# Waimakariri District Ocean Outfall Option

**NIWA Client Report: SKM02204/1**
**February 2002**

# Waimakariri District Ocean Outfall Option

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# Executive Summary

NIWA was commissioned in December 2001 by Sinclair Knight Merz (SKM), on behalf of the Waimakariri District Council (WDC), to perform a preliminary desktop study to:

*Identify the potential adverse effects on the receiving environment of a possible ocean outfall for Waimakariri District combined sewage.*

The objectives of the study were as follows:

- To identify the key environmental effects for a possible ocean outfall at Waimakariri
- To identify the key receptor impacts including aquatic and marine organisms, recreational users, aesthetic effects (colour), nuisance effects (odour), cultural effects
- To confirm the differences in effect between 1 km, 2 km and 3 km outfall lengths
- To review the difference in effect between existing UV-treated oxidation pond effluent and secondary treated effluent.

An ocean outfall comprises a delivery pipeline tied to down or buried under the seabed, terminating in a section of pipe with multiple small holes (called ports), which is called the diffuser. The effluent discharges as a series of separated jets from each circular port. These jets entrain seawater which dilutes the effluent. As the jets slow down and spread, they become plumes as they rise towards the surface because of their buoyancy (freshwater is about 2.5% lighter than seawater). The ocean outfall options considered in this report would discharge into Pegasus Bay, north of the Waimakariri River mouth at either Woodend Beach or The Pines Beach.

### Consenting issues

Any direct discharge of 'human sewage' to the Coastal Marine Area, which has not passed through soil or wetland, is a 'Restricted Coastal Activity' under Schedule 1.10 of the NZ Coastal Policy Statement 1994 and will require final approval from the Minister of Conservation. An ocean outfall discharge off either The Pines Beach or Woodend Beach also must meet the relevant Rules in the Proposed Regional Coastal Environment Plan (RCEP) administered by Environment Canterbury. The RCEP classifies Waimakariri River mouth and adjacent coastal areas, out to a distance of approximately 500 m offshore, as Class Coastal CR Water, i.e., 'being coastal waters managed for contact recreation and the maintenance of aquatic ecosystems'. Although all three proposed pipeline lengths (from 1 to 3 km length) discharge further offshore than the

Class Coastal CR area, the minimum standards must be met prior to an effluent plume encroaching into the classified area. We recommended that WDC adopt the Class Coastal CR minimum standards and those under Rule 7.3 of the RCEP for any sewage-effluent discharge, even if the discharge location is well outside the classified Coastal CR area.

The water quality standards defined in the RCEP apply 'after reasonable mixing' with the receiving water. Using reasoning based on physical mixing processes, we define this area (often termed the 'zone of initial dilution' or ZID) to encompass the initial, rapid dilution of the outfall plumes as they rise and reach the water surface. For discharge into a slow moving coastal current, a radius of 250 m centred on the diffuser location will enclose the ZID in most of the outfall scenarios assessed in this Report.

## Analysis of field data and numerical simulations

Field data collected for the Christchurch City Wastewater Study and from a NIWA current meter were used to provide a description of oceanography in the region of the discharge. This showed the long-term wind record to be dominated by onshore winds from the east and northeast. The coastal water currents showed a pronounced longshore alignment, alternating between heading south or north. Non-tidal processes such as local wind, coastal currents and coastal-trapped-waves are important forcing mechanisms for currents in the wider Pegasus Bay.

A simple numerical model was used to predict the spreading and dilution of an effluent plume discharging from an outfall diffuser at 1, 2 and 3 km offshore (at depths of 9, 14 and 17 m respectively). Effluent discharge rates were varied using data supplied from SKM, from a minimum flow of 30 L/s to a Maximum Wet Weather Flow (MWWF) of 500 L/s. Most of the scenarios examined discharged into a 'slow-moving' ambient current, though the greater dilution achieved for higher ambient currents was also investigated. The model predicts the size, location (relative to the coastline) and average (bulk) dilution of the effluent plume, assuming an ambient current flowing parallel to the local shoreline. Surface wind effects were not included in these preliminary simulations. Concentrations of water quality variables were then calculated from the plume dilution. Higher dilution factors (lower concentrations of water quality variables) are obtained by discharging at increasing depths (increasing the length of the outfall). For example, the average dilution at the edge of a 250 m mixing zone is expected to be at least 80 fold for a 1 km outfall, 130-fold for a 2 km outfall and 160-fold for 3 km outfall, during average wet-weather flows. The dilution will be markedly higher for typical dry-weather periods. A longer pipeline has the added benefit of discharging the effluent further from the shore, so the likelihood of diluted effluent contacting the shore is reduced. These advantages need to be weighed up against the increased cost of a longer pipeline, while satisfying the water quality standards, community perceptions and cultural concerns.

## Public health guidelines and water quality standards

The results of the computer simulations indicate that public health guidelines and water quality standards (i.e., Class Coastal CR standards and Rule 7.3) could be met by all of the proposed outfall lengths, after allowing an area for reasonable mixing (i.e. outside a 250 m radius from the outfall diffuser). However, the proximity of the 1 km outfall options to the classified Class Coastal CR region (centred on the Waimakariri River mouth), and cultural/community concerns for any effects on such popular bathing areas will probably make the 1 km option unacceptable.

The main water quality issues that emerge from the preliminary desk-top study are:

- Public-health issues and cultural concerns from the discharge of treated sewage into a water body used for recreation and food supplies

- Aesthetic appearance and water clarity for the shorter outfalls for an oxidation-pond effluent (via the infrequent, but high, suspended solids concentrations)

- Potential for stimulating naturally-occurring algal blooms in coastal waters of the region, and in the Brooklands Lagoon (for The Pines Beach option).

Other water quality standards in the Class Coastal CR schedules Rule 7.3 would easily be met by the assessed outfall options. These included the impacts of dissolved oxygen reduction, excess temperature, odour and appearance for the secondary treatment effluent option, and pH. This is due to the large initial dilutions possible by an ocean outfall coupled with the large buffering capacity of the ocean, compared with, for example, a shallow river outfall. If an ocean outfall option is pursued, then the most effective ways to reduce the environmental and public-health risks are: a) improving the effluent quality prior to discharge, particularly the upper-limit concentrations, with best practicable technology; and, b) increasing the separation from most of the resource users, which in this case will be mainly recreational beach users at the shoreline.

Environment Canterbury has recently received a resource consent application for a marine farm (to culture mussels) due east of the Waimakariri River mouth, and some 10.5 km offshore. A desk-top analysis indicates that the risk from any impact of a 1 to 3 km outfall discharge on the marine farm will be negligible.

Recommendations are given for further investigations if an ocean outfall option is to be pursued further. This would include measurements of coastal water quality, ocean current measurements, dispersion model simulations with realistic currents and winds, virus risk assessment, ecological surveys, recreational and community surveys and wide consultation because the discharge is likely to be a ‘Restricted Coastal Activity’.

# 1. INTRODUCTION

NIWA was commissioned in December 2001 by Sinclair Knight Merz (SKM), on behalf of the Waimakariri District Council (WDC), to perform a preliminary desk top study to:

*Identify the potential adverse effects on the receiving environment of a possible ocean outfall for Waimakariri District combined sewage.*

Options for a wastewater outfall would discharge treated sewage from the Kaiapoi and Rangiora areas into Pegasus Bay, north of the Waimakariri River mouth. The objectives of the study were as follows:

- To identify the key environmental effects for a possible ocean outfall at Waimakariri
- To identify the key receptor impacts including aquatic and marine organisms, recreational users, aesthetic effects (colour), nuisance effects (odour), cultural effects
- To confirm the differences in effect between 1 km, 2 km and 3 km outfall lengths
- To review the difference in effect between existing UV-treated oxidation pond effluent and secondary treated effluent

Within these objectives, key issues to be addressed were:

- Predict adverse effects on the environment of the outfall including RMA S.107 assessment
- Compliance with receiving environment standards including NZCPS and Canterbury Regional Coastal Environmental Plan at locations specified by NIWA
- Comparison of effects predicted with effects of other New Zealand coastal sewage outfalls
- Discussion of virus risk issues and an overview of how this issue should be addressed including recommended further monitoring work

- Identification of key receptors in the receiving environment including coastal marine farms and how they may be affected by the proposal.

Data provided by SKM for the purposes of this study included the discharged effluent flow rates (Table 1.1) and the effluent quality parameters (Table 1.2).

**Table 1.1:** Design effluent flowrate specifications (up to year 2030)

| Discharged Effluent Flowrate | L/s | $m^3$/day |
|---|---|---|
| Minimum Flow | 30 | 2,592 |
| Average Dry Weather Flow (ADWF) | 121 | 10,500 |
| Average Wet Weather Flow (AWWF) | 207 | 17,980 |
| Maximum Wet Weather Flow (MWWF) | 500 | 43,820 |

**Table 1.2:** Discharged effluent quality parameters

| Effluent Quality Parameters | Option 1<br>Oxidation Pond + UV Disinfection | | | Option 2<br>Secondary Treatment | | |
|---|---|---|---|---|---|---|
| | Min | Median | Max | Min | Median | Max |
| Faecal coliforms [cfu/100 mL] | 20 | 200 | 2000 | 20 | 200 | 2000 |
| Viruses | | unknown | | | unknown | |
| Dissolved reactive phosphorous [mg/L] | 1 | 5 | 12 | 1 | 5 | 12 |
| Ammoniacal nitrogen [mg/L] | 6 | 16 | 26 | <0.1 | 0.2 | 5 |
| Nitrate nitrogen [mg/L] | 0 | 1 | 7 | 1 | 10 | 15 |
| Nitrite nitrogen [mg/L] | 0 | 0.1 | 0.5 | <0.1 | <0.1 | 0.5 |
| Total Kjeldahl nitrogen [mg/L] | 18 | 29 | 38 | 1 | 2 | 8 |
| Total suspended solids [mg/L] | 12 | 60 | 220 | 4 | 10 | 20 |
| 5 day BOD [mg/L] | 13 | 32 | 88 | 2 | 8 | 20 |
| Ph | 7.0 | 7.3 | 8.8 | 6.8 | 7.0 | 7.2 |
| Temperature [°C] | 10 | 11 | 20 | 10 | 11 | 20 |
| Dissolved Oxygen [mg/L] | 0.4 | 5 | 12 | 2 | 2.5 | 3 |
| Chemical Oxygen Demand [mg/L] | 150 | 160 | 200 | 30 | 50 | 70 |

Field data collected for the Christchurch City Wastewater Study (Cox, 1999) and a NIWA current meter, deployed for research purposes in 1999, was used to provide a description of oceanography in the region of the discharge (Section 2). A simple numerical model was then used to predict the spreading and subsequent dilution of an effluent plume discharging from an outfall diffuser at 1, 2 and 3 km offshore (Section 3). The pertinent issues regarding a consent for an ocean outfall are discussed in Section 4 and Section 5 discusses the performance of the proposed outfall, including issues such as fresh water influence from the Waimakariri River, comparison of the two proposed discharge locations and meeting the water quality guidelines.

# 2. DESCRIPTION OF LOCAL OCEANOGRAPHY

Two possible locations for an outfall option were proposed by the District Council; off Pines Beach, or off Woodend Beach further north. Both sites are situated north of the Waimakariri River mouth (Figure 2.1). At each location, outfall discharge options of 1, 2 or 3 km offshore were assessed in this initial Study.

## 2.1 Offshore depth profiles

Depth profiles at the two proposed outfall locations were obtained from a Royal New Zealand Navy sounding fair-sheet and are shown in Figure 2.2. Also shown is the profile from New Brighton Beach, for comparison. The seabed drops off at a rate of 1:100 within 1 km of the shore, but flattens out to a slope of 1:2500, 3 km from the shore.

## 2.2 Coastal currents

Few direct measurements of coastal currents within Pegasus Bay were available prior to the Christchurch City Wastewater Study, when a bottom-mounted profiling current meter was deployed 2.5 km offshore off South Brighton Beach from January to April 1999 (Cox, 1999). A further current-meter was also deployed by NIWA for research purposes, partially overlapping the South Brighton mooring. The NIWA mooring was approximately 30 km offshore from Leithfield Beach from February to May 1999, being 21 m above the bed in 47 m water depth (see Figure 2.1). Cox (1999) summarised both the wind conditions and the oceanography of Pegasus Bay, and the information presented here is largely summarised from that report, but is supplemented here by an analysis of the NIWA current-meter record.

The long-term wind record is dominated by onshore winds from the east and northeast, these two quarters each accounting for approximately 30% of all winds. Approximately 10% of winds blow offshore, which would transport the effluent plume towards a proposed mussel farm (shown in Figure 2.1).

The mean twice-daily lunar tide has a range of 1.69 m measured at Sumner Head by the NIWA/Environment Canterbury sea-level gauge. The monthly maximum perigean-spring tide range is ~2.2 m at Sumner Head.

Currents measured at both the 'inshore' (South Brighton Beach) and 'offshore' (30 km offshore from Leithfield Beach, Figures 2.3 to 2.6) sites showed a pronounced longshore alignment, partially due to tides that flow parallel to the coast, but also with strong non-tidal contributions. At the inshore site the cross-shore variance was approximately 30% of the longshore variance, and 15% at the offshore site. Inshore currents more than ~3 m below the surface showed similar directional behaviour throughout the water column and the current direction was longshore ~75% of the time, with greater wind-driven variability above this. Currents at both sites were aligned parallel to the local shoreline.

