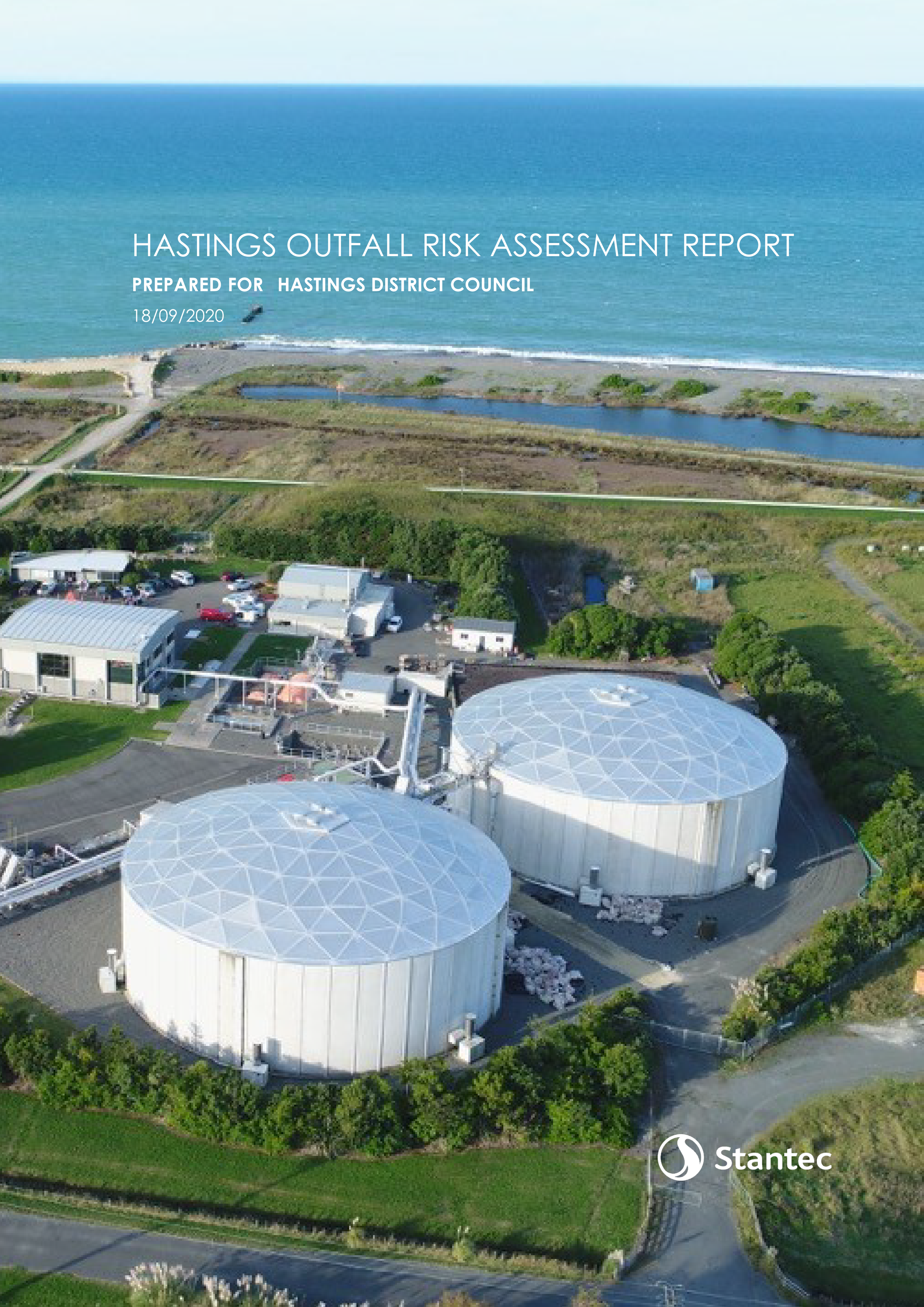
HASTINGS OUTFALL RISK ASSESSMENT REPORT

PREPARED FOR HASTINGS DISTRICT COUNCIL

18/09/2020



Stantec

QUALITY STATEMENT

PROJECT MANAGER

Mark Wollina

PROJECT TECHNICAL LEAD

Wayne Hodson

PREPARED BY

Olivia Lester — 21/09/2020

CHECKED BY

Ryan Abrey — 21/09/2020

REVIEWED BY

Wayne Hodson — 22/09/2020

APPROVED FOR ISSUE BY

Mark Wollina — 22/09/2020

HAWKE'S BAY
1st Floor, 100 Warren Street South, Hastings 4122
PO Box 13-052, Armagh, Christchurch 8141
TEL +64 6 873 8900, FAX +64 6 873 8901

REVISION SCHEDULE

Rev No.	Date	Description	Signature or Typed Name (documentation on file)			
			Prepared by	Checked by	Reviewed by	Approved by
00		Draft for Comment	OL	RA	WH	MW

Hastings District Council

Hastings Outfall Risk Assessment Report

CONTENTS

1. Introduction 1
1.1 Scope 1
1.2 Background 1
1.3 Summary of the Initial Hastings Outfall Pipe Inspection Reports 1
2. Structural Assessment 2
2.1 Assessment Basis 2
2.2 Results 3
2.3 Discussion 4
3. MetOcean Results Analysis 4
4. Risk Assessment 8
5. Mitigation Techniques 10
6. Conclusions & Recommendations 11
7. References 12

LIST OF TABLES

Table 1-1: Indicative Force Reduction based on Linear Wave Equations (for comparison only) 2
Table 4-1 Pre mitigation scores for each risk in the three scenarios and their average 9
Table 5-1 Post mitigation scores for each risk in the three scenarios and their average 10

LIST OF FIGURES

Figure 1-1 Pipeline seen in Outfall Bathy Survey (Fugro, 2019) 3
Figure 1-2 Allowable Span vs Seabed Penetration Depth 4
Figure 3-1 Failure scenarios analysed for the Dispersion Modelling Study 5
Figure 3-2 Maximum concentration gradient of the plume at the end, midway and quarter way offshore .5
Figure 3-3 Maximum dilution across the bay at the three locations 6
Figure 3-4 Mean concentration gradient of the plume at the end, midway and quarter way offshore 6
Figure 3-5 Mean dilution across the bay at the three locations 7
Figure 3-6 Number of occurrences at each location 7
Figure 3-7 Number of occurrences distributed against the dilution 8

APPENDICES

Appendix A MetOcean Dispersion Report
Appendix B MetOcean Excel Analysis
Appendix C Risk Register

1. Introduction

1.1 Scope

The Clive Wastewater Treatment Plant (WWTP) outfall pipeline is a critical asset that disposes treated wastewater via a diffuser into Hawke Bay in accordance with the approved Resource Consent conditions. The outfall was constructed in 1980 and is comprised of several components: a land-based steel manifold section which is attached to the pump station; a land-based section of the concrete pipeline; a submarine section of the concrete pipeline; and a diffuser over the last 300m of the pipeline.

This report is related to the submarine section of the outfall pipeline and provides a risk assessment to assist with the planning of future renewals and intervention works. The following scope is proposed as Stage 2 of the condition assessment, as detailed in the signed offer of service dated 11 October 2019:

- Analyse previous reports, surveys and tests completed in Stage 1 to conduct a preliminary investigation and risk assessment study
- Carry out a structural assessment of the pipeline to determine the loading on and need for the pre-stressed tendons
- Produce a risk register to determine the level of risk associated with the various elements if failure occurred, with high level timeframes
- Assessment of failure dispersion risk to feed into interim monitoring recommendations.

1.2 Background

A key component of the outfall is the approximately 2.5 km long submarine section of concrete pipeline. The pipeline has a novel design with articulating joints which are tied together with prestressed steel strands. There is limited information available about the long-term performance of this type of pipeline. There is sparse information of the original design material available, with only a more recent study by Opus of joint components from this pipeline which had been recovered during a repair in 2016.

This pipeline has experienced damage to three joints from what was suspected to be a trawler, with complete failure of one joint that caused a visible discharge plume approximately half-way along the outfall. Repairs were carried out in 2016 to seal the pipeline with stainless steel bands at each of the three damaged joints.

A key uncertainty for the long-term performance of the submarine outfall pipeline is the integrity or degradation/corrosion of the 12 prestressing strands that tie the pipeline together.

1.3 Summary of the Initial Hastings Outfall Pipe Inspection Reports

As the prestressed concrete pipe arrangement used for the Hastings outfall is a unique arrangement, it is difficult to estimate the remaining design life of the asset. While there are several technologies available to inspect pipelines, none are designed specifically for the application or materials used in this case. Hence a pragmatic approach, recommended below, is required to assess the pipeline condition while implementing an appropriate monitoring and contingency plan to address any damage to the pipeline in the interim.

It was agreed that the project will proceed in the following stages with interim workshops between each stage:

Stage 1 (COMPLETE) Proposed high level investigations (<u>carried out within this stage</u>):

- Pipe layout and burial – Data collected during NZDS diffuser maintenance contract
- Structural assessment of pipeline to determine pre-stressed tendons capacity
- Cores taken and concrete assessed, however structural assessment was not carried out
- Engage with NZDS to develop a repair contingency and procedure.

Stage 2 (IN PROGRESS) These surveys will feed into a preliminary investigation and risk assessment study to determine the level of risk associated with the various elements if failure occurred with high level timeframes. This study should include an assessment of failure dispersion risks to feed into interim monitoring recommendations.

Stage 3 (FUTURE PROPOSED) Prioritise more detailed investigation work required for the risk elements to manage/mitigate risk based on the types of survey outlined in the report together with high level costs. Investigations may require more detailed work that could result in reviewing of priorities:

- Concrete condition – possible internal sonar inspection/diver cores
- Joint condition – If any leaks are detected, a diver inspection may be required
- Internal inspection via Sonar or Electro.

Stage 4 (FUTURE PROPOSED) Detailed design and construction of work packages starting off with highest priority to minimise the risk of treated wastewater disposal via a break into Hawke Bay and the approved Resource Consent conditions being compromised.

2. Structural Assessment

2.1 Assessment Basis

A high-level assessment was carried out to estimate the performance of the existing pipe in bending and shear (global and local joint transfer).

A wave load of 5.1 kN/m was applied to the pipeline based on drag forces generated by an on bottom maximum wave velocity of 2.9 m/s and maximum acceleration of 1.5 m/s² as used in the diffuser design report corresponding to a conservative max depth limited wave of 7.5 m at a period of 12 s (OCEL, 2014). It should be noted that the extreme value analysis of the groyne renewal design waves carried out by MetOcean in May 2020 found a 1 in 100-year maximum wave height of 6.5 m at 10 m water depth. Hence the larger waves used by OCEL relate to a return period more than this. Table 1-1 provides indicative reduction factors for the current velocities to that used in the diffuser design report for comparison, however due to the nature of non-linear waves this close to shore, a more complex investigation is required to determine the actual wave orbital velocities.

Table 1-1: Indicative Force Reduction based on Linear Wave Equations (for comparison only)

Return Period (Yr.)	1	10	25	50	100	Diffuser Design
Indicative Velocity Reduction	0.6	0.7	0.8	0.8	0.8	1 (2.9 m/s)

For bending, it was assumed that the tension face is resisted only by the cables. We determined the allowable unsupported span that can develop if all 6 cables on the side of the pipe in tension are working. We then removed cables from the evaluation to determine the reduced allowable spans.

For shear resistance, the concrete pipe is assumed to be one continuous length held together by the strands and the shear is resisted by concrete section alone. For local joint shear transfer, a strut and tie model were developed. The struts are checked against the local compressive strength of the concrete while the tie is checked against the spiral reinforcing of the pipe from which the allowable unsupported spans for shear are calculated.

Initial results showed that the allowable span was not indicative of what has been observed in the 2019 bathy survey where approximately 40m is at least partly exposed. Hence a Load Reduction factor was used as per Figure 3-5 (DNV-GL, 2017) which is approximately 0.3 for the observed pipeline burial of 0.7 m. This reduction factor is due to wave shielding caused by the upstream build-up of material on the seabed.

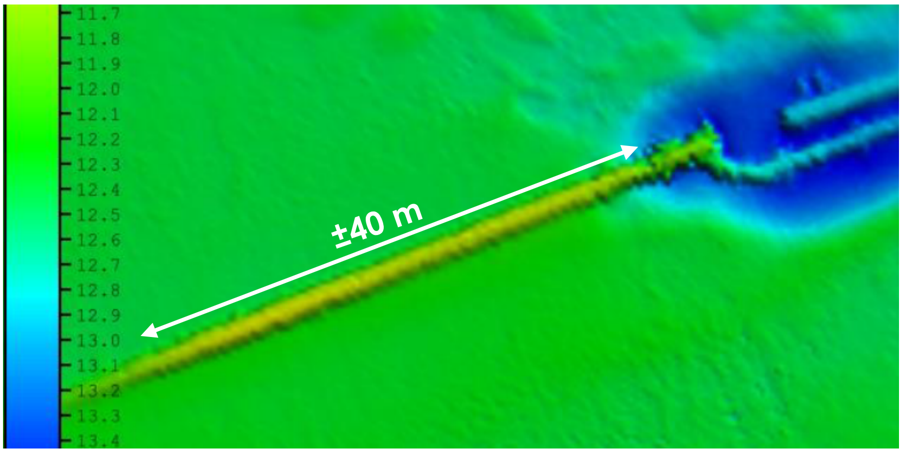


Figure 1-1 Pipeline seen in Outfall Bathy Survey (Fugro, 2019)

2.2 Results

2.2.1 Flexural capacity

With 6 cables working on the tension face, the moment capacity is approximately 1500kNm and we can accept an unsupported span of 49m. Then with 4 cables, moment capacity reduces to 1000kNm and span reduces to 40m and finally with only 2 cables, moment capacity reduced to 500kNm and span reduces to 28m. This assumes that the pipeline has no burial, and with the current burial of 0.6m the force reduces, and the allowable lengths increase to 73m, 60m and 42m respectively, which exceeds the 40m observed. Hence the pipeline is stable even if some of the cables failed assuming the pipe burial does not change drastically.

2.2.2 Shear capacity (global)

The shear capacity of the concrete pipe section is equal to 85kN which translates to an unsupported span of 26m however allowing for burial to 0.7m this span increases to 96m.

2.2.3 Local shear at joint

Considering the local effects of the joint reduced the shear capacity considerably from 85kN to 24kN which reduces the allowable unsupported span to 9m allowing for no burial and assuming a conservative tension zone developing in the cross section. Hence this is considered the critical case, however allowing for a less conservative tension zone as well as for burial of the pipe, the current condition is within a moderate risk zone, see Figure 1-1. There is, however, a risk that some joints may fail should there be localised scour around the pipe along with an extreme wave condition.

This also assumes that there is no passive resistance to horizontal loads by the seabed behind the pipeline as turbulence is expected to mobilise this material due to vortex sheading which is highlighted by the lower seabed on the downstream side of the pipe to the natural sediment transport regime. A more complex analysis, however, could estimate the bed mobilisation and account for the more solid material behind the pipe which resists pipeline shear forces.

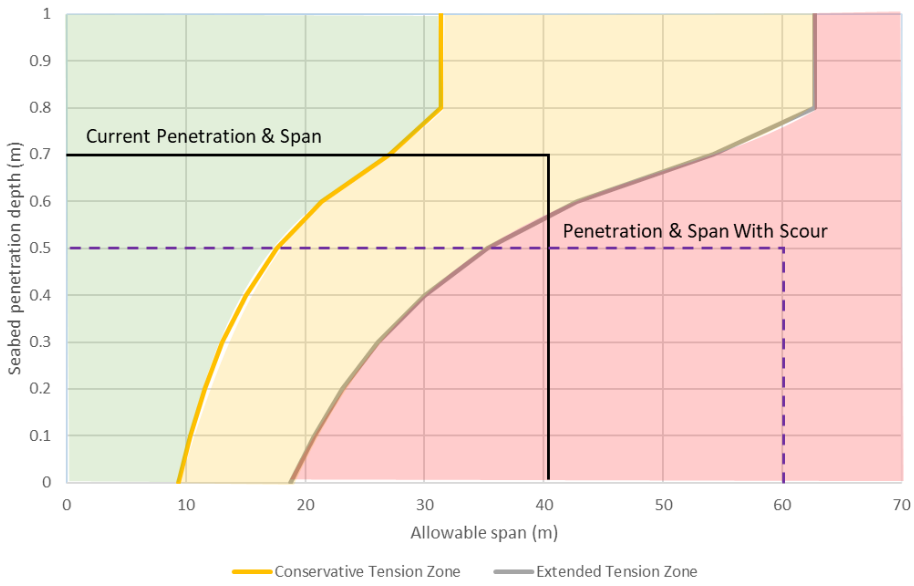


Figure 1-2 Allowable Span vs Seabed Penetration Depth

2.3 Discussion

Based on the results above, the only structural risk to the pipeline is where the pipeline is exposed, specifically the last 40 to 80 m before the diffuser as the remainder of the pipeline is anticipated to be buried below the seabed and would require significant scour before wave forces would be experienced on the pipeline. This can be monitored with subsequent bathymetric scans such as that carried out by Fugro for NZDS in 2019 as part of the diffuser maintenance contract.

The analysis also indicates that the redundant post-tensioned cables can restrain bending even if 2/3 of the cables fail on one side. There is, however, a risk that the exposed portion of pipeline could be damaged in extreme wave events due to shear at the joints, which could require further investigation and possible mitigation such as additional piled restraints or lateral rock support.

3. MetOcean Results Analysis

A MetOcean report was completed to understand the potential impact a plume from various failure scenarios along the pipeline could have on the ocean. The scope of work was to run three Langrangian particle tracking scenarios, using the open source Langrangian particle tracking model, OpenDrift. Each scenario assumes a full flow leak at an average daily flow rate of 48,000 m3/day, this was based on the existing effluent discharge data. The three failure scenarios considered were a breach at the diffuser end of the outfall (2750m offshore), halfway along the pipeline (1375m offshore) and a quarter way offshore (685m). The results obtained were the concentrations, frequency and time taken at 9 different locations in the bay, see Figure 3-1. The full MetOcean report can be found in Appendix A.

The results from the report were used to develop a consequence rating for each of the three scenarios. The analysis was completed in excel and can be found in Appendix B. The three different sets of data analysed were the maximum and mean concentrations found at each location and the time taken to reach these concentrations and the other was a histogram of the dilutions.

The maximum and medium concentrations were analysed using a concentration gradient formula. The concentration gradient is relationship between the change in concentration over the change in time. The concentration gradient values at each of the seven locations modelled by the MetOcean report were found and averaged for both the maximum and mean at the three modelled scenarios (End, Mid and Quarter), see Figure 3-1.

