Mixing and dilution studies in the Ruamahanga River below the Masterton Wastewater Treatment Plant

NIWA Client Report: HAM2007-038
January 2007

NIWA Project: BCH07201

Mixing and dilution studies in the Ruamahanga River below the Masterton Wastewater Treatment Plant

J Oldman
J Nagels
K Rutherford
C Hickey

Prepared for

Beca Carter Hollings & Ferner Ltd (Beca), Wellington

Cover Photo: NIWA staff conducting river dispersion measurements using dye in the Ruamahunga River adjacent to the Masterton WWTP (Site A2).

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

Contents

Reviewed and approved for release by:

D. Roper

Formatting checked

A. Bartley

Executive Summary

Mixing and dilution in the Ruamahanga River was studied to support decisions on the discharge of treated wastewater from Masterton. The studies comprised of field dye tracer measurements of mixing and mathematical modelling of dilution from a range of discharge diffuser options.

Measurements of transverse mixing using a dye tracer and river flow gaugings over 3 reaches in the Ruamahanga River at sites adjacent to and below the Masterton wastewater treatment ponds were carried out to evaluate the mixing characteristics of the river.

The field program was carried out between 2-4 August 2004 with dye releases to the Ruamahanga River flow at gauged flows between 19 m^3/s to13.6 m^3/s. For these flow conditions the average transverse dispersion coefficient (E_z) at the site B location (adjacent and to the south of pond 3) was significantly higher than that downstream of the other option at site A, (upstream adjacent to pond 1) and also higher than at the existing outfall site into the Makoura stream (Site C).

Based on the estimated transverse dispersion coefficient predictions, mixing distances for a flow of 6.5 m^3/s (half the median flow) were made. At this flow the predicted mixing distances were similar for sites B and C but significantly longer at site A.

Because the transverse dispersion coefficient (E_z) at site B is higher (and therefore the mixing distance shorter) and channel characteristics are more stable than other sites, site B is the preferred option from a mixing perspective.

A CORMIX model was calibrated against the transverse mixing data from the Ruamahanga River and used to make estimates exit velocity and plume width for two river discharge scenarios (median & half-median flow) and a range of outfall configurations. For a four pipe protruding outfall configuration, the distance at which the discharge is fully mixed across the river is increased with decreasing pipe size. The predicted downstream dilutions for a four pipe 0.5 m diameter outfall configuration showed minimal dilution differences between a discharge to half-median or median flow for distances greater than 200 m downstream. These data indicate that full mixing would occur 600 – 800 m downstream of the discharge point.

If a recessed rockwall option is to be pursued, then the design of the rockwall should be such that the pore spacing does not become too small. The model showed that reducing the pore spacing below 0.3 m will result in low jet momentum resulting in the plume remaining close to the bank over the first 80-100 m and an increase the distance at which the plume is fully mixed across the river.

The predicted downstream concentrations for key water quality parameters for effluent discharge and groundwater leakage are were calculated and indicated that the proposed discharge initiation at median flow (12.3 m^3/s) in summer and half-median flow in winter will not result in water quality guideline exceedance after reasonable mixing with the Ruamahanga River.

1. Introduction

Mixing and dilution in the Ruamahanga River was studied to support decisions on the discharge of treated wastewater from Masterton. The studies comprised of field dye tracer measurements of mixing[1] and mathematical modelling of dilution from a range of discharge diffuser options.

This report presents the results of a field experiment to measure the rate at which effluent from the Masterton Wastewater Treatment Plant (WWTP) mixes across the Ruamahanga River. The brief specified that the study was to be conducted during winter flows and include two possible new outfall locations and also measure the mixing in the Ruamahanga River of the existing discharge into the Makoura stream. Also estimates were required of river transverse mixing to enable predictions of mixing at 6.5 m^3/s (half median flow). It was planned to carry out the field work in the period 26 - 28th July 2004 but a significant flood event during this period delayed the work until the period 2 - 4 August 2004.

The study was commissioned by Beca Carter Hollings & Ferner Ltd (Beca), Wellington in order to collect information (refer Figures 1 and 3):

a. to assess the mixing distance to full vertical and horizontal mixing downstream of a site to the east of the oxidation ponds (site A);

b. to assess the mixing distance to full vertical and horizontal mixing downstream of a site to the southwest of pond 3 (site B);

c. to assess how quickly effluent mixes across the river with the present discharge into the tributary – the Makoura Stream (site C);

d. to enable predictive modelling to be done to estimate the river mixing patterns at a flow of 6.5 m^3/s (half the median flow) at the 2 proposed sites (A and B) and the existing discharge point (site C);

e. to give estimates of mixing of the river at the recreational area near Wardells Bridge under existing and proposed discharge options.

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[1] This report incorporates the full contents of the NIWA (2005) mixing report.

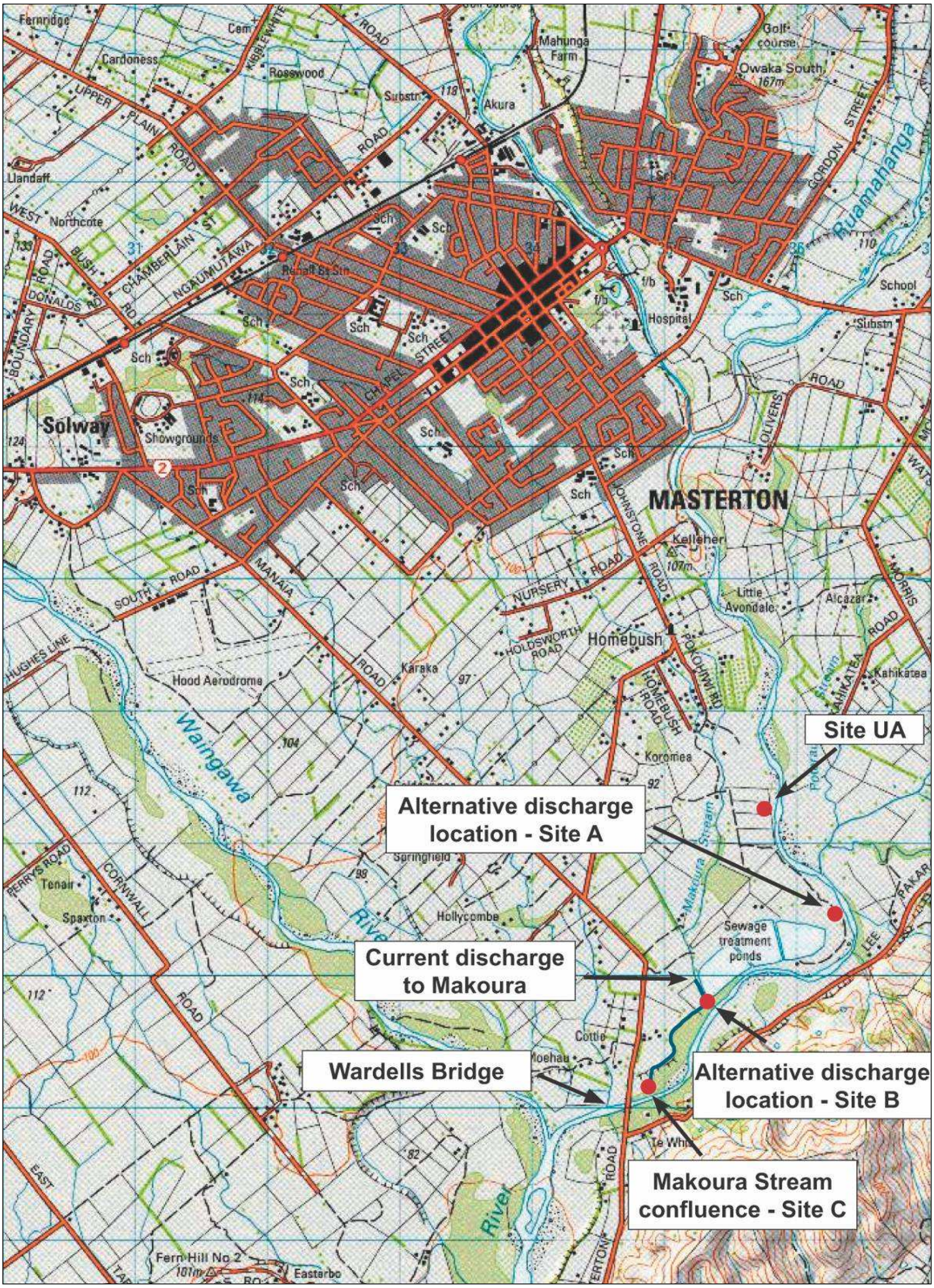


Figure 1: Generalised location map showing discharge site options.

During the study an additional site (labelled UA or Upper A) was identified as a possible option. After an initial dye study and site examination, it was judged unsuitable due to the river channel being unstable due to shifting stone and cobble beds. Currently also, the river flow was predominantly on the left side of the river, so detailed analysis of the data collected was not warranted at this site.

The flow in the Ruamahanga River (at Wardells Bridge recorder site) during the study was on a recession – ranging from 24 to 18.5 m^3/s (Figure 2) which was within the range agreed between NIWA and Beca. The study was restricted to flows under 25 m^3/s because higher flows would compromise our ability to predict mixing at low flows. A flow gauging was undertaken for each dye release.

Currently, treated Masterton wastewater from the 3 pond system is discharged into the Makoura Stream, approximately 850 m upstream of the confluence with the Ruamahanga River. The Makoura Stream is not considered an appropriate receiving environment for the discharge because its low flow only provides dilution of approximately 1:1.

A discharge directly to the Ruamahanga River is being considered along with land disposal options. If the river discharge option was selected, this would likely be via a rock embankment and diffuser structures constructed on the bank of the river.

Dilution calculations were undertaken using the CORMIX model which was calibrated on the transverse mixing data from the dye study in the Ruamahanga River. CORMIX was then used to make estimates of exit velocity and plume width for two discharge scenarios (to median & half-median flow) and a range of outfall configurations.

2. Methods

The field program was carried out over the period 2-4 August 2004 during a period of calm weather and recession river flow. (Figure 2).

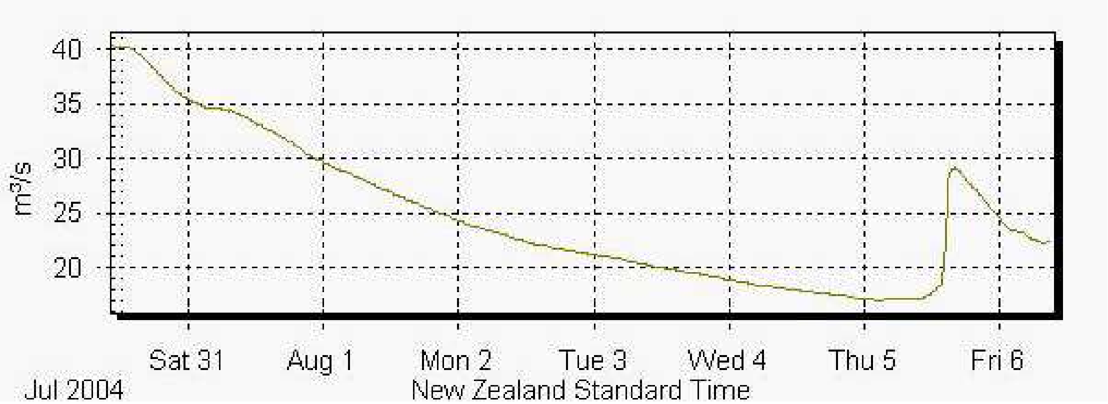


Figure 2: Ruamahanga River flow record at Wardells Bridge for the study period. Data supplied from the website of the Greater Wellington Regional Council.

River flow was measured at selected sites in the study reaches using standard river gauging methods. The flow in the two tributaries (the Whangaehu and the Makoura streams) in the study reach was also measured. All data are summarised in Appendix 1.

2.1 Dye injection and measurement

A solution comprising 10% of concentrated dye solution (25% active Rhodamine WT, supplied by APC Ltd) mixed with clean water was injected continuously into the river within 1 metre of the bank at each site. A metering pump (Model QB Fluid Metering Inc Syosset NY) was used with an injection flow rate of 200 mL/min for about 45 minutes, to achieve steady-state dye concentrations in the river during the measurements at each downstream cross section. The fully-mixed dye concentrations were planned not to exceed 50 ppb. A discharge consent was issued by Wellington Regional Council.

Dye measurements were made at ten or more intervals across each river cross section using a submersible Seapoint fluorometer (Seapoint Sensors Inc Exeter USA) and calibrated to Rhodamine WT dye to an accuracy of 1 mg/m^3 (1 ppb). The fluorometer was connected to a Licor LI-1000 data logger (LICOR Inc Nebraska USA). Dye massflow rate at each sampling site was calculated as the product of the average dye concentration times gauged flow for comparison with the injection rate to check for dye loss and sampling error.

2.2 Study sites

The site locations for the study are shown in Figures 1 and 3.

For site A (Option for alternative discharge location A) the injection point (A0) was east and adjacent to the Masterton WWTP pond 1. Down stream measuring sites were A1 located at 550 m, A2 at 1010 m, and A3 at 1450 m below the injection point.

For site B (Option for alternative discharge location B) the injection point was at the end of pond 3 at the last set of rock structures along this bank. Downstream measuring sites were B1 at 450 m, B2 at 750 m and B3 at 900 m below the injection point.

For site C (the existing discharge via the Makoura stream) the injection point for the dye was in the Makoura stream (C0) 10 m upstream of the confluence of the stream and the Ruamahanga River. Downstream measuring sites were C1 at 200 m (Wardells Bridge), C2 at 500 m and C3 at 1350 m below the injection point (C3 was below the confluence of the Waingawa River).

Sites were located using an ETREX Garmin GPS to a precision of approximately 2 m.

3. Results

The following section gives a summary of the field measurements, the derivation of estimates of transverse mixing parameters and predictions of transverse mixing both at the gauged flow and at a flow of 6.5 m^3/s (half the median flow).

3.1 Summary of field measurements

Measured dye concentration distributions, derived massflow curve and ratio of observed to fully-mixed concentration for each of the dye tests (and transects, see Figure 3) are given in Figures 4a to 4j. Measured dye concentrations (mg/m^3) are presented with cross section distances given from the right bank. For each measured dye concentration (mg/m^3) and discharge (m^3/s) the mass of dye (mg/s) at each station across the transect can be derived. From these data the total mass flow (g/s) for the transect and the cumulative sum of the mass flow across the section (zero at right bank and total mass flow at left bank) can be derived. Normalised plots of the cumulative sum of the massflow are presented in the following figures (i.e., a value of 1 is assigned to the left bank value). From the total mass flow the dye concentration at each station across the transect assuming the dye was fully-mixed (i.e., there was no variation in dye concentration across the transect) can be derived. The following figures present the measured/fully-mixed ratio for each of the transects. For example, a value of 3 indicates that the observed dye concentration was actually 3 times the value that would occur if all the dye was evenly mixed across the transect. A value of close to one across the transect indicates that the dye is actually very close to being fully-mixed.

The additional site at UA was recognised as not a suitable site for a discharge point, so further analysis of the data collected was not warranted, but is presented in Appendix 2.