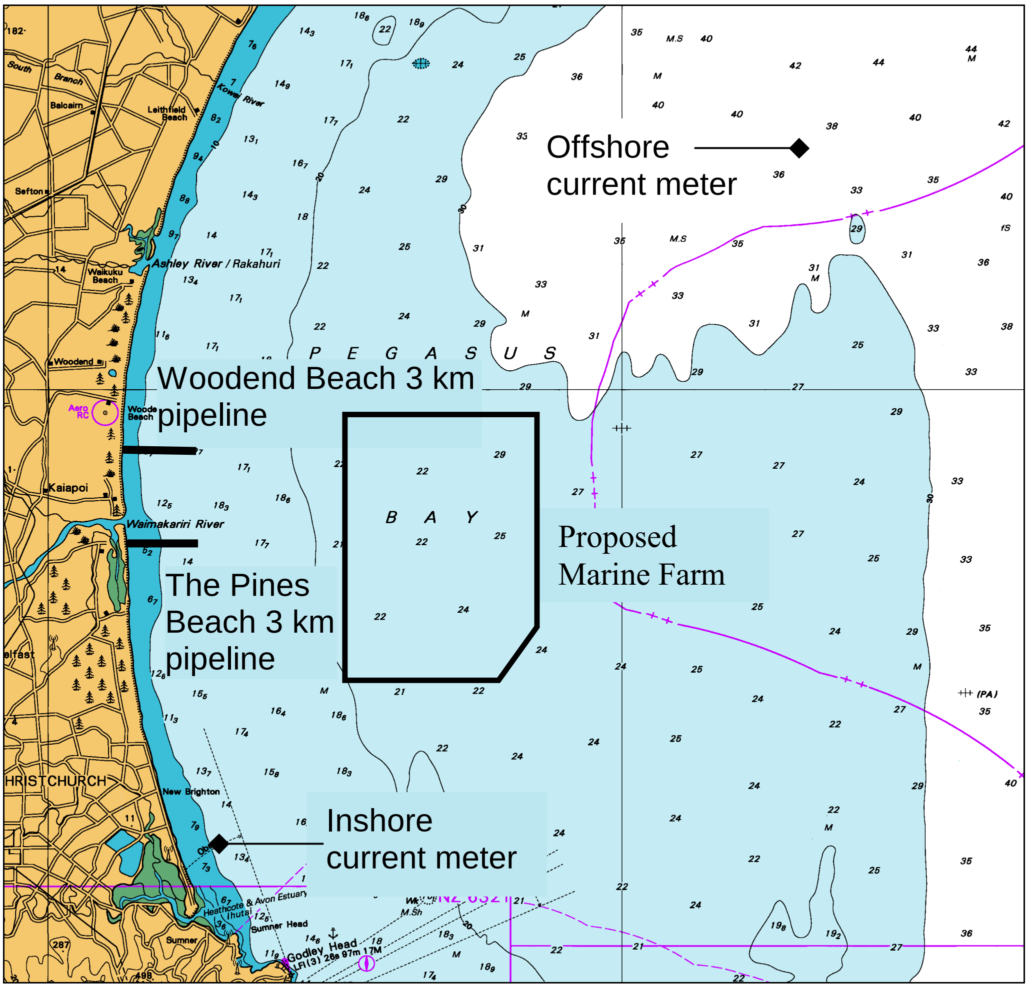

**Figure 2.1:** Pegasus Bay bathymetry showing proposed pipeline locations at Woodend Beach and Pines Beach (drawn to ~3 km offshore) and the locations of the inshore and offshore current-meters referred to in the text. (Chart sourced from Land Information New Zealand data. Crown Copyright Reserved. NOT TO BE USED FOR NAVIGATION.)

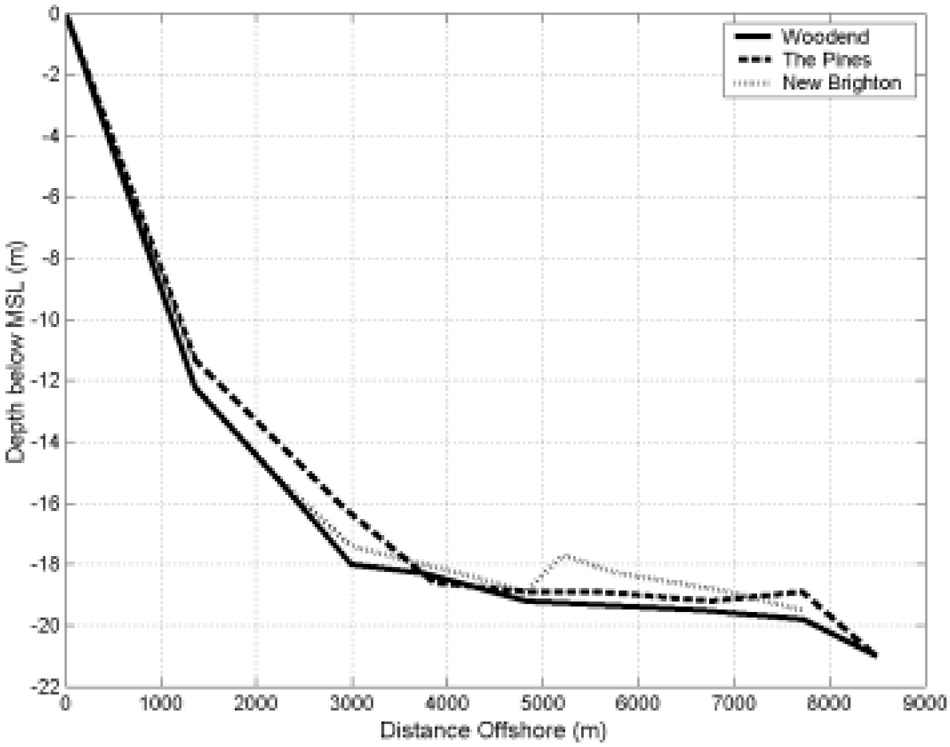

**Figure 2.2:** Depth profiles offshore from Woodend Beach (latitude 43° 20.6'), Pines Beach (latitude 43° 23.2') and perpendicular to New Brighton Beach. Depths are relative to mean sea level.

**Table 2.1:** Current speed percentiles at the inshore site.

| Depth | P10 (m $s^{-1}$) | P30 (m $s^{-1}$) | P50 (m $s^{-1}$) | P70 (m $s^{-1}$) | P90 (m $s^{-1}$) |
|---|---|---|---|---|---|
| 2.8 m | 0.08 | 0.14 | 0.22 | 0.31 | 0.48 |
| 4.8 m | 0.05 | 0.08 | 0.12 | 0.16 | 0.24 |
| 7.8 m | 0.04 | 0.07 | 0.09 | 0.13 | 0.21 |
| 14.8 m | 0.03 | 0.06 | 0.08 | 0.11 | 0.16 |

Tides accounted for 42% of current variance at the inshore site and ~30% at the offshore site (Figures 2.3 and 2.5), therefore non-tidal processes such as local-wind, coastal currents and coastal-trapped-waves are important forcing mechanisms in Pegasus Bay. Cox observed a number of events when the non-tidal component of the longshore current was either to the north or south for a period of several days. At the inshore site mean tidal current speeds were ~0.06 m $s^{-1}$ in the mid-water column, while mean non-tidal currents were ~0.09 m $s^{-1}$. Table 2.1 gives the current speed percentile values at various depths. Similar behaviour was observed in the offshore record with low-frequency currents reversing in the longshore direction (Figure 2.6). At the offshore site mean tidal current speeds were ~0.07 m $s^{-1}$ in the mid-water column, while mean non-tidal currents were ~0.09 m $s^{-1}$. The non-tidal flows are generally of similar or greater strength than tidal flows, and it is the non-tidal flows that dictate the general flow direction along the coast. Figure 2.4 indicates an overall net southerly drift at the offshore current meter site within Pegasus Bay. Gibb and Adams (1982) also find sedimentary and geomorphic evidence that suggests that there is a net southerly drift of sediment at the shoreline, noting that the Waimakariri River mouth migrates south. However there will be periods when southerly waves and swell can generate a northerly drift in the nearshore/beach zone, causing sediment to move northwards. This wave-driven longshore transport is not to be confused with alongshore currents further offshore that can be in the opposite direction to the shoreline drift.

The forcing of non-tidal currents is unclear, some local-wind forcing occurs (~15% of variance) but there is also evidence of remotely-forced coastal-trapped-waves. Cox found a correlation between wind and current at low-frequencies, and also observed a non-isobaric response to local atmospheric pressure change and weak correlation between low frequency water levels and currents. These imply coastal-trapped-wave activity but a cause and effect relationship is difficult to define. Brown (1976) also observed weekly to fortnightly cycles in beach process conditions, thought to be related to the regular occurrence of southerly winds.

Temperature stratification from January to April 1999 was generally less than 1.5 °C, with a maximum of 3 °C, but no data exist to place these measurements in a seasonal or long-term context. However, because the measurements were taken over the summer period when thermal inputs are highest, temperature stratification will probably be small throughout the year. Long-term surface temperature records from Lyttleton Harbour and Little Pidgeon Bay show temperatures peaking at ~20°C during summer and ~8°C during winter. Little rain-event-induced stratification was observed 2.5 km offshore, but Cox suggested that this may be more significant near the Waimakariri river, with a 1-in-100-year flood influencing currents for a few kilometre radius around the Waimakariri River mouth.

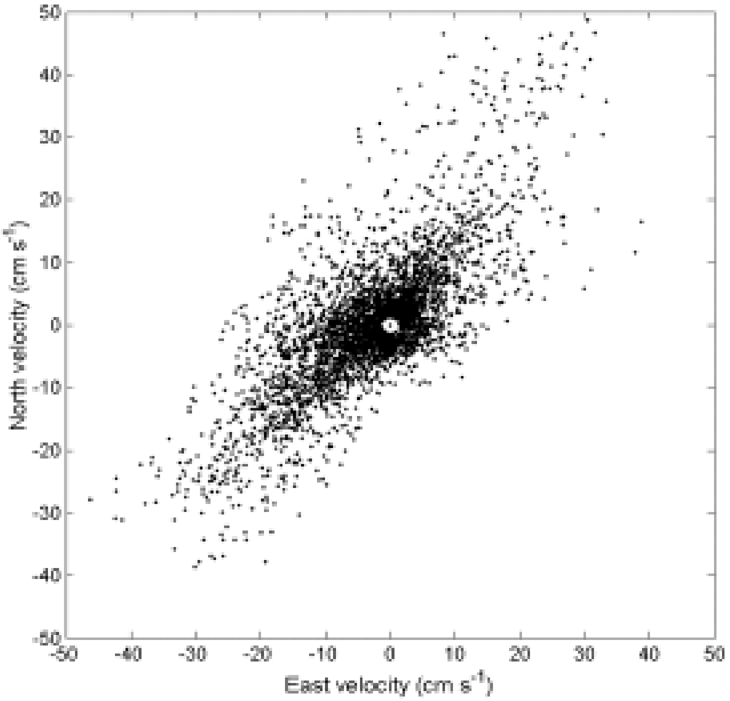

**Figure 2.3:** Scatter plot of Pegasus Bay currents measured at the offshore site. The principle component is through 43°T.

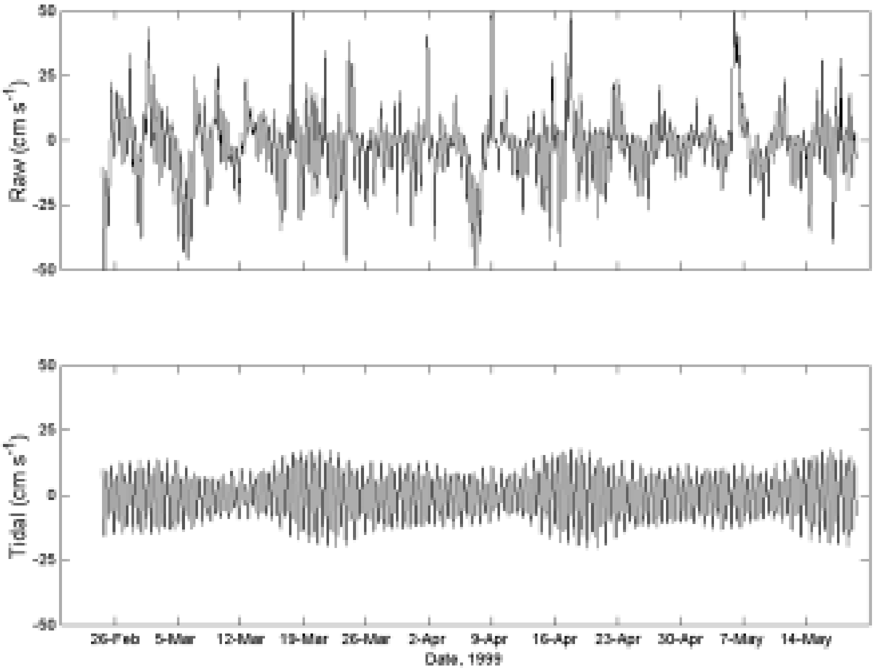

**Figure 2.4:** Pegasus Bay raw current measured at the offshore site and predicted tidal current (cm $s^{-1}$) in the principle longshore direction (43°T). Tidal currents account for 37% of the raw current variance.

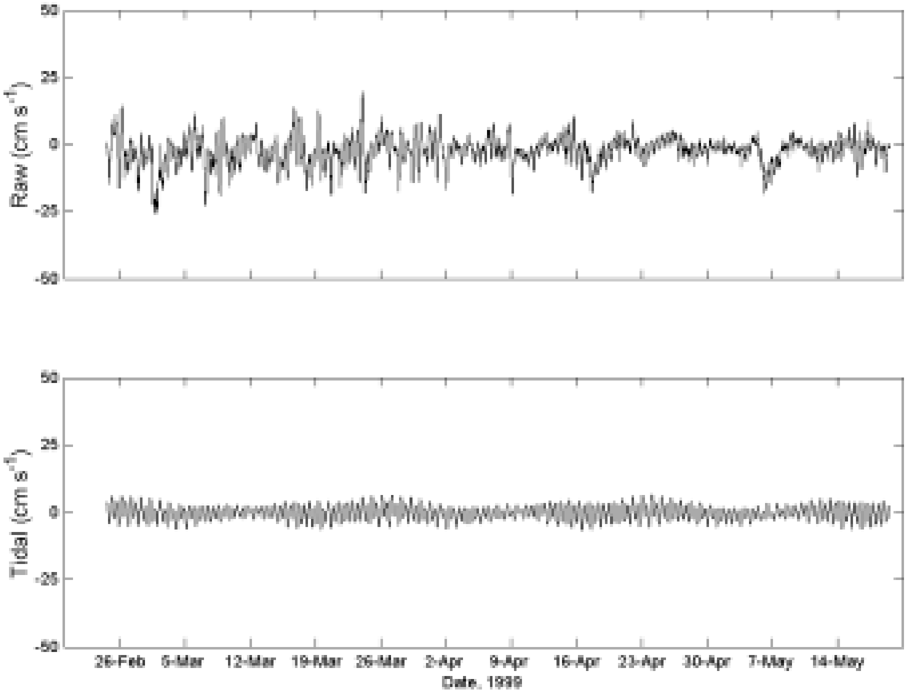

**Figure 2.5:** Pegasus Bay raw current measured at the offshore site and predicted tidal current (cm $s^{-1}$) in the principle cross-shore direction (133°T). Tidal currents account for 26% of the raw current variance.