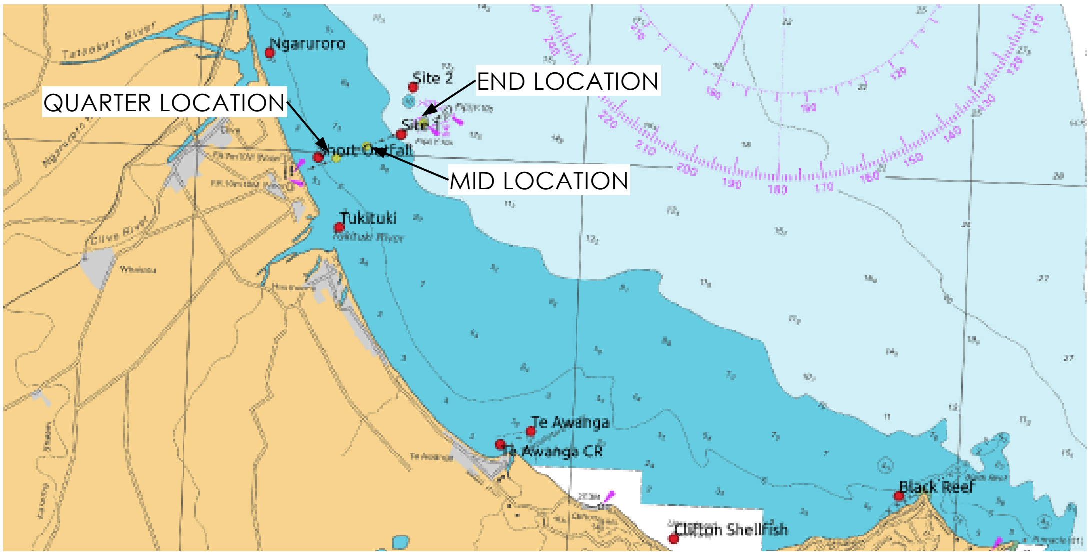


Figure 3-1 Failure scenarios analysed for the Dispersion Modelling Study

In the MetOcean report there were a total of nine locations analysed. Two locations were not considered in this analysis and are labelled as Site 1 and Site 2 in the report. These locations were not analysed because they are located near the end source plume, not near the beach. They may have skewed the data and are not an area of concern to the discharge consent requirement.

Figure 3-2 shows the maximum concentration gradients plotted for the three different scenarios. Figure 3-3 shows the maximum concentrations at the three different scenarios, with the End on the left and Quarter way offshore on the right. The analysis completed on the graph correlates to what is seen in the figure. The plume at the end of the pipeline shows high levels of concentration at the source and smaller amounts of high concentrations areas in the rest of the bay with majority of the bay experiencing a lower concentration (green). The plume at quarter way shows high concentrations at the source as well as at the mouth of the rivers and a slightly lower concentration (yellow colouring) along the length of the whole bay.

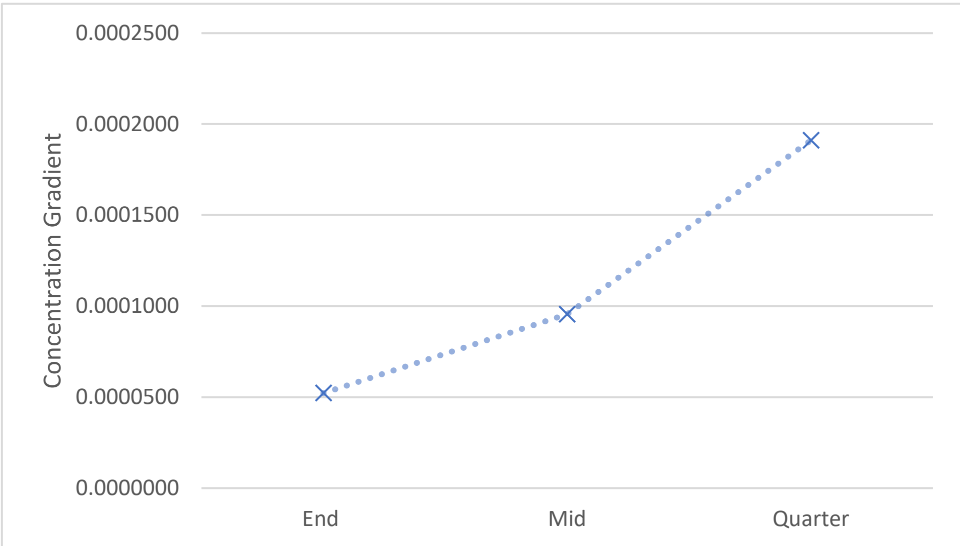


Figure 3-2 Maximum concentration gradient of the plume at the end, midway and quarter way offshore

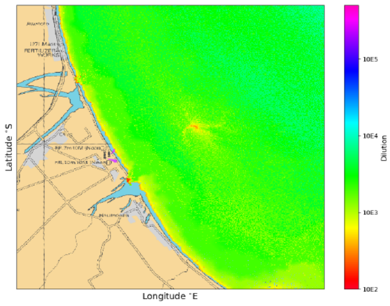


Figure 3.10 Maximum dilution during a month-long release at a rate of 48,000 m 3 day-1 for the 'normal' operation scenario. Dilutions above 5.10^5 have been masked.

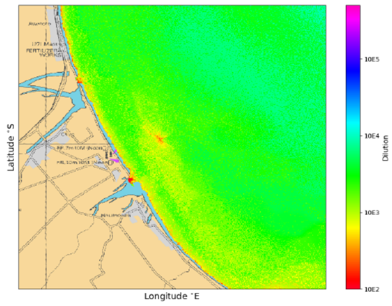


Figure 3.11 Maximum dilution during a month-long release at a rate of 48,000 m3 day1 for a pipe break halfway along the pipe. Dilutions above 5.10^5 have been masked.

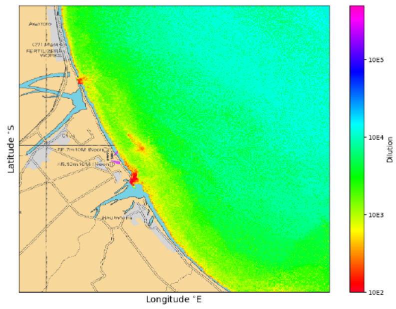


Figure 3.12 Maximum dilution during a month-long release at a rate of 48,000 m3 day-1 for a pipe break a quarter of the way along the pipe. Dilutions above 5.10^5 have been masked

Figure 3-3 Maximum dilution across the bay at the three locations

Figure 3-4 shows the mean concentration gradients plotted for the three different scenarios. Figure 3-5 shows the mean concentrations for the three different scenarios, with the end on the left and quarter way offshore on the right. The analysis completed in the graph correlates to what is seen in the figure. The figures show the mean level of concentration across the bay. The plume at the quarter way offshore shows a significantly higher severity than at the end plume. This can be seen in Figure 3-5 by the large amount of dark blue at quarter way in comparison to the midway and end figures. This confirms the validity of the graph and the use of it to determine the consequences for the risk assessment.

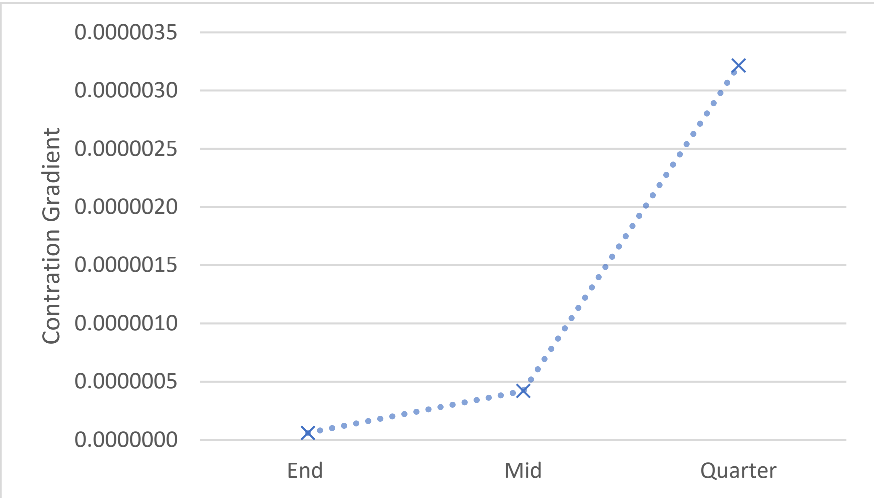


Figure 3-4 Mean concentration gradient of the plume at the end, midway and quarter way offshore

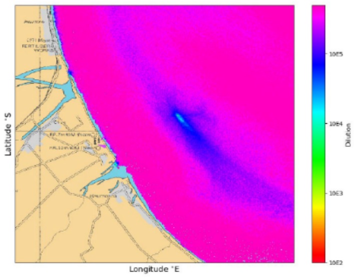


Figure 3.13 *Mean dilution during a month-long release at a rate of 48,000 m 3 day-1 for the 'normal' operation scenario. Dilutions above 5.10⁵ have been masked.*

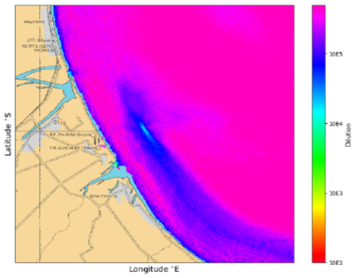


Figure 3.14 *Mean dilution during a month-long release at a rate of 48,000 m 3 day-1 for a pipe break halfway along the pipe. Dilutions above 5.10⁵ have been masked.*

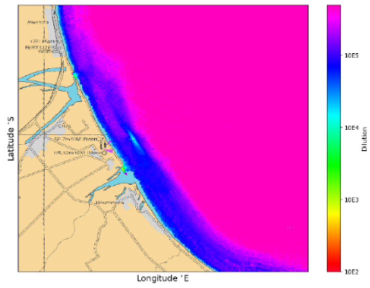


Figure 3.15 *Mean dilution during a month-long release at a rate of 48,000 m3 day-1 for a pipe break a quarter of the way along the pipe. Dilutions above 5.10⁵ have been masked.*

Figure 3-5 Mean dilution across the bay at the three locations

The final data analysed was the dilution histogram. The histograms demonstrate the frequency of occurrences at various dilutions. The number of occurrences at a dilution level were taken and entered into a table at their dilution value. The occurrences for each of the three scenarios were averaged and then plotted. Another graph was produced to show the distribution of the occurrences against the dilution levels. These two graphs can be seen in Figure 3-6 and Figure 3-7.

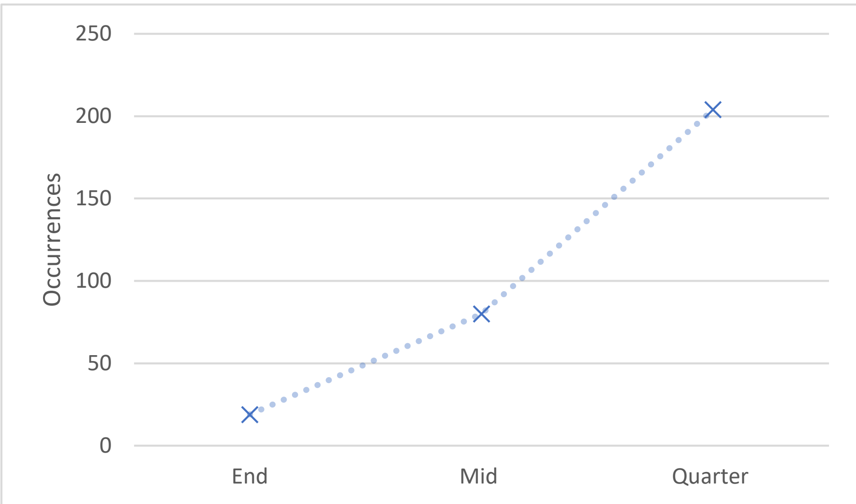


Figure 3-6 Number of occurrences at each location

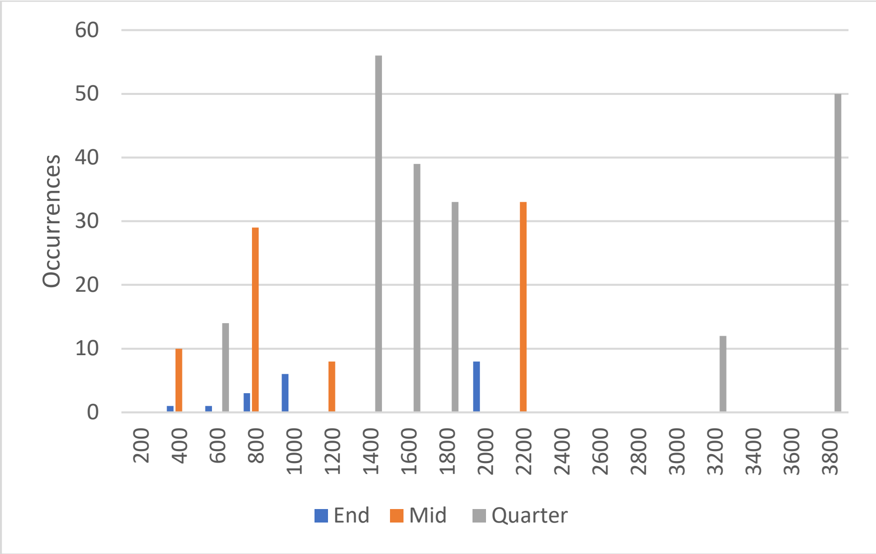


Figure 3-7 Number of occurrences distributed against the dilution

Figure 3-6 shows the sum of the number of occurrences at all dilutions at the three scenarios which suggests that the severity is worse at the quarter way point as the most occurrences happen in this location. However, the distribution graph of the occurrences against the distributions (see Figure 3-7) shows that these events occur at a lower dilution. At the end point there are less events occurring, however, they are happening at a higher dilution. It is also important to consider the public's perception if a plume were to occur. Though the higher concentrations may have a worse environmental impact, they are still far below the required nearfield dilutions set out in the diffuser consent of 1:100. It is assumed that the higher level of occurrences corresponds to an increase in frequency of the public noticing the plume if it were to occur at the quarter way.

From these observations it is considered that the overall consequence would be worse if the plume were to occur at the quarter way end and hence the consequence rating given to each risk will be scored according to the location of the leak. The graphs developed in excel were used to develop the consequence level for the risk assessment. This is discussed in the next section of this report.

4. Risk Assessment

The risk assessment was conducted on the risks identified in the previous Stantec report on failure modes. The nine risks investigated were:

- Failure of the rubber rings at the joints
- Corrosion/rupture of the post tensioning wires
- Internal/External degradation of the concrete wall
- Failure of the anchoring blocks
- Corrosion of the reinforcing wires
- Open Joints
- Damage to the pipe due to impact (e.g. boats)
- Failure of GRP & titanium collars
- Failure of rubber rings
- Failure of the manholes.

There are five levels of consequence – Very Low, Low, Medium, High, and Very High, with Very Low being allocated to the number one and Very High correlating to number five. The graphs in Section 3 were used to determine the consequence levels of the failures if they were to occur. Low represents the consequence to the bay should a plume occur at the end of the pipeline. Medium was selected for the midway point of the pipeline. This was because the graphs in Section 3 shows that a plume at the midway point is slightly worse than at the end point. A plume at a quarter of the way offshore has a consequence of Very High. This is because there is a significant increase from the halfway and end point in all three data sets. Note that the consequence level of the risk does not change after the mitigation techniques are applied, it is only the likelihood of the risk occurring that does.

The five likelihood levels are the same as the levels used for consequence – Very Low, Low, Medium, High, and Very High. A meeting between Ryan Abrey, Wayne Hodson and Olivia Lester was held to scrutinise the likelihood pre and post mitigation. For example, the discussions assessed the internal/external degradation of the concrete wall to allocate a likelihood score as low across all three locations. This was because the WSP report gave an estimate of remaining life to be 29-42 years, and the pipeline for the majority of its length is buried, suggesting the likelihood of degradation is low. The comparison to this is the risk of plume by damage to the pipe due to impact load like a boat trawler. The likelihood a fishing boat will be travelling over the pipe is high, and even higher the further out to sea making the risk very high. These types of discussions were had for all the risk likelihoods. The pre mitigation scores from the risk register for each risk in the three scenarios are in Table 4-1.

Table 4-1 Pre mitigation scores for each risk in the three scenarios and their average

Risk	End	Midway	Quarter Way	Average
Failure of the rubber rings at the joints	6	9	15	10
Corrosion/rupture of the post tensioning wires	6	6	10	7
Internal/ External degradation of the concrete wall.	4	6	10	7
Failure of the anchoring blocks.	8	6	10	8
Corrosion of the reinforcing wires	4	3	5	4
Open Joints	10	9	15	11
Damage to the Pipe due to Impact Load (e.g. boat)	10	12	20	14
Failure of GRP & Titanium Collars	6	9	15	10
Failure of Repair Bands	8	12	20	13
Failure of Manholes	6	9	15	10

The full risk register can be found in Appendix C. The average of each risk across the three locations was found, to understand the highest risk to the pipeline pre mitigation. The top risk identified was damage to the pipe due to impact load, scoring a pre mitigation score of 14. The average post mitigation score significantly dropped to 6.67 if the mitigation techniques mentioned in Section 5 were to be applied. The risk that poses the next highest threat is failure of repair bands, scoring an average pre mitigation risk of 13.33. However, again if the mitigation risks mentioned below were applied, the post mitigation risk drops to 6.67, significantly reducing the risk.

The mitigations techniques of each risk are discussed below. It is seen in the register that if these are applied the majority of risks reduce to an average post mitigation score of 6.67. Therefore, the risk of a plume occurring is low. The risk is slightly higher for the open joints which scored an average post mitigation of 8 and corrosion/rupture of the post tensioning wires which scored 7.33. This suggests further mitigation techniques should be investigated to reduce these risks.

5. Mitigation Techniques

The mitigation techniques developed for each risk are discussed below. The post mitigation risk scores can be found in the risk register in Appendix C. The post mitigation scores from the risk register for each risk in the three scenarios are in Table 5-1, these are the scores after the mitigation techniques discussed below were applied.