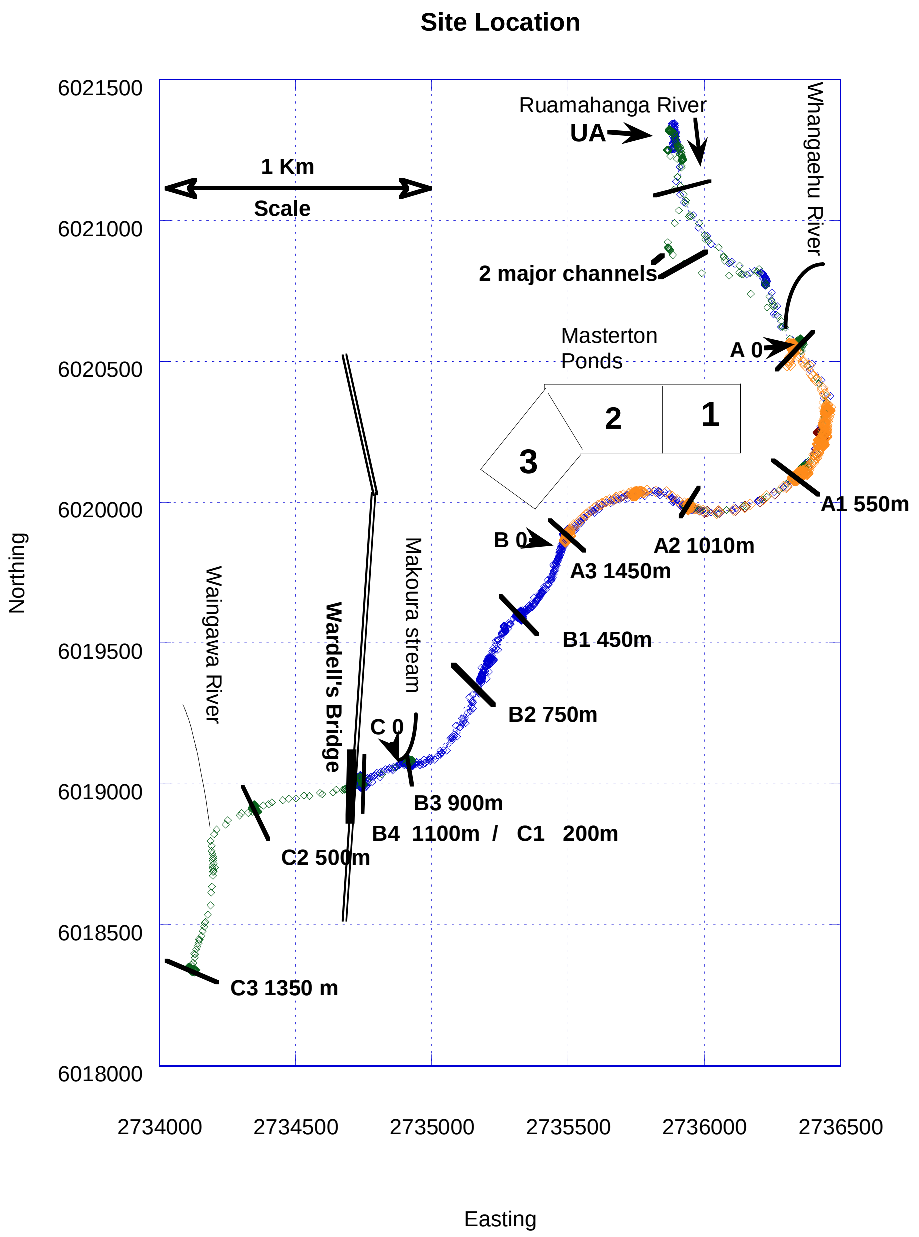


Figure 3: Location diagram for dye tests and transects. Dye injection points were UA, A0, B0, and C0.

3.1.1 Injection at site A

At site A1 (550 m from the release point A0) a peak concentration of 33 mg/m^3 was observed 5 m from the right bank (Fig. 4a). 50% of the dye massflow is contained within 13 m of the right bank. The peak observed/fully-mixed ratio was 3 indicating that dye was not fully-mixed across the width of the river at this site.

At site A2 (1010 m from the release point A0) a peak concentration of 15 mg/m^3 was observed 6 m from the right bank and 50% of the dye massflow occurred within 12 m of the right bank. The maximum observed/fully-mixed ratio of 1.4 indicates the dye was not yet fully-mixed across the width of the river (Fig. 4b).

At site A3 (1450 m from the release point A0) a peak concentration of 10 mg/m^3 was observed 5 m from the right bank. 50% of the dye massflow occurred within 7 m of the right bank. By this point the dye was essentially fully-mixed across the width of the river.

3.1.2 Injection at site B

At site B1 (450 m from the release point B0) a peak concentration of 23 mg/m^3 was observed 4 m from the right bank (Fig. 4d). 50% of the dye massflow was contained within 5 m of the right bank. The peak observed/fully-mixed ratio of 2 indicated that dye was not fully-mixed across the width of the river at this site.

At site B2 (750 m from the release point B0) a peak concentration of 16 mg/m^3 was observed at the right bank. 50% of the dye massflow occurs within 6 m of the right bank (Fig. 4e). The maximum observed/fully-mixed ratio of just over 3 indicated the dye was not fully-mixed across the width of the river and the mass flow was ‘bulking’ on the right bank. The observed massflow at B2 was significantly lower than at B1, B3 or B4 (see Table 1). The likely reason is that flow was concentrated along the right bank where only 3 dye and flow measurements were made. Also there was some measurable ‘loss’ of flow (Table 1), possibly caused by entrainment into the coarse alluvial river bed. The resultant data were insufficient to fully define the dye plume. While it is clear dye was not well-mixed at site B2, data from this site are not sufficiently reliable for more detailed analysis of transverse mixing, **so this site was excluded from the predictive modelling**.

At site B3 (900 m from the release point B0) a peak concentration of 9 mg/m^3 was observed 11 m from the right bank. 50% of the dye massflow occurred within 12 m of the right bank. By this point the dye was essentially fully-mixed across the width of the river with a maximum observed/fully-mixed fraction just over 1 (Fig. 4f).

At site B4 (Wardells bridge, 1100 m from the release point B0) a peak concentration of 7 mg/m^3 was observed at the left bank. 50% of the dye massflow occurred within 21 m of the right bank. There was a noticeable influence from the Makoura Stream which diluted the dye concentrations on the right bank but did not significantly change the observed/fully-mixed ratio (Fig. 4g).

3.1.3 Injection at site C (Dye release from Makoura Stream)

At site C1 (at Wardells bridge, 200 m from the release point C0) a peak concentration of 31 mg/m^3 was observed at the right bank (Fig. 4h). 50% of the dye massflow was contained within 18 m of the right bank. The peak observed/fully-mixed ratio was 4.5 which indicated that the dye was not fully-mixed across the width of the river.

At site C2 (500 m from the release point C0) a peak concentration of 23 mg/m^3 was observed 2 m from the right bank. 50% of the dye massflow occurred within 7 m of the right bank. The maximum observed/fully-mixed ratio of 3.2 indicates the dye was not fully-mixed across the width of the river.

At site C3 (1350 m from the release point C0 and below the confluence of the Ruamahanga River and the Waingawa River) a peak concentration of 8 mg/m^3 was observed at the right bank. 50% of the dye massflow occurred within 12 m of the right bank (Fig. 4j). By this point the dye was essentially fully-mixed across the width of the river.

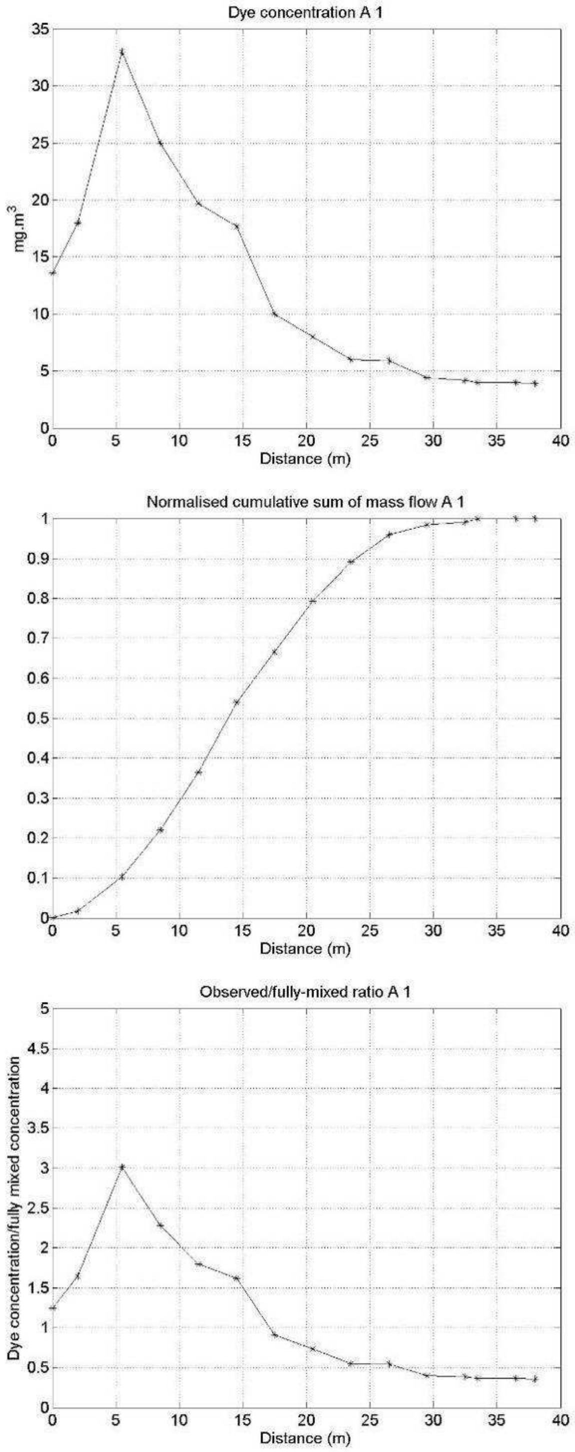


Figure 4a: Injection site A0. Site A1 (550 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration. Note: a value of 1 = river fully mixed.

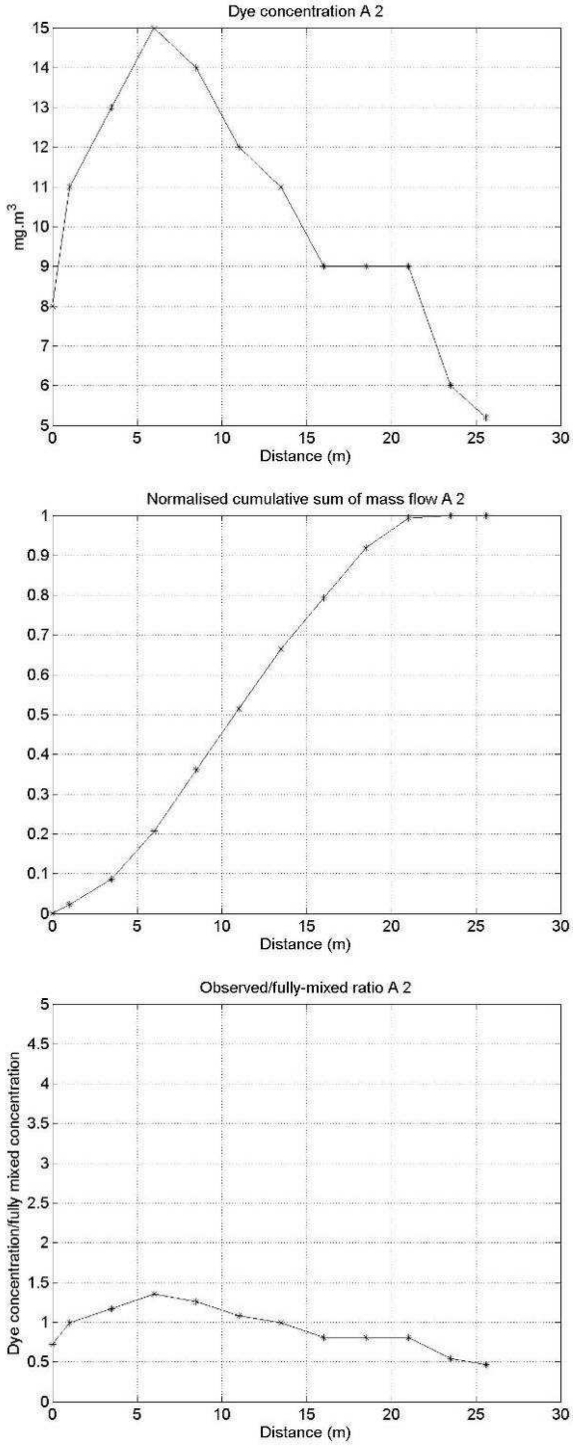


Figure 4b: Injection site A0. Site A2 (1010 m from the release point. (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