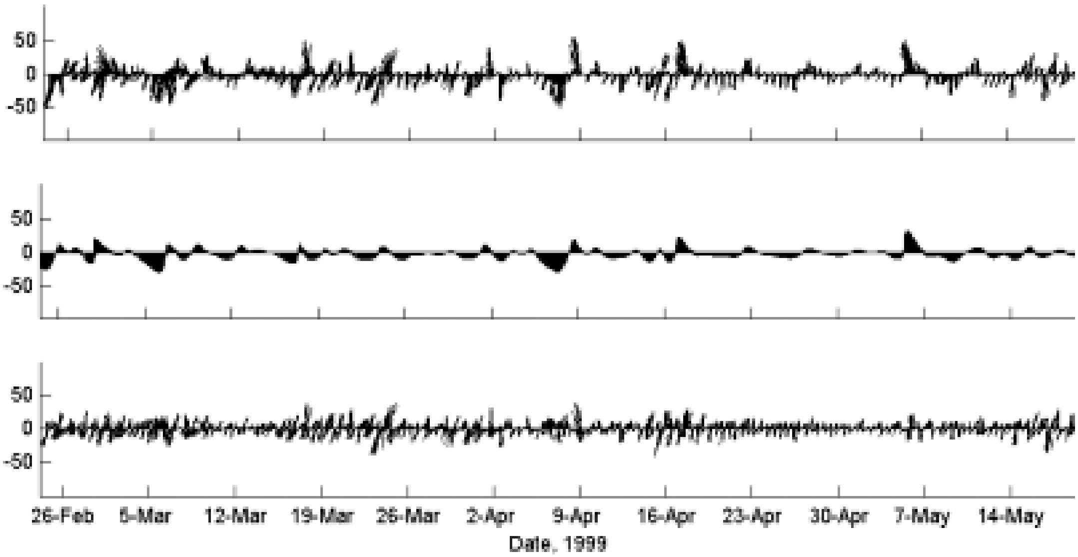

**Figure 2.6:** Feather plots of Pegasus Bay currents (cm $s^{-1}$) measured at the offshore site. Currents have been rotated 43° anticlockwise to align the principal longshore component to vertical on the plots. The upper plot is the raw data, the middle plot has been low-pass filtered to remove tidal and other data of period < 40-hours, while the lower plot contains data of period < 40-hours.

## 3. NUMERICAL MODEL OF PLUME DISPERSAL

The outfall diffuser design used within these numerical simulations is a preliminary design agreed between NIWA and Sinclair Knight Merz, chosen to give a ‘conservative’ estimate of plume dilutions. Details of the diffuser design are given in Table 3.1 and Figure 3.1. To obtain the depth at the discharge location, the profile at The Pines Beach was used (Section 2), however this stretch of coast is fairly uniform and conditions at the alternative site of Woodend Beach would not be very different. Section 4 discusses the implications of these two locations on the wastewater plume. It is also assumed that the receiving environment is not stratified, i.e., it is ‘well mixed’ and of uniform properties throughout the whole vertical water column. Section 4 also discusses the implications of stratification of the discharge for effluent from the two sites.

The design flow rates are given in Table 1.1. It is recommended that field measurements, further diffuser design and numerical simulations are performed before the final design is approved.

**Table 3.1:** Details of pipeline and diffuser design

| **Pipeline and diffuser pipe diameter** | **0.55 m** | | |
|---|---|---|---|
| Number of ports | 20 | | |
| Port type | Sharp edged | | |
| Port arrangement | Staggered alternate arrangement with horizontal orientation, 2 m between centre of adjacent ports | | |
| Diffuser length | 19 m | | |
| Port diameter* | 100 mm | | |
| Pipeline length | 1 km | 2 km | 3 km |
| Depth (wrt MSL) at diffuser | 9 m | 14 m | 17 m |

* The diameter of the ports was calculated using the condition (Williams 1985):

Combined port area $\left(\sum A_p\right)$ = 60% of pipe cross section area

The individual port diameter is then: $2 * \sqrt{\sum A_p \big/ N\pi}$ where N is the number of ports.

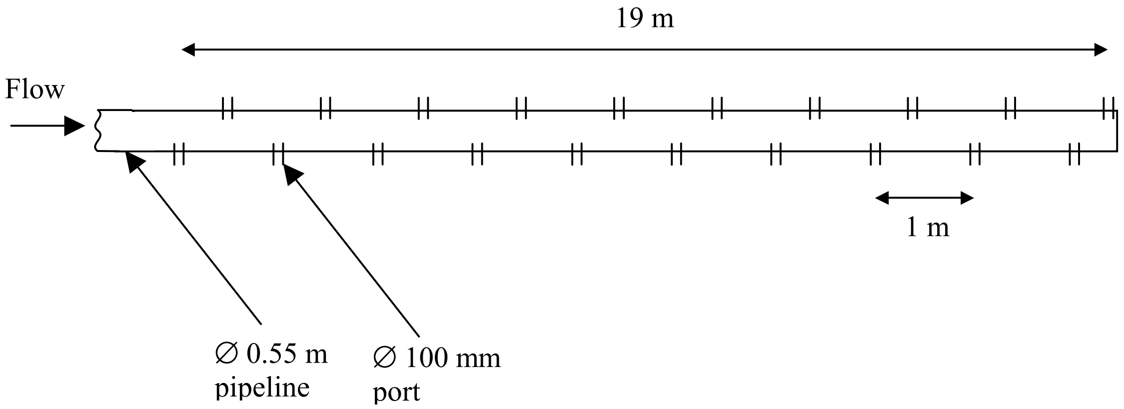

**Figure 3.1:** Diffuser design adopted for this preliminary report.

A simple hydraulic analysis was performed on the diffuser design to check that pumping heads are reasonable. The required total energy heads ($\Delta H$), relative to the instantaneous sea level, that would achieve the specified flow rates through the outfall diffuser were computed (Table 3.2.). Energy losses taken into account were friction losses in the pipe and diffuser head losses, which includes a 2.5% difference in density between the effluent and seawater.[1]

To obtain the absolute energy head, $\Delta H$ must be added above the design sea level (including spring tide and storm tide elevations).

These energy head losses are shown in Table 3.3 for the 1 km pipeline discharging into a depth of 9 m, for the various design flow rates. Adoption of longer outfall pipelines will have proportionally larger frictional losses within the pipe. Note that the pumping head required increases markedly with higher flow rates and is predominantly due to overcoming the frictional losses within the pipe. These high losses (see for example, flow 500 L/s corresponding to MWWF) occur because of the relatively high pipe velocities generated within the given pipe diameter. Note that this pipe friction will be approximately 3 times greater (42 m) for the 3 km long outfall pipe.

Also shown in Table 3.3 are the densimetric Froude numbers ($Fr$) and the minimum initial dilution ($S_o$) above the outfall diffuser for quiescent conditions at sea (i.e., zero current conditions).

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[1] For friction losses, a Mannings $n$ value of 0.015 was assumed, and pipe fitting losses were taken as $2(V^2/2g)$ where $V$ is the pipe velocity.

The densimetric Froude number (*Fr*) gives an indication of the relative strengths of the inertial and buoyancy forces operating on the discharge jet. If this number is large, then the high momentum of the discharging effluent generates a high-velocity 'jet' from each port, transporting the effluent horizontally away from the diffuser, before buoyancy starts to lift it towards the surface. If the Froude number is small, then the 'jet' is very weak and the positive buoyancy of the effluent is the stronger influence. In this case, the discharged effluent behaves as a 'buoyant plume' rising more quickly towards the sea surface. (This simple description assumes horizontal ports and a stationary receiving water body).

The initial minimum dilution ($S_o$) gives an estimate of the minimum dilution factor which would occur at the centreline of the plume, as it reaches the water surface, assuming the receiving ambient water is not moving (quiescent, or stationary conditions). In reality the ambient flow is rarely completely stationary, and never for very long periods of time. Also, the minimum dilution only applies to a small portion of each plume, that being the centre of the plume, which gets diluted last by the surrounding seawater.

**Table 3.3:** Hydraulic analysis of diffuser at 9 m depth and a 1 km pipeline, showing total pumping head requirements ($\Delta H$) for each design flowrate, the relative strength of the emanating jets (*Fr*) and the minimum initial dilution factor in stationary seawater ($S_o$).

| Case | flow rate [$m^3/s$] | pipe velocity [m/s] | diffuser head loss [m] | friction loss [m] | $\Delta H$ [m] | *Fr* Froude No. | $S_o$ min. diln |
|---|---|---|---|---|---|---|---|
| Min flow | 0.030 | 0.13 | 0.01 | 0.05 | 0.3 | 2 | 109 |
| ADWF | 0.121 | 0.51 | 0.09 | 0.82 | 1.2 | 9 | 53 |
| AWWF | 0.207 | 0.87 | 0.26 | 2.39 | 3.0 | 16 | 44 |
| MWWF | 0.500 | 2.10 | 1.52 | 14.02 | 16.2 | 38 | 40 |

Numerical simulations of the jet/plume dispersal and subsequent effluent dilution were performed using the Cornell Mixing Zone Expert System (CORMIX, v3.2), (Jirka, Doneker and Hinton, 1996). This version of the model is widely accepted by regulatory agencies worldwide (e.g., US Environmental Protection Agency). Although adequate for this preliminary study, this version of the model has recently been updated and a new version released. It is recommended that the new version be used for future simulations if the outfall option is pursued further.

## 3.1 Low ambient current

Initially, 12 simulations were performed, one for each of the 4 effluent flow rate cases (Table 3.2) and for each of the 3 pipeline lengths shown in Table 3.1. For these simulations it was assumed that the effluent was discharged into an ambient body of seawater, moving quite slowly (at a velocity of 0.05 m/s) in a direction perpendicular to the pipeline and diffuser (i.e., flowing parallel to the local coastline). This represents a 'worse case' in terms of current speeds, in that higher dilutions will be expected for higher current velocities, but rarely is the ocean stationary. Physically, such a low ambient flow will occur during the turn of the tide, or possibly if the tidal forcing and non-tidal forcings (e.g., wind-driven currents) are opposing each other and are in approximate balance for short periods during a reversal in coastal currents. Both of these conditions will only exist for a relatively short time due to ever-changing tidal currents and wind conditions.

The numerical model predicts the dimensions of the effluent plume and the average (bulk) dilution of the plume (as distinct from the minimum centreline initial dilution in Table 3.3). The plume-average concentration of effluent constituents can be calculated from the dilution of the effluent plume with the ambient seawater and is discussed in Section 4.

The vertical and horizontal extent of the plumes are shown in Figures 3.2 and 3.3 for a southward-moving coastal current. (A mirror image of the plots would apply equally to a northward-moving current.) The discharged effluent will have a lower density than seawater, therefore the resulting plume will be positively buoyant, rising to the sea surface. It will then spread on the surface (including upstream, except in the case of minimum discharge) and subsequently be transported downstream. The average dilution of the plumes is shown in Figure 3.4. The mechanisms that affect the spreading, transport, and dilution of the plume can be split into distinct processes:

For the case of minimum discharge, the port Froude Number is very low, indicating that the jet momentum is very low. Although the ambient receiving water is moving slowing at 0.05 m/s, it is still a relatively strong cross flow compared to the weak momentum of the effluent jet. This stronger cross flow will bring 'new' seawater into the jets and allow more 'efficient' dilution (i.e., higher dilutions for a given degree of mixing). The effluent will be diluted approximately 50 times before the jets lose all their momentum (due to turbulent friction) and form a buoyant plume, which continues to rise to the surface. This plume will continue to be deflected downstream due to the ambient current as it rises to the surface. Due to the low volume of effluent discharged, there will be much opportunity for mixing with the ambient seawater and high dilution rates will occur. The longer pipeline options discharge into deeper water and therefore take longer to reach the surface, allowing for greater mixing and dilution to take place. Once the plume reaches the surface it will already be very dilute (by a factor of approximately 700 for the shortest 1 km outfall) and will therefore form a relatively thick, low-concentration surface layer that will be transported downstream. Further lateral spreading will occur by ‘gravitational spreading’, due to the lighter plume spreading over the top of the heavier seawater. Turbulent mixing will also continue as eddies on the plume boundary entrain more of the ambient seawater, and the plume will start to mix downwards as well.

For higher discharge rates the discharge Froude Number increases (see Table 3.3). This means that near the vicinity of the diffuser, the horizontal momentum of the jets emanating from each diffuser port (hole) becomes more dominant over both the vertical buoyancy forces, and the horizontal momentum of the ambient flow across the diffuser. For a given period of time, there is a lot more effluent to be diluted for higher flow rates, but the same amount of ambient seawater in which to dilute the effluent. The same degree of mixing will therefore not lead to such efficient dilution. By the time the jets lose momentum and become a buoyant plume, the dilution factor will be approximately 10 for the Maximum Wet Weather Flow rates (MWWF). Due to the relatively weak ambient cross flow, the buoyant plume will then rise vertically to the sea surface, entraining seawater into the effluent plume. Again, the longer pipeline options discharging into deeper water will allow for greater dilution during this process. On reaching the surface the effluent will be diluted by a factor of approximately 25 for MWWF with a 1 km pipeline, and 50 for MWWF with a 3 km pipeline. The plume will then spread in all horizontal directions, including upstream, while being transported downstream by the ambient current. Due to the full depth of seawater being entrained into the upstream boundary of the surface plume, the dilutions at this location will be significantly higher than the equivalent distance downstream from the diffuser (Figure 3.5). The surface plume will continue to spread and be diluted with the ambient water through the action of gravitational spreading and turbulent mixing as it migrates downstream, and eventually starts to mix downwards as well. The lateral spread of the surface plume will mean that, for the short (1 km) pipeline under MWWF, diluted effluent could make contact with the shore 1700 m downstream of the discharge point for a weak ambient current of 0.05 m/s (given that the current can flow in either direction). Similarly, diluted effluent could contact the shore 2500 m downstream for AWWF and 3500 m downstream for ADWF. Within the 5000 m downstream of the coastal zone modelled for a shore-parallel weak current, only discharges from the shorter 1 km pipeline came into contact with the shoreline. This analysis assumes that the ambient flow remains parallel with the shoreline. Obviously it is possible that the wind and local currents could transport the effluent onshore, though the field data (Section 2) suggests that the majority of the mid-water column currents are shore-parallel. However, onshore winds can considerably alter surface currents causing the plume to drift more quickly to the shoreline.

## 3.2 Higher ambient currents

Because such low ambient currents, as modelled in the previous section, are unlikely to occur for any significant length of time, simulations were also performed at other higher ambient current velocities. These simulations assume a pipe length of 2 km and discharging Average Wet Weather Flow (AWWF) into an ambient velocity of 0.05 m/s, 0.25 m/s and 0.5 m/s. The resulting plumes are shown in Figures 3.6 and 3.7 (side and plan view), and the average dilutions in Figure 3.8.

The stronger ambient cross flow has three major influences on the jet and plume behaviour:

- the momentum of the ambient current deflects the rising buoyant plume, transporting it downstream before it reaches the surface. On reaching the surface, the stronger flow will continue to transport the plume more rapidly downstream than for low ambient currents.