Table 5-1 Post mitigation scores for each risk in the three scenarios and their average

Risk	End	Midway	Quarter Way	Average
Failure of the rubber rings at the joints	4	6	10	7
Corrosion/rupture of the post tensioning wires	6	6	10	7
Internal/ External degradation of the concrete wall.	4	6	10	7
Failure of the anchoring blocks.	4	6	10	7
Corrosion of the reinforcing wires	4	6	10	7
Open Joints	8	6	10	8
Damage to the Pipe due to Impact Load (e.g. boat)	4	6	10	7
Failure of GRP & Titanium Collars	4	6	10	7
Failure of Repair Bands	4	6	10	7
Failure of Manholes	4	6	10	7

- *Damage to the pipe due to impact load (i.e. boat anchor)* – One mitigation technique would be to extend the current navigation exclusion zone to run along the length of the pipeline, coupled with stricter enforcement. Additional navigation buoys should be installed along the pipe route. The other mitigation technique would be to provide rock armour or concrete mat protection over areas that are at high risk of being hit.
- *Failure of the rubber rings at the joints* – A study was carried out on a set of rubber rings by WSP in 2017 to assess the integrity of the joints (WSP, 2017). The findings show that the risk of failure in the following ten years is low. However, it was noted that the sand seal was starting to deteriorate and may fail at some point. It is suggested that a sample of the joints be tested in 2028.
- *Corrosion/rupture of the post tensioning wires* – There are 12 cables (6 on each side) that offer some form of redundancy. Only one cable is required on each side to keep the joints together, and if the pipe is buried there is very little lateral force. The last 40m of pipe that is uncovered should be inspected during the annual diver campaign. The rest of the pipeline should be monitored with a bathymetric sonar scan to check for seabed movement which may uncover further sections, which can then be inspected.
- *Internal/External degradation of the concrete wall* – Concrete testing was carried out by WSP of concrete core samples. The cores were found to be dense, well-consolidated concrete with no discernible excess voids. They estimated a remaining life of between 29-42 years (WSP, 2019). However, another inspection with concrete core samples taken should be carried out in 10 years, to verify the condition of the concrete. This can occur at the same time as the rubber ring joint sampling.
- *Failure of the anchoring blocks (special anchor pipes)* – A specific inspection of the final anchor block (pipe) at the diffuser should be included in the annual diver maintenance inspection. This section should

be uncovered and while some of the anchor points may be obscured by the new diffuser steel support clamp, there should be at least two anchor points accessible. If during monitoring a strand anchor is found to have failed or is close to failure additional monitoring should be implemented to ensure that the joint integrity is not compromised with further specific anchors being uncovered for inspection.

- *Corrosion of the reinforcing wires* – As previously stated in the bullet 'internal/external degradation of the concrete wall' the condition of the concrete was good. WSP estimated the remaining life of the concrete to be between 29-42 years (WSP, 2019). The pipeline is also buried below the seabed along the majority of it and accordingly the corrosion risk is low in an anoxic condition. The annual bathymetric survey can be used to monitor that the pipeline will remain buried.
- *Open Joints* – Periodic monitoring of the exposed joints along the pipeline should reduce the likelihood of failure. Installation of piles around the joints in the exposed section can occur to reduce the movement in the pipeline and significantly lessen the risk of failure by reducing the span length. The risk of open joints in buried sections is low as the surrounding material will provide lateral support.
- *Failure of GRP & titanium collars* – The titanium collars should be periodically inspected to identify the collars that may be close to failure. This will allow for pre-emptive repairs on the collars which will reduce the risk of complete failure. This can take place at the same time as the rubber ring joint inspection in 2028.
- *Failure of repair bands* – Again, like the titanium collars, the repair bands installed during construction and in 2016, should be periodically inspected to identify the bands that may be close to failure. This will allow for pre-emptive repairs on the bands which will reduce the risk of complete failure.
- *Manholes* – The manholes should be periodically inspected, to identify manholes that may be close to failure. This will allow for pre-emptive repairs on them reducing the risk of complete failure. This inspection should be considered to take place with the diffuser maintenance inspections, as there is currently no information on the current condition of the manholes. It should be noted that manholes would need to be located below the seabed and uncovered to allow inspection.

In addition to the inspections described above it is recommended that surface monitoring is carried out more frequently than the quarterly boat inspection along the pipeline length closer to shore, where the consequence is very high. This could be undertaken with a drone inspection as proposed by the stage 1 report, as well as being triggered by monitoring unusual pressure drops in the outfall pipeline which could indicate a leak. This will assist in a rapid response to any issues.

6. Conclusions & Recommendations

From the structural assessment the prestressed tendons are currently utilised to hold the pipe joints together as well as resist bending moments exerted on the pipeline. As there are 12 tendons (6 on each side) there is sufficient redundancy that two thirds of the tendons could fail prior to the flexural capacity becoming critical. The joint shear seems to be critical based on the simple analysis available at this stage, with a risk that extreme wave loading on the exposed portion of the pipeline could overload the joints in shear. Monitoring is required to ensure that scour does not increase the span length in this area and further study is recommended to determine if mitigation such as rock protection or lateral restraints are warranted.

The dispersion modelling results illustrate that the consequence increased as the discharge location moved closer to the shore with a failure discharge quarter way from the shore being substantially worse than a discharge midway in both beach impact as well as number of elevated concentrations experienced at monitoring points along the beach.

The risk assessment highlighted that the likelihood of damage and failure of the pipeline is greatest just before the diffuser section where a portion of the pipeline is exposed, yet due to the consequence of a near shore break being substantially greater, the overall risk rating was greatest at a break a quarter way out from the shore, with the biggest two risks being damage to the pipe due to impact loads as well as failure of the repair bands. Post the mitigation measures proposed, the reduced risk profile is now even among the named risks however on average the risk of open joints does stand out due to the likelihood of failure at the end of the outfall.

Stage 2 investigations have now been completed and it is recommended that Stage 3 will comprise predominately of monitoring with specific future investigations such as the 2028 rubber ring joint inspection.

Subsequent diffuser maintenance inspection should include a periodic inspection of the final prestressed tendon anchors near the diffuser and the next inspection should also include an inspection of one of the steel manholes. The bathymetric survey should also be used to monitor the burial of the pipeline, particularly at the diffuser where the pipeline is partially exposed to wave loading.

The predominant risk area is closest to the shore and hence special attention should be made to monitor for any future leaks through pressure monitoring and aerial inspections.

7. References

DNV-GL. (2017). *RP-F109 On-bottom stability design of submarine pipelines.* Det Norske Veritas.

Fugro. (2019). *Final Report | Outfall Pipeline Survey.* New Plymouth: Hastings District Council.

OCEL. (2014). *Design Report - Hastings Outfall Diffuser Replacement.* Christchurch: Hastings District Council.

WSP. (2019). *Hastings Outfall Cores: Concrete Durability & Residual Life Assessment.* Lower Hutt.

HDC Acceptance of Report		
	Signature	**Date**
Preferred Option (Insert preferred option)		
	Signature	**Date**
Proceed to Next Phase **Please circle Yes / No** (Insert brief comment of next phase)		
	Signature	**Date**

Appendices

Appendix A MetOcean Dispersion Report

East Clive, Hawkes Bay

Hastings Outfall Stage 2 Assessment

Report prepared for Hastings District Council

August 2020

MetOcean Solutions

Document History

Versions

Version	Revision Date	Summary	Reviewed by
0.1	19/7/2020	Draft for internal review	Goward Brown
0.2	20/7/2020	Draft for internal review	Berthot
0.3	23/7/2020	Draft for internal review	Goward Brown
0.4	26/7/2020	Draft for Client review	Berthot
0.5	16/7/2020	Revised Draft addressing Stantec Comments	Goward Brown
0.6	17/8/2020	Draft for Client review	Berthot
0.7	24/08/2020	Revised Draft addressing Stantec Comments	Goward Brown
0.8	25/08/2020	Draft for Client review	Berthot

Distribution

Version	Date	Distribution

Document ID:

MetOcean Solutions is a Division of Meteorological Services of New Zealand Ltd, MetraWeather (Australia) Pty Ltd [ACN 126 850 904], MetraWeather (UK) Ltd [No. 04833498] and MetraWeather (Thailand) Ltd [No. 0105558115059] are wholly-owned subsidiaries of Meteorological Service of New Zealand Ltd (MetService).

Contents

1. Introduction......6

2. Methods......8

2.1 Wastewater Plume Dispersion Modelling......8

2.1.1 OpenDrift Model description......8

2.1.2 Modelling Scenarios......12

3. Results......13

4. Summary......25

5. References......27

Appendix A:......28

List of Figures

Figure 1.1 Location of the East Clive Wastewater Outfall. Green points indicate the release locations for each scenario. The red circles show the locations where time series were extracted, given in Table 2.2. 7

Figure 3.2 Histograms of predicted dilutions at Black Reef for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom). 18

Figure 3.3 Histograms of predicted dilutions at Clifton Shellfish for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom)............18

Figure 3.4 Histograms of predicted dilutions at Ngaruroro for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom). 19

Figure 3.5 Histograms of predicted dilutions at Short Outfall for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom)............19

Figure 3.6 Histograms of predicted dilutions at Te Awanga for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom). 20

Figure 3.7 Histograms of predicted dilutions at Te Awanga CR for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom)............20

Figure 3.8 Histograms of predicted dilutions at Tukituki for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom). 21

Figure 3.9 Histograms of predicted dilutions at Site 1 for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom). 21

Figure 3.10 Histograms of predicted dilutions at Site 2 for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom). 22

Figure 3.11 Maximum dilution during a month-long release at a rate of 48,000 m 3 day-1 for the 'normal' operation scenario. Dilutions above 5.105 have been masked..........23

Figure 3.12 Maximum dilution during a month-long release at a rate of 48,000 m3 day1 for a pipe break halfway along the pipe. Dilutions above 5.105 have been masked..........23

Figure 3.13 Maximum dilution during a month-long release at a rate of 48,000 m3 day-1 for a pipe break a quarter of the way along the pipe. Dilutions above 5,105 have been masked. 23

Figure 3.14 Mean dilution during a month-long release at a rate of 48,000 m 3 day-1 for the 'normal' operation scenario. Dilutions above 5.105 have been masked. 24

Figure 3.15 Mean dilution during a month-long release at a rate of 48,000 m 3 day-1 for a pipe break halfway along the pipe. Dilutions above 5.105 have been masked. 24

Figure 3.16 Mean dilution during a month-long release at a rate of 48,000 m3 day-1 for a pipe break a quarter of the way along the pipe. Dilutions above 5.105 have been masked..........24

List of Tables

Table 2.1 Summary of Scenarios..........12

Table 2.2 Description of the sites from which time series of concentration are extracted within the model domain (Figure 1.1)..........12

Table 3.1 Statistics derived from the time series extracted at Black Reef for each of the three scenarios..........15

Table 3.2 Statistics derived from the time series extracted at Clifton Shellfish for each of the three scenarios..........15

Table 3.3 Statistics derived from the time series extracted at Ngaruroro for each of the three scenarios..........15

Table 3.4 Statistics derived from the time series extracted at Short Outfall for each of the three scenarios..........16

Table 3.5 Statistics derived from the time series extracted at Tukituki for each of the three scenarios........16
Table 3.6 Statistics derived from the time series extracted at Site 1 for each of the three scenarios........16
Table 3.7 Statistics derived from the time series extracted at Site 2 for each of the three scenarios........17
Table 3.8 Statistics derived from the time series extracted at Te Awanga CR for each of the three scenarios........17
Table 3.9 Statistics derived from the time series extracted at Te Awanga for each of the three scenarios........17

1.Introduction

The Hastings District Council (HDC) operates the East Clive Wastewater Outfall, located to the northeast of the City of Hastings. The outfall (Figure 1.1) extends some 2750 m offshore and has 52 diffuser ports discharging in approximately 9 m of water depth (mean sea level). The treated effluent discharge flows range from 51,000 m^3 per day (average dry weather flow; ADWF) to 120,000 m^3 per day (peak wet weather flow; PWWF).

Previous hydrodynamic and diffusion modelling of the outfall was commissioned by HDC in 2009 and 2012. The report commissioned in 2010 explored the outfall plume dynamics under a range of expected environmental conditions to quantify bacterial, viral and suspended solids concentrations within the receiving coastal environment. A wave, wind and current hindcast model was developed covering regional and local scales to quantify the range of environmental conditions at the site. The hydraulics of the pipeline were quantified, and diffuser modelling was undertaken to provide boundary conditions for the lagrangian based model for the plume dynamics. The report commissioned in 2012 expanded this further to produce spatial maps of dilution statistics and generate a time-series of predicted dilutions at discrete monitoring locations.

After damage was sustained to three adjacent pipeline joints, HDC now require modelling to assess the risks associated with the complete failure of the damaged joints to feed into a condition assessment of the pipeline which is being undertaken by Stantec. The scope of work is to run three Lagrangian particle tracking model scenarios, using the open source lagrangian particle tracking model, OpenDrift. The scenarios assume a full flow leak at an average daily flow rate of 48,000 $m3.day^{-1}$ based on the existing effluent discharge data.

The three proposed scenarios are as below:

1. Scenario 1 assumes normal operation of dispersion at the end of the outflow (2750 m from the shore)
2. Scenario 2 assumes a flow occurring halfway along the pipe (1375 m from the shore)
3. Scenario 3 assumes a breach a quarter of a way from the shoreline (685 m from the shore).

The report is organised as follows: Section 2 provides a summary of the existing model data and a description of the particle-tracking model and its application to the plume dispersal scenarios simulated, Section 3 provides the results of the plume simulations. Section 4 gives a concise summary of the results presented in Section 3. Finally, Section 5 gives the references cited in this report.

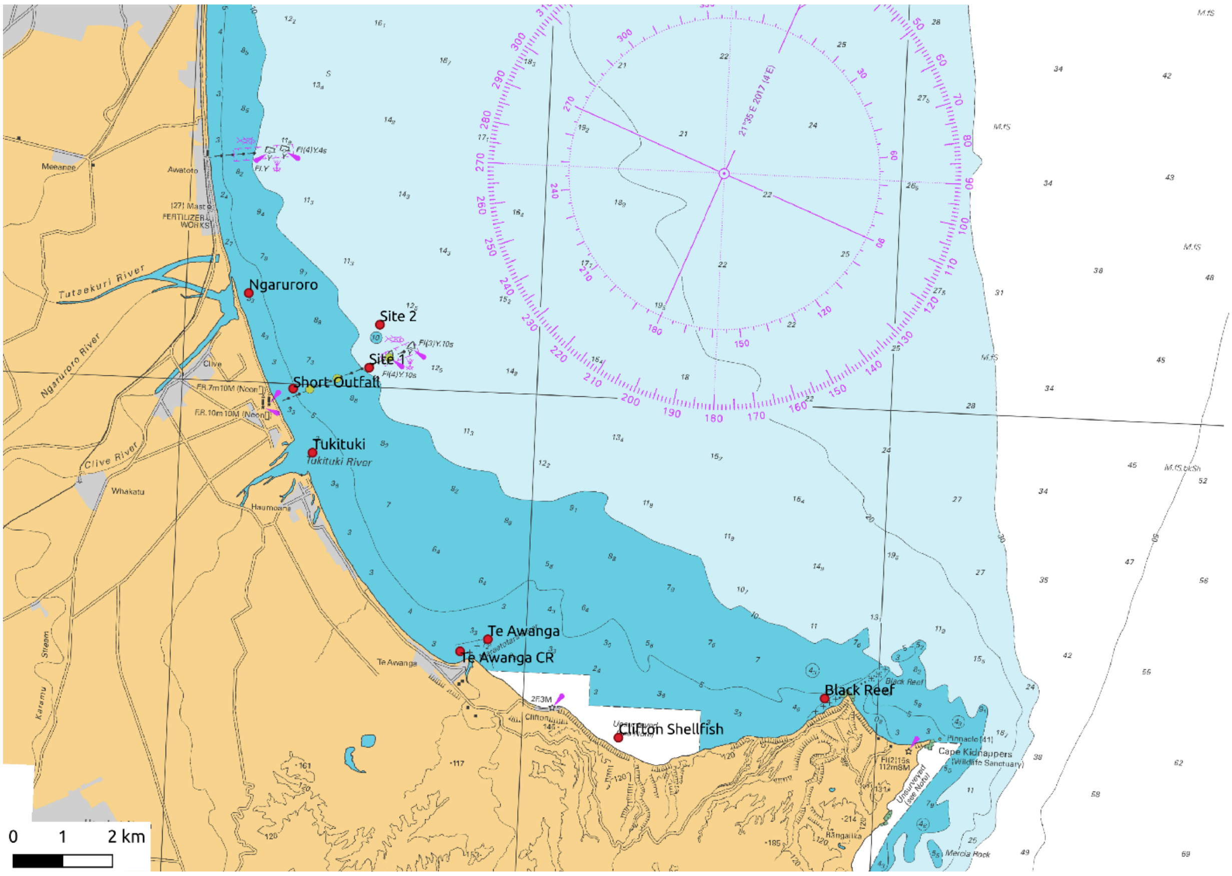


Figure 1.1 *Location of the East Clive Wastewater Outfall. Green points indicate the release locations for each scenario. The red circles show the locations where time series were extracted, given in Table 2.2.*

2. Methods

A full description of the 3D hydrodynamic model, SELFE, used to provide the 3-dimensional current and wind conditions for the Lagrangian particle tracking model are given in the previous MOS report (2010)[1]. From the previous studies, the transport and dispersion results from the previous MOS reports[1,2], showed similar results for both modelled El Niño and La Niña years. El Niño conditions tend to impose a west-southwest anomaly on the 'normal' wind conditions. For La Niña events, the opposite is generally true, and this results in an east-north-easterly wind field anomaly. Previous reporting (MOS, 2010) suggested that whilst directional distribution is not significantly altered between modelled scenarios, the El Niño year sees an increase in mean and median current speeds compared to the La Niña year, suggesting that El Niño will enable greater particle dispersion. The hydrodynamic model data used for these simulations was for June – July 2002 (an El Niño climatic regime).

2.1 Wastewater Plume Dispersion Modelling

2.1.1 OpenDrift Model description

The transport and dispersion of a conservative tracer was simulated using the ocean trajectory modelling framework OpenDrift[3] (Dagestad et al. 2018). OpenDrift is an open-source Python-based framework for Lagrangian particle tracking developed by the Norwegian Meteorological Institute, where it is notably used operationally as an emergency response tool 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. Several modules have already been developed, including an oil drift module (see Röhrs et al., 2019), a stochastic search-and-rescue module, a pelagic egg

---

[1] MSL (2010). East Clive Wastewater Outfall Hydrodynamic modelling. Report prepared for Hasting District Council by MetOcean Solutions Ltd and Cawthron Institute.

