, so these results are very similar for the A catchment.

The 50th percentile currents provide a picture of more usual current speeds and they are larger further downstream as the tidal currents become increasingly dominant.

Within the 10 m mixing zone, the current speeds are generally largest for the Upper location. However, the higher percentile current speeds vary by location with the highest 99th percentile current speeds at the Upper outfall within the 10 m mixing zone but at the Middle location for towards the 50 m mixing zone.

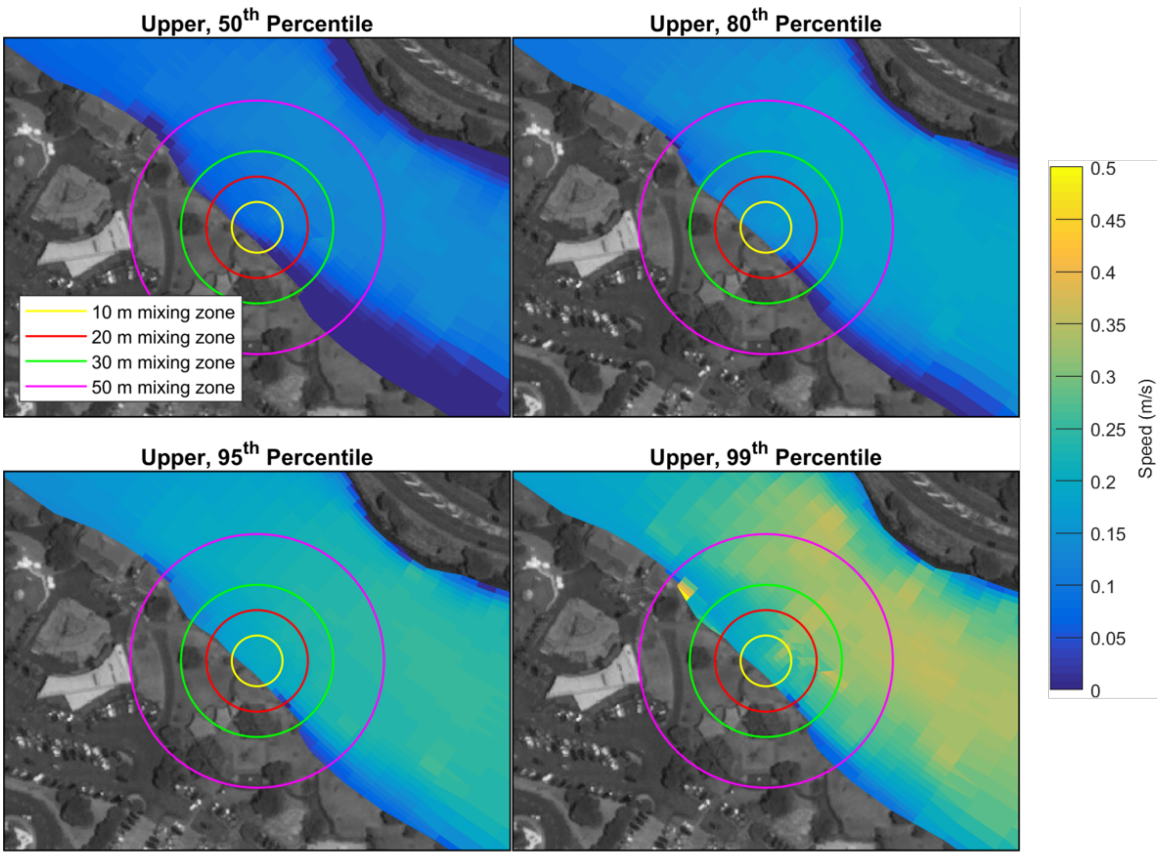

Figure 3.1: Percentile current speed plots at the **Upper** location.