- the increasing ambient current presents a large volume (per unit time) of ‘new’ seawater relative to the discharged effluent volume. This will lead to more efficient mixing and higher dilutions.

- the higher currents will increase the general turbulence within the ocean. The turbulent eddies will therefore be larger and stronger, generating increased mixing by turbulent diffusion.

These influences can be seen in the resulting figures. In plan view the plume is narrower at higher ambient current velocities, due to the plume being transported more rapidly downstream. The large amount of mixing will result in a thick plume (large vertical dimension), although within this layer the effluent is very dilute (Figure 3.8). At the highest current velocity modelled (0.5 m/s), the vertical mixing is so great that the water column becomes ‘fully-mixed’ at approximately 2,700 m downstream of the discharge point. The effluent here is very dilute—approximately 8,000 fold.

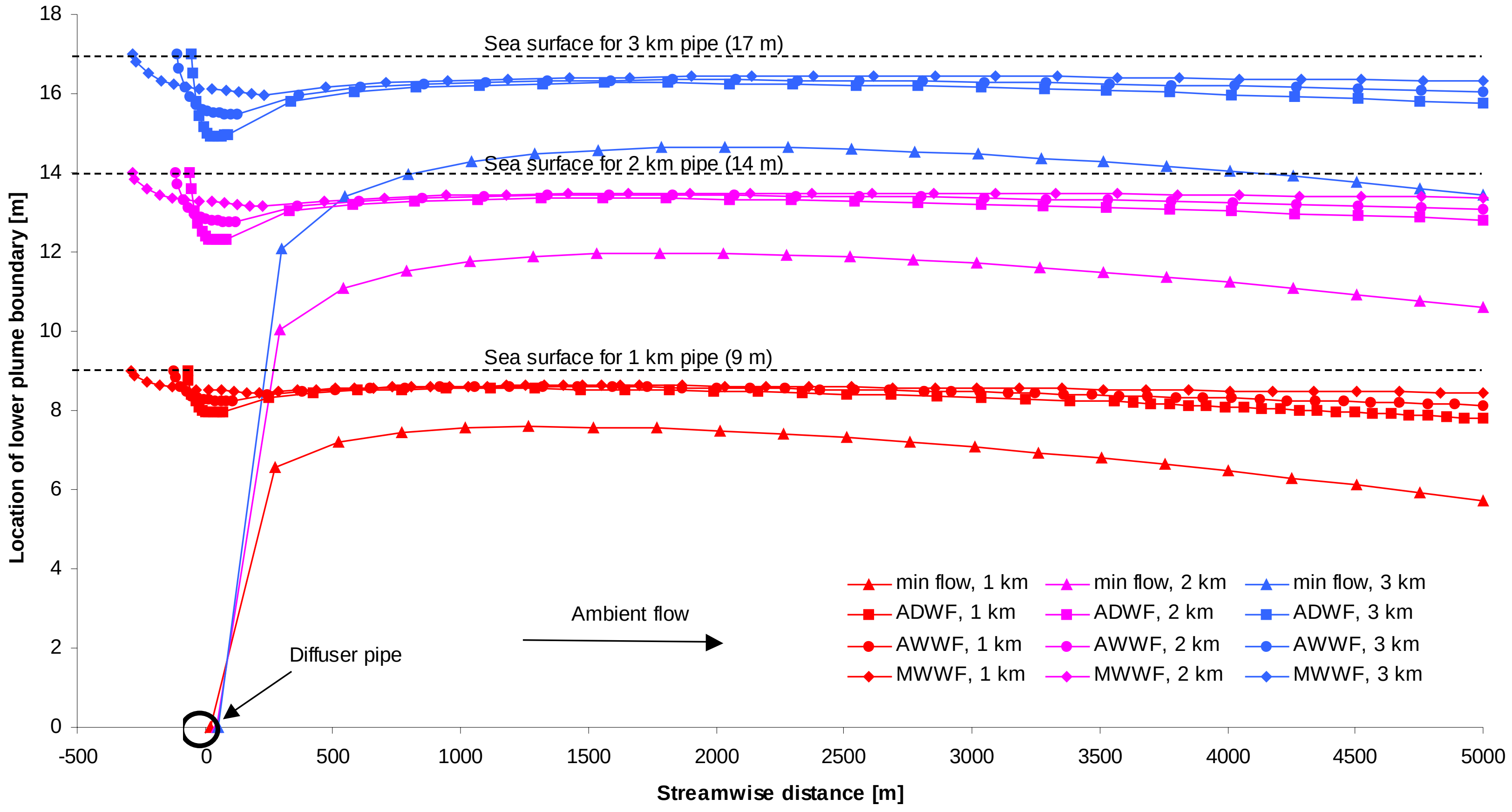

**Figure 3.2:** Side view of buoyant plumes being transported downstream by a low ambient current (0.05 m/s), undergoing mixing and dilution. The lower boundaries of the plumes are shown, the upper boundaries coincide with the sea surface. Note the upstream spreading of all but the minimum discharge plumes.

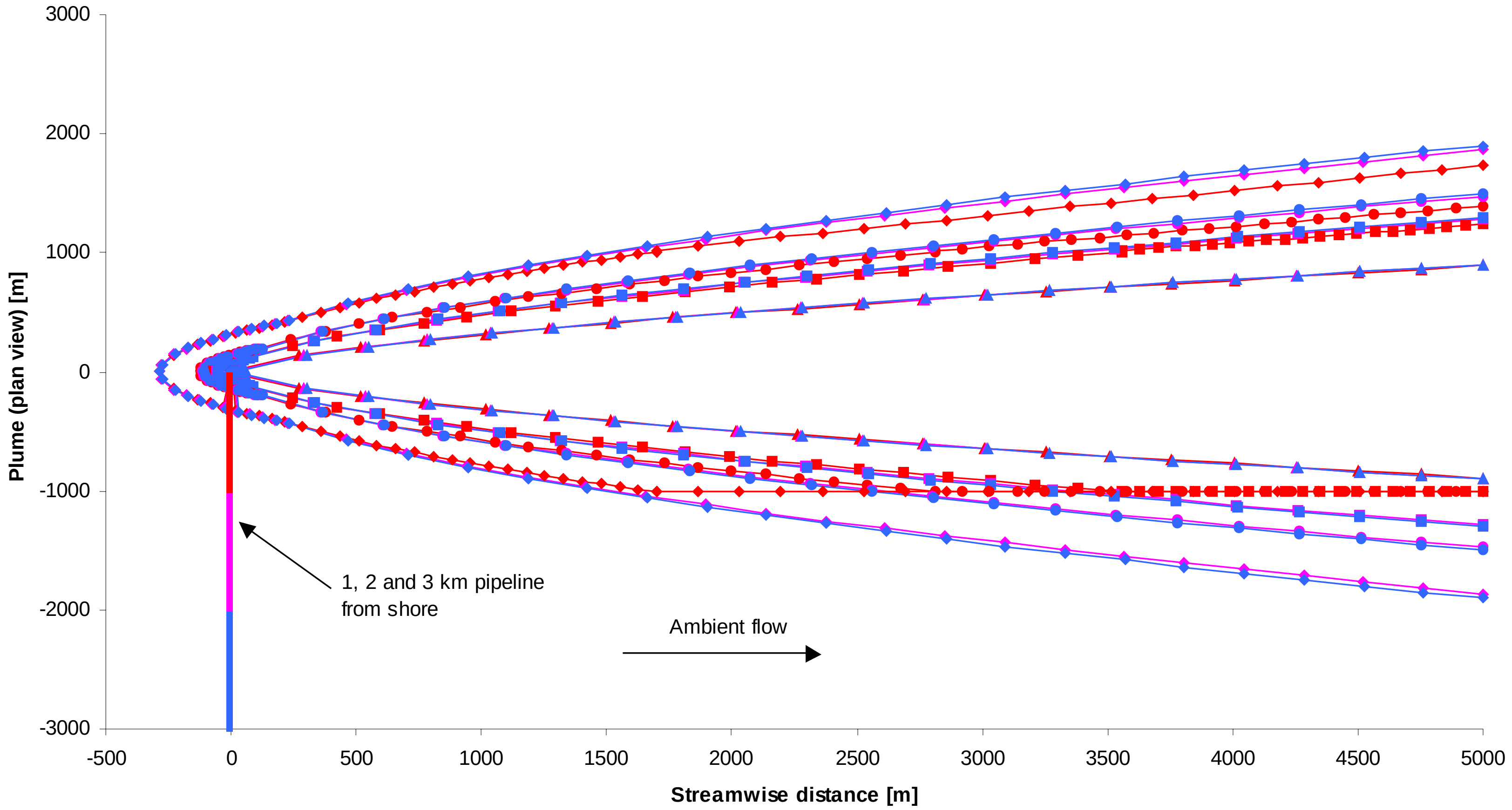

**Figure 3.3:** Plan view of the plumes as they spread horizontally on the sea surface for a low ambient current (0.05 m/s). Note the upstream spreading of all but the minimum discharge plumes and the shoreline contact resulting from discharge from the 1 km pipeline. The plumes use the same legend as Figure 3.2 above.

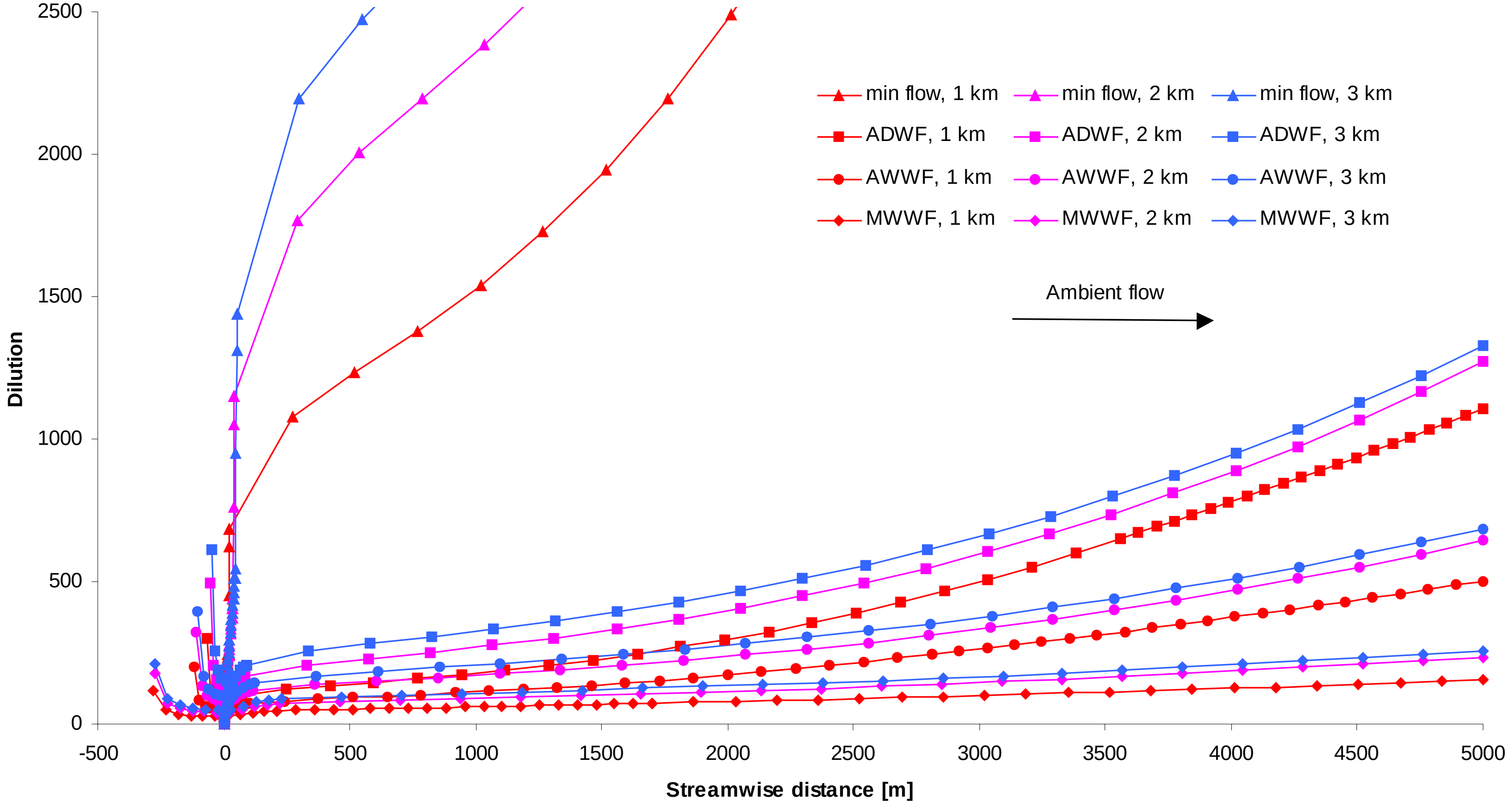

**Figure 3.4:** Showing the average dilution of the plumes as they spread upstream and get transported downstream by a low ambient current (0.05 m/s). Note that for the minimum discharge case the dilution actually reaches approximately 10,000 after 5000 m downstream (not shown).