[2] MSL (2012). East Clive Wastewater Outfall Dilution Statistics. Report prepared for Hasting District Council by MetOcean Solutions Ltd.

[3] https://github.com/OpenDrift/opendrift7

module, and a plastic drift module. The dispersion simulations described in the study were undertaken using the generic OceanDrift3D [4] module. The wastewater dispersion modelling consists of a trajectory tracking scheme applied to discrete particles in time and space-varying 3D oceanic currents (2.1):

$$\frac{dx_p}{dt} = \tilde{u}(x,y,z,t) + u_t$$

$$\frac{dy_p}{dt} = \tilde{v}(x,y,z,t) + v_t$$

$$\frac{dz_p}{dt} = w_t$$

(2.1)

where (xp, yp, zp) 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.

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 (2.2):

$$\int_t^{t+\Delta t} u_t \cdot d_t = \sqrt{6K_{u,v} \cdot \Delta t} \cdot \theta(-1,1)$$

(2.2)

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 and $K_{u,v}$ is the horizontal eddy diffusivity coefficient in $m^2 \cdot s^{-1}$.

In the vertical plane, particles are subject to diffusive displacement (w_t) due to vertical turbulent motion through the water column. In OpenDrift, the vertical mixing process is parameterised using a numerical scheme described in Visser (1997) which is similar

---

4 https://github.com/OpenDrift/opendrift/blob/master/opendrift/models/oceandrift3D.py

to equation 2.2 when using a constant vertical diffusion coefficient, Kz (as employed here).

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

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

$$k_{u,v} = 0.103 \cdot L^{1.15} \qquad (a)$$

$$k_{u,v} = \alpha \cdot L^{\frac{4}{3}} \qquad (b)$$

(2.3)

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 applicable over a large range of scales (10 m to 1000 km) (Okubo 1974; Okubo, A. 1971). A similar relationship was found by List et al. (1990) in coastal waters.

In the present study, since high resolution flows are resolved, the amount of added diffusion should be limited. A generic horizontal coefficient of 0.01 m^2 s^{-1} was applied which is consistent with a length scale of the order 20 - 40 m. The spatial scales of the vertical turbulent motions within the water column are one or several orders of magnitude smaller than horizontal turbulence. The vertical diffusion coefficient was set to a value of 1 cm^2 s^{-1}.

Particles are released continuously over a month and are given a further 14 days to disperse after the final release. In addition, the particles are each given a maximum age of 30 days which prevents a build-up of particles towards the end of the simulation; The particles are assumed to be passive (neutrally buoyant with no decay and to facilitate comparison between each three release locations), and are released randomly over the full depth of the water column. In terms of dispersion within the nearfield, the jet trajectory is assumed to be dominated by the momentum of the discharge from the pipe (Zhao, Chen, and Lee 2011). Distributing the particles randomly across the water column enables further spread of the particles and reduces the possibility that the particles will become trapped on the seabed next to the release location. For scenario 1: The ‘normal’ operation scenario, particles are given additional randomness to their starting positions through horizontal distribution over a radius of 10 m. This simulates the additional, and initial, dispersion provided by the diffusers at the end of the outflow.

An average daily flow rate has been assumed to be 48,000 m^3 day^{-1} for all three scenarios. Time series of the concentrations are extracted from the model every half an hour over a month, to capture tidal variation in the signal.

Statistical maps of dilution are produced from the particle distribution at each output timestep of the particle tracking model; the dilution fields can be scaled to any reference concentration (e.g. $mg.L^{-1}$, $cfu.L^{-1}$, $pfu.L^{-1}$) to obtain absolute results. The particle distribution is obtained by generating a grid with the smallest grid size as is computationally practical, in this case, grid cells were 20 m by 20 m.

The normalized depth-averaged tracer concentration is obtained by a) computing the particle concentration at each cell (numbers of particles divided by cell volume), and b) normalizing by the nearfield particle concentration at the discharge location. This normalized tracer concentration quantifies the spatial relative dilution of the concentration near the discharge location (nearfield concentration).

A nominated nearfield concentration of 1 $mg.L^{-1}$was assumed to enable specific contaminant levels to be determined using concentration ratios. Based on this, a concentration of 0.001 $mg.L^{-1}$ is equivalent to a dilution factor of 1000, while a concentration level of 0.01 $mg.L^{-1}$ is equivalent to a dilution factor of 100.

In order to compare between the three scenarios, the outflow remains constant, as a result we would expect the dilutions extrema to be more conservative than in the previous MOS reports. Using the plume footprints, it will be possible to assess the impact of a breach closer to the nearshore region compared to normal operation.

2.1.2 Modelling Scenarios

Three scenarios are simulated (Table 2.1) and the results are presented in the form of time series of concentrations at a number of locations (see Table 2.2), and as statistical maps.

Table 2.1 Summary of Scenarios

Scenarios	Longitude	Latitude	Flowrate [m3/day]
Normal -End of Outflow Pipe	176.965	-39.5778	48 000
½ length of pipe	176.953	-39.582	48 000
¼ length of pipe (from the shore)	176.9467	-39.5842	48 000

Table 2.2 Description of the sites from which time series of concentration are extracted within the model domain (Figure 1.1)

	Site description and location		
	Latitude (° S)	**Longitude (° E)**	**Water Depth (m)**
Black Reef	39.6362	177.0708	5.00
Clifton Shellfish	39.6450	177.0228	2.00
Ngaruroro	39.5672	176.9314	2.50
Short Outfall	39.5842	176.9428	5.00
Te Awanga	39.6282	176.9911	2.00
Te Awanga CR	39.6306	176.9847	1.00
Tukituki	39.5957	176.948	1.00
Site 1	39.5798	176.9604	10.00
Site 2	39.5719	176.9625	10.00

3. Results

This section of the report presents results from a month-long particle tracking simulation, during June-July 2002. The dispersion modelling results presented below show the expected dilution and concentration of tracers for the following scenarios: 'Normal Outflow Operation', a flow halfway along the length of the pipe and at a quarter of the outfall length from the shore (Scenarios 1, 2 and 3 respectively). The daily average flow rate was kept constant to facilitate comparison between the scenarios.

The dilution maps (Figure 3.11-Figure 3.16) and levels can be interpreted in terms of relative concentration, where a dilution factor of 1000 is the equivalent of $1e^{-3}$ $X.L^{-1}$, while a dilution factor of 100 is equivalent to a concentration level of $1e^{-2}$ $X.L^{-1}$ (where X is represents an arbitrary unit of concentration measurement).

Note, the results in Figure 3.11 -Figure 3.16 are given on a logarithmic scale (base 10) due to the localised nature of the peaks in the data. Enlarged versions of Figure 3.11 to Figure 3.16 are given in Appendix A (Figure A. 1 to Figure A. 6).

Time-series of tracer concentration (assuming a concentration of 1 $mg.L^{-1}$) were extracted at several sites within the model domain (Figure 1.1). These sites cover the edge of near field region, shellfish sites, contact, fishing and boating recreation sites (Table 2.2). Statistical analysis of the time series comparing each of the three scenarios is presented for each of the extraction locations in Table 3.1 to Table 3.9. Presented are the maximum and mean values and the time taken for concentrations to reach, or exceed, these values, calculated from the start of the simulation.

From the extracted time-series histograms displaying the number of events which occur for different dilution thresholds (between 1 and 10000, split into 100 bins) are generated for each site and presented in Figure 3.2 to Figure 3.10.

In the present application, several sites are in shallow water (<10 m) and can even be dry at times. The result is that division by the water depth in the volume calculation can therefore result in artificial tracer spikes during periods of low water levels. Therefore, caution is advised during interpretation of tracer concentration at the shallowest of sites (notably Tukituki and Te Awanga CR).

As with the time series results, care should be taken when considering the particle counts in shallow water regions in Figure 3.1-Figure 3.6, as elevated particle accounts can occur in regions of shallow water where:

- Resident times of particles can be relatively long due to comparatively quiescent conditions resulting in higher concentrations when averaged over time
- Small fluctuations within the intertidal areas may maintain elevated levels of tracer due to the inability of the areas to effectively flush
- The process of converting the particle distributions to a volume will result in apparent elevation of concentrations in shallow water. To counter this, water depths shallower than 1m are masked out.

Table 3.1 Statistics derived from the time series extracted at Black Reef for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [mg.L^{-1}]	0.0005	0.000884	0.000306
Time taken to reach maximum [days]	18.729	17.125	1.8125
Mean [mg.L^{-1}]	7.10E-07	5.02E-06	1.74E-06
Time taken to reach mean [days]	18.729	1.229	1.812

Table 3.2 Statistics derived from the time series extracted at Clifton Shellfish for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [mg.L^{-1}]	0.001267	0.00112	0.001289
Time taken to reach maximum [days]	34	14.438	40.979
Mean [mg.L^{-1}]	6.00E-07	6.89E-06	8.85E-06
Time taken to reach mean [days]	34	14.438	5.208

Table 3.3 Statistics derived from the time series extracted at Ngaruroro for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [mg.L^{-1}]	0.001018	0.001737	0.001504
Time taken to reach maximum [days]	16.917	42.042	42.042
Mean [mg.L^{-1}]	2.89E-06	4.11E-06	1.19E-05
Time taken to reach mean [days]	16.917	21.646	14.354

Table 3.4 Statistics derived from the time series extracted at Short Outfall for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [$mg.L^{-1}$]	0.0005	0.000442	0.001018
Time taken to reach maximum [days]	22.771	14.583	19.208
Mean [$mg.L^{-1}$]	1.18E-06	2.30E-06	7.71E-06
Time taken to reach mean [days]	22.771	14.583	3.666

Table 3.5 Statistics derived from the time series extracted at Tukituki for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [$mg.L^{-1}$]	0.001264	0.001131	0.001298
Time taken to reach maximum [days]	43.146	14.875	4.063
Mean [$mg.L^{-1}$]	5.98E-07	4.82E-06	1.50E-05
Time taken to reach mean [days]	43.146	14.875	3.583

Table 3.6 Statistics derived from the time series extracted at Site 1 for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [$mg.L^{-1}$]	0.00075	0.000442	0.000254
Time taken to reach maximum [days]	23.958	22.104	22.937
Mean [$mg.L^{-1}$]	5.80E-06	4.08E-06	7.83E-07
Time taken to reach mean [days]	15.75	11.625	6.291

Table 3.7 Statistics derived from the time series extracted at Site 2 for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [$mg.L^{-1}$]	0.00025	0.000221	0.000254
Time taken to reach maximum [days]	6.792	6.604	22.5
Mean [$mg.L^{-1}$]	4.85E-06	2.72E-06	1.45E-06
Time taken to reach mean [days]	6.791	6.604	6.729

Table 3.8 Statistics derived from the time series extracted at Te Awanga CR for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [$mg.L^{-1}$]	0.002666	0.002049	0.003717
Time taken to reach maximum [days]	23.687	15.729	41.458
Mean [$mg.L^{-1}$]	1.26E-06	9.70E-06	1.41E-05
Time taken to reach mean [days]	23.687	15.729	3.562

Table 3.9 Statistics derived from the time series extracted at Te Awanga for each of the three scenarios

Statistics	Scenario 1	Scenario 2	Scenario 3
Maximum [$mg.L^{-1}$]	0.001355	0.001201	0.000693
Time taken to reach maximum [days]	17.52083	4.583333	1.083333
Mean [$mg.L^{-1}$]	1.28E-06	3.98E-06	9.51E-06
Time taken to reach mean [days]	17.52083	4.583333	1.083333

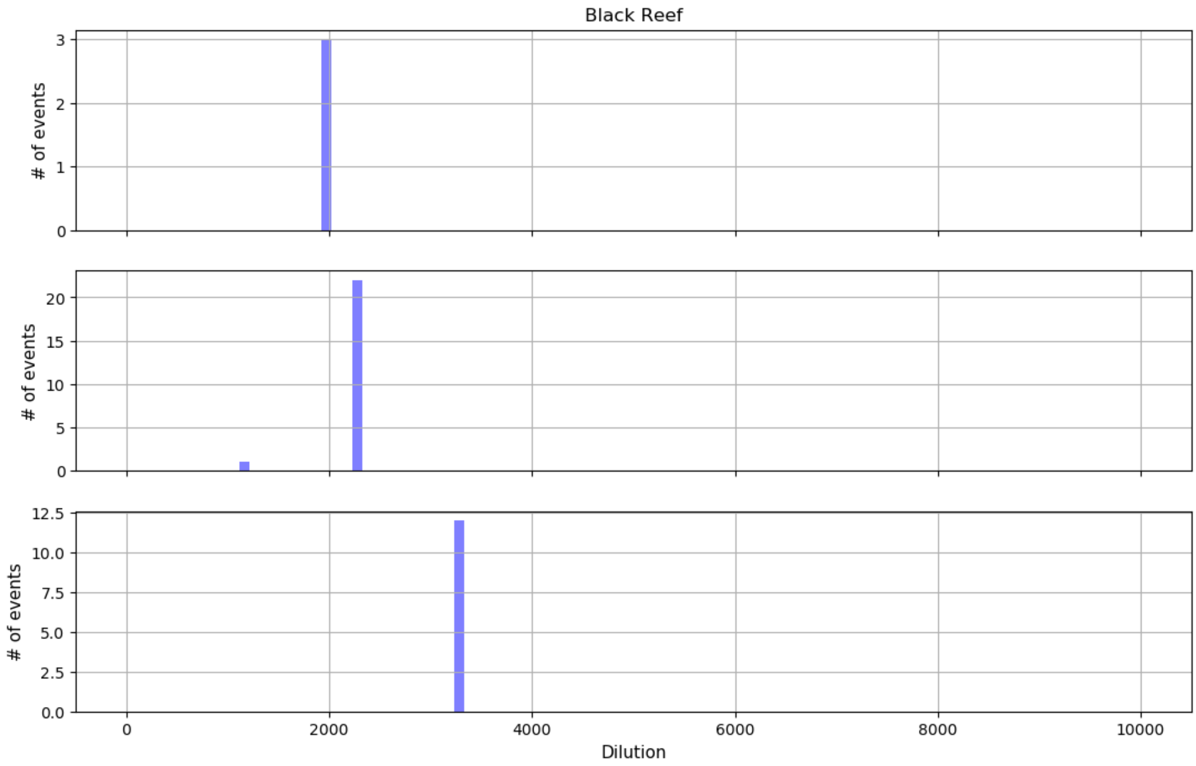


Figure 3.1 *Histograms of predicted dilutions at Black Reef for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).*

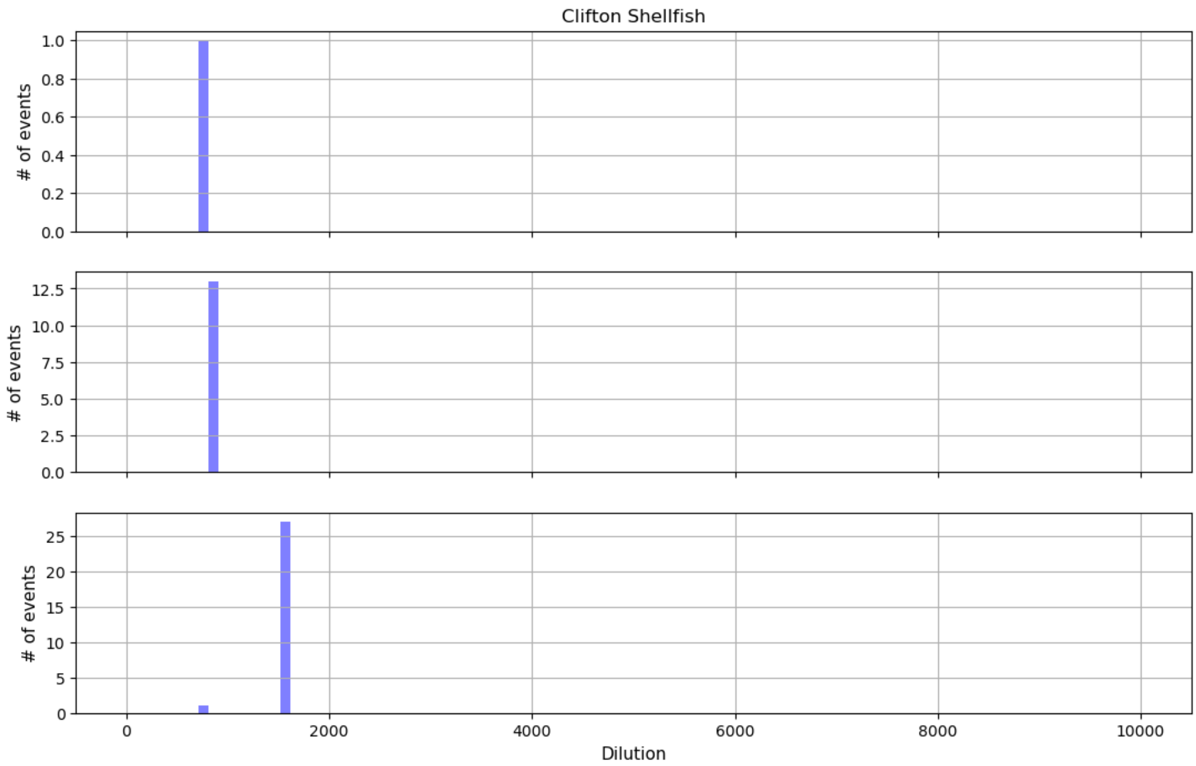


Figure 3.2 *Histograms of predicted dilutions at Clifton Shellfish for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).*

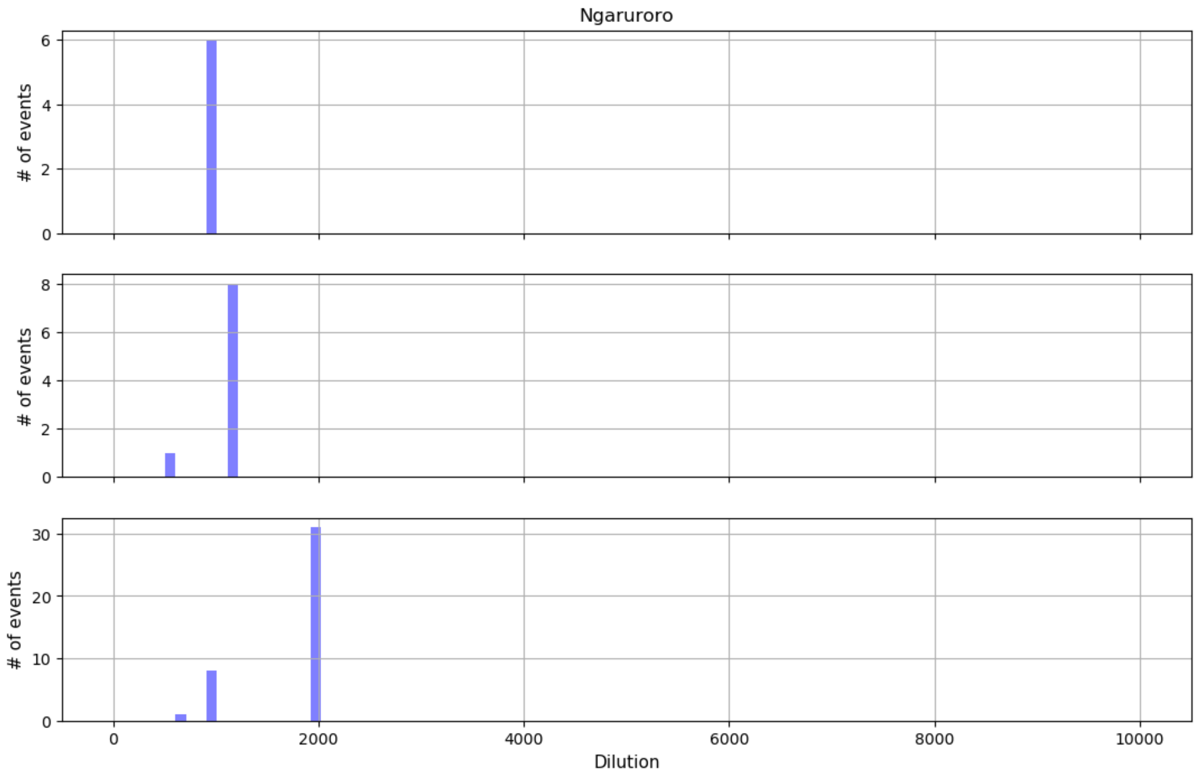


Figure 3.3 Histograms of predicted dilutions at Ngaruroro for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).