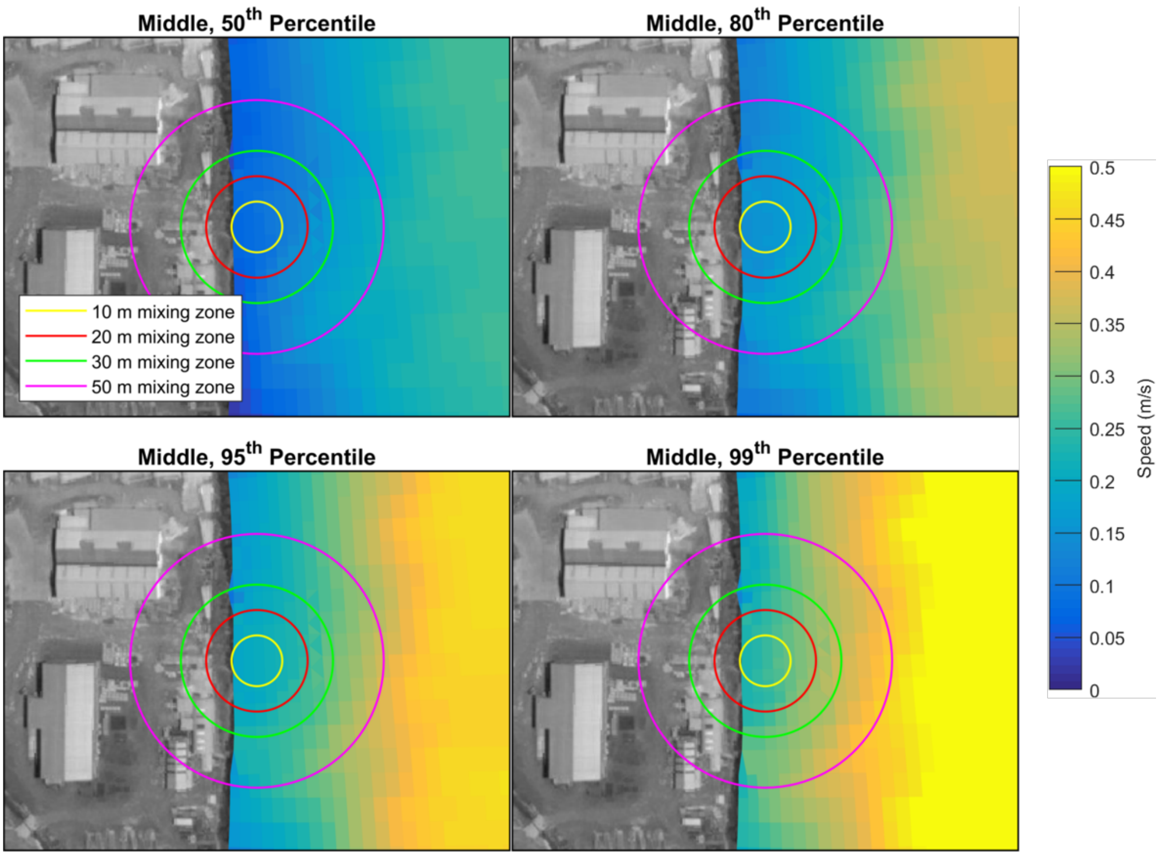

Figure 3.2: Percentile current speed plots at the **Middle** location.

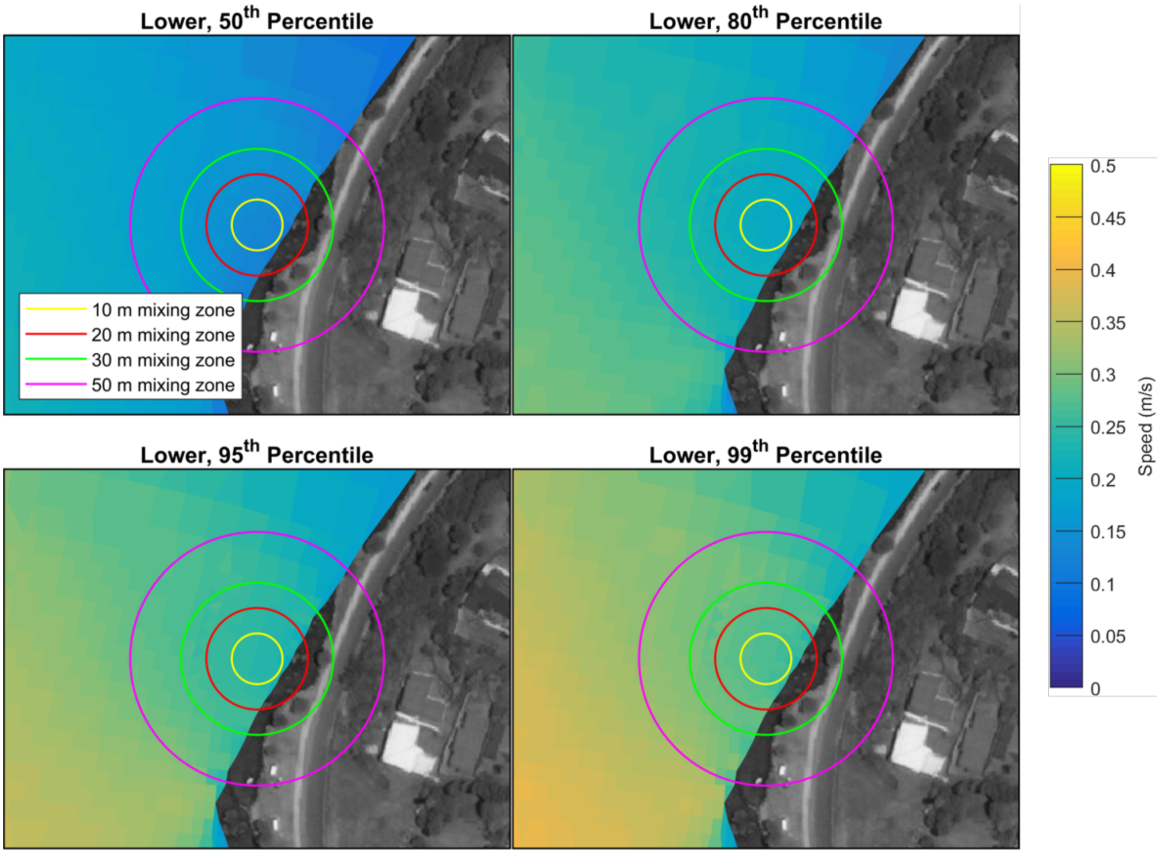

Figure 3.3: Percentile current speed plots at the **Lower** location.