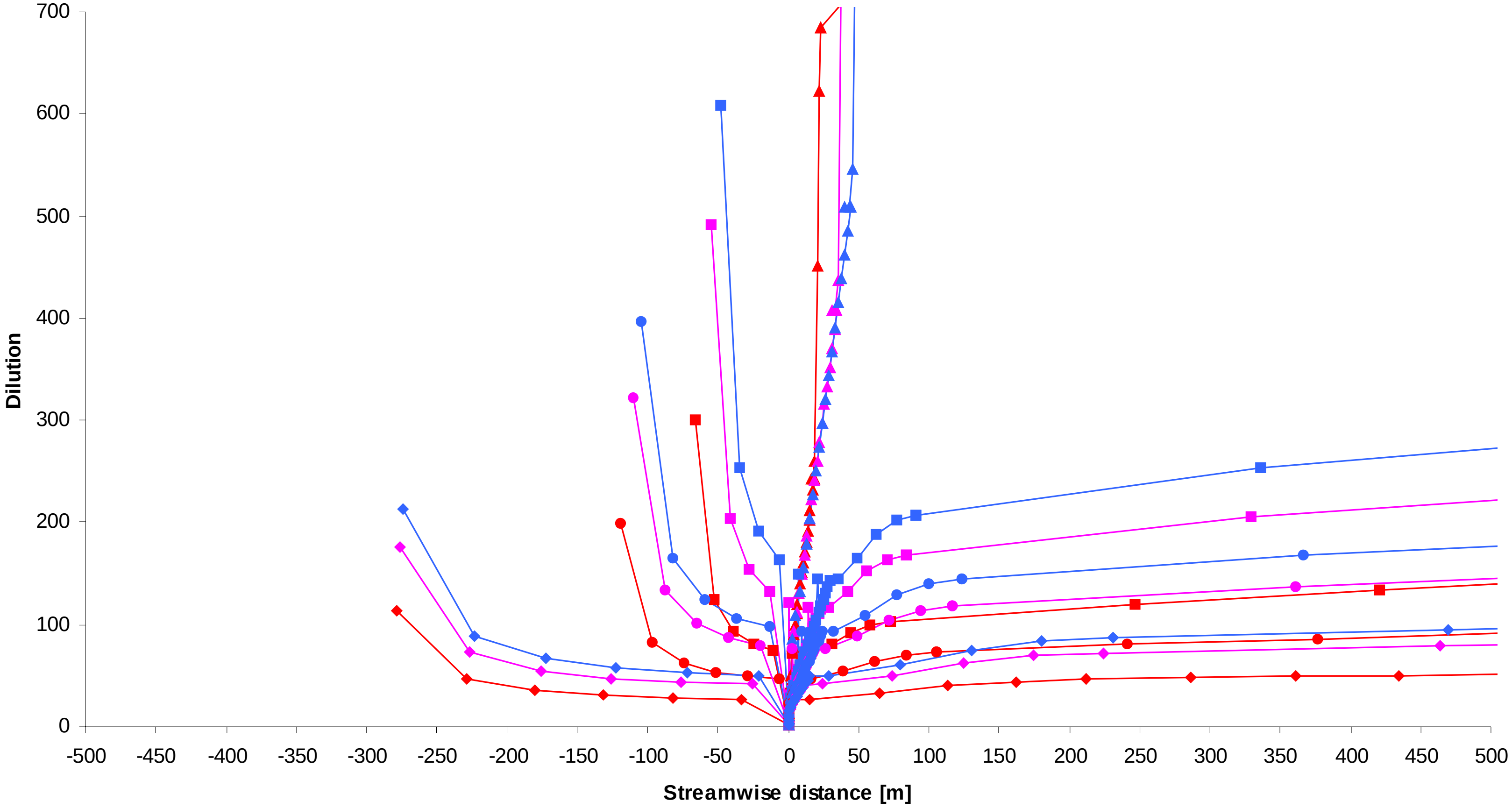

**Figure 3.5:** A magnified view of Figure 3.4 above showing the average dilutions in the 'near-field' region of the discharge for a low ambient current. The plumes use the same legend as Figure 3.4 above.

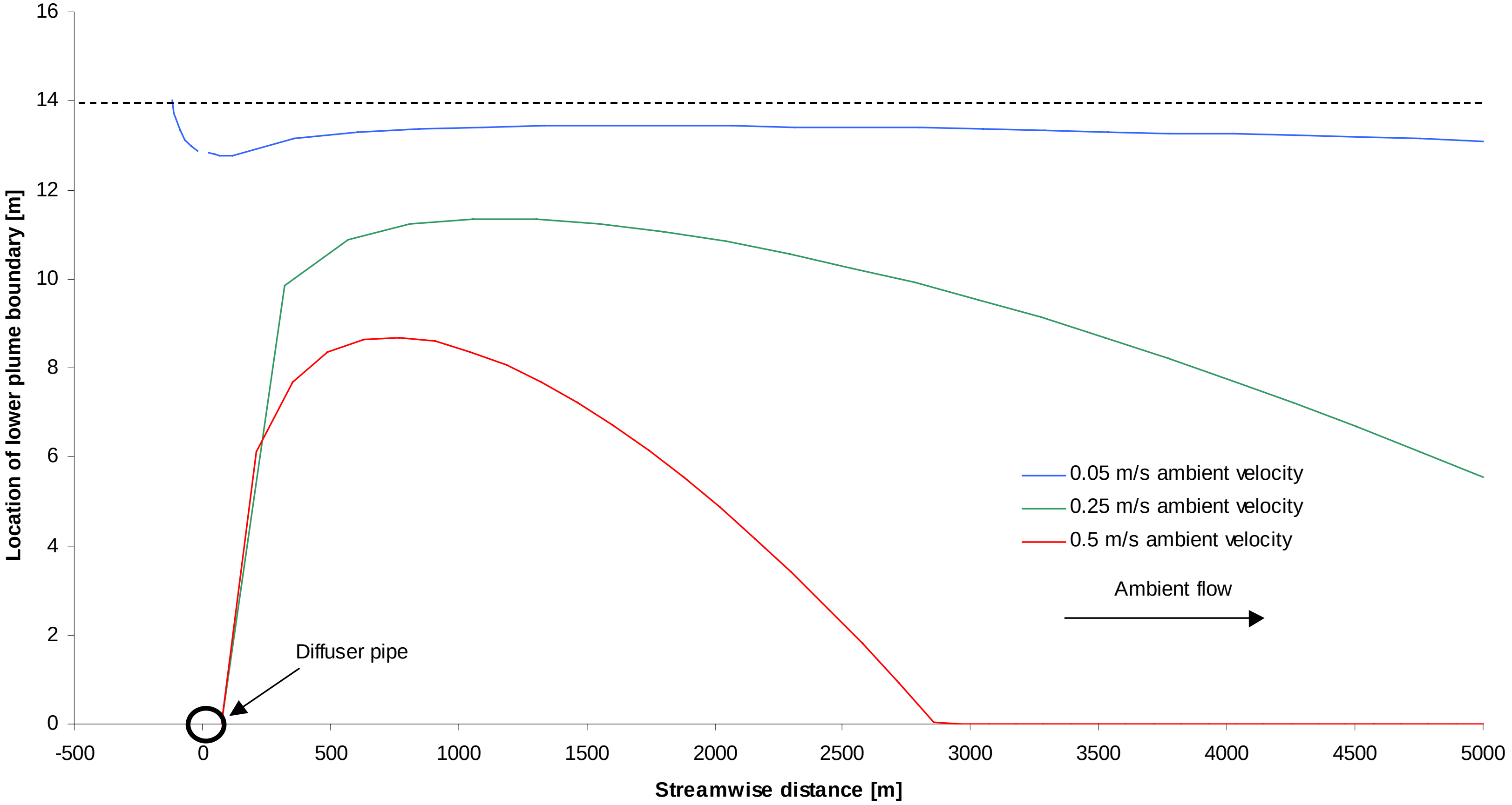

**Figure 3.6:** Side view of buoyant plumes being transported downstream under various ambient currents. The lower boundaries of the plumes are shown, the upper boundaries coincide with the sea surface.

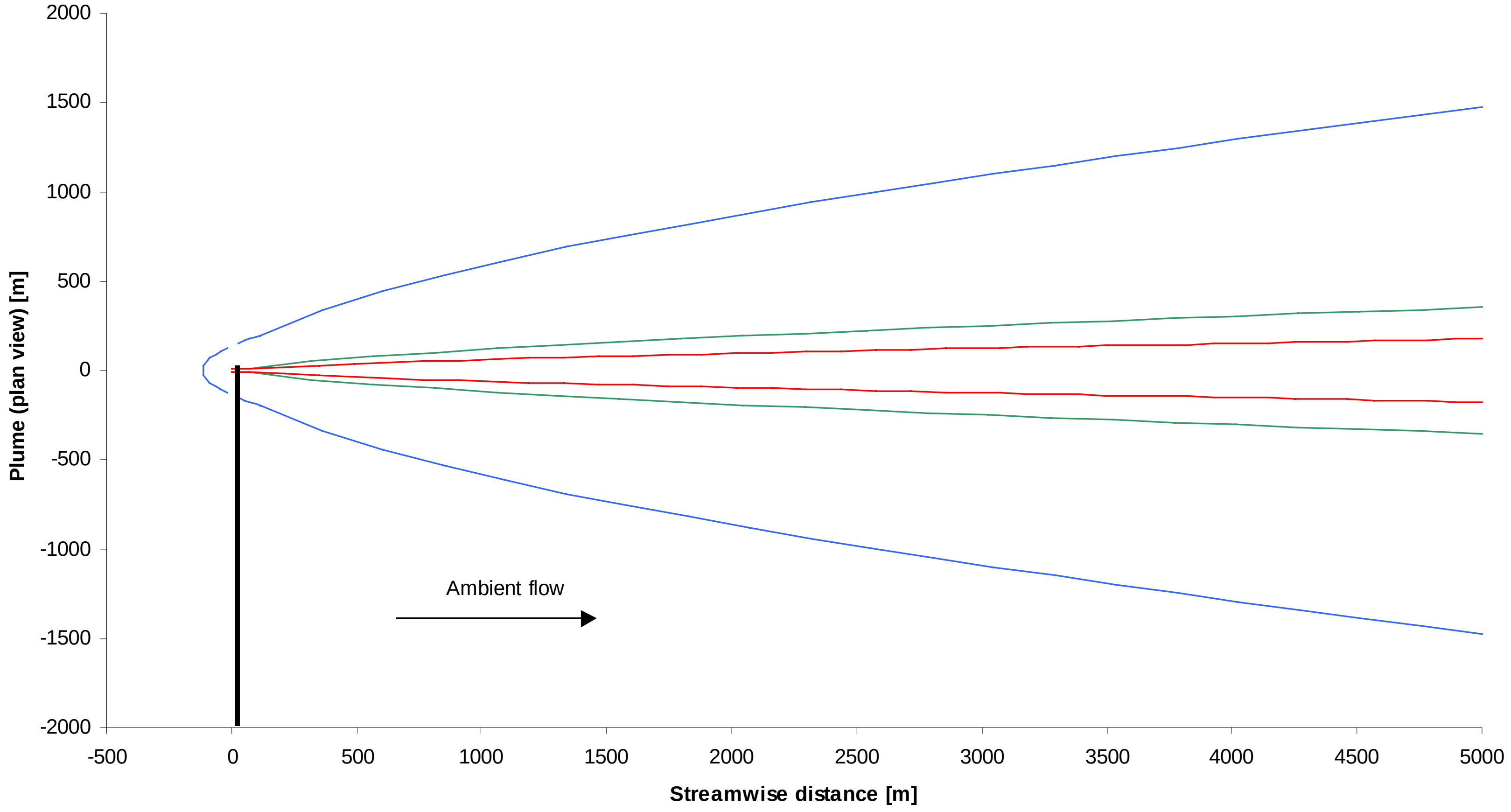

**Figure 3.7:** Plan view of plumes transported downstream under various ambient currents. The plumes use the same legend as Figure 3.6 above.

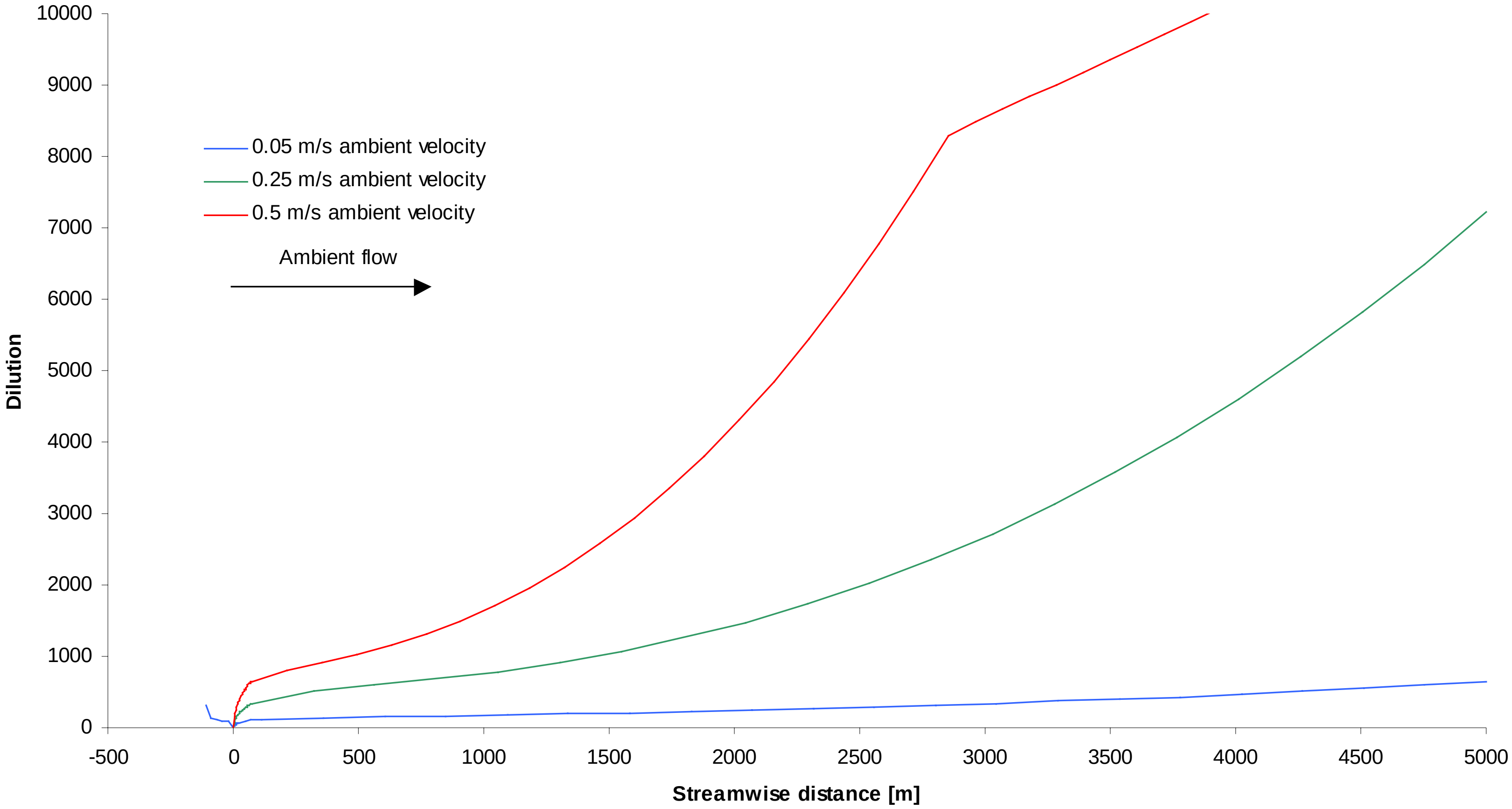

**Figure 3.8:** Average dilution of plumes as they are transported downstream under various ambient currents.

# 4. CONSENTING ISSUES FOR AN OCEAN OUTFALL OPTION

This section outlines the various issues associated with an ocean outfall option discharging treated sewage into Pegasus Bay. It covers consenting issues under the Resource Management Act (1991), the New Zealand National Coastal Policy Statement (1994), and the Regional Coastal Environment Plan promulgated by Environment Canterbury.