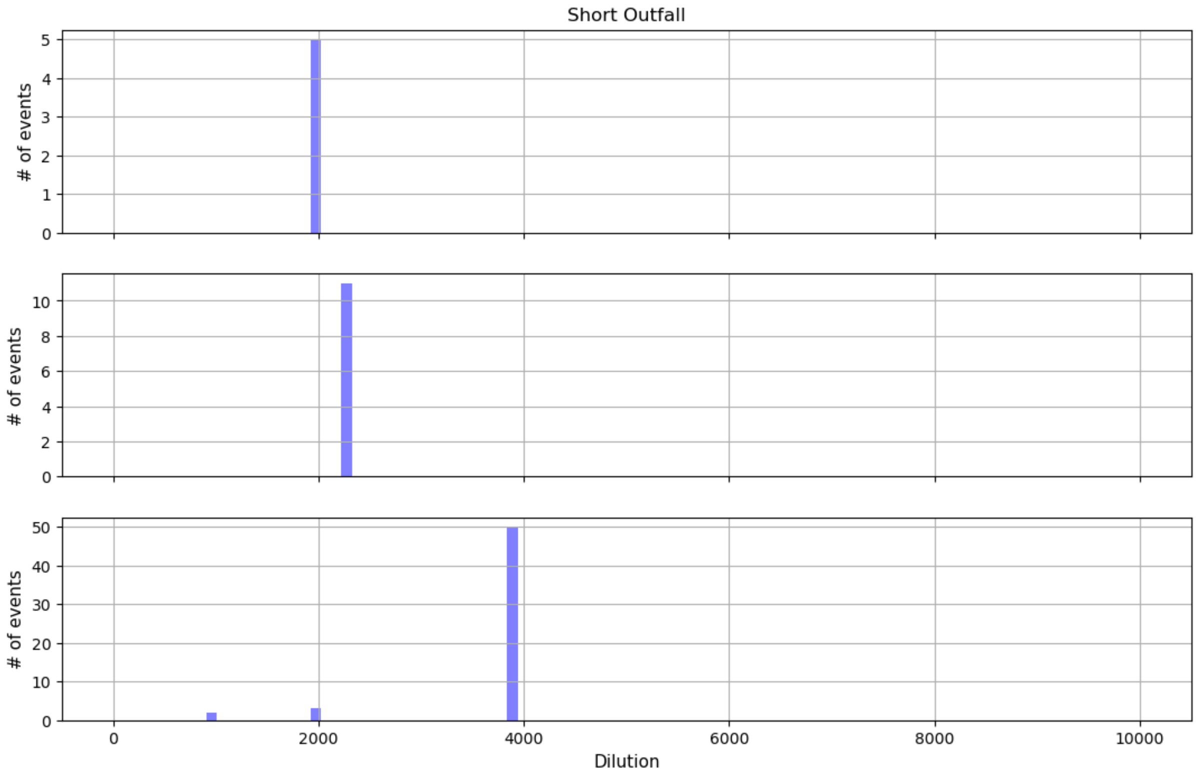


Figure 3.4 Histograms of predicted dilutions at Short Outfall for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).

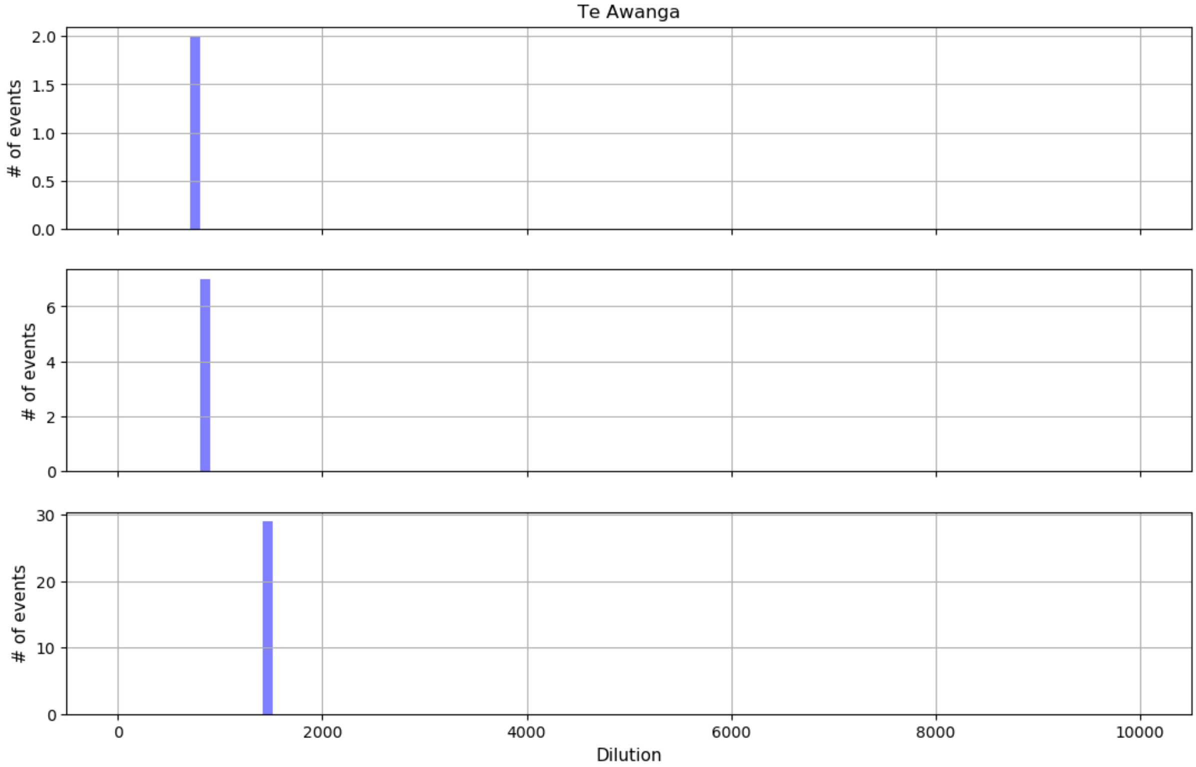


Figure 3.5 *Histograms of predicted dilutions at Te Awanga for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).*

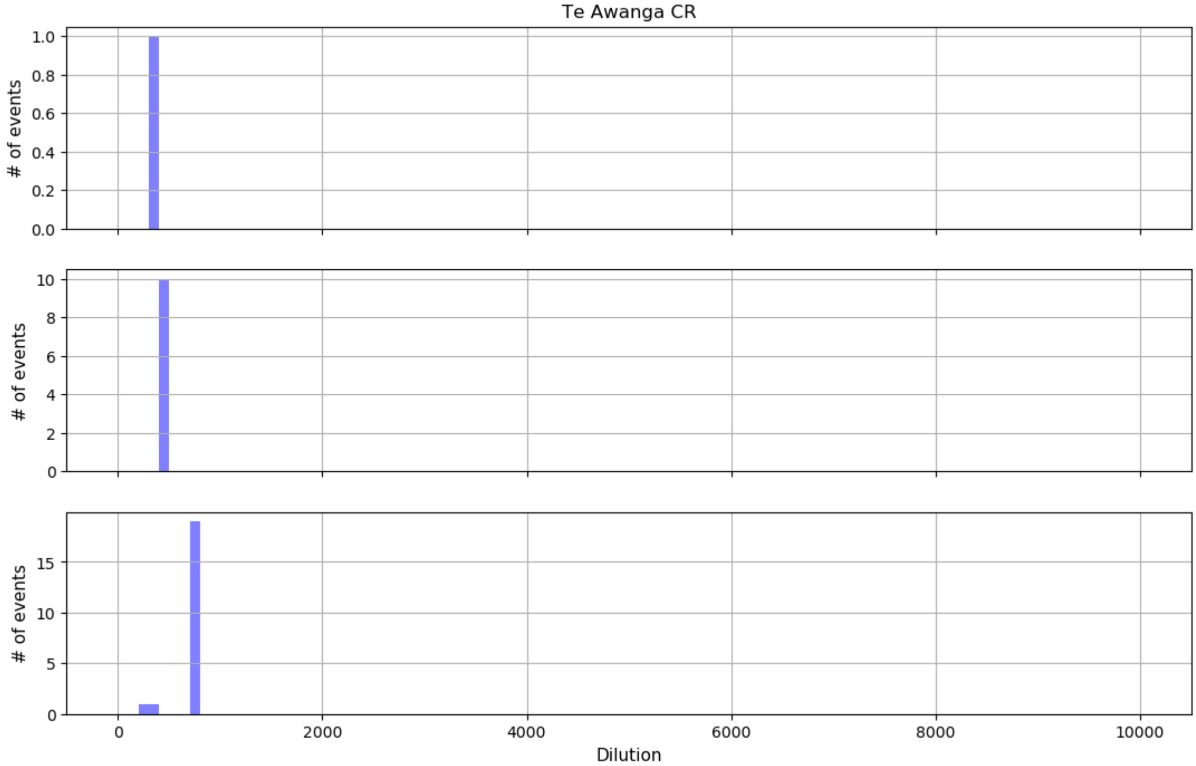


Figure 3.6 *Histograms of predicted dilutions at Te Awanga CR for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).*

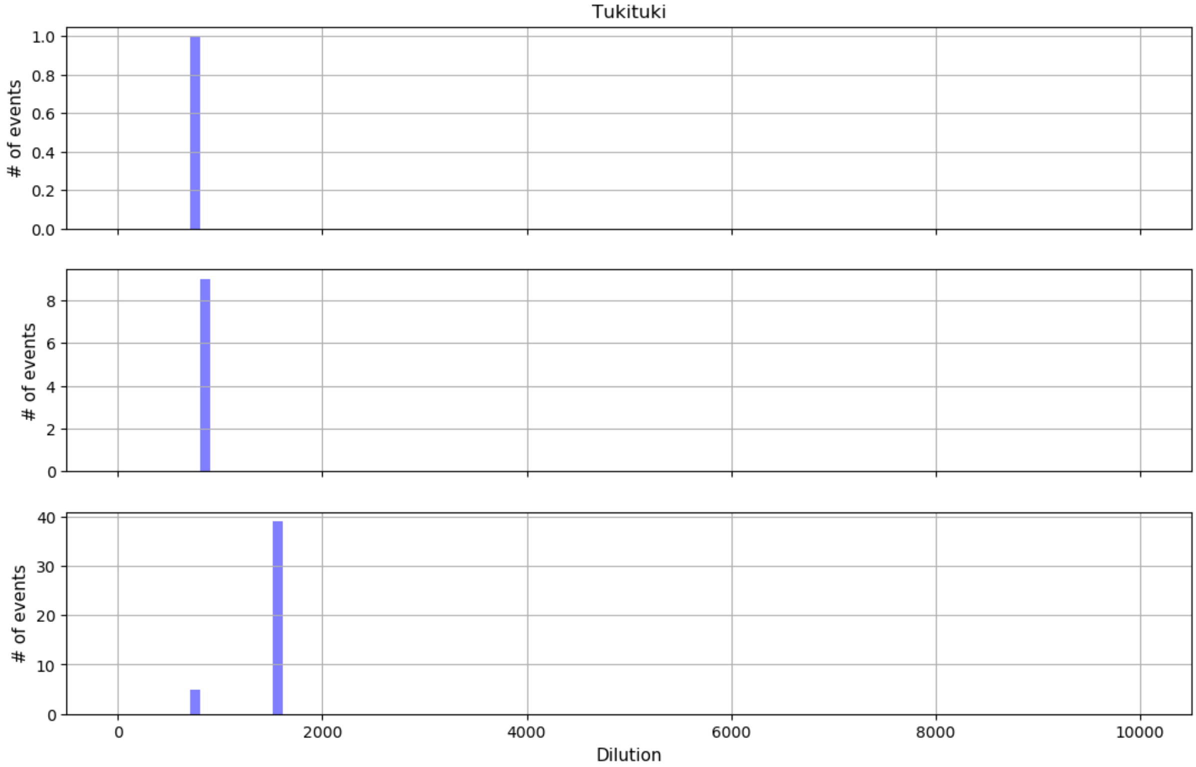


Figure 3.7 *Histograms of predicted dilutions at Tukituki for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).*

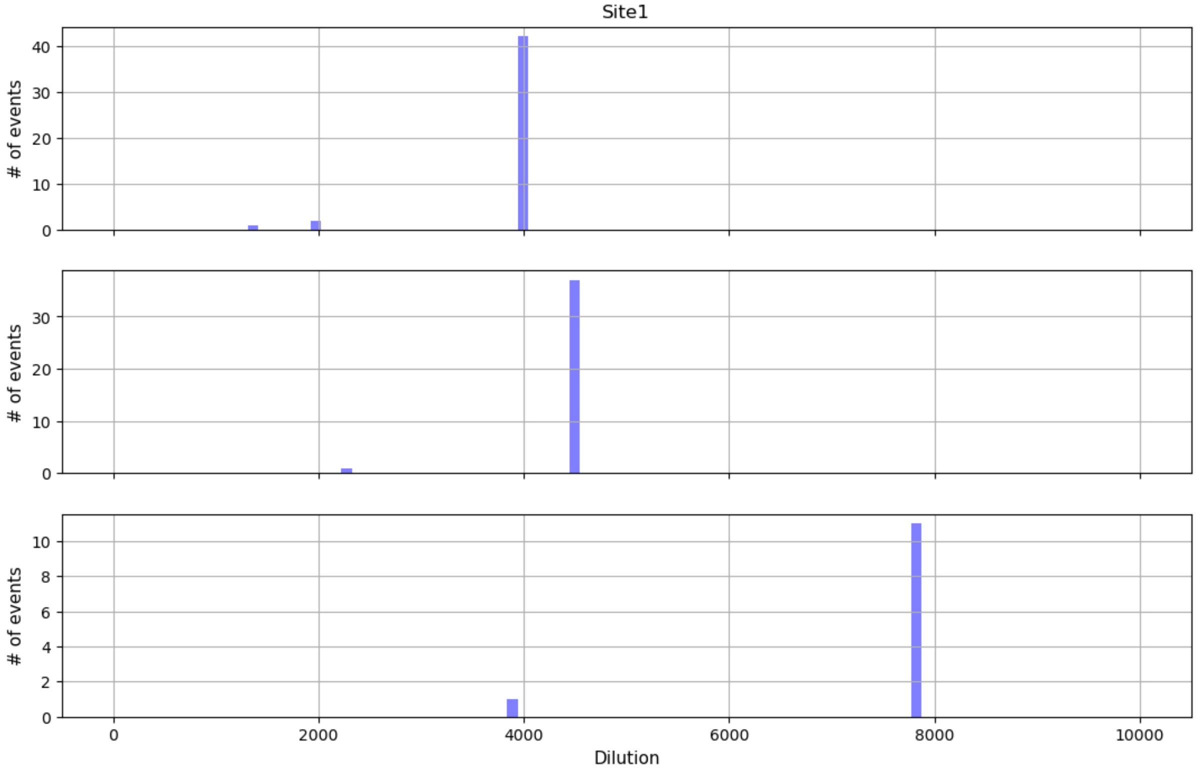


Figure 3.8 *Histograms of predicted dilutions at Site 1 for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).*

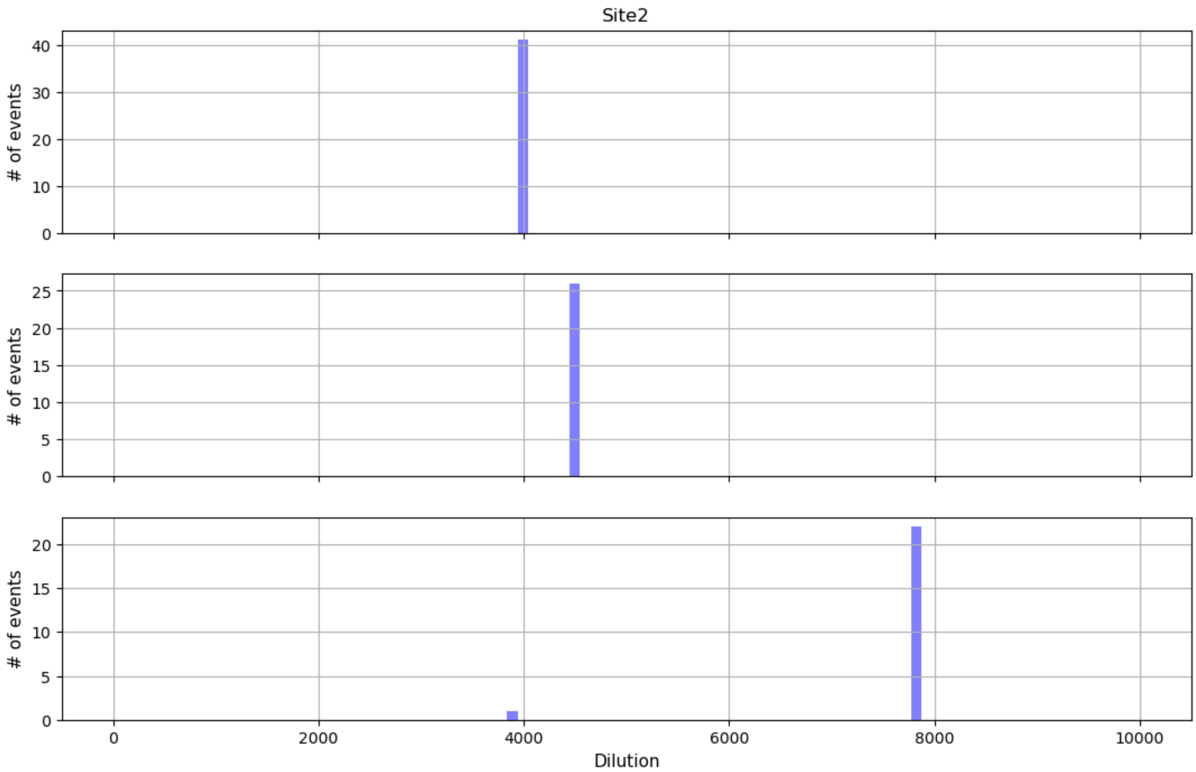


Figure 3.9 *Histograms of predicted dilutions at Site 2 for the 'Normal' scenario (top), the halfway along the length of the pipe scenario (middle) and the quarter of the length of the outflow scenario (bottom).*

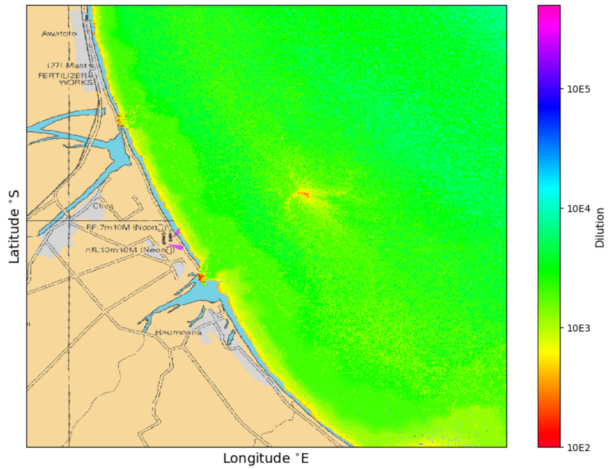


Figure 3.10 Maximum dilution during a month-long release at a rate of 48,000 m 3 day-1 for the 'normal' operation scenario. Dilutions above 5.10^5 have been masked.