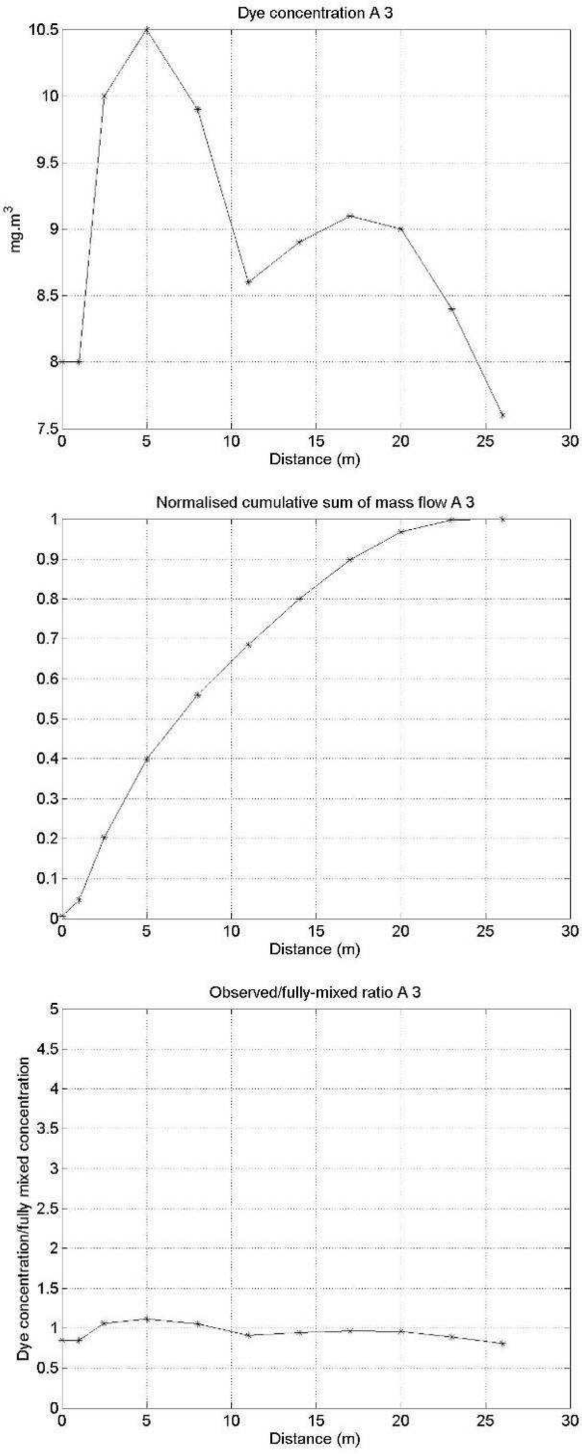
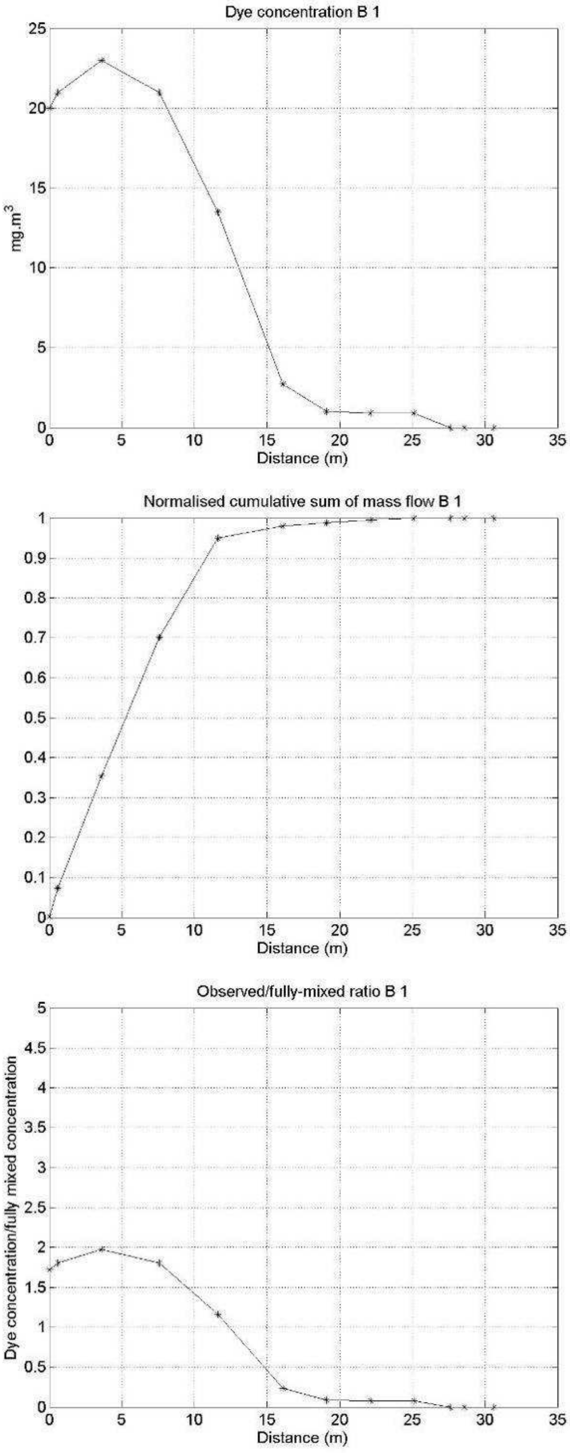


Figure 4c: Injection site A0. Site A3 (1450 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.


Dye concentration B 1

Normalised cumulative sum of mass flow B 1

Observed/fully-mixed ratio B 1

Figure 4d: Injection site B0. Site B1 (450 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

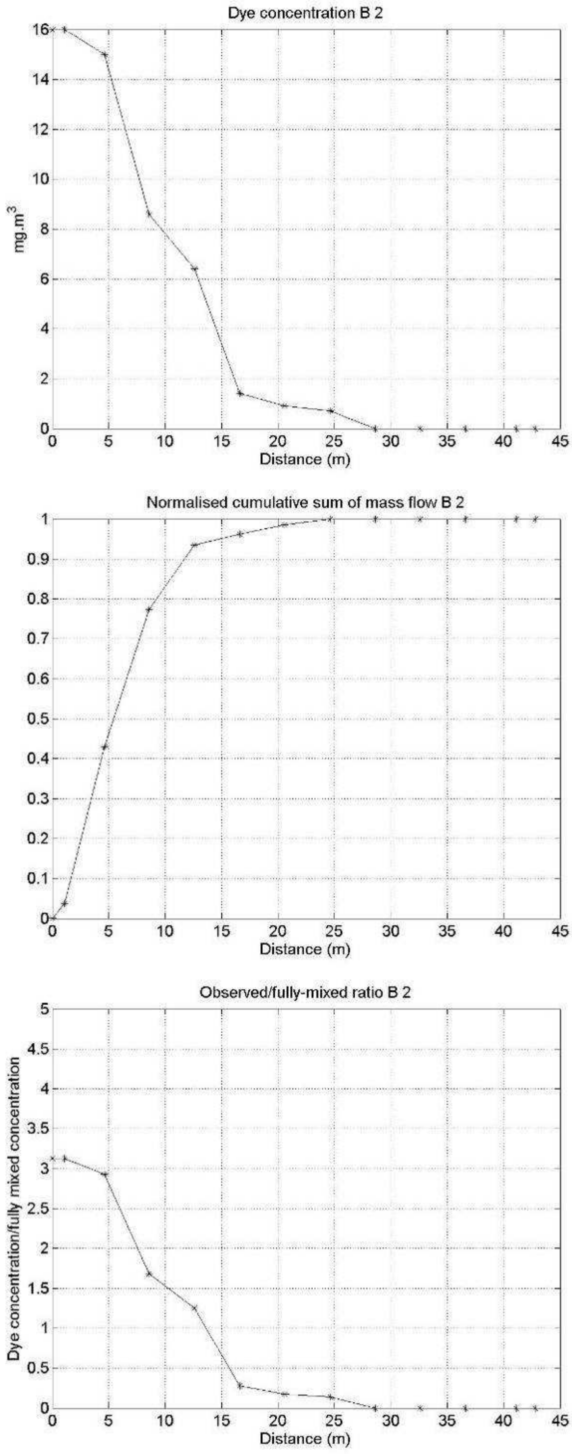


Figure 4e: Injection site B0. Site B2 (750 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

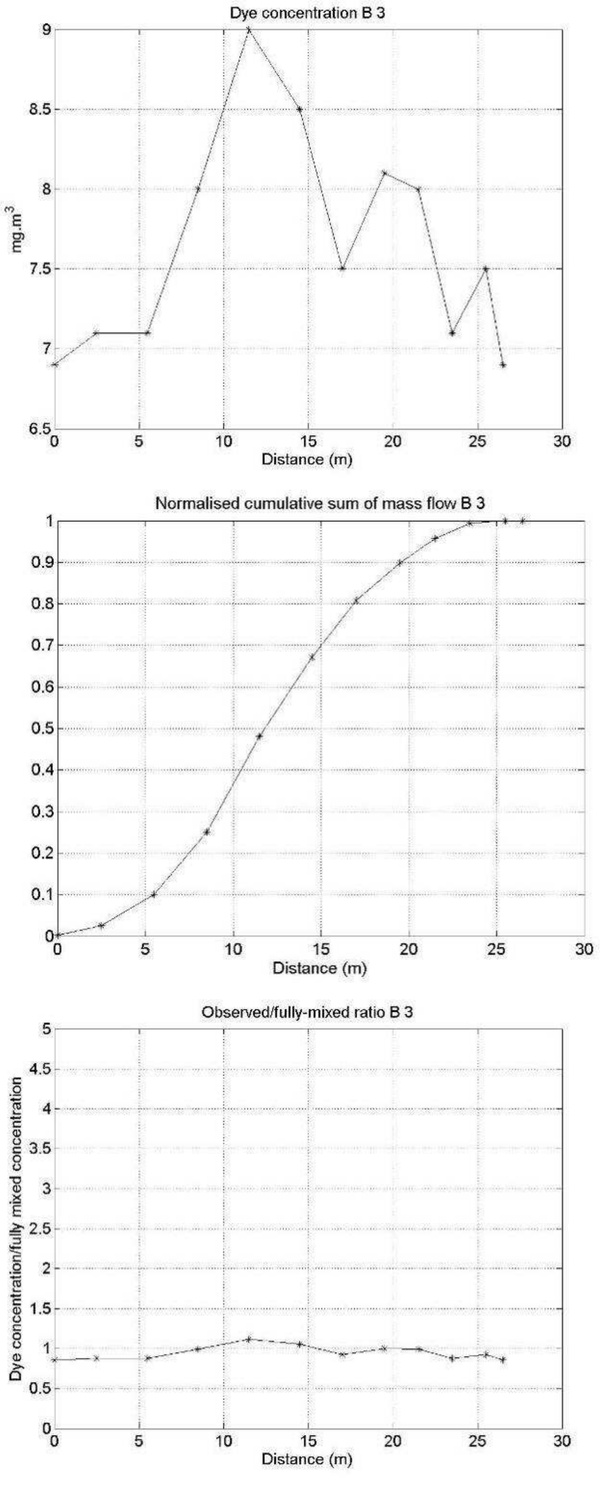


Figure 4f: Injection site B0. Site B3 (900 m from the release point. (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

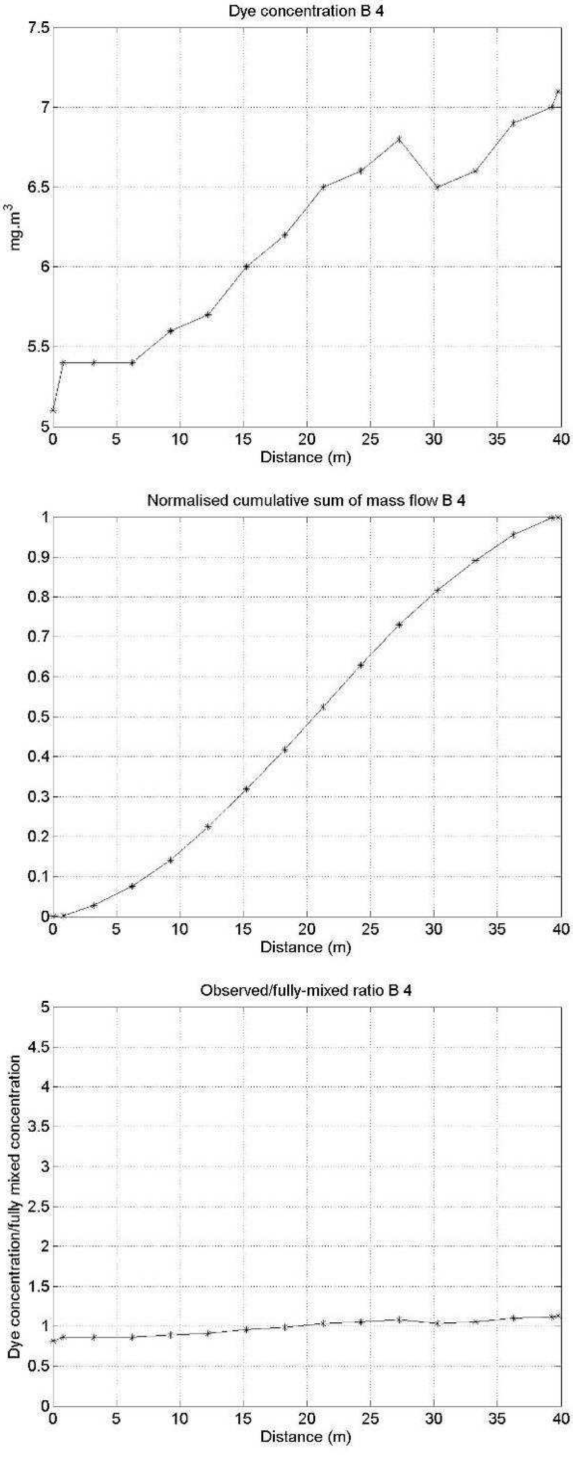


Figure 4g: Injection site B0. Site B4 (1100 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

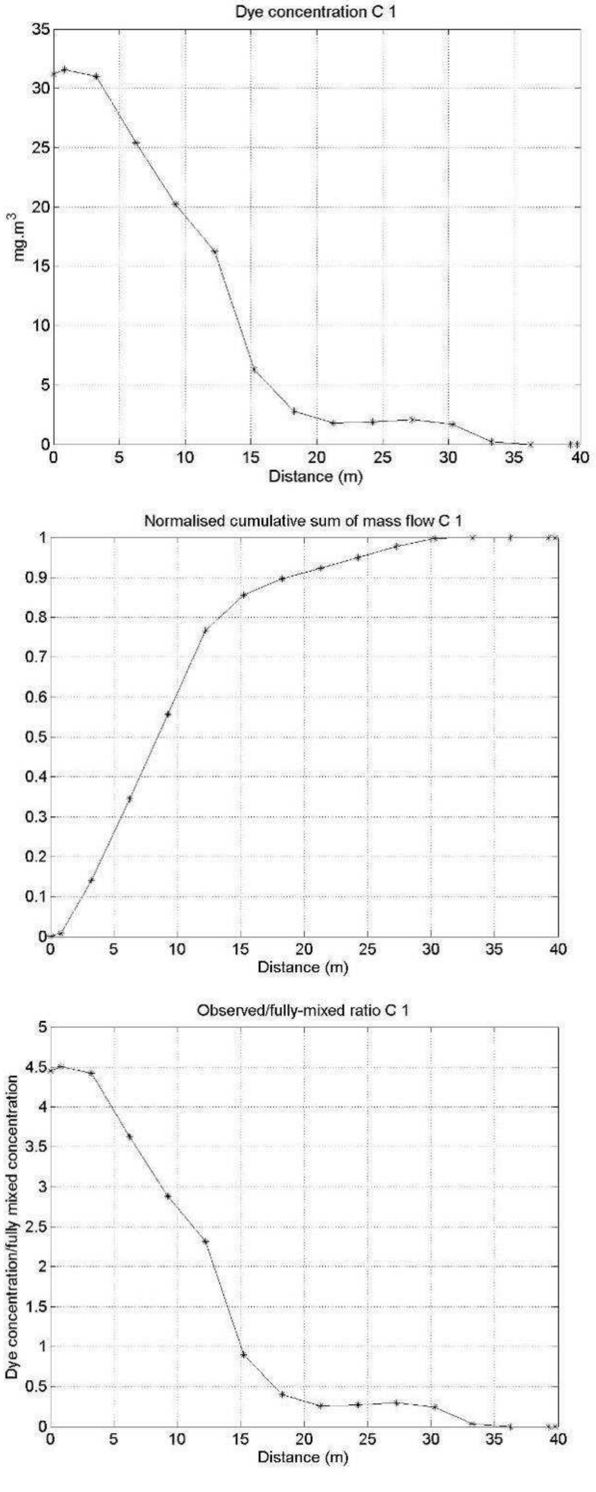


Figure 4h: Injection site C0. Site C1 (200 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