## 4.1 Consenting process for an ocean sewage discharge

Management of discharges to air, land or water is conducted under the framework of the Resource Management Act (RMA)—1991. The New Zealand Coastal Policy Statement (1994) supports the RMA, stating policies to be followed in achieving the purpose of the Act in relation to all coastal environments in New Zealand. Under this national framework, Environment Canterbury (ECAN) regionally manages the use of natural resources through statutory instruments such as the overarching Regional Policy Statement (RPS)[2] and the Regional Coastal Environment Plan (RCEP)[3], which includes policies and rules for managing discharges.

Any discharge of 'human sewage' to the Coastal Marine Area[4], which has not passed through soil or wetland, is a 'Restricted Coastal Activity' under Schedule 1.10 of the NZ Coastal Policy Statement (NZCPS–1994). Consents for a 'Restricted Coastal Activity' must have final approval from the Minister of Conservation.

A WDC outfall option discharging into Pegasus Bay would fall into this category, unless a concerted effort was made to include a land or wetland treatment process prior to discharging to the sea. Wide consultation with the tangata whenua of the region, coastal communities and resource users will be required to find the most satisfactory and acceptable treatment and discharge system, as required under Policy 7.5 of the RCEP.

An ocean outfall discharge off either The Pines Beach or Woodend Beach also must meet the relevant Rules in the Proposed Regional Coastal Environment Plan (1994). Rules and Schedules in the RCEP were modified in May 2001 after submissions to ECAN and are also available at the web site.[3] Rule 7.3 applies to discharges of human sewage into the Coastal Marine Area, re-iterating S1.10 from the NZCPS (as it must not be in conflict), but further describing the situation where the discharge has

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[2] can be found at http://www.ecan.govt.nz/Plans-Reports/rps/rps%20title&index.htm

[3] can be found at http://www.ecan.govt.nz/Plans-Reports/recp/rcep.htm

[4] defined under the RMA to include all coastal waters from mean high water springs out to 12 nautical miles (22 km) offshore, plus river mouths and estuaries.

previously passed through soil or a wetland outside the Coastal Marine Area. In the latter case, the RCEP defines this as a 'Discretionary Activity'.

Schedules 4 & 5 of the RCEP classifies coastal waters in the Canterbury region to be managed under a prescribed set of minimum standards. The Waimakariri River mouth and adjacent coastal areas from Spencerville (south) to Woodend Beach (north) are classified as 'Class Coastal CR Water', i.e., 'being coastal waters managed for contact recreation and the maintenance of aquatic ecosystems'. The classified area, centred on the Waimakariri River mouth, is defined in S5.3.3 of the RCEP (and shown in Map 1.3), enclosing:

> '*a line from Woodend Beach at map reference M35:866-638 to a point at map reference M35:870-638, approximately 400 metres from mean high water springs,*
>
> *a line from there to a point off Spencerville at map reference M35:874-518, approximately 400 metres from mean high water springs, and*
>
> *a line from there to the shore at map reference M35:869-518.*'

This Coastal CR–classified area therefore includes the landward location of the proposed outfalls at both Woodend Beach and The Pines Beach. The offshore boundary extends out approximately 500 m from the shoreline[5] (due to the concave curvature of the coastline in the region), but none of the pipeline length options (minimum of 1 km) would actually discharge directly into the classified area. Nevertheless, the minimum standards for Coastal CR waters must be met, prior to the outfall plume encroaching on the classified area, which have been put in place to protect public health where water-contact recreation, fishing and shellfish gathering are popular, and to maintain aquatic ecosystems.

## 4.2 What water-quality standards apply?

In the offshore, unclassified, areas beyond 400–500 m from the coastline, minimum water quality standards from section 107 of the RMA would apply (after reasonable mixing) for any outfall discharge location, plus Policy 7.5 of the RCEP (derived from NZCPS) must be followed before a resource consent application to discharge human sewage can proceed.

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[5] Ambiguous, as Map 1.3 shows an offshore boundary 400 m offshore that follows the coastline, while the legal definition defines the corner points with '… a line from there to a point…', which implies a straight line for the offshore boundary, that is up to 500–600 m offshore in places.

Because of the type of discharge (i.e., human sewage) and that it is a 'Restricted Coastal Activity' (unless land or wetland treatment is included), it has become a trend around New Zealand for dischargers to adopt the attainment of stricter water-contact recreation standards in the vicinity of an offshore discharge, than is necessary under say a nearshore coastal waters classification. Standards normally adopted in New Zealand in offshore areas are the water-contact recreational guidelines published by the Ministry for the Environment (1999) or maybe in this case the local Coastal–CR standards could be adopted and used for the design and consenting of a WDC offshore outfall to apply outside a reasonable mixing zone. If an ocean discharge option is to be further considered, it is recommended that this approach be adopted by WDC for any sewage-effluent discharge, even if well outside the classified Coastal-CR area, to have any chance of succeeding. [Note: both the Ministry for the Environment (1999) guidelines and Coastal-CR standards in the RCEP (May 2001 revision) use enterococci as the faecal indicator to test compliance for water-contact recreation in coastal waters.]

The RCEP lists water quality standards for class Coastal–CR in Schedule 4 and further standards for all sewage discharges under Rule 7.3, which apply 'after reasonable mixing of any contaminant or water with the receiving water'. We suggest that these standards be adopted for an offshore outfall. These standards are compared in Chapter 5 with effluent concentration targets suggested by WDC and considering a zone of reasonable mixing around the discharge. The full list of criteria to consider in setting a zone of reasonable mixing is given in Policy 7.6 of the RCEP.

# 5. IMPACTS AND ISSUES ASSOCIATED WITH AN OCEAN OUTFALL OPTION

This section outlines the various issues associated with an ocean outfall discharging into Pegasus Bay. It covers various aspects of outfall performance, general effects on the receiving environment, the effects on users and stakeholders and the degree to which two effluent quality options (oxidation pond/UV disinfection and secondary treatment) can meet required water-quality standards or guidelines. Some context is provided by way of issues that have arisen for other New Zealand ocean outfalls.

## 5.1 Overall outfall performance

The environmental impact, or risk, to public health arising from an ocean outfall discharge at a particular coastal locality is determined both by the magnitude of the hazard (i.e., concentration of the plume) and the likelihood of its occurrence. When an ocean outfall is being considered as a discharge option, there are three ‘tuning knobs’ that can be controlled to reduce the risk of any adverse impacts on coastal ecosystems and resource users:

- **Effluent concentration**—the level of treatment prior to discharge directly affects the final concentration or hazard that may arise at any coastal location. For instance, a log-order (10 times) reduction in faecal indicator bacteria in the effluent will result in the same order of reduction at a beach site, for the same outfall system and ocean conditions.

- **Initial dilution**—the degree of initial dilution is partially governed by the type of outfall diffuser, and water depth, which can be optimised by good diffuser design (e.g., small ports or holes) and/or selection of sites with deeper water or faster moving currents. This tuning knob will mainly lead to a reduction in concentration at a beach site, but to a lesser extent than the above.

- **Separation**—the length of outfall selected greatly affects the likelihood of any remnants of the plume reaching the shoreline or area of concern (e.g., mussel farms or reefs), thus separating the discharge from resource users or a sensitive ecosystem. It also can have a major affect on reducing concentrations at the shoreline, if the outfall length is long enough.

Other than these controls, the fate of an effluent plume and its impact on the receiving environment is determined by variable oceanographic and meteorological conditions e.g., wind velocities, currents, stratification in the water column etc.

## 5.2 Effect of freshwater stratification arising from the Waimakiriri River

An ocean outfall discharges lighter freshwater effluent into heavier seawater at the seabed. As a consequence of the buoyancy of the plumes emanating from the diffuser, the plumes rise towards to surface, diluting and spreading as they go (Figure 3.2). Stratification in the water column alters the near-field performance of an outfall discharge, particularly dilution and suppression of the rising plume. Stratification refers to a layer of less dense fluid floating on top of a heavier fluid, which can also mean the top layer travels in a different direction to the bottom layer. In Pegasus Bay, stratification can occur when either:

- Sufficient solar heating of surface waters in summer can cause a marked differential in water temperature down the water column, from warm at the surface to colder at the bottom; or

- A layer of fresher water overlays ocean water, due to river discharges for example. In the vicinity of the Waimakariri River mouth, the river outflow will cause freshwater stratification in adjacent coastal waters. The higher the river flow, the more stratified the coastal waters will become and the area affected by stratification will increase.

The latter is more likely to affect the outfall performance, particularly the shorter outfall options off The Pines Beach, which are close to the river mouth. To quantify the influence of the stratification, field studies would need to be performed at the discharge locations in order to measure seawater temperature and salinity, and therefore the degree of stratification.

If the receiving water is stratified, then two effects on outfall performance are:

- The buoyant plume would not rise to the surface, but become stable at a near-surface depth at which the density of the diluting effluent plume matches the density of the surrounding ambient seawater. This will reduce any surface visual or odour effects at the discharge site and reduce the vulnerability of the plume to surface wind drift; however

- With the plume trapped beneath the surface, it reduces the depth over which the plume could undergo mixing and initial dilution as it progressed up through the water column. An effluent plume discharging into stratified water will therefore generally be less dilute at the edge of any defined reasonable mixing zone, than if it were discharged into a well-mixed water column.

## 5.3 Discharge regime

For an ocean outfall in exposed coastal waters, it is recommended that the effluent is discharged continuously to avoid the ingress of fine sediment and shellfish larvae. Fitting duck-bill valves to each port of the diffuser, while expensive, can further reduce the ingress of material and increase the dilution performance during low-discharge periods. There is no reason in this situation to warrant a tidally-staged discharge.

## 5.4 Concentration of effluent constituents in the receiving environment (Pegasus Bay)

For this preliminary study it is sufficient to assume that:

1) The ambient or 'background' concentration of water quality variables (except nutrients, temperature, pH and dissolved oxygen), are negligible in coastal waters in the region of the discharge. [Note: this will need to be confirmed later with water quality measurements].

2) All of the water quality variables or substances have been considered to behave conservatively, i.e., they do not grow or decay, so a reduction in concentration is solely ascribed to physical dilution. In reality, many of these parameters are not conservative, for example faecal coliforms are inactivated by solar UV light, and nitrates and total ammonia are readily taken up by phytoplankton (algae). A decay coefficient can be used to account for this in later investigations, if required. However, these decay processes are slow-response effects relative to the degree of physical dilution and are not usually invoked for near-field studies. Adopting a conservative approach will mostly give rise to higher far-field concentrations than if a decay process was invoked.

The average (bulk) concentration (C) some distance from the outfall ('far-field') of a given effluent constituent or concentration excess over the ambient seawater (temperature, dissolved oxygen) is then given by:

$$C = {}^{C_0}\!/_{S}$$

where $C_o$ is the concentration (or concentration excess over the receiving waters) of the effluent constituent at the point of discharge, and $S$ is the average dilution, as given in Figure 3.4 for example. Assuming an effluent faecal coliform concentration of $C_o$ = 200 colony-forming units (cfu) per 100 mL for the average wet-weather flow

(AWWF), then the resulting average concentration across the effluent plume for a slow moving ambient current (0.05 m/s) is shown in Figure 5.1. For other effluent concentrations, such as $C_o$ =2000 (upper limit) or $C_o$ =20 (lower limit), simply multiply the values in Figure 5.1 by 10 or 0.1 respectively. [Note: the average wet-weather flow (AWWF) discharge rate was chosen as a more severe case, as the dilutions are markedly lower than those that would be obtained more routinely under a typical dry-weather day.]

In order to test the feasibility of an ocean outfall option to meet water quality standards expressed in Rule 7.3 and Schedule 4 for Class Coastal CR water, a preliminary reasonable mixing zone needs to be defined.

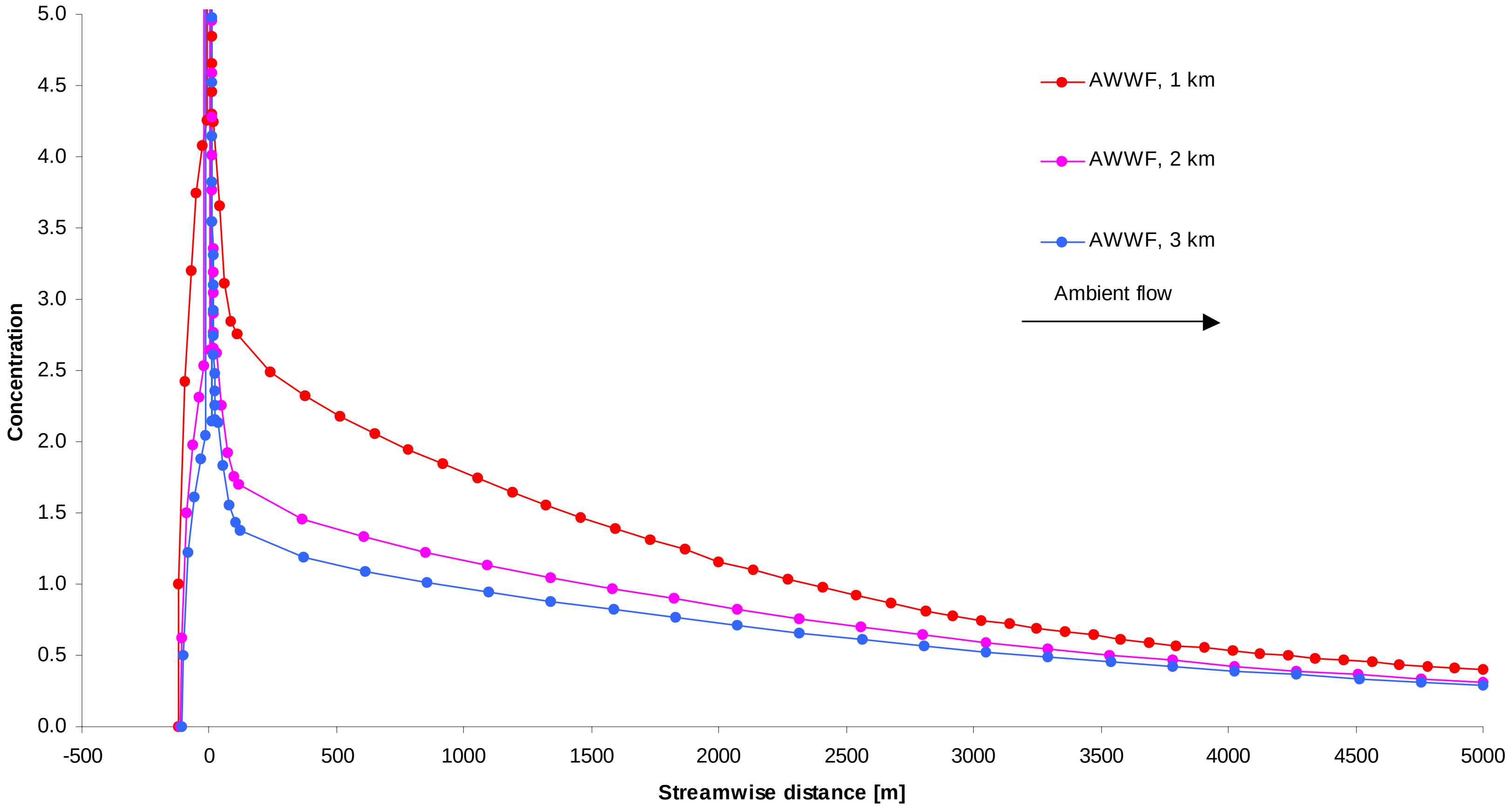

**Figure 5.1:** Surface concentrations following an AWWF discharge of effluent with concentration of Co =200, into a slow moving ambient current for 1, 2, and 3 km outfall options.