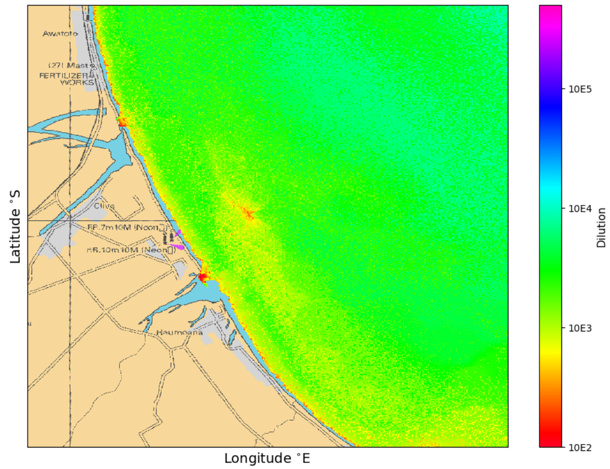


Figure 3.11 Maximum dilution during a month-long release at a rate of 48,000 m3 day1 for a pipe break halfway along the pipe. Dilutions above 5.10^5 have been masked.

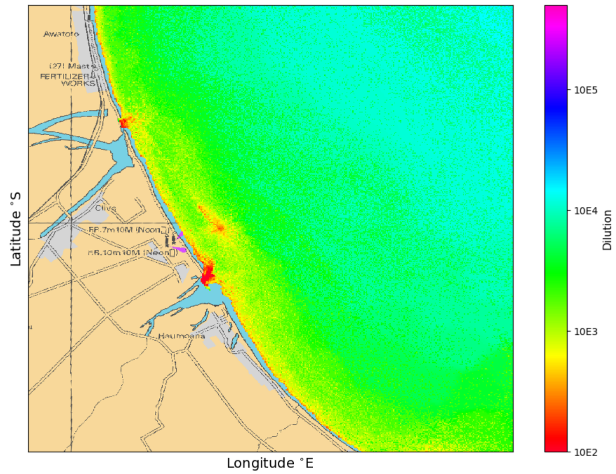


Figure 3.12 Maximum dilution during a month-long release at a rate of 48,000 m3 day-1 for a pipe break a quarter of the way along the pipe. Dilutions above 5.10^5 have been masked.

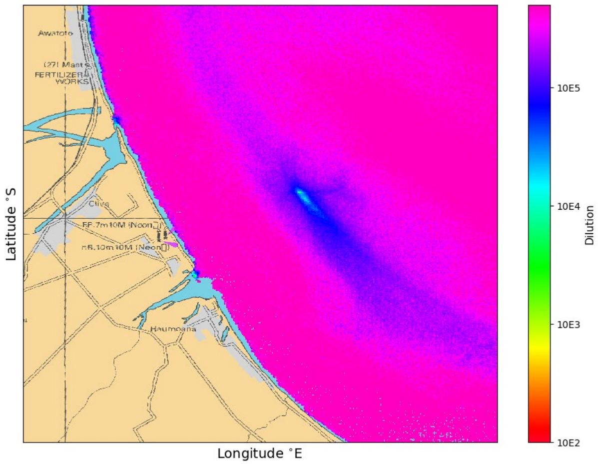


Figure 3.13 *Mean dilution during a month-long release at a rate of 48,000 m 3 day-1 for the 'normal' operation scenario. Dilutions above 5.10^{5} have been masked.*

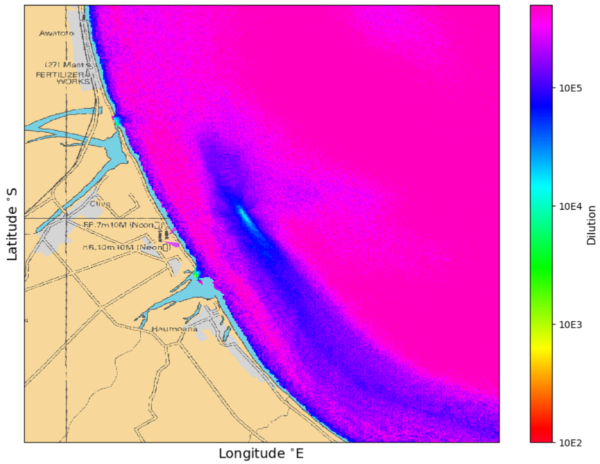


Figure 3.14 *Mean dilution during a month-long release at a rate of 48,000 m 3 day-1 for a pipe break halfway along the pipe. Dilutions above 5.10^{5} have been masked.*

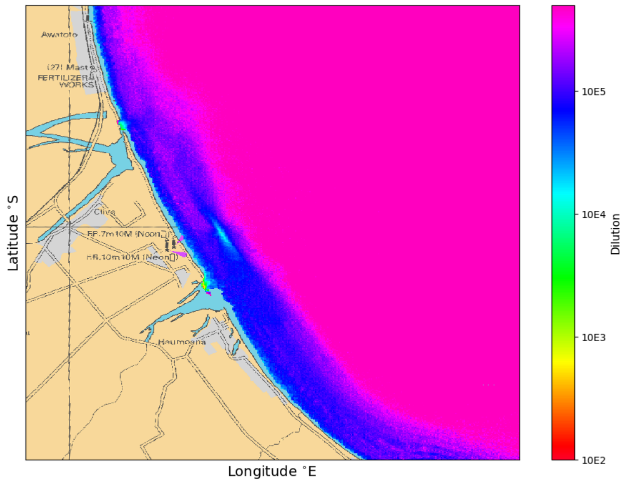


Figure 3.15 *Mean dilution during a month-long release at a rate of 48,000 m3 day-1 for a pipe break a quarter of the way along the pipe. Dilutions above 5.10^{5} have been masked.*

4. Summary

Lagrangian tracer simulations have been undertaken to investigate the dispersion of water discharged from the East Clive Wastewater Outfall, from both normal operation and discharge due to a leak along the pipe. Three different scenarios were considered: 'Normal Outflow Operation', a flow halfway along the length of the pipe and at a quarter of the outfall length from the shore. Results were postprocessed in terms of dilution, giving flexibility to the user to apply a reference concentration.

The maximum dilution maps show the peak pollutant accumulation during 30 days of release for each location. The pipe break closest to the shore (scenario 3) has the greatest impact within the coastal area. Although the values in the shallow water regions should be considered with caution, there are accumulations of particles around the river mouths and along the coast. A pipe break at half the length of the outfall, sees a reduction in the spatial extent of plume and coastline affected. "Normal" operation shows the minimal amount of coastal impact.

The mean dilution maps illustrate how the plume footprint typically spreads south-west from the discharge location, consistent with the previous MOS reports. Dilutions can be converted into concentrations and the particles scaled to link to the consent. A key comparison between the previous MOS reports and the work presented here, is the change in extent of the plume relative to the release location. We see a greater plume footprint for the release closer to the shore than we do for the normal release where the particles experience more dispersion which suggests higher concentrations of pollutants will be found at greater distance from the source.

The concentration timeseries, assuming a concentration of $1 mg.L^{-1}$ per particle, reflect the results shown in the spatial distribution statistical maps, with more sites receiving higher concentrations of the tracer during scenario 3. During "normal" operations (scenario 1), locations further afield (i.e Black Reef), infrequently receive raised levels ($\sim 0.0005\ mg.L^{-1}$) of tracer, and do so towards the end of the simulation, when the particles have had more time to disperse, compared to peak values of 0.0003 mg.L-1 during the nearshore release, scenario 3 which took 1.81 days to reach. Where the particles are released closer to the shore, all sites see more frequent peaks, although similar levels of tracer concentration are observed, with increasing frequency between scenarios 2 and 3.

The number of peak events at each site increases as the particles are released closer to the shore and indicates the greater likelihood of pollutant spikes reaching these locations than for the ‘normal operation’ scenario (scenario 1).

The exception to this are the offshore sites: 1 and 2, which are affected similarly for all cases.

5.References

Batchelor, G.K. 1952. “Diffusion in a Field of Homogeneous Turbulence. II. The Relative Motion of Particles.” *Cambridge Philosophical Society*, no. 48: 345–62.

Dagestad, Knut-Frode, Johannes Röhrs, Øyvind Breivik, and Bjørn Ådlandsvik. 2018. “OpenDrift v1.0: A Generic Framework for Trajectory Modelling.” *Geoscientific Model Development* 11 (4): 1405–20. https://doi.org/10.5194/gmd-11-1405-2018.

List, E., G. Gartrell, and C. Winant. 1990. “Diffusion and Dispersion in Coastal Waters.” *Journal of Hydraulic Engineering.,* 116(10): 1158–79.

Okubo. 1974. “Some Speculations on Oceanic Diffusion Diagrams.” *Rapports et Procès-Verbaux Des Reunions Du Conseil Permanent International Pour l'Exploration de La Mer*.

Okubo, A. 1971. “Oceanic Diffusion Diagrams.” *Deep-Sea Research* 18: 789–802.

Richardson, L.F. 1962. “Atmospheric Diffusion Shown on a Distance Neighbour Graph.” *Proc. R. Soc. London,* Ser A, (110): 709-737.

Röhrs et al. 2019. “The Effect of Vertical Mixing on the Horizontal Drift of Oil Spills.” *Ocean Science* 14: 1581–1601.

Stommel, H. 1949. “Horizontal Diffusion Due to Oceanic Turbulence.” *Journal of Marine Research*, no. 8: 199–225.

Visser A. 1997. “Using Random Walk Models to Simulate the Vertical Dis-.” *Marine Ecology-Progress Series*, no. 158: 275–281.

Zhao, Chen, and Lee. 2011. “Modelling the Dispersion of Wastewater Discharges from Offshore Outfalls: A Review.” *Environmental Reviews* 19 (1): 107–20.

Appendix A:

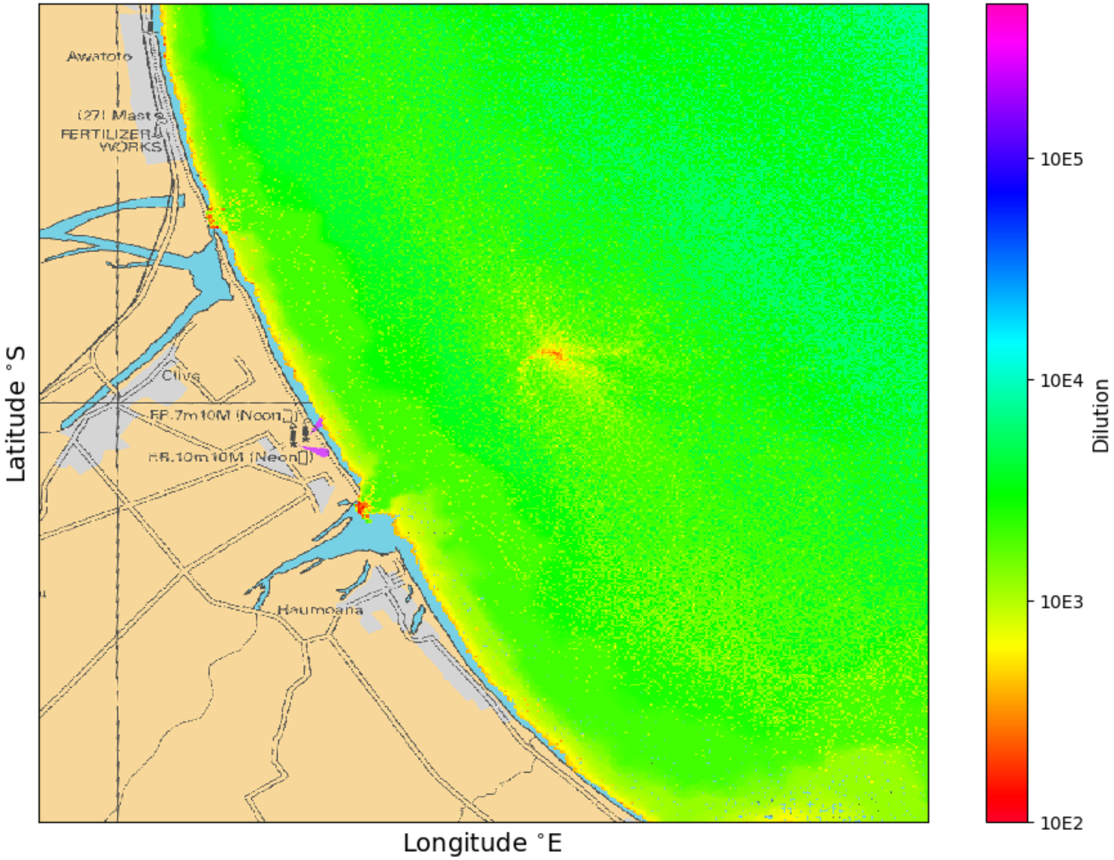


Figure A. 1 Maximum dilution during a month-long release at a rate of 48,000 m 3 day-1 for the 'normal' operation scenario. Dilutions above 5.10^5 have been masked.

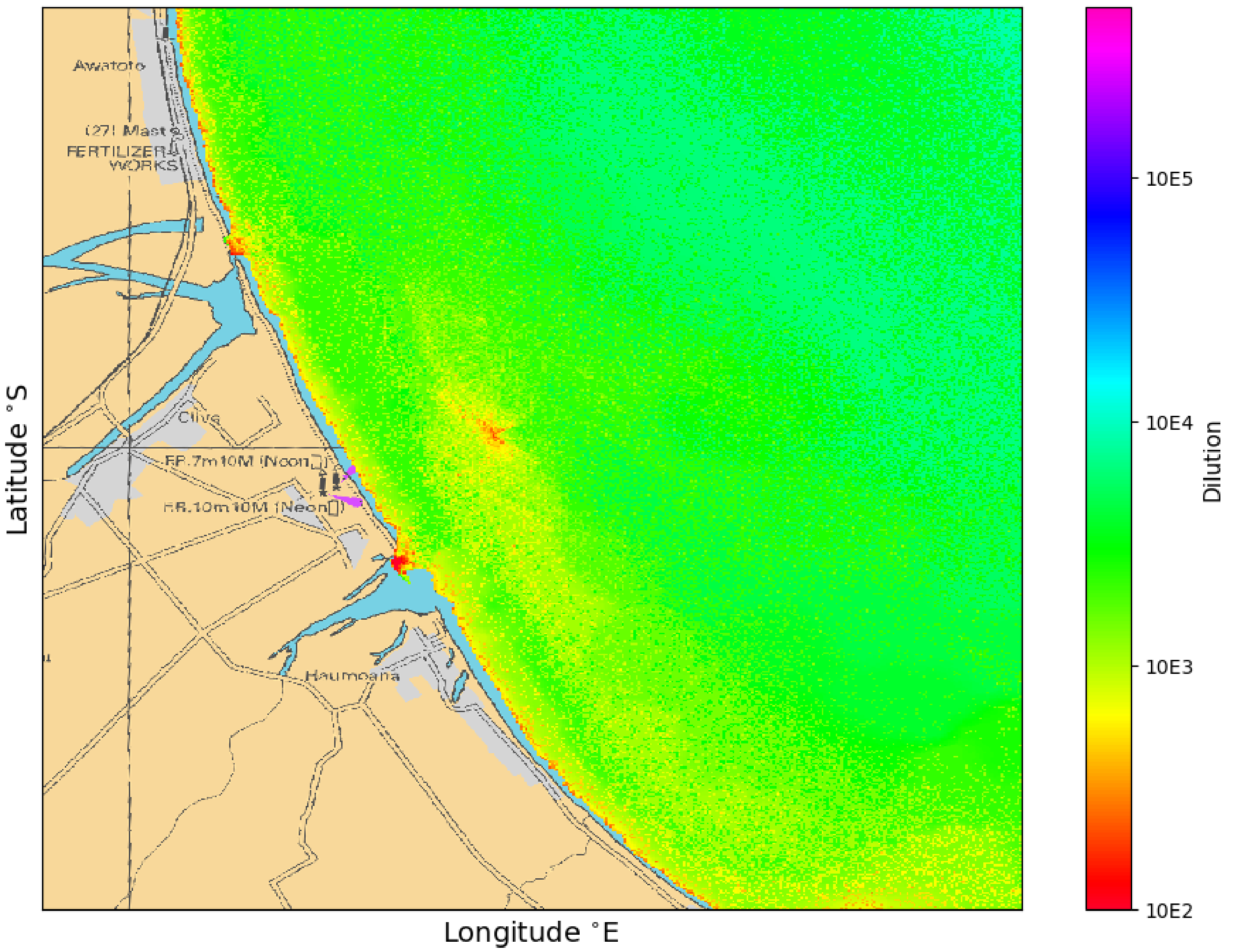


Figure A. 2 Maximum dilution during a month-long release at a rate of 48,000 m^3 day^1 for a pipe break halfway along the pipe. Dilutions above 5.10^5 have been masked.