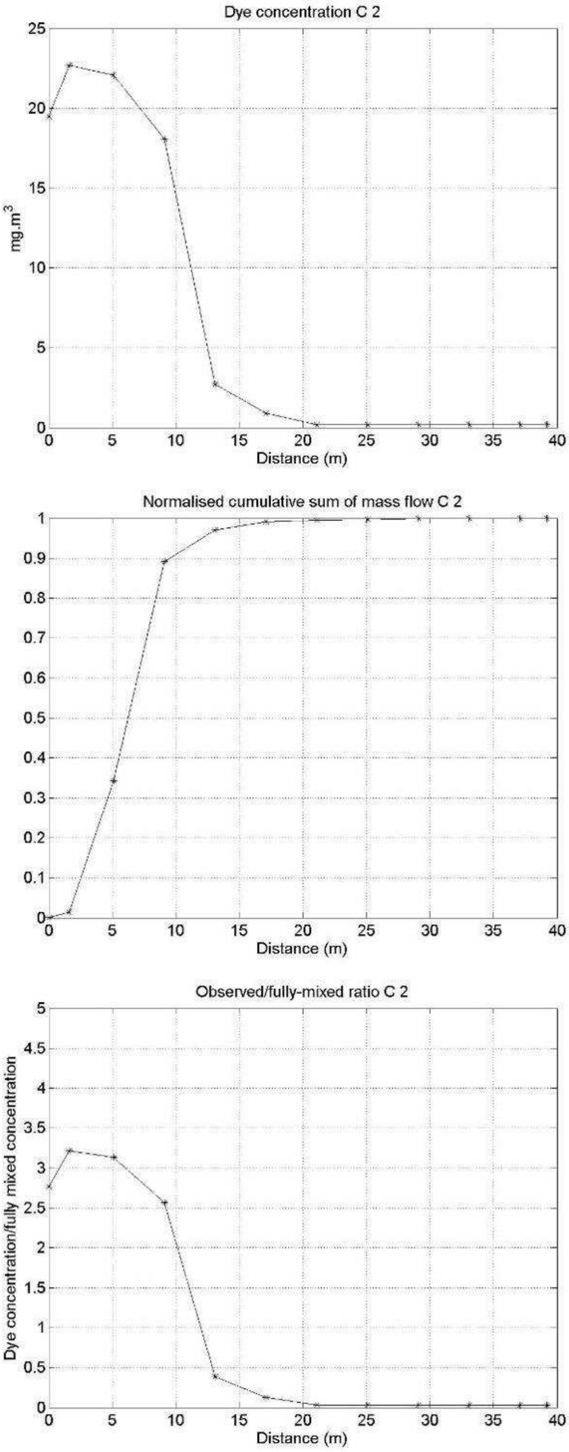


Figure 4i: Injection site C0. Site C2 (500 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

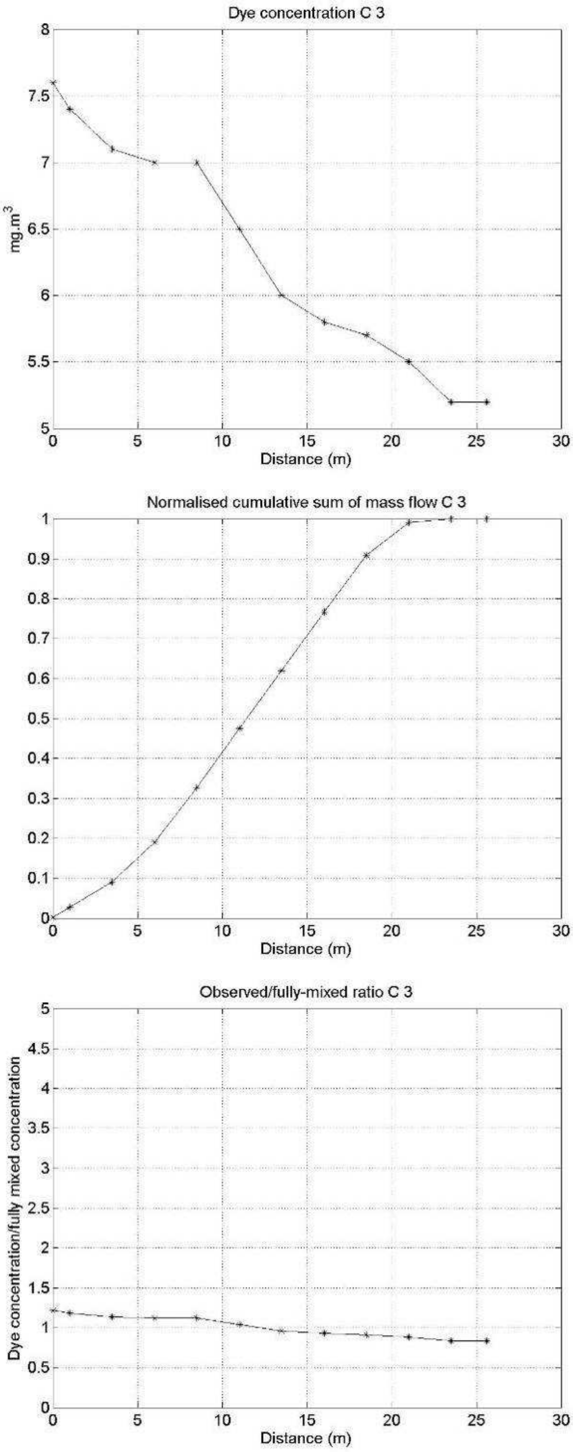


Figure 4j: Injection site C0. Site C3 (1350 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

A further site (labelled UA or Upper A) was also examined but was judged unsuitable due to the river channel being unstable and predominantly on the left side of the river. The general nature of the river terrain in this area looked unstable with large mobile gravel beds causing the river to divide into two major channels downstream. The fully mixed zone was achieved at 2200 m down stream. It was not considered to be a likely option, and so was not included in the predictive modelling analysis. However data from this dye test is summarised in Appendix 2 and not commented on further.

3.2 Channel Characteristics

The following table summarises channel characteristics, flow and massflows of dye for each of the dye tests and transects. Note that the total mass flow of dye (M) is not measured conservatively in all of the transects. Site B2 is most notable, as there is also measurable 'loss' of flow, possibly caused by entrainment into the coarse alluvial river bed, and not able to be measured by traditional flow measuring methods.

Table 1: Summary of channel characteristics, flow and massflows of dye.

Dye test transect number	Q Gauged flow (m^3/s)	A Cross sectional area (m^2)	W Cross sectional width (m)	D Width averaged depth (m)	U Width averaged velocity (m/s)	M Total mass flow (mg/s)	ψ Shape factor (-)
A1	13.58	2.76	38.0	0.49	0.73	149	1.39
A2	15.23	3.45	25.6	1.01	0.59	169	1.04
A3	14.22	2.03	26.0	0.56	0.97	134	1.14
B1	15.97	4.12	30.6	0.80	0.65	186	1.05
B2	15.32	2.92	42.8	0.48	0.74	78	1.18
B3	16.29	3.99	26.5	0.97	0.63	133	1.20
B4	18.93	2.91	39.8	0.89	0.54	119	1.15
C1	18.93	2.91	39.8	0.91	0.52	133	1.33
C2	18.61	4.16	39.2	0.64	0.74	131	1.27
C3	15.23	3.45	25.6	1.01	0.59	95	1.04

3.3 Transverse dispersion coefficients

The rate at which effluent mixes across the river was modelled using the streamtube model (Yotsukura & Cobb 1972). This model requires estimates of the 'factor of diffusion' (denoted K_q). The measured dye profiles together with the measured profiles of cumulative flow were analysed to determine values of K_q between the outfall and each of the sampling points using the method of moments as adapted to the streamtube model by Rutherford (1993). The transverse dispersion coefficient E_z is more commonly reported than K_q and the two are related by the equation:

$$K_q = \psi H^2 U E_z \qquad (1)$$

where K_q = factor of diffusion (units: m^5/s^2); H = width-averaged depth (m); U = width-averaged velocity (m/s); E_z = width-averaged transverse dispersion coefficient (m^2/s) and the dimensionless 'shape factor' accounts for variations in depth and velocity across the channel is:

$$\psi = \frac{1}{b}\int \left(\frac{h}{H}\right)^2 \frac{u}{U} dz \qquad (2)$$

where u = local velocity; h = local depth; b = channel width and z = transverse distance.

Transverse dispersion coefficients are often reported in non-dimensional form as E_z/HU^* where H = reach-averaged depth and U^* = reach-averaged shear velocity defined as;

$$U^* = \sqrt{gHs} \qquad (3)$$

where g is 9.81 m^2/s and s is the bed-slope.

Table 2 summarises estimates of K_q made from the concentration distributions shown in Figure 5a-f. Estimates in column 2 are made between the outfall and the measuring site assuming that effluent originates from a point source at the bank, those in column 3 are made between site 1 and the measuring site and so on. Table 3 summarises estimates of E_z made from the data in Table 1. Table 4 gives the non-dimensional form of the transverse dispersion coefficient.

Table 2: Estimates of K_q (units: m^5/s^2) E_z (units: m^2/s) and E_z/HU^* for each of the dye tests.

	K_q (m^5/s^2)	E_z (m^2/s)	E_z/HU^*
A0-A1	0.018	0.074	1.324
A1-A2	0.035	0.056	0.338
A2-A3	0.070	0.202	2.960
B0-B1	0.030	0.183	3.280
B2-B3	0.100	0.130	0.785
B3-B4	0.100	0.513	7.529
C0-C1	0.015	0.090	1.618
C1-C2	0.018	0.019	0.114
C2-C3	0.075	0.390	5.715

The range of published values for curved channels is ($1 < E_z/HU^* < 3$; Rutherford 1993) and for straight channels is ($0.1 < E_z/HU^* < 0.26$; Rutherford 1993).

The transverse mixing for section B is higher than the published values of E_z/HU^* (both straight and curved) suggesting that channel morphology plays a crucial role in determining transverse mixing for this section of the river.

For curved sections between A0-A1 and A2-A3 the predicted values of E_z/HU^* fall within the curved channel range. The value of E_z/HU^* for the section between A1-A2 is low for a curved section of river and is closer to the upper end of the published values for a straight channel. This suggests that the deep channel on the right bank, the relative straightness of this section (Figure 3) plus the possible effects of the groynes present in this section results in lower transverse mixing here compared to sections A0-A1 and A2-A3 occurring between cross section A1 and A2.

For sections between C0-C1 and C2-C3 the value of E_z/HU^* is well above the published range for both straight and curved channels. The Makoura Stream and the Waingawa River clearly amplify transverse mixing in these reaches. Between sections C1-C2 the value of E_z/HU^* is at the lower end of the published straight channel value.

Overall, transverse mixing is much more rapid for reach B (immediately downstream of the site B discharge location) than for sites A or C.

3.4 Estimates of transverse mixing at gauged flow

Based on estimates of K_q given in Table 2 this section uses the modified streamtube model approach (Yotsukura & Cobb 1972) to give estimates of transverse mixing at the gauged flows (Table 1). The following three figures give contours of the predicted/fully-mixed concentrations of 5.00, 4.00, 3.00, 2.00, 1.50, 1.10, 0.91, 0.66, 0.50, 0.33, 0.25 and 0.20 at sites A, B and C. Note that a breech in slope of some of the dye contours (particularly in Figure 5b and 5c) are where a change in average mixing condition occurs.

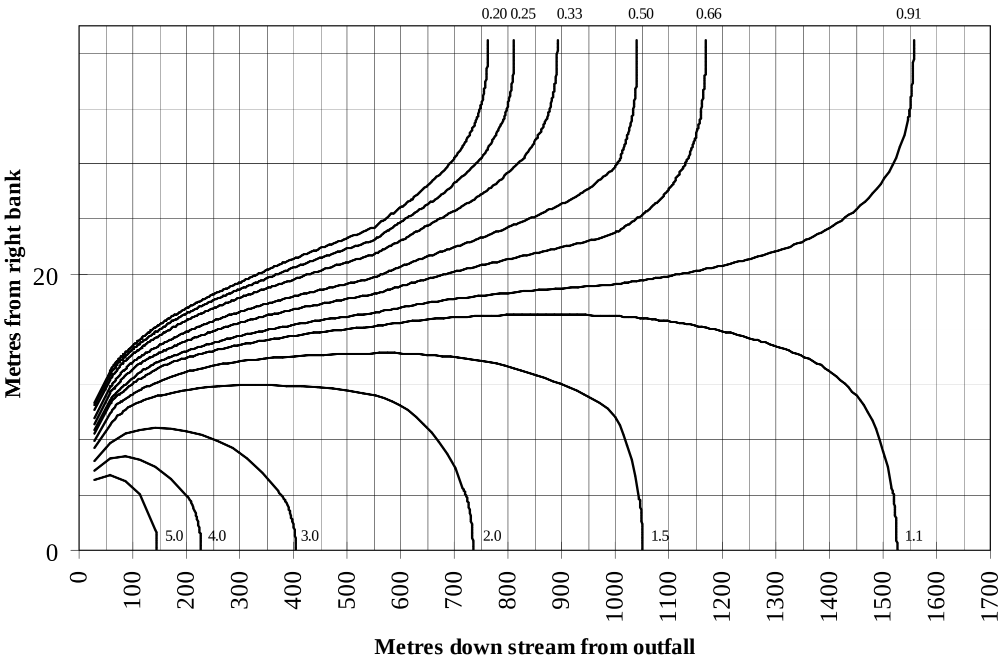


Figure 5a: Predicted dye concentrations using predicted values for K_q (Table 2) for the gauged flow of 14.3 m^3/s for site A. Values are expressed as the ratio of predicted /fully-mixed concentrations.

Figure 5b: Predicted dye concentrations using predicted values for K_q (Table 2) for the flow of 16.6 m^3/s site B. Values expressed as the ratio of predicted /fully-mixed concentrations.

A comparison of Figure 5b (for site B) with Figures 5a and 5c (for sites A and C) shows that mixing is appreciably more rapid at site B than at sites A and C and the distances to full mixing are summarised in Table 5.

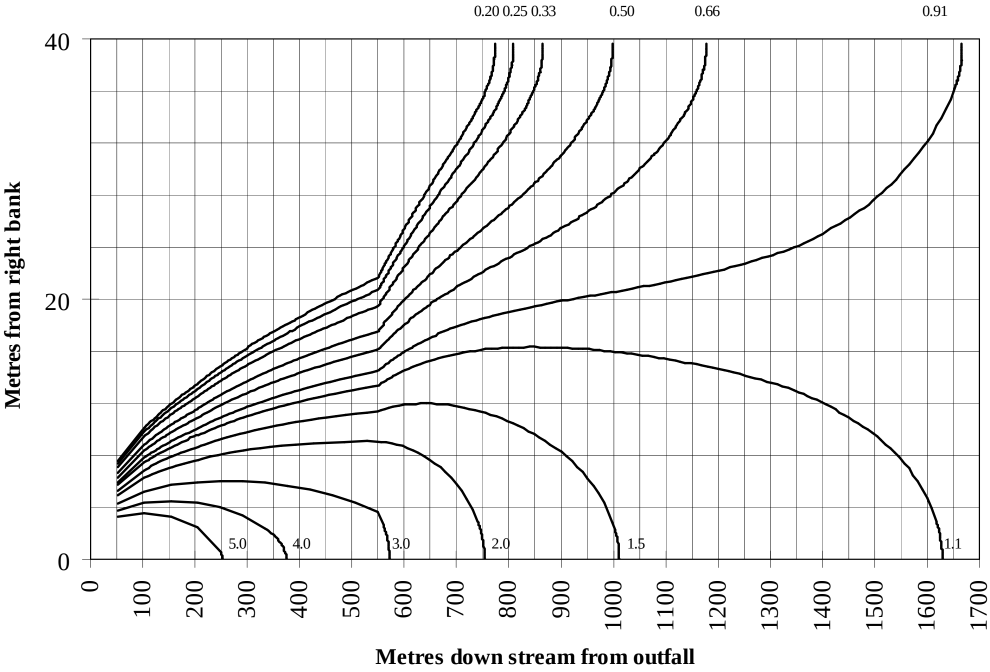


Figure 5c: Predicted dye concentrations using predicted values for K_q (Table 2) for the flow of 17.6 m^3/s for site C. Values expressed as the ratio of predicted /fully-mixed concentrations.