Criteria for the size of a ‘reasonable mixing zone’ are listed in Policy 7.6 of the RCEP. Using reasoning based solely on physical mixing processes, we may define this area to encompass where the initial, rapid dilution of the outfall plumes occur, and the plumes have reached the water surface or have reached a stable horizontal level in the water column i.e., a distance from the outfall diffuser out to the line where the buoyant plume contacts the surface and the process of ‘gravitational spreading’ becomes a dominant spreading mechanism and the ambient current dominates the overall movement of the diluted effluent plume. This zone is often termed the ‘zone of initial dilution’ (ZID) and will be largest for the highest discharge during severe wet weather (MWWF) into deep water (3 km pipeline). For discharge into a slow moving ambient, a radius of 250 m centred on the diffuser location will enclose the ZID in most of the outfall scenarios assessed in the Report (refer to Figures 3.2 and 3.5). Plume dilutions and concentrations at the edge of the ZID are given in Table 5.1. The results in Table 5.1 are conservative, in that they are only likely to occur occasionally under moderate to heavy rainfall conditions, while during dry weather the dilutions will be markedly better.

It is important to note that surface-wind effects on the plume have not been taken into account with the preliminary modelling. An onshore wind will tend to transport the sea-surface layer towards the shoreline, but not usually directly to the shore, as the alongshore (shore-parallel) current will continue to influence surface plume movement. More complex coastal flow and dispersion models are required to assess the suitability of an outfall length in terms of minimising onshore wind drift that could carry remnants of the effluent plume towards the nearshore area. However as a rule of thumb, the wind blown near-surface layer has a down-wind speed of around 2% of the local wind speed after sufficient time for the ocean surface to adjust. Assuming a sustained ‘fresh breeze’ with wind speed of 10 m/s (20 knots), the sea surface speed could reach 0.2 m/s and the effluent will take approximately 1.5 hours to drift 1 km. Within this time the plume will continue to dilute. Taking a worst-case scenario of no alongshore current i.e., a direct onshore drift of the plume, a 1 km outfall would provide a 1.5 hour travel-time buffer to the shoreline, while a 2 km outfall would provide at least a 3 hour buffer for such a wind speed. Note that stronger winds will generate waves and whitecapping, which then create sea-surface conditions that are much less efficient at generating wind drift currents, and besides will cause substantial vertical mixing of the surface layer, resulting in further dilution.

**Table 5.1:** Design dilutions and concentrations (expressed as a percentage of the effluent concentration assuming $C_o=1$) for the AWWF discharge into a slow-moving ambient; at 250 m (edge of ZID) downstream from the diffuser, and also the concentration where the plume reaches the Class Coastal CR waters (500 m off shore) for each outfall length. Assuming ambient flow is parallel to the coastline, the CR zone is reached 780 m downstream for the 1 km pipeline, and 5 km downstream for the 2 km pipeline. (Within the area modelled, the discharge from the 3 km pipeline does not enter the Class Coastal CR waters off the Waimakiriri River mouth, but may well do eventually with unfavourable onshore winds.) Also shown is the minimum dilution that occurs during quiescent coastal conditions with a negligible current running.

| Pipe length [km] | Minimum dilution (zero ambient current) | | 250 m downstream after reasonable mixing | | At the offshore boundary of Class Coastal CR zone | |
|---|---|---|---|---|---|---|
| | dilution | concentration (% effluent) | dilution | concentration (% effluent) | dilution | concentration (% effluent) |
| 1 | 44 | 2.3% | 80 | 1.3% | 100 | 1.0% |
| 2 | 72 | 1.4% | 130 | 0.77% | 640 | 0.16% |
| 3 | 103 | 1.0% | 160 | 0.63% | N/A | N/A |

Using the conservative dilutions and concentrations at the edge of a 250 m radius mixing zone (Table 5.1), the various design effluent-quality constituents for two treatment-plant options (Table 1.2) can now be assessed against water quality standards (Schedule 4 and Class Coastal CR rules in the RCEP).

## 5.5 Meeting water-quality standards or guidelines (after reasonable mixing)

***Public health standards or guidelines***

Guideline 1

Meet the Class Coastal CR standard for contact-recreation coastal waters throughout the year outside a 250 m radius offshore mixing zone around the outfall diffuser, even though not strictly required outside the classified CR region, nor required outside the summer (November–March) bathing season.

The standard for Class Coastal CR is based around a series of five consecutive samples (5–9 days apart) for enterococci, where the running median shall not exceed 35 cfu/100 mL, with no single sample exceeding 277 cfu/100 mL. (The approximate[6]

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[6] Equivalent faecal coliform (FC) concentrations are based on an assumption that the FC/Enterococci ratio is 5.7 (i.e., 200/35 from the old and new water-contact recreation guidelines), although the effluent ratio can vary markedly depending on the influent and treatment processes.

faecal coliform concentrations are 200 cfu/100 mL and 1580 cfu/100 mL respectively.)

Guideline 2

Meet a stricter faecal coliform (FC) guideline by safeguarding shellfish-gathering waters at the offshore boundary of the Waimakiriri Class CR region, rather than just safeguarding water-contact recreation. The Ministry for the Environment (1999) guideline for shellfish-gathering waters, based on faecal coliforms using the five-tube decimal dilution test, is that the sample median shall not exceed 14 MPN[7]/100 mL and a 90-percentile not exceeding 43 MPN/100 mL (no equivalent enterococci levels are given in the guidelines).

The expected receiving-water concentrations for an average wet-weather flow are listed in Table 5.2 for 1, 2, and 3 km outfall lengths, with even lower concentrations applying for the more routine average dry-weather flow rates. In all cases, both public health Guidelines 1 & 2 suggested above, can be met by the design discharge rates including the maximum wet-weather flow (Table 1.1) and design effluent qualities (Table 1.2) once outside of the ZID. In some situations of very low coastal currents and high wet-weather discharge rates, the 1 km outfall may not meet the shellfish-gathering Guideline 2 at the offshore boundary of the Class Coastal-CR region. There is also an important restriction in the guidelines, which say that they should be applied in conjunction with a sanitary survey (i.e. a survey of various sources of faecal material and the health risks associated with each). The guidelines state that there may be situations where bacteriological levels suggest the waters are ‘safe’, but a sanitary survey may indicate that there is an unacceptable level of risk. The restriction is directly relevant to outfall discharges, which in this case means that eating shellfish from outside the ZID, 250 m from the outfall, is not likely to be safe, even though the faecal-coliform guidelines are met. The coastal waters in the Woodend/Kaiapoi area are designated for management of water-contact recreation, so any requirements to meet shellfish-gathering guidelines and where they are to apply will largely be driven by community and cultural aspirations, and would need to involve the Medical Officer of Health.

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[7] MPN denotes Most Probable Number

**Table 5.2:** Expected receiving-water concentrations of faecal coliforms (FC) and enterococci (Ent) for the scenario of an AWWF discharge into a slow-moving ambient based on relative % effluent concentrations from Table 5.1. The effluent concentrations used are the median and upper-limit faecal coliform concentrations of 200 cfu/100 mL and 2000 cfu/100 mL suggested by WDC (Table 1.2), with enterococci estimated using a FC/Ent ratio of 5.7.

| Pipe length [km] | Effluent FC [cfu/100 mL] | Concentration 250 m downstream of diffuser after reasonable mixing [cfu/100 mL] | | | Concentration at offshore boundary of Class Coastal CR zone [cfu/100 mL] | | |
|---|---|---|---|---|---|---|---|
| | | % effluent | FC | Ent | % effluent | FC | Ent |
| 1 | 200 | 1.3% | 2.6 | 0.5 | 1.0% | 2 | 0.4 |
| 2 | 200 | 0.77% | 1.5 | 0.3 | 0.16% | 0.3 | <0.1 |
| 3 | 200 | 0.63% | 1.3 | 0.2 | N/A | N/A | N/A |
| 1 | 2000 | 1.3% | 26 | 4.6 | 1.0% | 20 | 3.5 |
| 2 | 2000 | 0.77% | 15 | 2.7 | 0.16% | 3 | 0.6 |
| 3 | 2000 | 0.63% | 13 | 2.2 | N/A | N/A | N/A |

The caveat on these preliminary results arises from the use of simplified dispersion model simulations, which exclude wind effects and assume a shore-parallel coastal current and no water-column stratification. Consequently, more detailed and realistic modelling, along with a virus-risk assessment, is likely to indicate that a 1 km outfall is probably too short, particularly given the perceived proximity to the Class Coastal-CR area. While the discharge would easily met ‘water-contact recreational’ standards and guidelines at the edge of a 250 m radius mixing zone around the diffuser, such proximity to a sewage discharge is usually regarded by public health officials as too close to truly safeguard water-contact recreational activities (which can include yachting, jet skiing, diving, if not swimming). This is where a virus risk assessment in the Assessment of Environmental Effects is becoming normal practice, despite meeting faecal-indicator based guidelines close to the discharge.

The other aspect that requires further investigation is the specification of the upper-limit for enterococci and faecal coliforms. Treatment plant design and consent applications based on a maximum limit are not recommended (because for various reasons that value can usually be exceeded at some time in the future), but instead the upper-limit is better defined by a percentile such as 90%ile or a 95%ile (McBride et al., 2000; Bell et al., in press). Such upper-limit percentiles for faecal coliforms or enteroccoci have usually governed the final length of outfalls around New Zealand, rather than the lower median concentration.

### *Aesthetic standards or guidelines*

Aesthetic impacts are generally associated with surface water effects that may catch the human eye, reduce the natural character of the seascape or create unpleasant odours. Impacts in this category (Section 107, RMA) include:

- Conspicuous oil/grease/fat films, scums, foams, floatable and suspended materials;
- Conspicuous change in the colour or visual clarity
- Emission of objectionable odours

Modern treatment plant systems, with screening and settling processes, considerably reduce the chance of any of the first or third groups causing any problems, particularly for ocean outfalls where high initial dilutions can be achieved above the outfall. The average dilution at the edge of a 250 m mixing zone is expected to be at least 80-fold for a 1 km outfall and 130-fold for a 2 km outfall during average wet-weather flows (Table 5.1), and markedly higher for typical dry-weather periods.

Long-standing outfall and treatment-plant design criteria based on field observations are used to determine the least initial dilution required to have ‘no conspicuous’ and ‘no perceptible’ aesthetic impacts (Wood et al., 1993). The latter applies to situations where an observer knows where the outfall diffuser is and can perceive a slight change in the appearance of the surface waters or odour at the discharge site. Generally, for biological secondary treatment, an outfall diffuser needs to achieve an initial dilution of only 15-fold to have ‘no conspicuous’ impact and more than 40-fold to have ‘no perceptible’ impact for oil/grease films, odour or discoloration. The initial dilutions achievable by even the 1 km outfall would be sufficient to have ‘no conspicuous’ impact on odours or water appearance for the secondary treatment option.

However, further investigations will be required to assess the impact on discoloration and turbidity of an oxidation-pond effluent option, as suspended solids concentrations may reach high levels up to 220 mg/L (Table 1.2). Suspended solids in oxidation ponds are primarily derived from freshwater algae cells, rather than sewage particles, but nevertheless could cause changes in water clarity and colour that exceed Rule 7.3 in the RCEP. Depending on the classification, this Rule states that the colour of the receiving waters is not changed by greater than 5 or 10 points on the Munsell Scale, or visual clarity is not reduced by greater than 20 to 33%. For an oxidation pond effluent, this Rule may dictate that a 1 km outfall is too short, unless the suspended solids concentrations are reduced. Further fieldwork is necessary to establish the background levels of colour, clarity and suspended solids in Pegasus Bay before a more definitive answer on outfall length can be given, particularly with the influence of the Waimakiriri River outflow.

### *Dissolved oxygen, $BOD_5$ and temperature*

Taking the lowest design dissolved oxygen (DO) concentration for a Pond + UV disinfected effluent from Table 1.2 of 0.4 mg/L, the largest reduction in ocean dissolved oxygen for any of the discharge scenarios or outfall lengths would be no more than 0.12–0.14 mg/L or no less than 98% saturation in surface waters immediately above the diffuser. This easily meets the standard for Class Coastal CR Waters in the RCEP, where DO in the receiving waters must not be reduced below an 80% saturation concentration.

Biochemical oxygen demand over a 5-day test ($BOD_5$) can reach reasonably high levels in the Oxidation Pond effluent option of up to 88 mg/L. However, after allowing for reasonable mixing, the resulting concentration for a 1 km outfall and an average wet-weather discharge rate would be 1.3% of the effluent concentration (from Table 5.1) or 1.1 mg/L for a $BOD_5$ concentration. This meets the standard for Class Coastal CR Waters in the RCEP, where $BOD_5$ in the receiving waters must not exceed a concentration of 2 mg/L. The $BOD_5$ concentration in the outfall plume would continue to reduce quickly with ongoing dilution, and therefore would be unable to exert any detectable oxygen demand over a five-day period used for the laboratory test.

Any excess temperature of the effluent, relative to the ocean temperature, will be diluted to at least 1.3% of the original excess temperature after reasonable mixing. Effluent excess temperatures are not expected to exceed 2–3°C, which means the receiving water excess temperature would be no more than 0.03–0.04°C after reasonable mixing.

In summary, DO, $BOD_5$ and any excess temperature discharged from any of the outfall options, are not expected to result in any detectable impacts on the receiving environment.

### *Nutrients*

Two potential impacts are possible with the nutrients present in the effluent: a) ammonia toxicity to aquatic life; and b) the stimulation of naturally occurring marine algal blooms.