3.2 Dilution

Dilution is calculated from salinity using the following relationship:

$$D = \frac{35}{35 - s}$$

Where D is dilution and s is salinity. Dilution is related to concentration c by the relationship:

$$D = \frac{1}{c}$$

Stormwater dilution can be visualised spatially by calculating specific percentiles of dilution over time at each grid node within the model. 95th and 99th percentile dilution are shown in Figure 3.4 to Figure 3.6 for the Upper, Middle and Lower outfalls. Note that because percentiles are calculated for each grid node separately, the percentile plots do not represent a simultaneous point in time for all grid nodes.

As expected, the dilutions are considerably lower for all of the B catchment simulations compared to corresponding A catchment simulations due to the larger flow associated with the larger B catchment.

Dilution occurred most rapidly at the Upper location due to faster overall current speeds which carry the plume away from the outfall. However at this location, a region of approximately 200 fold dilution persisted for a considerable distance up and downstream at the 95th percentile. For the Middle and Lower outfalls, the dilutions were lower closer to the outfalls but dropped off more rapidly with distance from the outfalls than for the Upper outfall. Because of the wide intertidal flat directly offshore from the Middle outfall, at lower tides the discharge ran along the mudflats before entering the river which led to a rivulet of low dilution water running through the mixing zones. This is reflected in the spatial plots of dilution as well as the subsequent timeseries analysis. Since this does not represent a region inside the mixing zones where mixing can take place, observation points in the rivulet were removed prior to undertaking timeseries analysis.

For each mixing zone, the minimum dilution was defined as the minimum dilution from all of the observation points associated with that mixing zone for each point in time. This provided a timeseries of minimum dilution for each mixing zone in each scenario throughout the model run. The full timeseries of dilution is shown for Catchments A and B in in Figure 3.7 and Figure 3.8. Zoomed in timeseries for a high flow event between 19 and 20 July 2014) are shown in Figure 3.9 and Figure 3.10. Percentile summaries for each case are presented in Table 3.1 and Table 3.2.

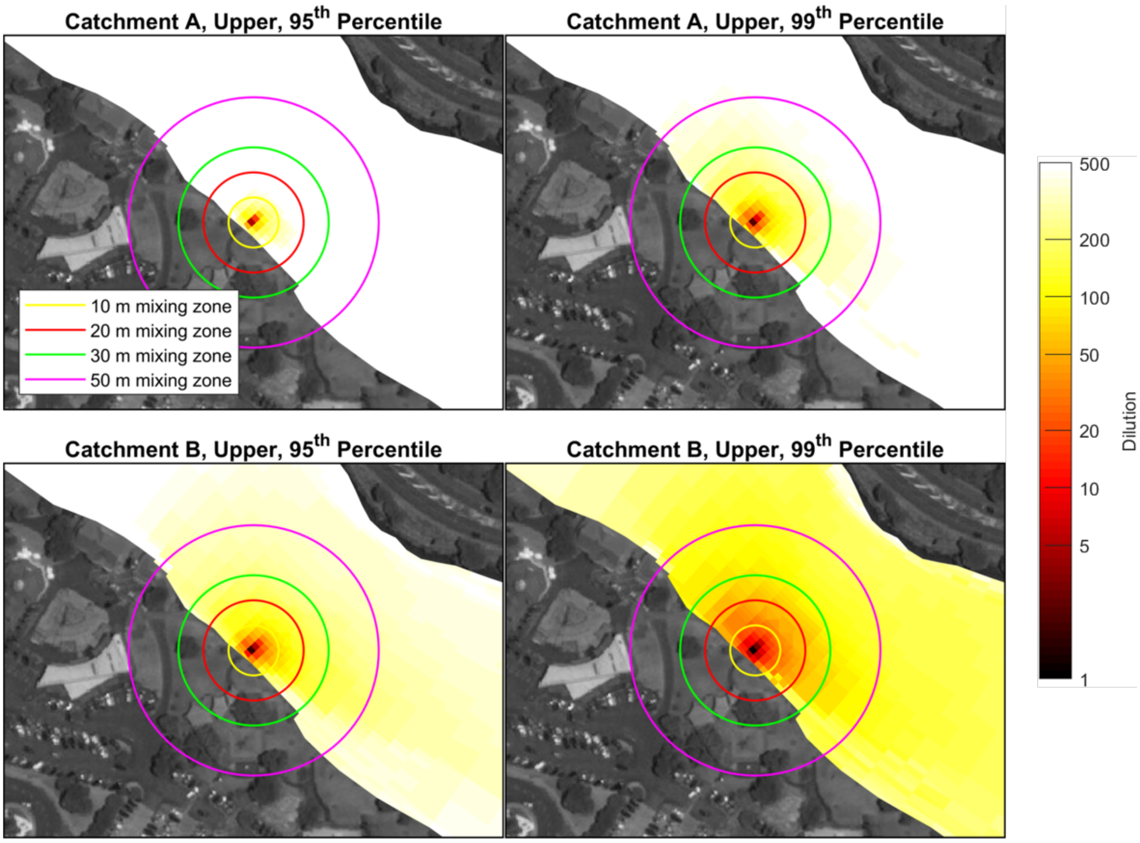

Figure 3.4: 90th and 99th percentile dilution for scenario A and B for the **Upper** outfall location.