3.5 Predictions of transverse mixing at a flow of 6.5 m^3/s (half the median flow)

Assuming that the non-dimensional form of the transverse dispersion coefficient (E_z/HU^*) remains constant, estimates of K_q at a flow of 6.5 m^3/s can be made.

$$E_{znew} = \frac{E_{zgauged} H_{new} U^*_{new}}{H_{gauged} U^*_{gauged}} \qquad (4)$$

From the rating curve for Wardells Bridge[2] (Appendix 3) a flow of 6.5 m^3/s would result in a water level drop of between 0.17 and 0.21 m from the levels during the dye tests. Applying formulas 3 and 4 gives new estimates of E_z. By applying equation 1 new estimates of K_q can be obtained (Table 3). Note that (E_z/HU^*) data are identical to those in Table 2- consistent with equation 4.

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[2] Data supplied by Greater Wellington Regional Council.

Table 3: Estimates of K_q (units: m^5/s^2) E_z (units: m^2/s) and E_z/HU^* for river flow of 6.5 m^3/s.

	K_q (m^5/s^2)	E_z (m^2/s)	E_z/HU^*
A1	0.003	0.039	1.324
A2	0.009	0.042	0.338
A3	0.013	0.117	2.960
B1	0.005	0.083	3.280
B3	0.022	0.093	0.785
B4	0.018	0.265	7.529
C1	0.002	0.039	1.618
C2	0.002	0.013	0.114
C3	0.018	0.039	5.715

Based on the estimates of K_q given in Table 3 for flows of 6.5 m^3/s the following figures give contours of the predicted/fully-mixed concentrations of 5.00, 4.00, 3.00, 2.00, 1.50, 1.10, 0.91, 0.66, 0.50, 0.33, 0.25 and 0.20.

Figure 5d: Predicted dye concentrations at a flow of 6.5 m^3/s for site A. K_q values from Table 3. Values expressed as the ratio of predicted /fully-mixed concentrations.

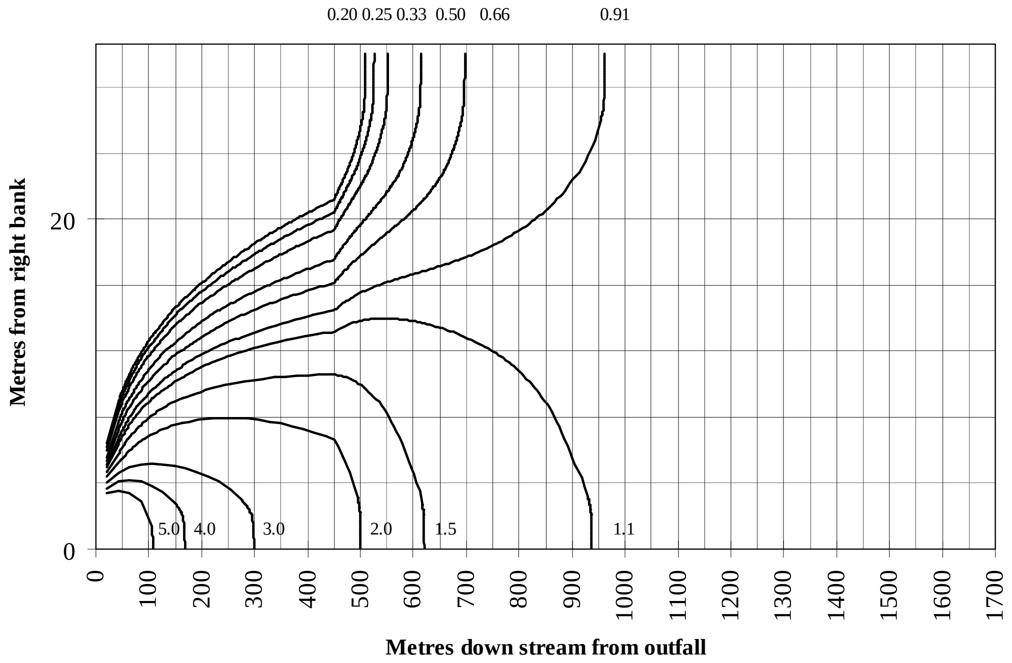

Figure 5e: Predicted dye concentrations at a flow of 6.5 m^3/s for site B. K_q values from Table 3. Values expressed as the ratio of predicted /fully-mixed concentrations.

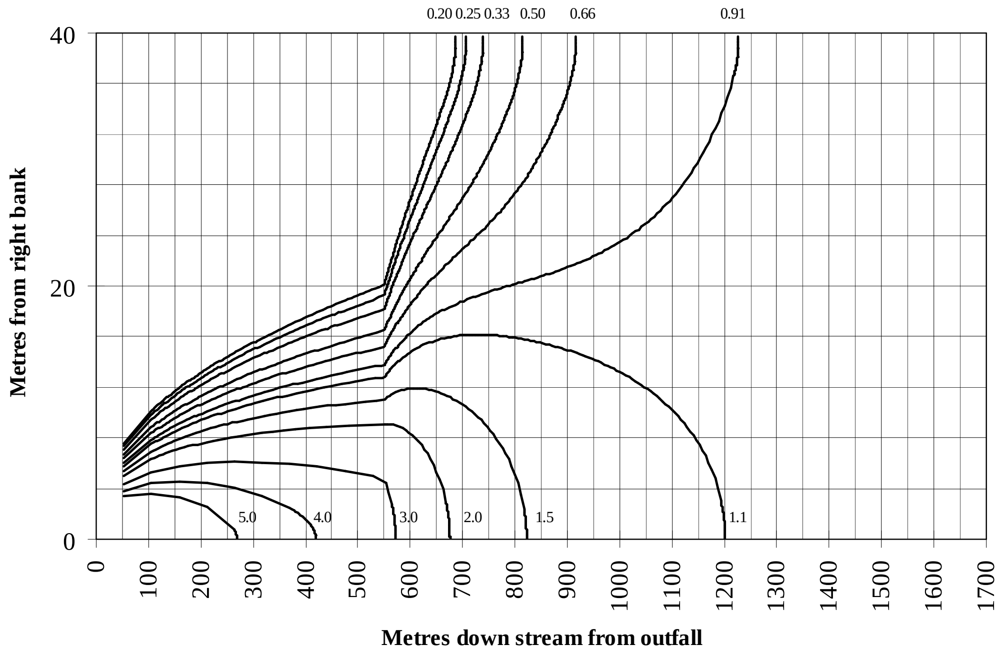

Figure 5f: Predicted dye concentrations at a flow of 6.5 m^3/s for site C. K_q values from Table 3. Values expressed as the ratio of predicted /fully-mixed concentrations.

The following table compares and summarises the distance at which the discharge becomes fully-mixed at the gauged flow and at a flow of 6.5 m^3/s (half the median-flow).

Table 5: Summary of estimated fully-mixed distances for the Ruamahanga River at gauged flows and at a flow of 6.5 m^3/s.

At gauged flows (13.6 – 9.0 m^3/s)			At 6.5 m^3/s		
Site	**Figure**	**Distance range (m)**	**Site**	**Figure**	**Distance range (m)**
A	5a	1500-1600	A	5d	1450-1550
B	5b	1100-1200	B	5e	900-1000
C	5c	1600-1700	C	5f	1150-1250

3.6 CORMIX predictions of transverse mixing at gauged flow

In addition to the streamtube modelling a CORMIX model of the Ruamahanga River was setup with a continuous effluent discharge into the Ruamahanga River at site B. Data from the dye test between section B0 and B3 (Table 1) show that the mixing parameters are relatively uniform over the first 950 m downstream of the proposed discharge point. It is only in the next 350 m to Wardells Bridge where there is a marked increase in mixing. Therefore, constant parameters were applied within the CORMIX model to simulate the mixing within the Ruamahanga downstream of site B.

River flow was set to the gauged flow measured during the dye test for site B (16.6 m^3/s) with an effluent flow rate of 0.12 m^3/s (equivalent to the 200 mL/min dye injection rate). Calibration of CORMIX was achieved by adjusting the bed roughness and meandering factor.

Three levels of meander are available within CORMIX. These are:

1) straight channel with uniform cross sections;
2) moderately meandering;
3) strongly winding with highly irregular cross sections.

Based on the cross section data collected and the Ruamahanga River geometry (Fig. 1) the meander factor was set to type 2 (moderately meandering).

Using the method adopted by the USGS to estimate bed roughness (Arcement and Schneider, 1994) a Manning's n roughness of 0.045 was derived. This assumed a gravel bed roughness of 0.028, irregularity roughness of 0.006 (moderate), cross section variation roughness of 0.005 (alternating occasionally), obstruction roughness of 0.004 (negligible) and a vegetation roughness of 0.002 (small). This value of roughness and meandering gave a fully mixed distance of 1177 m - in close agreement with the transverse mixing distance predicted using the streamtube model under gauged flows (Table 5). Under half median river flows (6.5 m^3/s) the transverse mixing distance was predicted to be 980 m which is in the range of values predicted by the streamtube modelling (Table 5).

3.7 CORMIX predictions with proposed outfall design at Site B

Having established that CORMIX can be used to make estimates of transverse mixing within the Ruamahanga River, CORMIX was used to make estimates of transverse mixing, dilution, exit velocity and plume width for two discharge scenarios and a range of outfall configurations.

Two scenarios were modelled for an outfall consisting of four protruding 0.5 diameter pipes. These were:

1) River flows at half median flow discharge (6.15 m^3/s) giving the water depth at discharge site of 1.76 m a discharge flow rate of 0.205 m^3/s (i.e., 30x dilution fully mixed).

2) River flows at half median flow discharge (12.3 m^3/s) giving the water depth at discharge site of 1.98 m a discharge flow rate of 0.410 m^3/s (i.e., 30x dilution fully mixed).

In addition to the above outfall configuration an option to recess the pipes and discharge via a rockwall was modelled. To model this option CORMIX was configured using a number of recessed smaller ports across the face of the rockwall. The second outfall configuration consisted of twelve 0.3 m ports - equating to four 2 m pipes with the rock wall configured to give 0.3 m pore spacing. The third outfall configuration consisted of 24 0.1 m ports - effectively giving 6 ports per pipe with the rockwall pore spacing at 0.1m. It was assumed that the total effluent discharge was split evenly between each of the ports.

Results for the outfall consisting of four protruding 0.5 diameter pipes are given in Table 6.

Table 6: Predictions from CORMIX for the four pipe 0.5 m diameter outfall configuration at half-median and median river flows.

	Four pipe 0.5 m diameter outfall at half median flows (6.15 m^3/s)	Four pipe 0.5 m diameter outfall at median flows (12.3 m^3/s)
Dilution at 200 m (% mixed)	16.4 (55%)	17.6 (59%)
Transverse mixing distance (m)	731	639
Exit velocity (m/s)	0.26	0.52

Figure 6a shows the predicted dilution versus distance predictions for the four pipe outfall configuration at the two different river flow rates. For these two simulations the plume remains close to the right bank over the first 80-100 m (Fig. 6b) at which stage it becomes fully vertically mixed. Between 120 and 150 m downstream of the discharge the plume begins to move away from the right bank and begins to attach to the left bank.

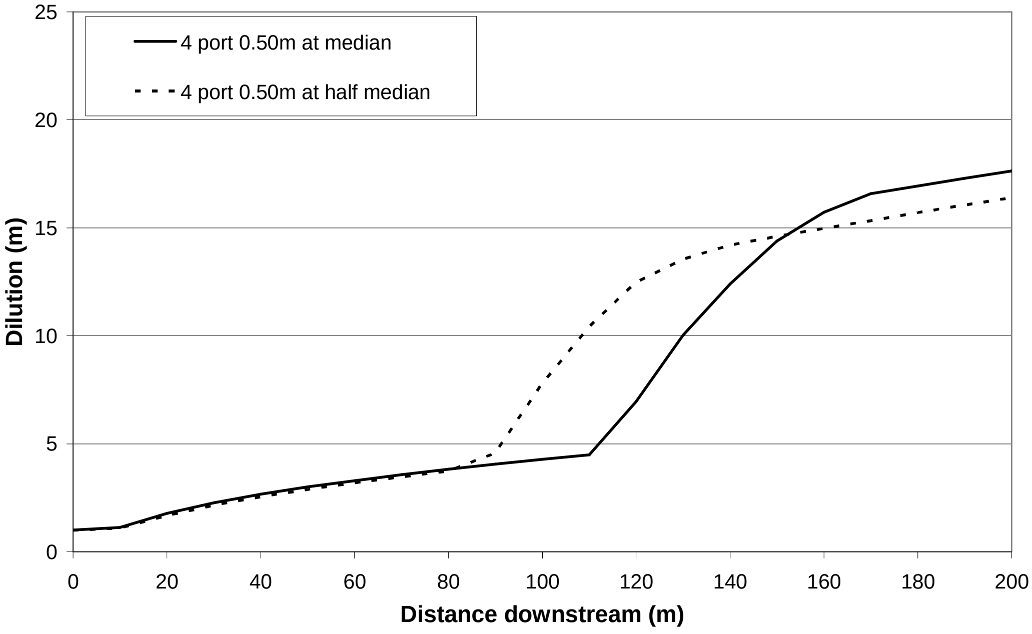

Figure 6a: Plume dilution versus distance downstream from the calibrated CORMIX model for four 0.5 diameter pipes discharging into the Ruamahanga River at site B at half median (6.15 m^3/s) and median flow (12.3 m^3/s).