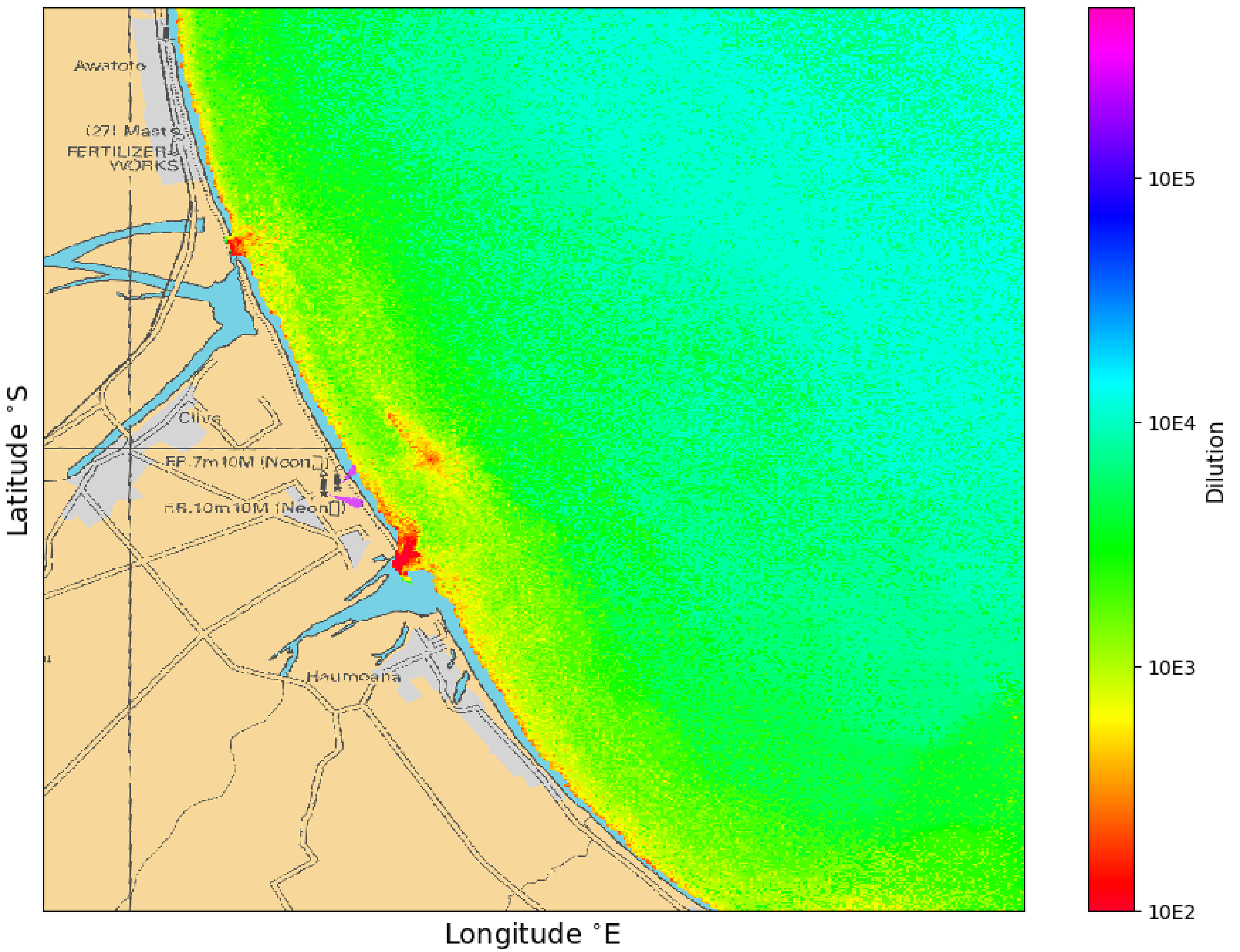


Figure A. 3 *Maximum dilution during a month-long release at a rate of 48,000 m3 day-1 for a pipe break a quarter of the way along the pipe. Dilutions above 5.10^5 have been masked.*

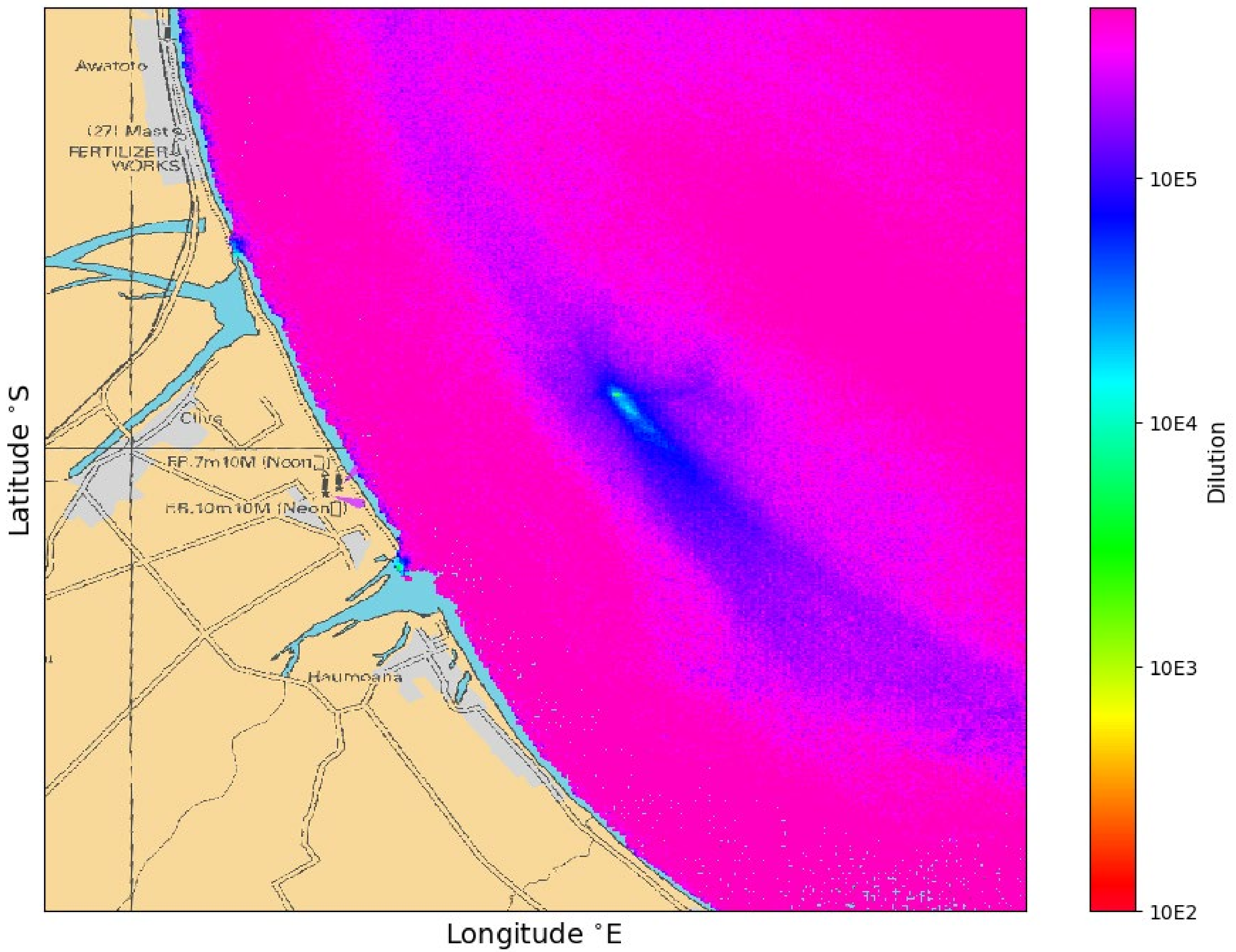


Figure A. 4 Mean dilution during a month-long release at a rate of 48,000 m 3 day-1 for the 'normal' operation scenario. Dilutions above 5.10⁵ have been masked.

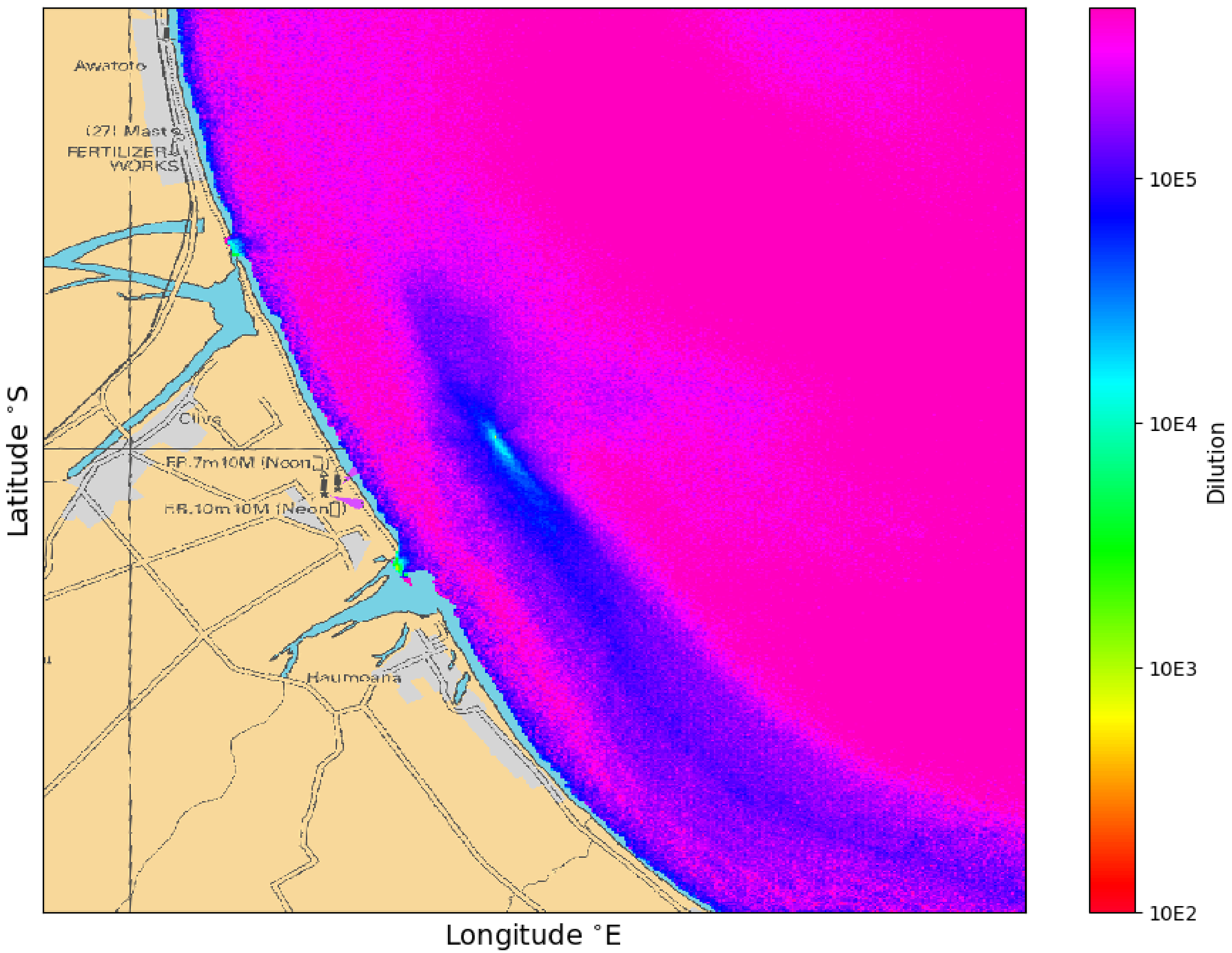


Figure A. 5 Mean dilution during a month-long release at a rate of 48,000 m 3 day-1 for a pipe break halfway along the pipe. Dilutions above 5.10^5 have been masked.

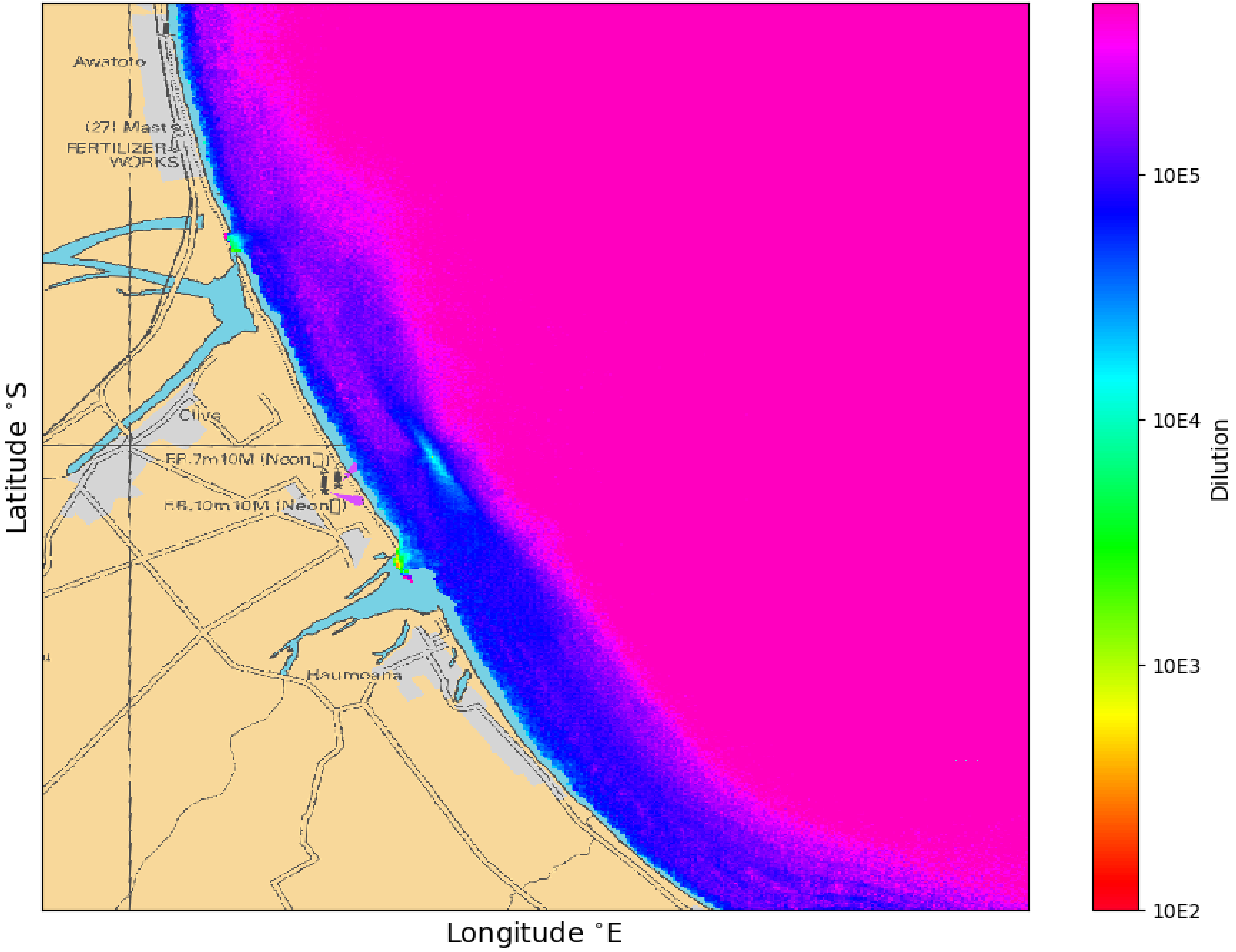
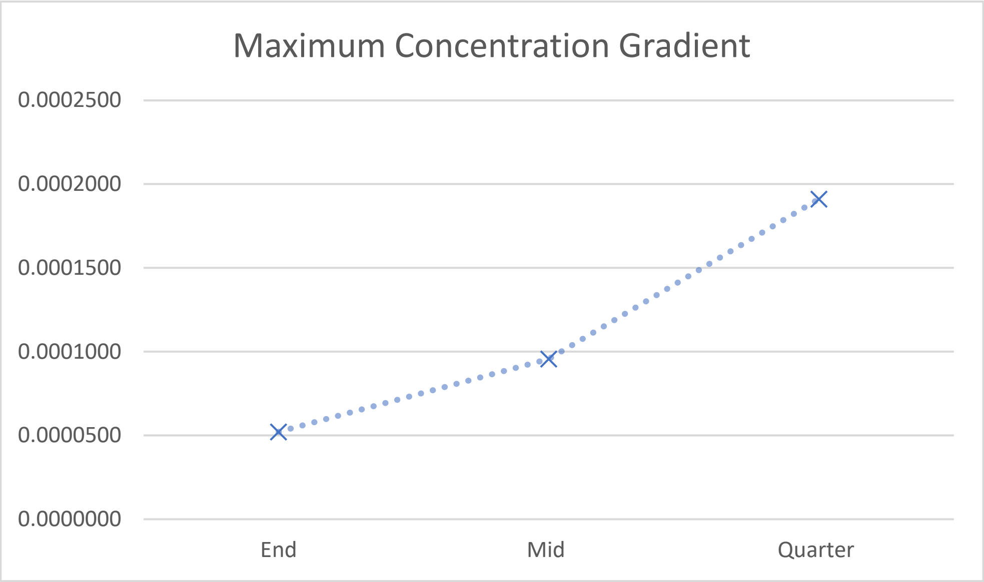


Figure A. 6 Mean dilution during a month-long release at a rate of 48,000 m3 day-1 for a pipe break a quarter of the way along the pipe. Dilutions above 5.10^5 have been masked.