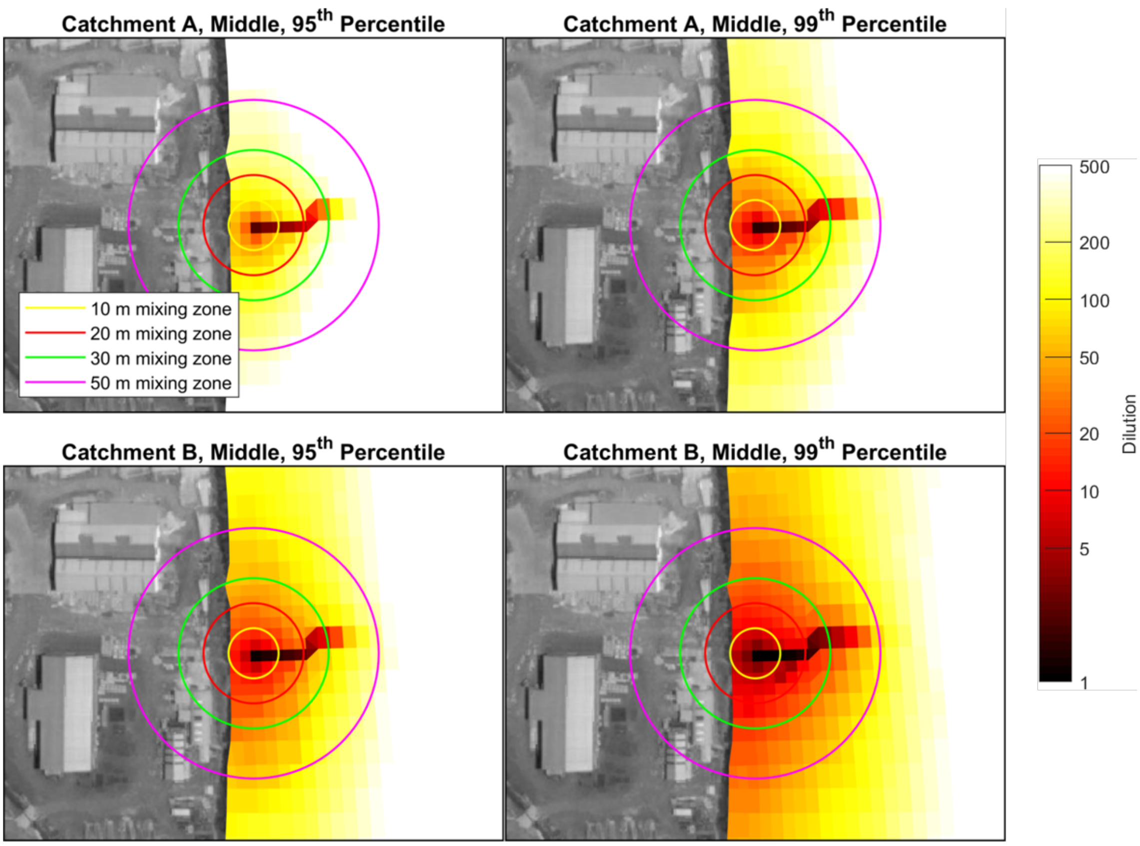

Figure 3.5: 90th and 99th percentile dilution for scenario A and B for the **Middle** outfall location.