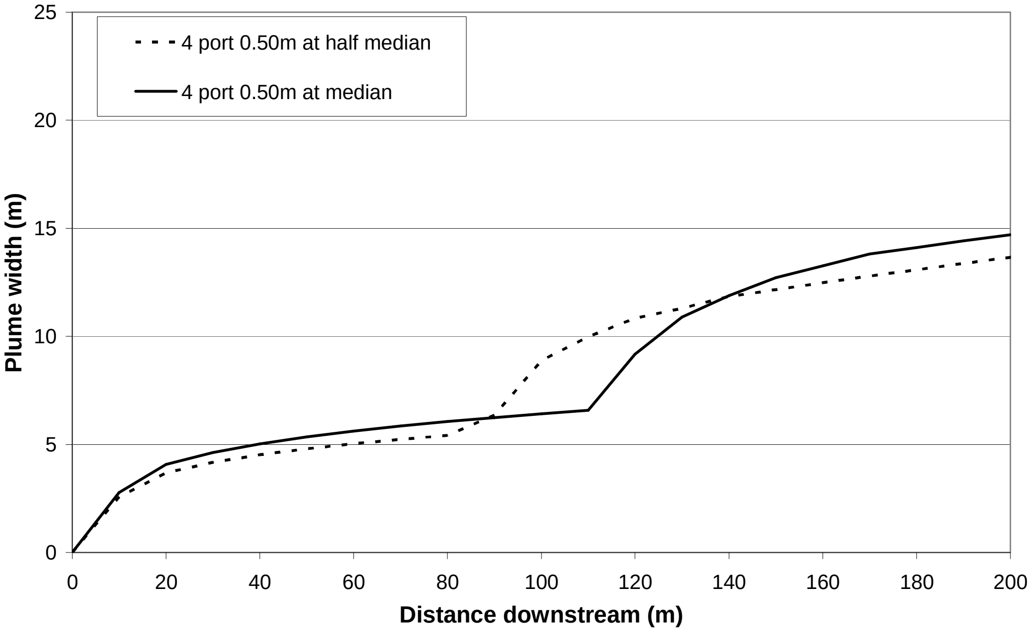

Figure 6b: Predicted plume width versus distance downstream from the calibrated CORMIX model for four 0.5 diameter pipes discharging into the Ruamahanga River at site B at half median (6.15 m^3/s) and median flow (12.3 m^3/s).

Predictions from the CORMIX modelling show that decreasing the pipe diameter increases the dilution achieved within the first 200 m of the discharge point (Fig. 6c). Recessing the pipes into the rockwall decreases the dilution achieved within the first 200 m of the discharge (Fig. 6c). For the 24 port rockwall configuration the port momentum becomes significantly reduced (i.e., high jet velocities but with significantly less discharge through each port) resulting in the plume remaining attached to the bank for more than 100m (Fig. 6d).

Figure 6g gives the predicted transverse mixing distance for each of the CORMIX simulations. The plot shows that decreasing the pipe diameter decreases the transverse mixing distance. Recessing the pipes within the rockwall further increases the transverse mixing distance.

The predicted downstream dilutions for the four pipe 0.5 m diameter outfall configuration at half-median and median river flows are summarised in Table 7, with detailed data for all scenarios provided in Appendix 4. This diffuser option shows minimal dilution differences between a discharge to half-median or median flow for distances greater than 200 m downstream. A ‘nominal dilution’ value is the rounded average dilution value for this diffuser configuration. These data indicate that full mixing would occur 600 – 800 m downstream of the discharge point.

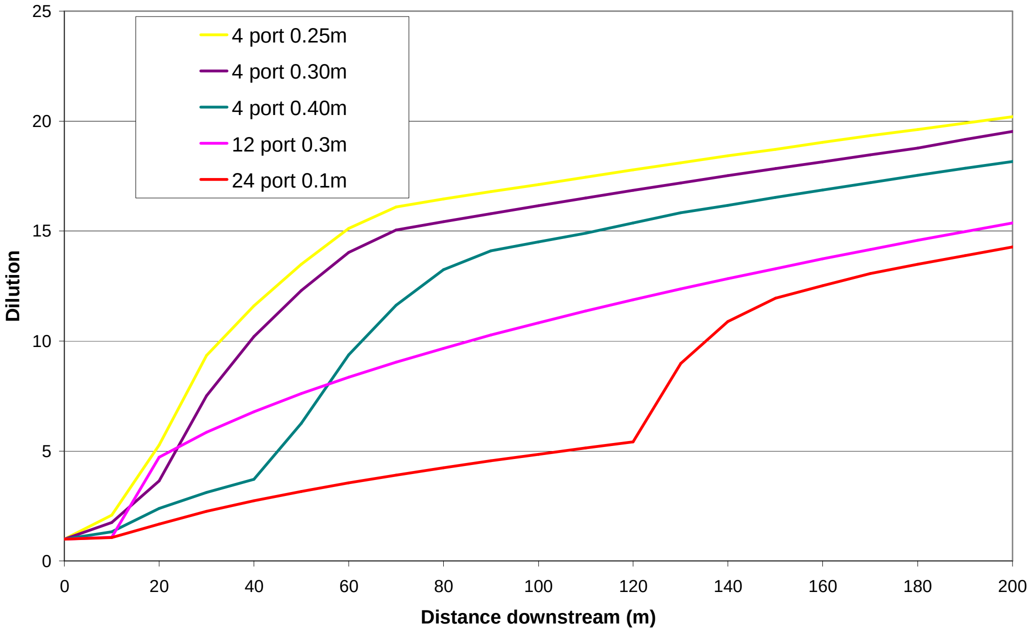

Figure 6c: Predicted plume dilution versus distance downstream from the calibrated CORMIX model for five different pipe configurations – four protruding pipes at 0.40, 0.30 and 0.25 m diameter and two recessed options giving 12 or 24 openings in the rockwall. All runs at half median river flow (6.15 m^3/s) and total effluent discharge of 0.205 m^3/s.

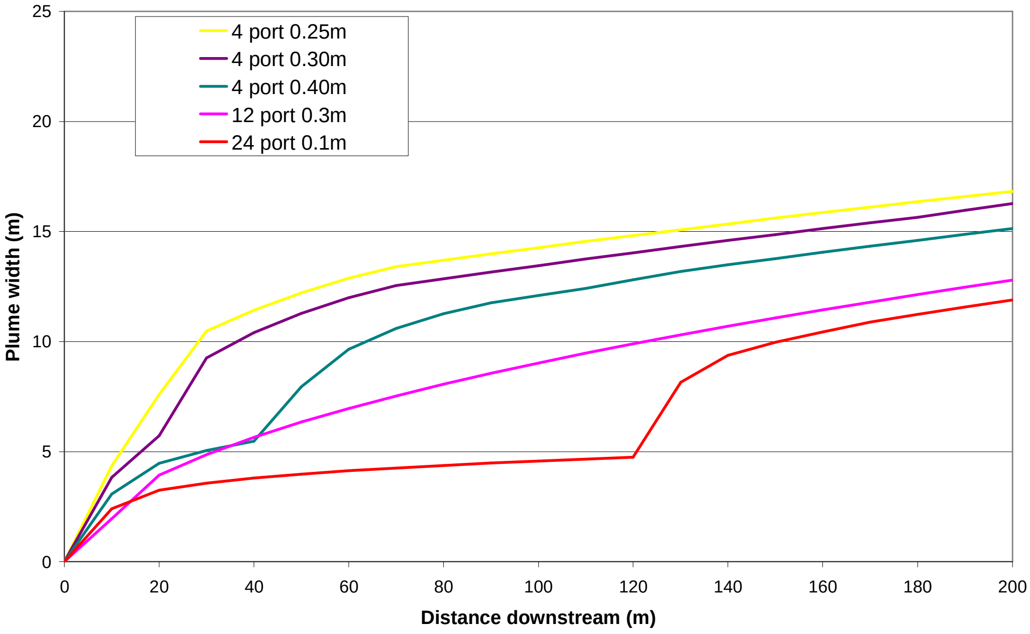

Figure 6d: Plume width versus distance downstream from the calibrated CORMIX model for five different pipe configurations – four pipes at 0.4, 0.3 and 0.25 m diameter and two recesses options giving 12 or 24 openings in the rockwall. All runs at half median flow (6.15 m^3/s).

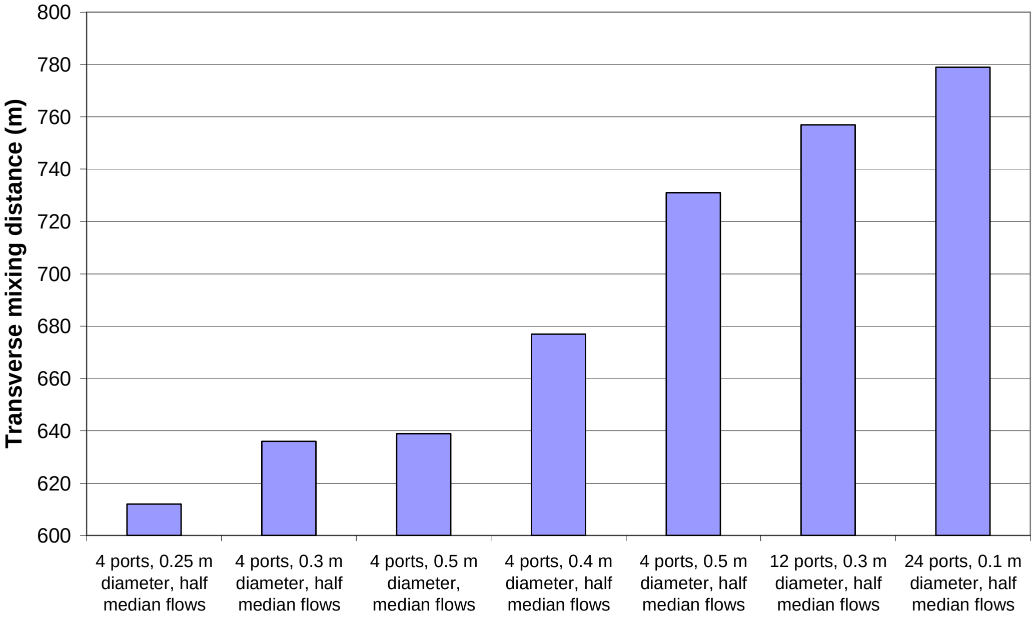

Figure 6g: Predicted distance at which full transverse mixing occurs for each of the options simulated using the calibrated CORMIX model of the Ruamahanga River and oxidation ponds outfall discharging at site B for median flow (12.3 m^3/s).

Table 7: Predicted dilutions from CORMIX for the four pipe 0.5 m diameter outfall configuration at half-median and median river flows.

Distance Downstream from Discharge Point (m)	Half Median River Flow	Median River Flow	Nominal Dilution
	(%mixed)	(%mixed)	
200	16.4 (55%)	17.6 (59%)	17
300	19.8 (66%)	21.1 (70%)	20
400	22.5 (75%)	25.0 (83%)	24
600	27.3 (91%)	29.1 (97%)	28
800	30.0 (100%)	30.0 (100%)	30

3.8 Predicted concentrations of contaminants within the mixing zone

An analysis was carried out to determine the concentrations of various water quality parameters in the mixing zone and at just above and just below the summer trigger flow for discharge initiation at median river flow. The approach was to take the median upstream water quality for a parameter and appropriately diluted effluent from both the primary discharge and the small pond leakage which percolates through the gravel bed of the ponds. The assessment approach generally used a highly conservative seasonal effluent 95%ile parameter value and a median effluent value for the leakage, with the leakage expected to be of average composition because of the time taken for transport through the gravels. The fully mixed summer effluent is diluted 30x and the leachate 443x with a discharge trigger at median flow (12.3 m^3/s). The winter effluent concentrations are included for key parameters. The leakage only assessment is based on a conservative dilution at half-median flow (6.15 m^3/s; 221x) for comparison with trigger values. The predicted receiving water concentrations are compared with receiving water guidelines (Appendix 5) for a range of dilutions which have been predicted for the river downstream of the discharge.

A specific modelling approach was used for the assessment of *E.coli* and clarity effects with results presented later in this Section. The Monte-Carlo modelling approach was used to statistically combine the upstream river and pond effluent distributions for these parameters and then to predict a downstream concentration after mixing. This statistical approach was required to provide a predictive model appropriate for existing and upgraded pond contaminant concentrations. This model was calibrated on summer river data for a data range around median flow, in order to provide predictions relevant to the threshold flow range where the discharge is initiated (NIWA 2005a,b).

The predicted values for key parameters for effluent and leakage are summarized in Table 8 for the 95%ile effluent concentrations and leakage to a median river flow based on mixing dilutions given in Table 7. These predicted values are based on the highest anticipated leaching rate (2400 m^3/d, dilution 443x; C. Callander, Beca, pers. com) for conditions of maximum pond retention. All downstream values are well within guidelines for both partially mixed sites from 200 m to the fully mixed site at 800 m downstream. The ammoniacal-N concentrations maximally reach about 35% of the toxicity guideline value. The values for DRP have not been included in this summary table as the intermittent nature of the discharge, together with the discharge at high flows (i.e., high scour) and turbid waters, will not result in significant stimulation to cause in nuisance algal periphyton growths in the downstream Ruamahanga River. The effects of *E. coli* and clarity are addressed in the following section.

Ammoniacal-nitrogen is the major potential toxicant of concern in the oxidation pond treated discharge. The predictions for the potential pond discharge effects are conservatively based on the measured summer and winter 95%ile values, which are maximally 41% of the guideline value at 200 m downstream (55% mixed), declining to 24% of the guideline at 800 m (fully mixed) (Table 8). The risk to receiving water organisms is further reduced by: (i) the intermittent nature of the discharge; (ii) use of the 95%ile effluent ammoniacal-nitrogen concentration (note the summer median value is 10x lower as used for median leakage, Table 8); and (iii) application of the chronic ANZECC (2000) guideline value to this assessment. Studies with New Zealand native fish and macroinvertebrate species have indicated that compliance with the chronic ANZECC guideline would provide good protection for most species (Hickey et al 1999, Hickey 2000).

Table 8: Predicted mixing zone concentrations for key parameters with direct effluent discharge

	Concentrations (g/m^3)					Distance downstream of outfall (m)					
Parameter	Median Upstream	95%ile Effluent	Median Leakage	Receiving Water Guideline		200	300	300 %GL	400	800 & Wardells Bridge	800 %GL
fBOD	0.3	6.1	3.7	2.00		0.66	0.60	30%	0.56	0.51	26%
NH_4-N(S)	0.01	11.3	1.1	1.61		0.65	0.55	34%	0.47	0.39	24%
NH_4-N(W)	0.01	11.1	6.7	1.61		0.66	0.56	35%	0.47	0.40	25%
NO_2-N	0.002	2.01	0.14	9.00		0.12	0.10	1%	0.08	0.07	1%
NO_3-N	0.5	4.29	0.84	7.20		0.75	0.71	10%	0.67	0.64	9%

Notes: Upstream Background with pond discharge (30x dilution fully mixed) + Leakage (2400 m^3/d; 443x dilution) to Median River Flow, with (s) = summer; (w) = winter; (ii) Pond and leakage BOD uses a 22% factor to convert measured total carbonaceous BOD_5 to soluble fBOD (Davies-Colley et al. 1995) (BOD 95% = 28 g/m^3; median = 17 g/m^3); (iii) Leakage medians for other contaminants are median summer value, except where winter is specified; (iv) Receiving water guideline (GL) values are given in Appendix 5

Table 9 below presents the results for the scenario for below median flow in summer when there is no effluent discharge, but there is leakage from the base of the ponds. The values were conservatively calculated based on the dilution available at half-median flow in the river and the maximum anticipated leakage rate. These predicted values are based on the highest anticipated leakage rate (2400 m^3/d, 221x dilution) for conditions of maximum pond retention. This indicates that only the DRP value at 200 m downstream may approach the site-specific guideline, and that all other parameters are markedly below guideline values both within and downstream of the reasonable mixing zone (RMZ). By 300m downstream (after reasonable mixing) the predicted DRP value is below the target value. The DRP increase within the RMZ may slightly increase periphyton growth, but nuisance growth thresholds will not be exceeded.