Appendix B MetOcean Excel Analysis

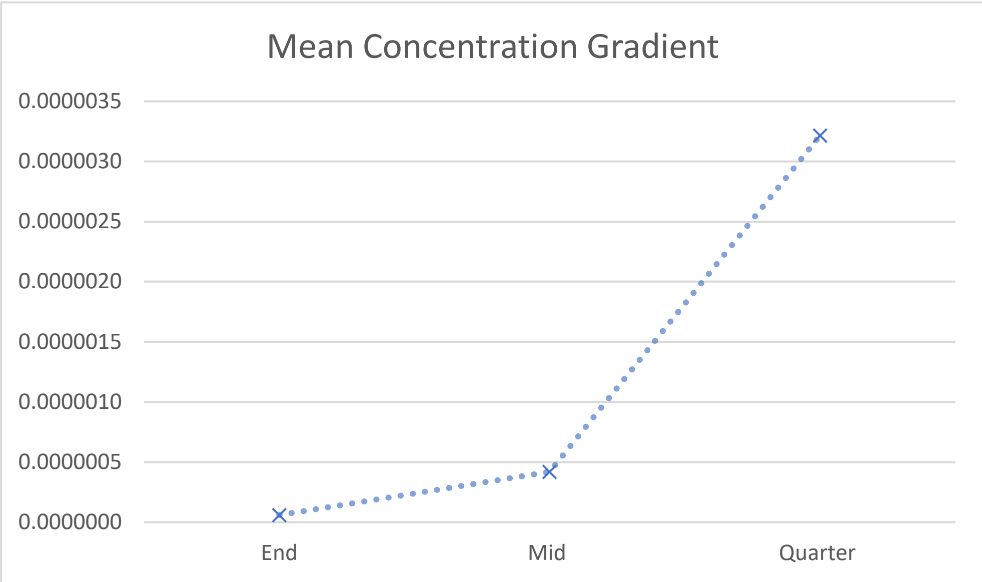
Maximum Analysis

		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	
End	Maximum	0.0005	0.001267	0.001018	0.0005	0.001264	0.002666	0.001355	
	Time T	18.729	34	16.917	22.771	43.146	23.687	17.52083	
	Conc Grad	0.0000267	0.0000373	0.0000602	0.0000220	0.0000293	0.0001126	0.0000773	0.0000522
Mid	Maximum	0.000884	0.00112	0.001737	0.000442	0.001131	0.002049	0.001201	
	Time T	17.125	14.438	42.042	14.583	14.875	15.729	4.583333	
	Conc Grad	0.000052	0.000078	0.000041	0.000030	0.000076	0.000130	0.000262	0.0000956
Quarter	Maximum	0.000306	0.001289	0.001504	0.001018	0.001298	0.003717	0.000693	
	Time T	1.8125	40.979	42.042	19.208	4.063	41.458	1.083333	
	Conc Grad	0.0001688	0.0000315	0.0000358	0.0000530	0.0003195	0.0000897	0.0006397	0.0001911



Minimum Analysis

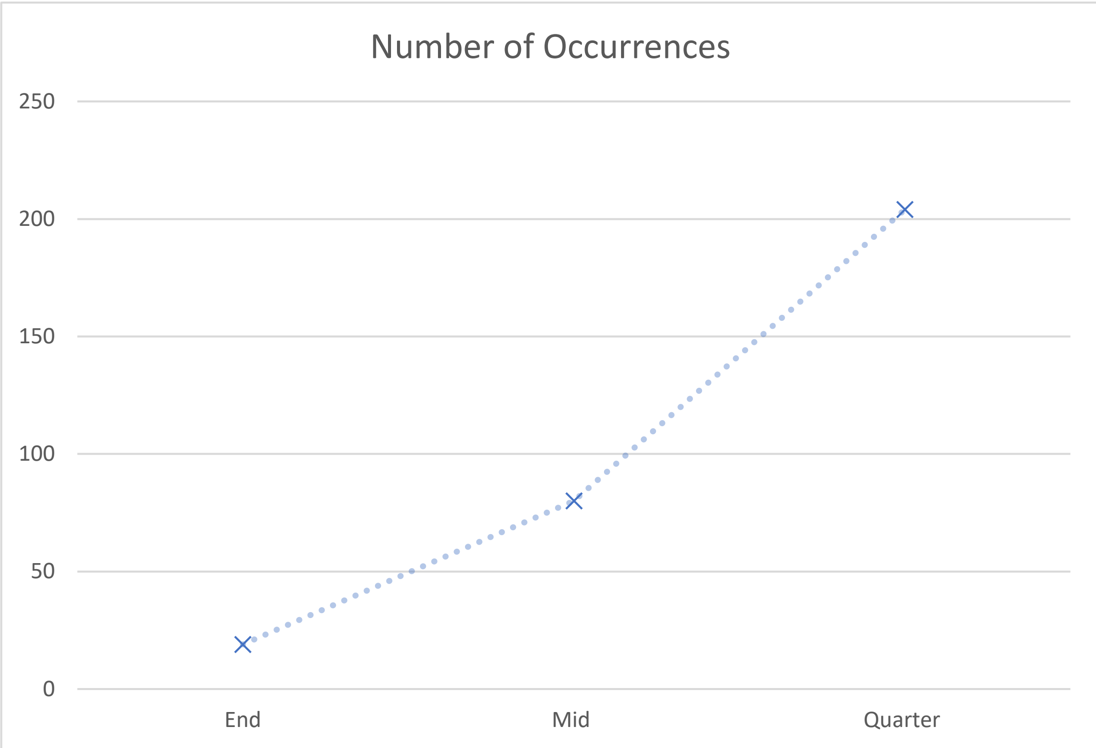
		Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	
End	Mean	0.00000071	0.0000006	0.00000289	0.00000118	0.000000598	0.00000126	0.00000128	
	Time T	18.729	34	16.917	22.771	43.146	23.687	17.52083	
	Conc Grad	0.0000000	0.0000000	0.0000002	0.0000001	0.0000000	0.0000001	0.0000001	0.0000001
Mid	Mean	0.00000502	0.00000689	0.00000411	0.0000023	0.00000482	0.0000097	0.00000398	
	Time T	17.125	14.438	21.646	14.583	14.875	15.729	4.583333	
	Conc Grad	0.000000293	0.000000	0.000000	0.000000	0.000000	0.000001	0.000001	0.0000004
Quarter	Mean	0.00000174	0.00000885	0.0000119	0.00000771	0.000015	0.0000141	0.00000951	
	Time T	1.812	5.208	14.354	3.66	3.583	3.562	1.083333	
	Conc Grad	0.0000010	0.0000017	0.0000008	0.0000021	0.0000042	0.0000040	0.0000088	0.0000032

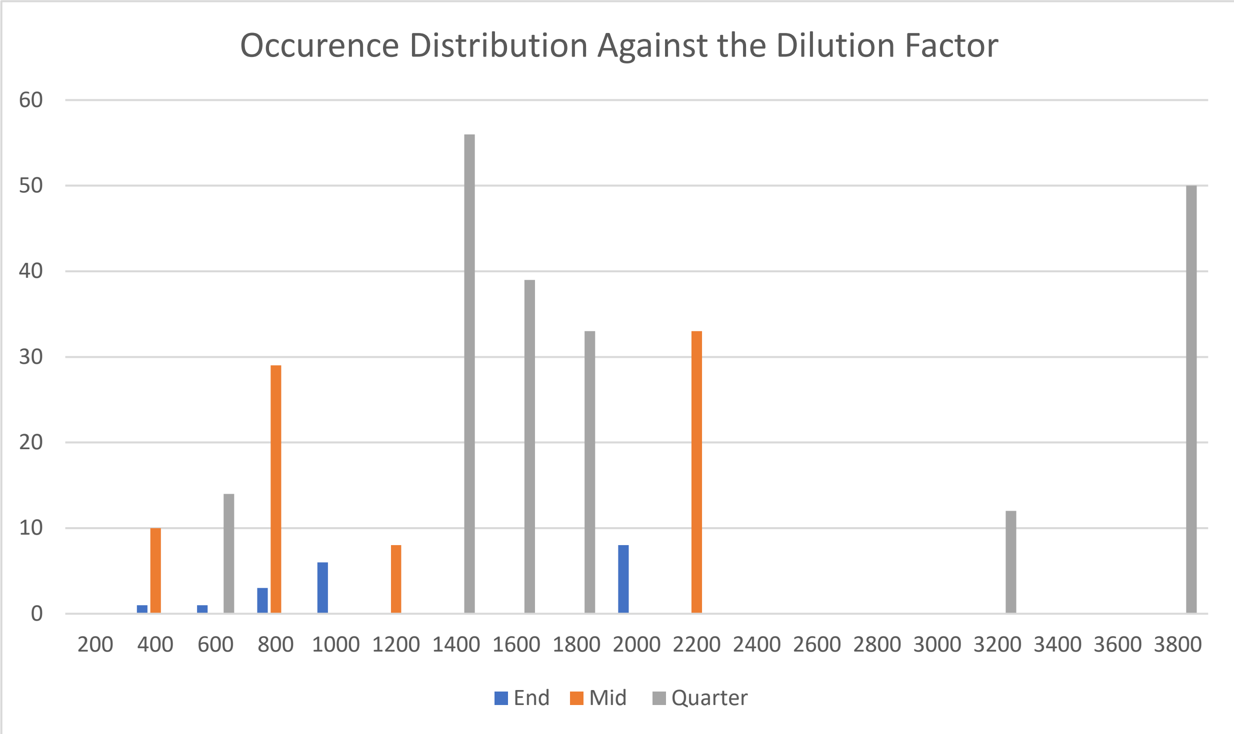


Occurrence Analysis

Dilution (occurrences)

0	200	400	600	800	1000	1200	1400	1600	1800	2000
End		1	1	3	6					8
Mid		10		29		8				
Quarter			14				56	39	33	
	2200	**2400**	**2600**	**2800**	**3000**	**3200**	**3400**	**3600**	**3800**	**SUM**
End										19
Mid	33									80
Quarter						12			50	204




Occurence Distribution Against the Dilution Factor
60
50
40
30
20
10
0
200 400 600 800 1000 1200 1400 1600 1800 2000 2200 2400 2600 2800 3000 3200 3400 3600 3800
End
Mid
Quarter

Appendix C Risk Register

Hastings Outfall Pipeline
Risk Register
Date: 16-09-20

Risk ID	Risk Title	Description/Cause/Consequence	Pre Mitigation Score: End			Mid			1/4 way			Total Pre-mitigation Score	Mitigation and Treatment	Post Mitigation Score: End			Mid			1/4 way			Total Post-mitigation Score
			Consequence	Likelihood	Pre-mitigation Score	Consequence	Likelihood	Pre-mitigation Score	Consequence	Likelihood	Pre-mitigation Score			Consequence	Likelihood	Pre-mitigation Score	Consequence	Likelihood	Pre-mitigation Score	Consequence	Likelihood	Pre-mitigation Score	
1	Failure of the rubber rings at the joints	There is a risk that gaps may form between two adjacent pipes sections should the rubber ring fail. The consequence of the risk is will lead to pipe leakage and excessive joint deflection above the design limit. The movement between the two sections will cause abrasions between the two concrete surfaces reducing the cover to reinforcement and post tensioned wires and facilitating corrosion/rupture of the post tensioning wires and Corrosion of the reinforcing wires further.	Low	Med	6	Med	Med	9	Very High	Med	15	10.00	A study was carried out on a set of rubber rings by WSP in 2017 to assess the integrity of the joints. Their findings show that the risk of failure in the following 10 years is low. However, they did note that the sand seal was starting to deteriorate and may fail at some point. Therefore, a reinspection of the joints is scheduled for 2028.	Low	Low	4	Med	Low	6	Very High	Low	10	6.67
2	Corrosion/rupture of the post tensioning wires	There is a risk that sea water reaches the post tensioned wires weakening the strands until failure, the release in tension may cause sudden forces within the ducts causing rupture. The consequence of the risk is the release of tension may damage the pipe at the point of rupture and possibly the anchor points. The broken strand can then no longer resist axial forces along the pipeline inducing increased stresses in the remaining strands. Hence, depending on the wave loading causing movement in the pipeline, there may be significant redundancy in these tendons should they only be restraining pressure forces.	Low	Med	6	Med	Low	6	Very High	Low	10	7.33	There are 12 Cables (6 on each side) providing some redundancy. Only 1 cable is required on each side to keep the joints together, and if the pipe is buried there is very little lateral force. The last 40m of pipe which is uncovered should be inspected during the annual diver campaign and the rest of the pipe should be monitored with sonar scan to check if further sections are uncovered.	Low	Med	6	Med	Low	6	Very High	Low	10	7.33
3	Internal/ External degradation of the concrete wall.	There is a risk of degradation to the internal surface of the concrete pipe from biological corrosion due to gasses collecting at a high point along the pipeline. The surface may also be abraded due to debris flowing down the pipeline as well as sediment movement over any exposed pipeline exterior surfaces. Chloride penetration where there is exposure to seawater would also degrade the concrete integrity. The consequence of the risk is a reduction in concrete thickness will reduce the cover to the reinforcing and the post tensioned wires, therefore worsening Corrosion/rupture of the post tensioning wires and corrosion of the reinforcing wires.	Low	Low	4	Med	Low	6	Very High	Low	10	6.67	Concrete testing was carried out by WSP to understand the condition of it. The cores were described as dense, well-consolidated concrete with not discernible excess voids. An inspection should be carried out in 10 years to assess the conditions of the concrete and will occur at the same time as the rubber ring joints inspection.	Low	Low	4	Med	Low	6	Very High	Low	10	6.67
4	Failure of the anchoring blocks.	There is a risk that that should the high tensile steel anchoring and coupling blocks fail, there could e some recoil in the lines, damaging the concrete and possibly comprising the axial strength of the pipeline. There are multiple redundant strands available to hold the joints together and no indication that deterioration of the strands is present The consequence of the risk is there will be a resulting loss of water tightness at the joints and could lead to further corrosion and joint opening.	Low	High	8	Med	Low	6	Very High	Low	10	8.00	Advance inspections of anchor blocks to occur. If during monitoring a strand is found to have failed then additional monitoring can be implemented to ensure that the joint integrity is compromised.	Low	Low	4	Med	Low	6	Very High	Low	10	6.67
5	Corrosion of the reinforcing wires	There is a risk that the corrosion of reinforcing wires could cause spalling, which will cause pieces of concrete to break off. The consequence of the risk is it will further increase the susceptibility to corrosion of the surrounding wires as well as reducing the strength of the pipeline as the wires will no longer provide tension resistance. It could cause leaks in the pipeline if a large portion of concrete breaks out.	Low	Low	4	Med	Very Low	3	Very High	Very Low	5	4.00	Concrete testing was carried out by WSP to understand the condition of it. The cores were described as dense, well-consolidated concrete with not discernible excess voids. WSP estimated a remaining life of between 29-42 years. The pipe is partially buried below the seabed in some locations. Corrosion risk low in an anoxic condition. Sedimentary transfer investigation should occur to understand when and where the pipeline is buried throughout the year.	Low	Low	4	Med	Low	6	Very High	Low	10	6.67
6	Open Joints	There is a risk that a joint may open due to the pipe flexing because of subsidence or movement from wave loading. The pressure in the pipeline may cause the joints to open up slightly should the prestressed reinforcing fail. The consequence of the risk is effluent would leak from the pipeline causing a plume.	Low	Very High	10	Med	Med	9	Very High	Med	15	11.33	Monitoring of the joints should occur periodically to reduce the likelihood of failure. Installation of piles around the joints would reduce the movement and significantly lessen the risk.	Low	High	8	Med	Low	6	Very High	Low	10	8.00
7	Damage to the pipe due to impact load (e.g. boat)	There is a risk of an anchor or drag net hitting the pipeline causing failure. E.g. breaking open a hole through the concrete or fibreglass collar, pulling the pipeline out of alignment, damaging the external concrete surface, damage to the anchor plates. The consequence of the risk is effluent leakage causing a plume, putting excessive stress on the post tensioned wires and joints, corrosion of reinforcing wires to compromising the structural integrity of the pipeline.	Low	Very High	10	Med	High	12	Very High	High	20	14.00	A mitigation technique would to extend the current navigation exclusion zone along the length of the pipeline. With additional navigation buoys along the pipe route. Another mitigation could be to provide rock armour/ or concrete mat protection over high risk locations.	Low	Low	4	Med	Low	6	Very High	Low	10	6.67
8	Failure of titanium collars.	There is a risk that gaps may form between two adjacent pipes sections should the titanium collars. The consequence of the risk is will lead to pipe leakage and excessive joint deflection above the design limit. The movement between the two sections will cause abrasions between the two concrete surfaces reducing the cover to reinforcement and post tensioned wires and facilitating corrosion/rupture of the post tensioning wires and Corrosion of the reinforcing wires further.	Low	Med	6	Med	Med	9	Very High	Med	15	10.00	Periodic inspections of the titanium collars should occur. This will identify collars that may be close to failure, allowing for pre-emptive repairs on the them reducing the risk of failure	Low	Low	4	Med	Low	6	Very High	Low	10	6.67
9	Failure of repair band.	There is a risk that gaps may form between two adjacent pipes sections should the repair bands fail. The consequence of the risk is will lead to pipe leakage and excessive joint deflection above the design limit. The movement between the two sections will cause abrasions between the two concrete surfaces reducing the cover to reinforcement and post tensioned wires and facilitating corrosion/rupture of the post tensioning wires and Corrosion of the reinforcing wires further.	Low	High	8	Med	High	12	Very High	High	20	13.33	Periodic inspections of the repair bands should occur. This will identify bands that may be close to failure, allowing for pre-emptive repairs on them reducing the risk of failure	Low	Low	4	Med	Low	6	Very High	Low	10	6.67
10	Failure of the manholes	There is a risk that corrosion of the manhole may occur. The consequence of the risk is will lead to pipe leakage. The corrosion if severe enough could causes holes in the manholes to form or the bolts to fail allowing the effluent to discharge.	Low	Med	6	Med	Med	9	Very High	Med	15	10.00	Periodic inspections of the manhole should occur. This will identify manholes that may be close to failure, allowing for pre-emptive repairs on them reducing the risk of failure	Low	Low	4	Med	Low	6	Very High	Low	10	6.67

Very Low	1
Low	2
Med	3
High	4
Very High	5

Very Low	1
Low	2
Med	3
High	4
Very High	5

Hawke's Bay
1st Floor, 100 Warren Street South
Hastings 4122
PO Box 13-052, Armagh
Christchurch 8141
Tel +64 6 873 8900
Fax +64 6 873 8901

Stantec