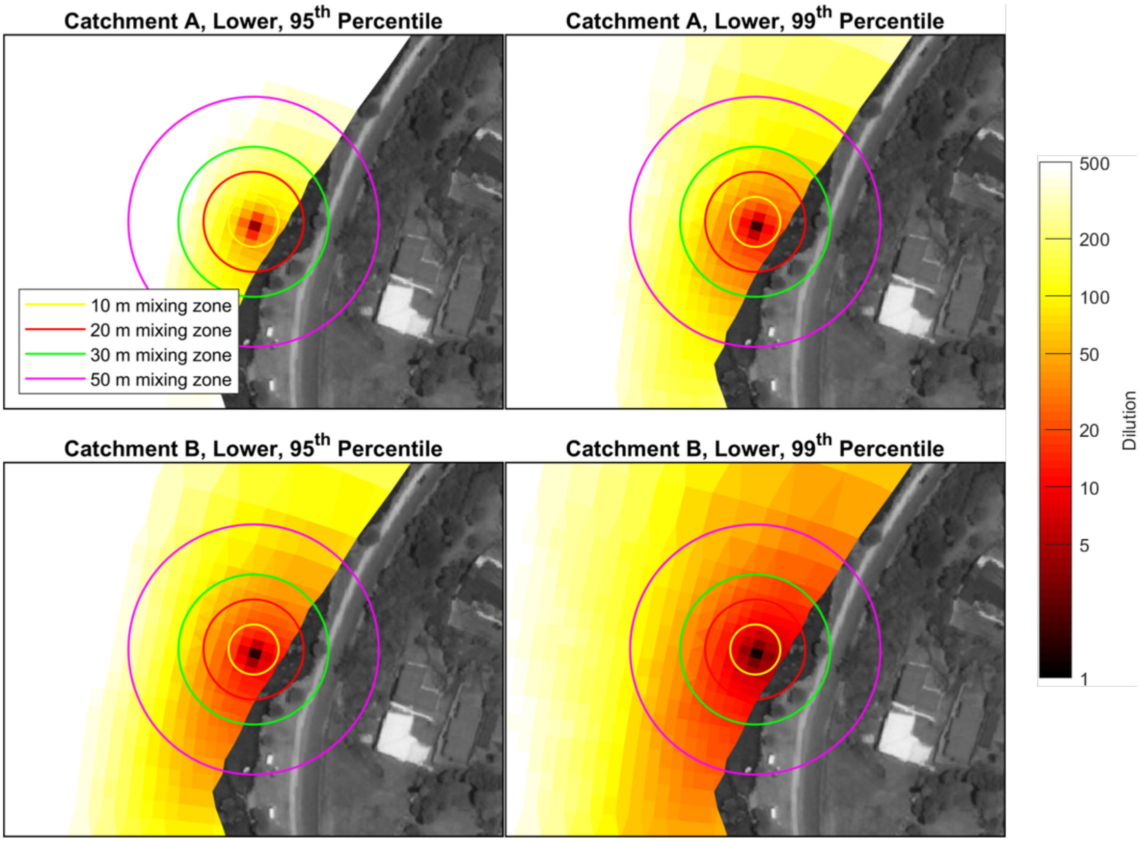

Figure 3.6: 90th and 99th percentile dilution for scenario A and B for the **Lower** outfall location.