Table 9: Predicted mixing zone concentrations for key parameters without direct effluent discharge

	Concentrations (g/m^3)					Distance downstream of outfall (m)					
Parameter	Median Upstream	95%ile Effluent	Median Leakage	Receiving Water Guideline		200	300	300 %GL	400	800 & Wardells Bridge	800 %GL
fBOD	0.30	0	3.7	2.00		0.33	0.32	16%	0.32	0.32	16%
NH_4-N(S)	0.01	0	1.1	1.61		0.02	0.02	1%	0.02	0.01	1%
NH_4-N(W)	0.01	0	6.7	1.61		0.061	0.053	3%	0.047	0.040	3%
NO_2-N	0.002	0	0.14	9.00		0.003	0.003	<0.1%	0.003	0.003	<0.1%
NO_3-N	0.5	0	0.84	7.20		0.51	0.51	7%	0.50	0.50	7%
E.coli(S)	103	0	200	130		105	104	80%	104	104	80%
E.coli(W)	49	0	260	130		51	51	39%	50	50	39%
DRP	0.010	0	2.7	0.030		0.031	0.027	92%	0.025	0.022	74%

Notes: (i) Upstream Background with Leakage (2400 m^3/d; 221x dilution) to Half- Median River Flow (ii) See footnotes of Table 8; (iii) Median *E.coli* values for summer (S) & winter (W) used based on data since pond upgrade and adjusted to a summer median of 200 cfu/100mL; (iv) "Winter" pond *E.coli* values are proportionately increased compared with the nominal summer median ratio (1.3x).

3.8.1 Comparison of upstream and downstream *E.coli* and clarity concentrations

Upstream *E.coli* and clarity values vary markedly with flow. In addition, the concentrations of *E.coli* and clarity in the effluent will typically be variable. In view of this inherent variability, the approach used to determine *E.coli* and clarity impacts of the effluent discharge, was to undertake a Monte-Carlo simulation (NIWA 2005a,b). Taking *E.coli* as the example, the approach used was to select a threshold flow range of 12.3 m^3/s to 14 m^3/s (i.e., a 15% flow increase just above the median trigger for discharge commencement in summer) and combine the upstream *E.coli* concentrations (based on monitored data) with the predicted distribution of *E.coli* in the effluent from the upgraded oxidation ponds. The upstream distributions of *E.coli* for the threshold flow range in the receiving water (Ruamahanga River), together with the monitoring data for other flow ranges are summarised in Table 10, with modelling output predicting concentrations downstream of the treatment plant are shown in Table 11 for partially mixed (300m) and fully mixed (Table 12) sites. The same approach was taken with clarity with data summarised in Tables 10, 11 and 12.

Table 10 shows a trend to higher *E. coli* values as flow increases and a marked reduction in river clarity. At flows below median, the river upstream of the discharge is relatively clear and has low *E. coli* levels. In these situations the existing discharge causes a reasonably significant deterioration in water quality, particularly in the partially mixed region of Wardells Bridge. At higher flows, the discharge does not have a significant effect on water quality, which is already relatively poor. Accordingly, the removal of the direct discharge from the river at flows below median has a considerable benefit in terms of effect on water quality. Discharge above median flow has considerably less impact than discharge at lower flows.

The downstream concentrations were predicted after reasonable mixing occurs at 300 m (20x dilution - Table 11) and for full mixing at 600 – 800 m (30x dilution, Table 12). The predictions showed slight increases at threshold flows for *E.coli* (average <6.5% for 300m, Table 11; & <4.3% for 800m, Table 12). The "No change" indicated for these predictions refers to flow periods where the discharge is not occurring, with "Negligible change" indicating that the magnitude of change would be very small at high flows. The upper 95%ile values are markedly elevated in the threshold flow region as a result of the high natural variability, with the predicted increase indicating a negligible change as a result of effluent addition. Compliance with the proposed target guideline value of 130 cfu/100 mL (Appendix 5) is based on the 95%ile concentration for conditions existing during recreational use (MFE 2003). The existing upstream 95%ile concentration for *E.coli* for below median flow is 127 cfu/100 mL indicating compliance with the proposed target for this flow range. Elimination of the discharge for below median flow will mean that river water quality downstream of the effluent discharge location is virtually the same (given the minimal impact of leakage on receiving water quality) as the upstream water quality.

There was an averaged reduction in clarity of 17% at 300m and of 13% at 800m (range 0 – 50% reduction, and 0 – 42% reduction respectively) at threshold flows. The upper 95%ile of clarity reduction for the partially mixed effluent in the threshold range is at the target range guideline value (Appendix 5). Flows in this threshold range only occur for 4% of the time in summer and thus any aesthetic impacts will be minimal. It is considered that a clarity change of at least 50% would be required to result in a conspicuous change in this shallow river, where the bed generally dominates the received clarity and colour. Clarity impacts will decline at higher river flows as a result of higher background levels and greater available receiving water dilution.

In conclusion, this analysis of summer data has shown that the predicted impact after reasonable mixing (at 300 m) and at Wardells Bridge for *E.coli* and clarity will be 'no change' or 'negligible change' as a result of discharges from the proposed upgraded ponds. The proposed elimination of discharge at below median flows would remove all effects for this period of high recreational use. The quantitative analysis has concentrated on the threshold flow region where effects would be most apparent after the initiation of the discharge. The analysis has shown that the *E. coli* increase is negligible in this region and that the slight clarity reduction is within guideline targets. The plume will be generally inconspicuous (i.e., <50% change in clarity) once reasonable mixing has occurred.

Table 10: Summer *E.coli* and Clarity in upstream Ruamahanga River in relation to flow

	***E.coli* (cfu/100 mL)**	**Clarity (visibility of Black Disc in metres)**
Flow category [a]	**Median (5 – 95%ile)**	**Median (5 – 95%ile)**
< Half-median	29 (7 – 87)	3.4 (1.1 – 5.8)
Half-median to Median	40 (4 – 219)	2.0 (0.22 – 4.3)
Threshold flow range	83 (13 – 1058)	1.0 (0.17 – 4.6)
High flow	207 (16 – 2909)	0.34 (0.09 – 1.92)

[a] <Half-median = < 6.25 m^3/s; Half-median to Median = 6.25 – 12.3 m^3/s; Threshold flow range = 12.3 – 14.0 m^3/s; High flow = >14 m^3/s. Data number for each of these categories is 21 – 36, except for the threshold flow range which are modelled values based on measured in the threshold flow range. Note: 'Threshold flow range' is the flow region where the discharge is initiated. This occurs approximate 4% of the time and 13% of the time when potentially discharging.

Table 11: Summer *E.coli* and Clarity after partial mixing at 300 m downstream (20x dilution) in relation to flow

	***E.coli* (cfu/100 mL)**	**Clarity (visibility of Black Disc in metres)**
Flow category [a]	**Median (5 – 95%ile)**	**Median (5 – 95%ile)**
< Half-median	No change	No change
Half-median to Median	No change	No change
Threshold flow range [b]	89 (15 – 1012)	0.85 (0.17 – 2.3)
High flow	Negligible change	Negligible change

[a] See Table 10; [b] Monte-Carlo model predicted values for upstream distributions with effluent median *E.coli* of 330 /100 mL (NIWA 2005a,b). 'No change' refers to distribution values upstream as given in Table 10. 'Negligible change' indicating that the magnitude of change would be very small.

Table 12: Summer *E.coli* and Clarity at Wardells Bridge (fully mixed) in relation to flow

	***E.coli* (cfu/100 mL)**	**Clarity (visibility of Black Disc in metres)**
Flow category [a]	**Median (5 – 95%ile)**	**Median (5 – 95%ile)**
< Half-median	No change	No change
Half-median to Median	No change	No change
Threshold flow range [b]	87 (14 – 1014)	0.89 (0.17 – 2.67)
High flow	Negligible change	Negligible change

[a] See Table 10; [b] Monte-Carlo model predicted values for upstream distributions with effluent median *E.coli* of 330 /100 mL (NIWA 2005a,b)

3.9 Summary

The measurements of transverse (and horizontal mixing) using a dye tracer and river flow gauging measurements in the Ruamahanga River has quantified the mixing characteristics of different reaches of the river.

The existing site of the Masterton WWTP discharge into the Makoura stream (site C) and then into the Ruamahanga River clearly does not mix to more than 50% of the river flow at Wardells bridge site. It takes at least 1600 m for full mixing to occur and this mixing is complicated by the confluence with the Waingawa River.

Site A has an unfavourable mixing zone, being complicated by the installation of (about) nine rock groynes around the base of the left side of the river bend above site A1. These also cause backwaters behind the rock walls and force the river away from the left bank. This does not appear to enhance river mixing in this area and the distance to full mixing was in the range of 1500 to 1600 m.

A site further upstream (site UA) was judged to be unsuitable for a wastewater discharge due to the river channel being unstable and predominantly on the left side of the river with several divided channels causing extended mixing distances. This was not considered a likely option.

Transverse mixing is much more rapid for the reach immediately downstream of site B than site A, or the existing outlet in the Makoura Stream (site C), at measured flows, and therefore site B would be the preferred discharge location.

The predictive modelling at 6.5 m^3/s (half the median flow) shows that site B has channel characteristics that enable river mixing in a shorter distance than site A and C.

Site C has a mobile gravel bed whereas site B has a better defined river channel and better river mixing (as defined by the transverse mixing estimations). Thus there is more certainty in the predicted mixing distance at the lower (half median) river flow of 6.5 m^3/s, and highlights site B as being the preferred option for most rapid mixing.

Predicted downstream dilutions were based on calibrated CORMIX modelling. Results for the four pipe protruding outfall configuration show that the distance when the discharge is fully mixing across the river is increased with decreasing pipe size. The degree of cross flow mixing (i.e., away from the bank) also increased with decreasing pipe diameter. Ultimately the sizing of the pipes for this option would be determined by possible local scour effects and the engineering aspects such as the need to either gravity feed or pump the discharge.

The predicted downstream dilutions for the four pipe 0.5 m diameter outfall configuration showed minimal dilution differences between a discharge to half-median or median flow for distances greater than 200 m downstream. These data indicate that full mixing would occur 600 – 800 m downstream of the discharge point.

If a recessed rockwall option is to be pursued, then the design of the rockwall should be such that the pore spacing does not become too small. The CORMIX simulations carried out suggest that reducing the pore spacing below 0.3 m will result in low jet momentum, resulting in the plume remaining close to the bank over the first 80-100 m and increasing the distance when the plume is fully mixed across the river.

Predicted mixing zone concentrations for key water quality contaminants were calculated for leakage to half-median flow and for discharge and leakage to median flow in the Ruamahanga River, based on CORMIX mixing dilutions. These predicted values are based on the highest anticipated leakage rate. The leakage only scenario to half-median flow indicates that only the DRP value at 200m downstream may approach the site-specific guideline (0.030 mg/m^3), and that all other parameters are well below guideline values after partial mixing at 300m downstream.

The predicted downstream concentrations for key parameters for effluent and leakage are were calculated using the 95%ile effluent concentrations added to the upstream median concentrations. These represent a highly conservative assumption for adding to background concentrations. All downstream values are well within guidelines for both partially mixed sites from 200m to the fully mixed site at 800m downstream. Predictions of discharge effects on *E. coli* and clarity were made using Monte-Carlo modelling of pond and receiving water data. This approach incorporated the variability of both the upstream river water and the pond discharge and predicted downstream distribution for the 'threshold flow range', which is the key period when the discharge is initiated. This approach is required because of the general increases in *E.coli* and decrease in clarity which naturally occur as the river flow increases during flood events. The downstream concentrations were predicted after partial mixing occurs at 300 m (20x dilution) and for full mixing at 600 – 800m (30x dilution). The predictions showed slight increases for *E.coli* (average <6.5% for partial mixed) and for clarity (average -17% for partial mixed, range 0 –

50% reduction) in this threshold flow range. River impacts would decline further at higher river flows as a result of higher background levels and greater available receiving water dilution. These analyses indicate that the proposed discharge initiation at median flow in summer will not result in water quality guideline exceedance after mixing with the Ruamahanga River.

4. Acknowledgements

Ron Haverland of Beca initiated and guided this study. The assistance, skill and local knowledge of John Murphy, the local jet boat operator (Adventure Jet Company) was greatly appreciated.

5. References

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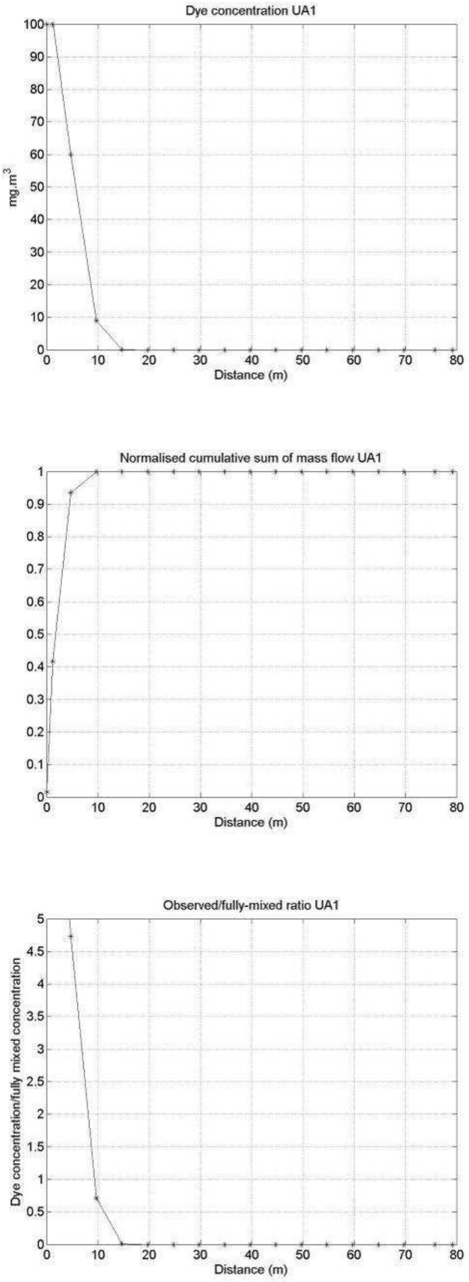
Appendix 1: Summary Table of Field Results

Site		GPS Readings		Flow	Comments	Date & Time
No.	**Name**	**WELB**	**WERB**	**m^3/s**		**NZST**
UA1	Ruamahanga at Upstream Whangaehu Confluence	S40º 59.232’ E175º 41.133’		13.61		3/8/2004 17:05
UA2	Downstream Whangaehu Confluence		S40º 59.520’ E175º 41.409’	16.64		3/8/2004 14:30
A2	Opposite jet boat launching site		S40º 59.828” E175º 41.151’	15.24		3/8/2004 16:00
A1	Bottom end of Cliff Pool, opposite pond 1	S40º 59.786’ E175º 41.438’		13.62	Dye measurements taken during gauging	4/8/2004 14:30
A3	Opposite Pond 3	S40º 59.895’ E175º 40.860’	S40º 59.894’ E175º 40.857’	14.22	Flow at an angle to river bank	4/8/2004 16:35
B1	Downstream oxidation ponds	S41º 00.063’ E175º 40.723’		15.98	Dye measurements taken during gauging	3/8/2004 10:20
B2	Half way from ponds to Makoura stream Confluence	S41º 00.152’ E175º 40.660’	S41º 00.143’ E175^{0}40.632’	15.32	Flow at an angle to river banks	3/8/2004 11:10
B3	5 metres up stream of Makoura Stream Confluence		S41º 00.340’ E175º 40.440’	16.30		3/8/2004 12:25
C1	Wardells standard gauging site	S41º 00.391’ E175º 40.321’		18.93		2/9/2004 1450
C2	Half way to Waingawa Confluence from bridge	S40º 00.462’ E175º 40.056’		18.61		2/8/2004 1615
C3	Downstream Waingawa Confluence		S41º 00.743’ E175º 39.859’	25.61		2/8/2004 1745
T1	Makoura Stream at Ruamahanga Confluence	S41º 00.340’ E175º 40.440’		0.60	Tributary	3/8/2004 1220
T2	Whangaehu at Ruamahanga Confluence	S40º 59.366’ E175º 41.287’		1.77	Tributary. River turbid	3/8/2004 1335
T3	Waingawa at Ruamahanga Confluence			7.00	Tributary. Calculation only not pegged or gauged, and no GPS reading	2/8/2004 1700

Appendix 2: Data for Site UA

Observed dye concentrations, normalised mass flow and observed/fully-mixed ratio for the Upper A (UA) sites plus rating curve for Ruamahanga river at Wardells Bridge.