Ammoniacal nitrogen, particularly in its un-ionised ammonia form ($NH_3$), can be toxic to marine aquatic life including fish. Ammonia toxicity is a function of water temperature, salinity and pH (USEPA, 1989). Assuming a coastal water background pH of 8.0–8.2, a salinity of 30, and a summer temperature of 18°C (more toxic for higher temperatures), the water quality criterion to protect aquatic life is a continuous concentration of ammoniacal nitrogen of no more than around 1 mg/L. This criterion is easily met by the concentration of 1.3% effluent for a 1 km outfall discharging an average wet-weather flow. Taking the upper-limit design concentration for a Pond effluent of 26 mg/L (Table 1.2), the ammoniacal concentration at the edge of a 250 m mixing zone would be no more than 0.34 mg/L, which is well below the 1 mg/L criterion for the worst case. Therefore, the outfall discharge would not be toxic to aquatic life by way of its ammonia concentration.

The second potential impact of a sewage-effluent discharge is the stimulation of marine algal blooms to nuisance levels, via the supply of an additional nutrient load to supplement oceanic and riverine sources. Algal blooms can cause impacts on aesthetic values and aquatic systems. Invariably, algal productivity in coastal waters is nitrogen limited. Therefore, marine algae will respond to increases in the dissolved inorganic forms of nitrogen or DIN (= ammoniacal+nitrate+nitrite forms of nitrogen), rather than to dissolved phosphorus forms. A thorough assessment will be required during the next phase to ascertain the risk of stimulating marine algal blooms, because further information on coastal and ocean concentrations of DIN in Pegasus Bay are needed. Some guidance can be obtained from experiments conducted by NIWA for the Christchurch Wastewater Study, where oxidation-pond effluent samples were diluted 1000-fold with Pegasus Bay seawater in containers (i.e., 0.002 mg/L ammonium-N), and monitored for algal growth (J Zeldis, pers. comm.). Initially, for the first two days, chlorophyll *a* concentrations decreased due to the freshwater algae from the oxidation pond dying when exposed to seawater. After that, marine algae growth caused an increase in chlorophyll *a* concentrations and algal cells doubled after 4 days, relative to a control with no effluent. This result indicates that the response time for stimulation of marine algae is relatively long in comparison with the rapid dispersion processes that eventually dilute the effluent plume to ‘background’ levels of DIN. However, more complex computer modelling is required to determine the region in which plume dilutions are likely to be below 1,000 to 5,000-fold and for how long, before a more definitive assessment can be made of the impact of the WDC discharge on causing nuisance algal blooms.

### *Trace metals*

Municipal sewage effluents contain low to moderate concentrations of trace metals that can potentially have effects on benthic (seabed) and aquatic ecosystems. Class Coastal CR Waters in the RCEP have limits on receiving water concentrations of trace metals that are to apply after reasonable mixing. There are only limited data on the trace metal content of the existing effluent (supplied by WDC), comprising one sample from each oxidation pond (Rangiora and Kaiapoi). While the laboratory detection limits could be increased to obtain better resolution for more confirmatory analyses, the two tests indicate that trace metal concentrations in the receiving waters would only require dilutions of up to 12-fold, before meeting Class Coastal CR concentrations. This is easily met by any of the outfall options investigated.

## 5.6 Implications of outfall discharge location

This section briefly discusses the broad implications and issues for an outfall location off either The Pines Beach or Woodend Beach.

### *Oceanographic factors*

In terms of oceanographic factors, such as coastal currents, wind/wave exposure, and water depths available offshore, both locations will be similar. The main differences for The Pines Beach location are that the depths at 2 km and 3 km offshore are 1 m and 2 m less than at Woodend Beach (which offers less opportunity for dilution per km outfall), and the likelihood of some interaction with the Waimakariri River mouth for the shorter outfall options. This interaction could involve the effect of a freshwater river plume spreading over the outfall site, causing stratification, and also a small possibility under low river flow conditions of remnants of the outfall plume entering the mouth and Brooklands Lagoon. Even under flood conditions it is unlikely that the river discharge will have any residual momentum effect more than 1 km offshore. The effluent discharge is therefore unlikely to be affected by currents generated from the river flows other than the slower gravitational-spreading process as the freshwater continues to ‘drift’ over the denser seawater. How far this extends offshore would need to be confirmed by field measurements of salinity and temperature down the water column.

### *Popularity for recreational uses*

Both The Pines Beach and Woodend Beach are popular for recreation, fishing and water-contact activities. This has been recognised by Environment Canterbury, classifying a coastal zone out to 400–500 m offshore as Class Coastal CR waters (being water managed for contact recreation and maintenance of aquatic systems). Public perceptions of an outfall discharging in proximity to either site, along with Māori cultural concerns over the discharge of sewage, will tend to govern the acceptable length of an outfall, rather than water quality assessments that indicate guidelines or standards are adequately met. Surveys and analysis of previous information on recreational uses of the area, together with wide and thorough consultation, will be vital components of the resource consent application. The extent of, and types of, offshore recreational pursuits and commercial fishing, together with their concerns, will also need to be established.

### *Pegasus Bay marine farm application*

Environment Canterbury has recently received a resource consent application for a marine farm (to farm mussels) that covers 10,664 hectares of Pegasus Bay (see Figure 2.1). The proposed marine farm is located due east from the Waimakariri River mouth, with its nearest landward boundary approximately 10.5 km from The Pines Beach or Woodend Beach. For a 2 km or 3 km long outfall, this would place the marine farm 8.5 km or 7.5 km away respectively. The main issue associated with a WDC outfall option is whether the discharge would compromise the activities of the marine farm by way of low-level faecal contamination. Firstly, coastal and tidal currents in the region mainly flow alongshore, parallel with the coast, as described in Section 2. Consequently, the diluting plume from an ocean outfall will tend to move along the coast, either north or south, and spread laterally.

The only way a remnant of the effluent plume could reach the marine farm is via wind drift of the near-surface layer generated by strong winds from the westerly quarter. For a ‘worst case’ scenario, where a westerly wind of 30 knots (15 m/s) was able to generate a wind-drift current directly to the marine farm in the absence of any coastal currents, it would take around 8 hours travel time to reach the farm. Given this length of travel time, and the strong vertical shear between the surface and underlying layers, plus wave and whitecap mixing, the dilution will be very large. The preliminary results for faecal coliforms at the edge of a 250 m mixing zone around an outfall (Table 4.2) show low concentrations can be achieved quite close to the outfall. Therefore, combining these concentrations with the large dilutions that would occur, if indeed any remnants reached the marine farm, means the chances of an outfall option up to 3 km long affecting the operation of the marine farm are negligible. If further proof is required, a more detailed computer model simulation of currents, winds and plume dispersion will help settle the public-health risk involved.

### *Fisheries and ecosystems*

An assessment of environmental effects will need to include a survey of the benthic (bottom-dwelling) and pelagic (water-column) ecosystems in the wider region, including any effects on fisheries offshore and in the Waimakariri River mouth. The main concern from an ecological perspective is likely to be the high suspended-solids load from an oxidation-pond effluent, and its effect on benthic animals and sediments when it settles either side of the outfall diffuser.

## 5.7 Virus risk assessment

Increasingly around New Zealand water-contact recreation standards or guidelines are being met in close proximity to an outfall discharge, because of the high effluent quality that can now be achieved by UV or ozone disinfection. A WDC outfall option with the proposed effluent quality (Table 1.2) would be no different, as shown by the results in Section 5.2, where water-contact recreation standards could be met 250 m from the outfall. This poses a public health dilemma, as water-contact recreation standards or guidelines are more applicable to beach sites some distance from a 'point source' discharge, and on the basis of using faecal indicator bacteria. In close proximity to an outfall discharge (say within 1 km), the indicator bacteria may have been reduced to 'safe' levels, meeting a standard, but the infectious dose for some water-borne illnesses may only require the ingestion of 1 or 2 virus or protozoa[8] cells. Both human viruses and protozoa are generally more hardy than faecal indicator bacteria, both through the disinfection process and their survival in seawater environments. Consequently, it has become normal practice to include a pathogen risk assessment in the resource consent application and interact with the regional medical officer of health, to ensure public health can be safeguarded. Further testing of viruses and protozoa within the effluent therefore recommended.

## 5.8 Comparison with other NZ coastal sewage outfalls

For open-coast ocean outfalls around New Zealand, the effluent constituents in municipal wastewaters which have predominantly governed treatment plant design and outfall site selection are faecal bacteria, protozoa and viruses. Faecal indicator bacteria are commonly-occurring bacteria groups, such as enterococci and faecal coliforms, that 'indicate' the presence and relative level of faecal contamination. This first-tier concern arises in the New Zealand scene from strong concerns about public-health effects arising from common pursuits of water-contact recreation and shellfish gathering, and cultural concerns and issues regarding the mauri (sustainability of life-capacity) of the water and the offensive nature of mixing human sewage into the rich food-basket available from moana (sea). The scenario of consenting an outfall option off the Waimakariri District would be no different than for other New Zealand coastal outfalls, which have all been primarily governed by a response to public health issues (water-contact recreation and shellfish gathering) and Māori cultural concerns. Studies at open-coast outfalls around New Zealand (e.g., Wanganui, South Brighton, Hawke Bay, Gisborne, Waitara) indicate that generally ocean outfalls of length greater than 2 km are less likely to have problems with shoreline visits of dilute remnants of the effluent plume, where most recreational activities take place. A recent trend is the increase in offshore recreational pursuits (yachting, jet-skiing, diving, sea kayaking,

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[8] The main protozoa of concern are *Giardia* cysts or *Cryptosporidium* oocysts

fishing), which means the public-health impacts of an ocean outfall are no longer confined to assessing the effect on beach users.

Second-tier concerns at other New Zealand outfalls circulate around constituents that may have some potential to cause impacts such as:

- Aesthetic appearance of the seascape—from discolouration, turbidity, and grease/oil sheens;
- Benthic (seabed) ecosystems—mainly from settlement of suspended sediments to the seabed (particularly oxidation-pond effluents), together with any contaminants that preferentially attach to fine particles;
- Stimulation of naturally-occurring algal blooms—in coastal waters, phytoplankton response is usually nitrogen limited, so assessing dissolved inorganic nitrogen loads from the outfall needs to be put in context with the often large nitrate contribution that upwells from the ocean, or the smaller exports from rivers.

Municipal outfall discharges into exposed open-ocean areas are very unlikely to experience any problems with pH, temperature or dissolved oxygen (DO) deficits from low DO levels in the effluent or $BOD_5$ exertion. This arises from the large initial dilutions possible by an ocean outfall coupled with the large buffering capacity of the ocean, compared with a shallow river outfall.

# 6. RECOMMENDATION FOR FURTHER WORK

Before the final design parameters are chosen for the outfall and effluent quality, it is recommended that fieldwork be undertaken at the proposed discharge site. More detailed numerical simulations will then need to be performed, which include the simulation of coastal currents and surface-wind effects on the plume movement. These further simulations could also be used to locate monitoring sites for when the outfall becomes operational. The fieldwork should include:

- Accurate depth measurements and sediment samples along the corridor of the proposed outfall alignment (also needed for engineering design and construction of the pipeline);

- Salinity and temperature profiles in summer and after Waimakariri River floods;

- Background water quality measurements in coastal waters, such as water clarity, suspended solids, colour (Munsell Scale), pH, nutrient species (e.g., nitrate+nitrite, ammoniacal nitrogen, TKN, dissolved reactive phosphorous), and complemented by data from any other sources including Environment Canterbury;

- Profiling current meter deployment at the preferred site for at least two months;

- Coastal wind measurements from one site;

- Drogue tracking (or dye tracing) of the behaviour of the surface layer relative to underlying water column, at different stages of the tide and different wind conditions;

- Further effluent testing (protozoa, trace metals, viruses, enteroccoci) and an assessment of all upper-percentile effluent quality limits (rather than maximums);

- Dispersion model simulations to ascertain affect of wind-driven currents on causing plume visits to adjacent beaches or to the proposed mussel farm;

- Pathogen risk assessment covering water-contact activities or eating gathered shellfish.

# 7. SUMMARY

This report is a preliminary desk-top assessment of the impacts and consenting issues associated with a Waimakariri District outfall option to discharge treated sewage from the Kaiapoi and Rangiora areas, into Pegasus Bay.

Outfall lengths considered were 1, 2, and 3 km offshore from The Pines beach and Woodend Beach.

Coastal current velocity information from the wider Pegasus Bay region and depths from hydrographic charts were used to set up and run a number of simple plume dispersion simulations from each of the six outfall options. These model simulations provided preliminary dilutions and concentrations of effluent constituents for a few kilometres away from the outfall. No surface-wind effects were included and the coastal currents were assumed to flow parallel with the coastline.

A preliminary analysis of plume mixing behaviour suggests that a mixing zone of 250 m radius around an outfall diffuser would provide sufficient area to allow reasonable initial mixing of the effluent with ocean water to take place.

Public health guidelines and standards to protect water-contact recreation (e.g., Class Coastal CR rules) could be met by all of the outfall lengths after allowing reasonable mixing. However, the proximity of the 1 km outfall options to the classified Class Coastal CR region (centred on the Waimakariri River mouth), and cultural/community concerns for such popular bathing areas will probably make the 1 km option unacceptable. Based on studies at other open-coast outfalls (e.g., Wanganui, South Brighton, Hawke Bay, Gisborne, Waitara), ocean outfalls of length 2 km or more are unlikely to have problems with shoreline visits of dilute remnants of the effluent plume. Detailed computer model simulations are normally required to confirm the final outfall length to safeguard the health of people and ecosystems, particularly as the direct discharge of treated sewage effluent is a ‘Restricted Coastal Activity’, requiring the consent of the Minister of Conservation.

The main water quality issues that emerge from the preliminary desk-top study are:

- Public-health issues and cultural concerns from the discharge of treated sewage into a water body used for recreation and food supplies;

- Aesthetic appearance and water clarity issues associated with the shorter outfalls options, and when discharging effluent from an oxidation-pond (due to the infrequent, but high, suspended solids concentrations);

- Potential for stimulating naturally-occurring algal blooms in coastal waters of the region, or in the Brooklands Lagoon (for The Pines Beach option).

The two tuning knobs that are most effective in reducing the environmental and public-health risk are: a) increasing the effluent quality, particularly the upper-limit concentrations, with best practicable technology; and, b) increasing the separation from most of the resource users, which in this case will be mainly recreational beach users. The third ‘tuning knob’ of optimising initial dilution by good diffuser design and selecting sites with either deep water or fast currents, will also reduce the environmental and public-health risk, but to a lesser extent.

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