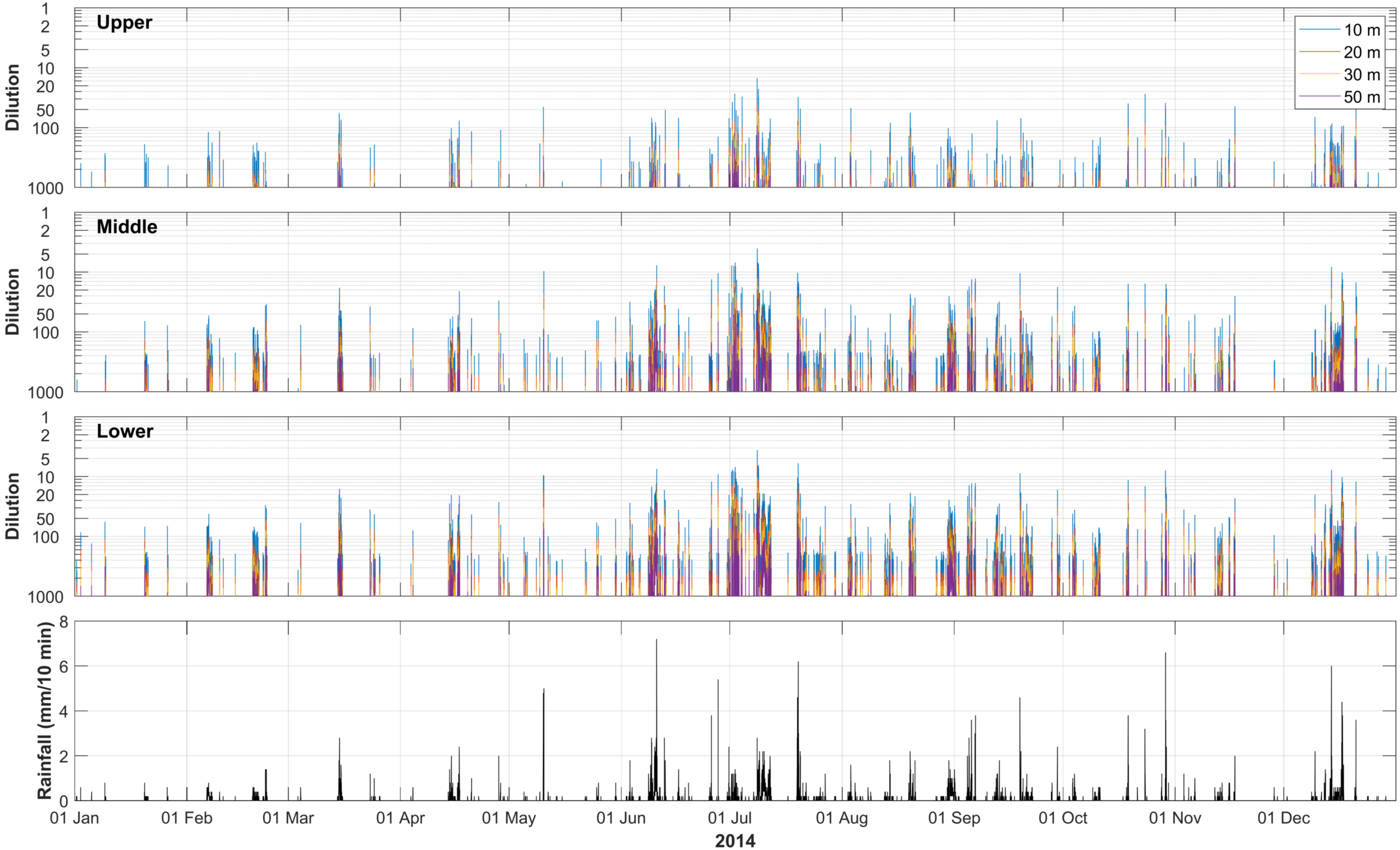

Figure 3.7: Timeseries of dilution for each mixing zone for **Catchment A**

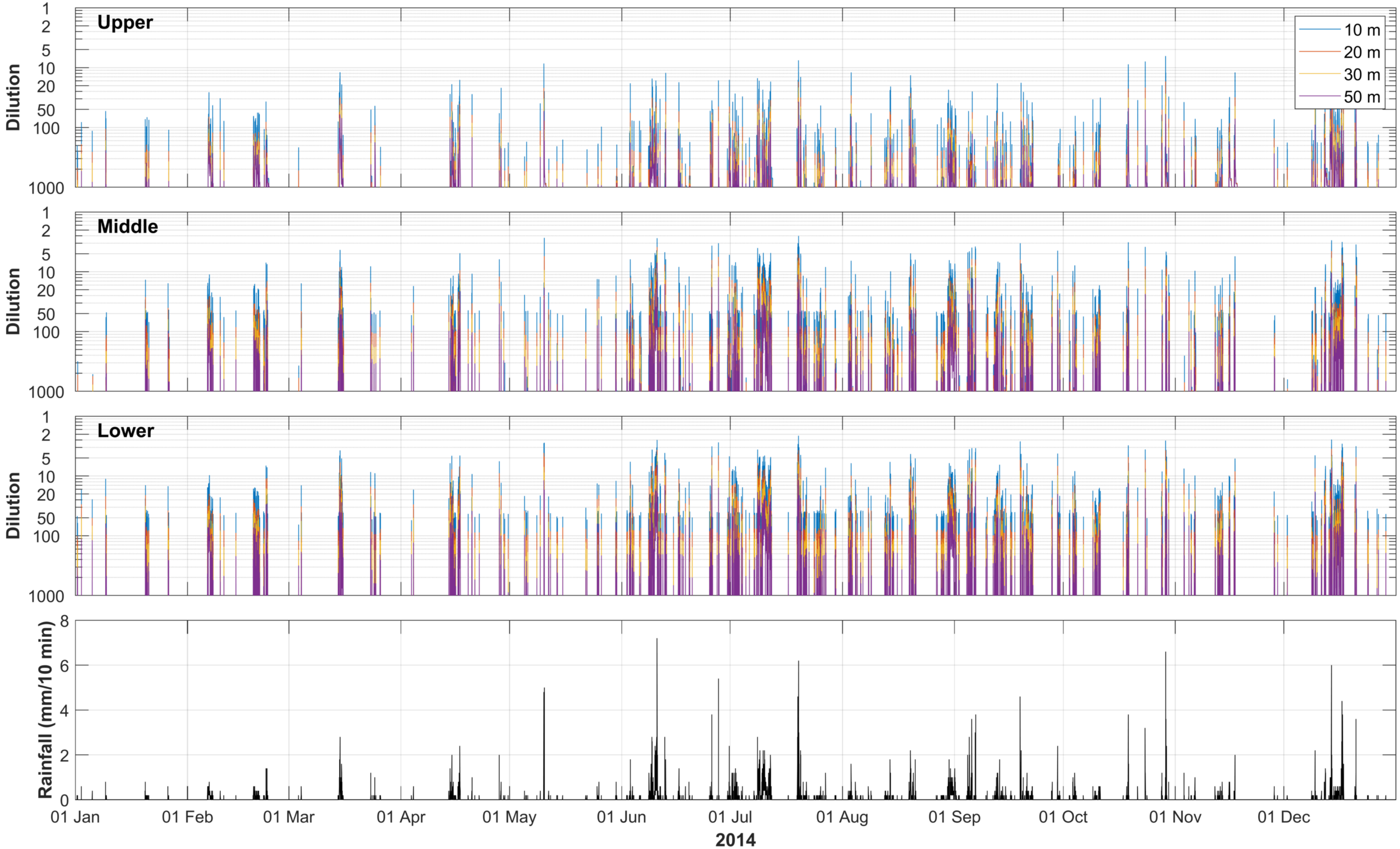

Figure 3.8: Timeseries of dilution for each mixing zone for **Catchment B**.

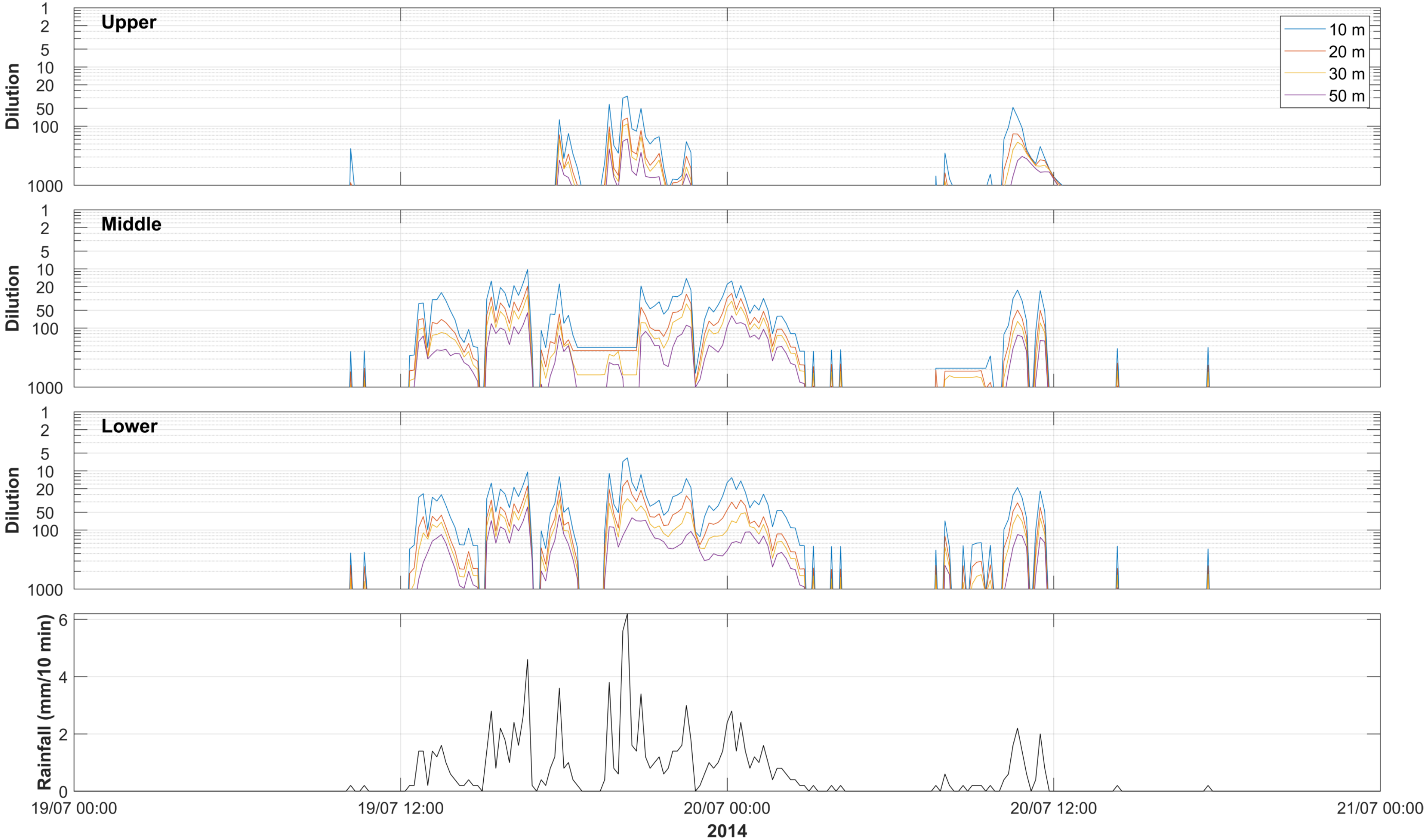

Figure 3.9: Timeseries of dilution for each mixing zone for **Catchment A** focusing on a large flood event between 19 and 20 July 2014.

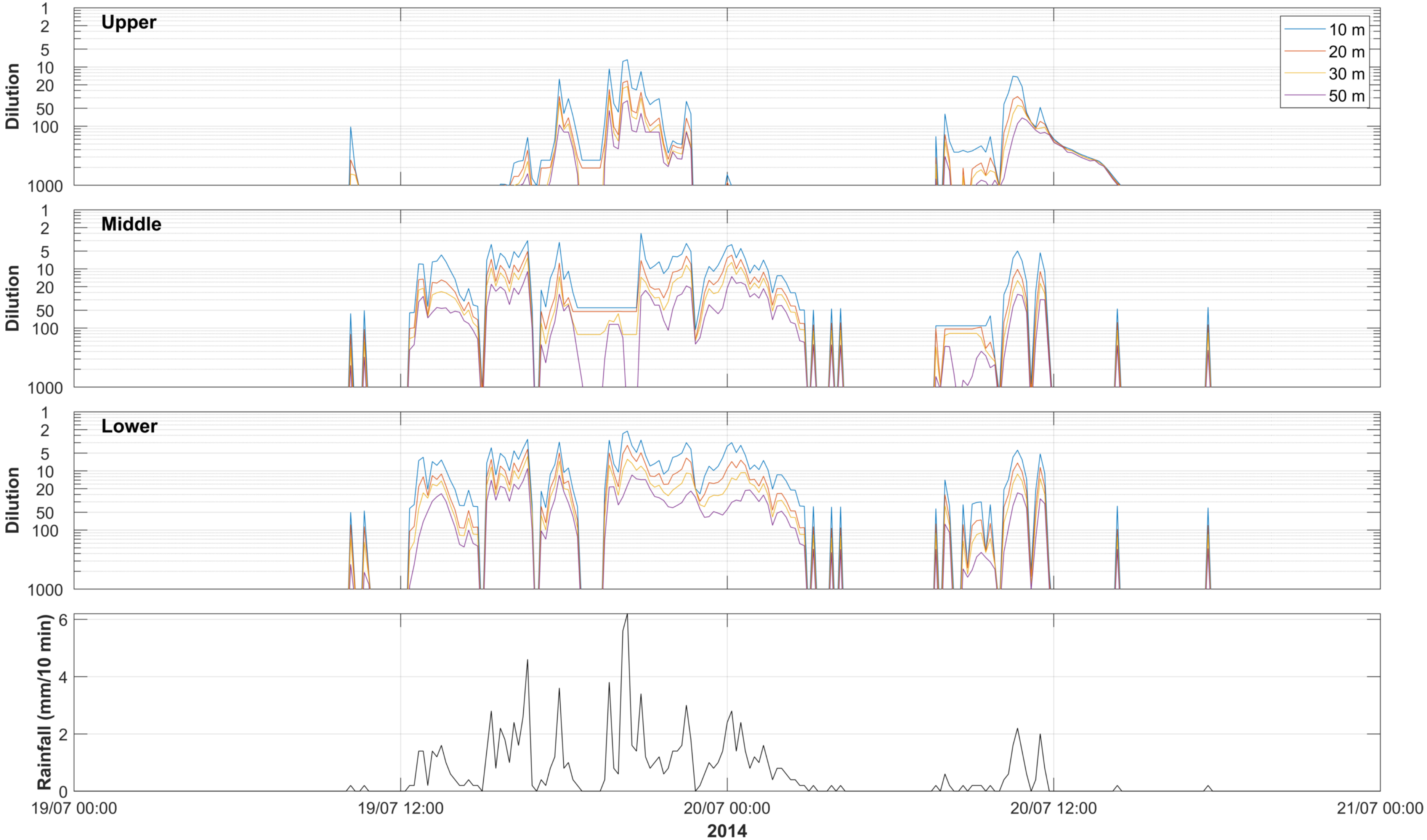

Figure 3.10: Timeseries of dilution for each mixing zone for **Catchment B** focusing on a large flood event between 19 and 20 July 2014.

Table 3.1: Percentile dilutions for each mixing zone in each outfall for **Catchment A**. Note dilutions are presented to 3 significant figures and only include times when the outfall was discharging.

		Upper		
	10 m	20 m	30 m	50 m
90th	197	415	553	836
95th	132	269	364	535
99th	48	109	147	228
Minimum	15	41	55	92
		Middle		
	10 m	20 m	30 m	50 m
90th	42	77	120	211
95th	26	51	83	133
99th	10	22	32	54
Minimum	4	8	13	20
		Lower		
	10 m	20 m	30 m	50 m
90th	32	62	92	161
95th	21	41	59	107
99th	9	17	24	42
Minimum	4	6	10	19

Table 3.2: Percentile dilutions for each mixing zone in each outfall for **Catchment B**. Note dilutions are presented to 3 significant figures. and only include times when the outfall was discharging.

		Upper		
	10 m	20 m	30 m	50 m
90th	48	100	130	192
95th	29	63	82	126
99th	15	33	45	69
Minimum	6	17	21	37
		Middle		
	10 m	20 m	30 m	50 m
90th	9	17	27	46
95th	7	14	20	32
99th	4	8	11	18
Minimum	3	4	5	7
		Lower		
	10 m	20 m	30 m	50 m
90th	8	14	20	35
95th	6	10	16	26
99th	4	6	9	15
Minimum	2	4	4	7

3.3 Extreme Value Analysis

Analysis of the year long record of dilution from the modelling shows that the minimum dilutions at the edges of the mixing zones are not simply associated with the largest rain events. Rather they are a complex interaction of tidal conditions and hydrographs. The model runs provide a medium term simulation of these interactions and the spatial variability in associated dilutions. Here we present the results of extreme value analysis undertaken on the timeseries of concentration at the edge of each mixing zone for each scenario.

Extreme value analysis was carried out using the WAFO (2011) toolbox developed by faculty of Engineering, Mathematical Statistics, Lund University, Sweden, which is a commonly used statistical toolbox for carrying out univariate extreme value analysis. The routines in WAFO were used for fitting a statistical distribution of concentrations.

The results of the extreme value analysis are shown in Table 3.3. The results presented here are similar in magnitude to the minimum dilutions presented in the previous section.

Table 3.3: Minimum dilutions associated with 1 and 2 year return intervals for mixing zones for each modelled scenario.

Catchment A			Catchment B		
Upper					
	1 year	**2 year**		**1 year**	**2 year**
10m	17	15	**10m**	7	6
20m	47	42	**20m**	17	17
30m	63	56	**30m**	22	21
50m	105	93	**50m**	37	36
Middle					
	1 year	**2 year**		**1 year**	**2 year**
10m	4	4	**10m**	3	2
20m	9	8	**20m**	4	4
30m	13	12	**30m**	5	4
50m	22	20	**50m**	7	7
Lower					
	1 year	**2 year**		**1 year**	**2 year**
10m	4	3	**10m**	3	3
20m	7	6	**20m**	4	4
30m	11	10	**30m**	4	4
50m	20	18	**50m**	7	6

3.4 Practical Application of the Model Guidance

As stated in the introduction, the purpose of this modelling was to develop a tool for assessing the dilution of storm water discharges. To this end we offer the following example for utilising the model output.

Suppose that a maximum concentration of copper of 1.0 µg/L is specified at the 50 m mixing zone boundary for a 25,000 m^2 catchment (Catchment B) at a location resembling the 'Lower' site based on a 1-year return period. The minimum expected dilution at this boundary in any given 1 year period is 7-fold (see Table 3.3) meaning that the maximum discharge concentration would be 7.0 µg/L. For the 2-year return interval, the minimum expected dilution is 6-fold providing a maximum discharge concentration would be 6.0 µg/L.

4 Summary

This project saw the successful development of a hydrodynamic model simulating marine and freshwater interaction between the Whangārei Harbour and inflowing rivers and streams. The model was calibrated against available sea level data and successfully reproduced sea level variability through flood events.

The model also successfully incorporated three hypothetical outfall configurations for two theoretical catchment sizes for a full yearlong simulation. Discharge rates for the outfalls were calculated based on rainfall data so that large flows were coincident with associated river flows.

The model output was used to produce tables of dilutions at four mixing zone limits (10, 20 , 30, and 50 m) for 1 and 2 year return interval rainfall and flow events. These can be used as look up tables to back-calculate discharge concentrations of known pollutants to produce maximum discharge concentrations.

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