Dye concentration UA1

Normalised cumulative sum of mass flow UA1

Observed/fully-mixed ratio UA1

Figure A2.1: Injection site UA. Site UA1 (80 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

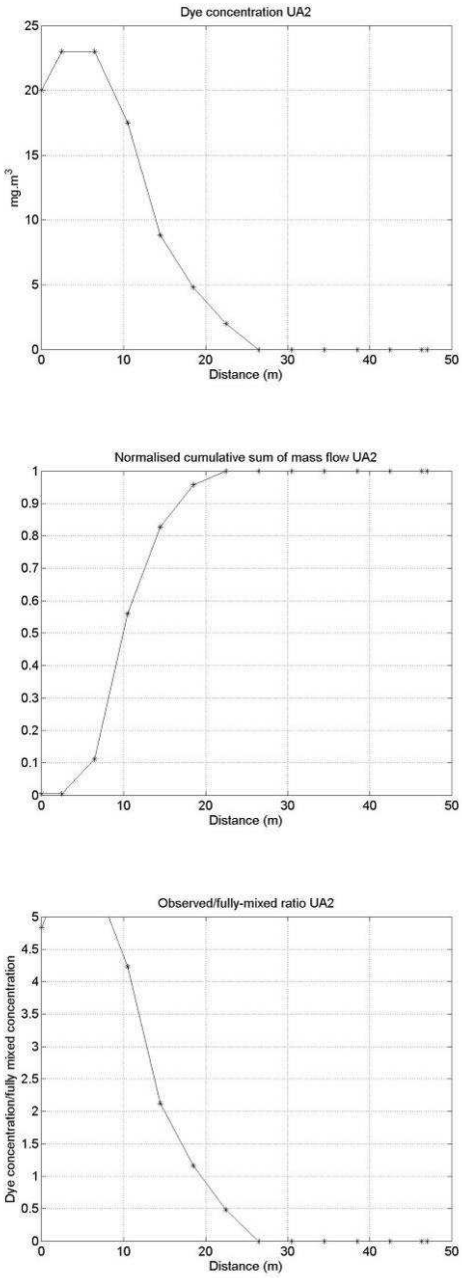


Figure A2.2: Injection site UA. Site UA2 (850 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

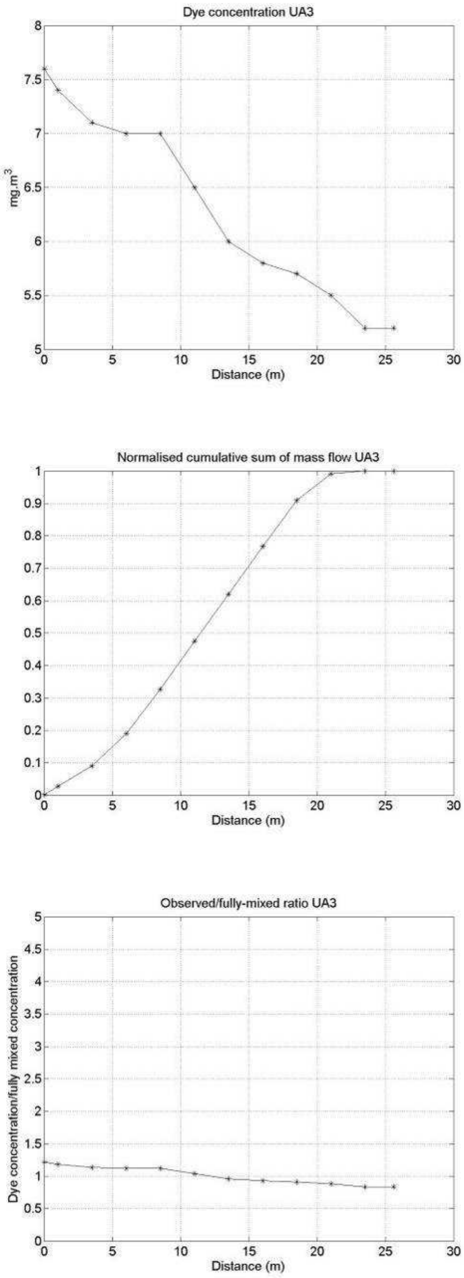


Figure A2.3: Injection site UA. Site UA3 (2200 m from the release point). (Upper panel) Observed dye concentration, (Middle panel) normalised cumulative massflow and (Lower panel) observed/fully-mixed ratio of dye concentration.

Appendix 3: Rating curve for Ruamahanga River at Wardells Bridge.

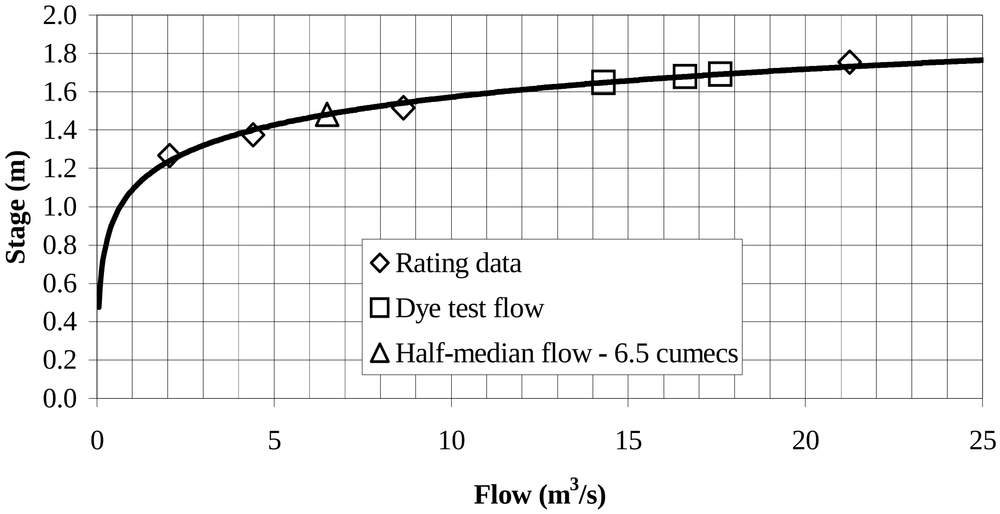


Figure A3: Rating curve for the Wardells Bridge site showing rating data (diamond plus log regression) and stage for a flow of 6.5 m^3/s (triangle) and the stage for each of the dye tests (square). Data supplied by Greater Wellington Regional Council.

Appendix 4: CORMIX predicted diffuser dilutions.

Table A4.1: Dilution versus distance for the outfall configurations and river flows modelled using the calibrated CORMIX model of the Ruamahanga River and discharge at site B.

Distance downstream (m)	Protruding - 4 port 0.25 m (half median)	Protruding - 4 port 0.30 m (half median)	Protruding - 4 port 0.50m (median)	Protruding - 4 port 0.40 m (half median)	Protruding - 4 port 0.5 m (half median)	Rockwall - 12 port 0.3m (half median)	Rockwall - 24 port 0.10 m (half median)
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10	1.90	1.65	1.12	1.30	1.09	1.09	1.06
20	4.76	3.54	1.77	2.34	1.67	4.72	1.68
30	9.16	7.39	2.26	3.09	2.15	5.85	2.26
40	11.51	10.10	2.66	3.70	2.55	6.79	2.74
50	**13.43**	**12.24**	**3.00**	**6.15**	**2.89**	**7.61**	**3.16**
60	15.09	14.00	3.30	9.32	3.19	8.36	3.55
70	16.09	15.05	3.57	11.59	3.47	9.04	3.90
80	16.45	15.42	3.82	13.22	3.73	9.67	4.24
90	16.80	15.79	4.06	14.11	4.58	10.27	4.56
100	**17.12**	**16.15**	**4.28**	**14.50**	**7.80**	**10.83**	**4.85**
110	17.45	16.50	4.49	14.90	10.42	11.37	5.14
120	17.78	16.85	6.95	15.36	12.49	11.88	5.42
130	18.10	17.18	10.03	15.83	13.54	12.37	8.99
140	18.42	17.52	12.40	16.18	14.21	12.84	10.89
150	18.72	17.84	14.39	16.52	14.60	13.29	11.96
160	19.03	18.15	15.72	16.87	14.98	13.73	12.52
170	19.34	18.47	16.57	17.19	15.33	14.16	13.06
180	19.61	18.77	16.95	17.53	15.71	14.58	13.48
190	19.91	19.17	17.29	17.85	16.05	14.97	13.89
200	**20.21**	**19.54**	**17.64**	**18.16**	**16.40**	**15.37**	**14.28**
210	20.55	19.81	17.99	18.47	16.81	15.75	14.66
220	20.90	20.11	18.40	18.78	17.22	16.12	15.04
230	21.17	20.39	18.82	19.09	17.54	16.49	15.49
240	21.43	20.67	19.14	19.38	17.85	16.84	15.93
250	21.71	20.95	19.46	19.74	18.16	17.19	16.28
260	21.97	21.21	19.76	20.10	18.47	17.53	16.61
270	22.23	21.48	20.08	20.38	18.77	17.87	16.95
280	22.48	21.76	20.45	20.65	19.05	18.19	17.27
290	22.75	22.00	20.83	20.93	19.41	18.52	17.59
300	**23.00**	**22.28**	**21.12**	**21.20**	**19.77**	**18.84**	**17.98**
310	23.24	22.52	21.40	21.46	20.05	19.15	18.36
320	23.49	22.77	21.69	21.73	20.33	19.46	18.66
330	23.71	23.02	21.97	21.98	20.59	19.76	18.95
340	23.96	23.27	22.31	22.25	20.86	20.06	19.24
350	24.21	23.52	22.65	22.50	21.14	20.35	19.53
360	24.43	23.83	22.92	22.75	21.38	20.64	19.81
370	24.73	24.14	23.18	23.06	21.72	20.93	20.16
380	25.02	24.36	23.44	23.37	22.03	21.21	20.50
390	25.25	24.60	23.71	23.62	22.28	21.48	20.77
400	25.48	24.83	24.02	23.84	22.52	21.76	21.03
410	25.70	25.05	24.33	24.09	22.77	22.04	21.30
420	25.92	25.29	24.58	24.32	23.02	22.30	21.55
430	26.14	25.51	24.83	24.56	23.26	22.57	21.81
440	26.36	25.74	25.08	24.78	23.49	22.83	22.13
450	26.58	25.96	25.33	25.02	23.79	23.09	22.44
460	26.79	26.18	25.63	25.24	24.07	23.35	22.68
470	27.00	26.40	25.92	25.46	24.31	23.60	22.93
480	27.22	26.62	26.16	25.69	24.53	23.85	23.17
490	27.42	26.83	26.39	25.91	24.76	24.09	23.41
500	**27.63**	**27.05**	**26.62**	**26.17**	**24.98**	**24.34**	**23.64**
510	27.84	27.25	26.85	26.45	25.20	24.58	23.93
520	28.04	27.52	27.13	26.67	25.48	24.82	24.22
530	28.30	27.77	27.41	26.88	25.75	25.06	24.45
540	28.56	27.98	27.63	27.09	25.96	25.29	24.67
550	28.76	28.19	27.86	27.30	26.18	25.53	24.90
560	28.96	28.39	28.07	27.50	26.38	25.76	25.12
570	29.16	28.59	28.35	27.71	26.60	25.99	25.39

Distance downstream (m)	Protruding - 4 port 0.25 m (half median)	Protruding - 4 port 0.30 m (half median)	Protruding - 4 port 0.50m (median)	Protruding - 4 port 0.40 m (half median)	Protruding - 4 port 0.5 m (half median)	Rockwall - 12 port 0.3m (half median)	Rockwall - 24 port 0.10 m (half median)
580	29.36	28.79	28.61	27.92	26.80	26.22	25.67
590	29.53	28.98	28.82	28.12	27.01	26.44	25.88
600	29.73	29.18	29.03	28.31	27.27	26.67	26.10
610	**30.00**	29.38	29.24	28.51	27.52	26.89	26.31
620	30.00	29.58	29.45	28.76	27.72	27.11	26.52
630	30.00	29.78	29.71	29.01	27.92	27.33	26.72
640	30.00	**30.00**	**30.00**	29.21	28.12	27.54	26.98
650	30.00	30.00	30.00	29.40	28.31	27.76	27.24
660	30.00	30.00	30.00	29.60	28.51	27.97	27.44
670	30.00	30.00	30.00	29.78	28.71	28.19	27.64
680	30.00	30.00	30.00	**30.00**	28.95	28.40	27.84
690	30.00	30.00	30.00	30.00	29.18	28.60	28.04
700	30.00	30.00	30.00	30.00	29.38	28.81	28.24
710	30.00	30.00	30.00	30.00	29.57	29.01	28.48
720	30.00	30.00	30.00	30.00	29.75	29.22	28.72
730	30.00	30.00	30.00	30.00	**30.00**	29.42	28.92
740	30.00	30.00	30.00	30.00	30.00	29.62	29.11
750	30.00	30.00	30.00	30.00	30.00	29.82	29.30
760	30.00	30.00	30.00	30.00	30.00	**30.00**	29.49
770	30.00	30.00	30.00	30.00	30.00	30.00	29.67
780	30.00	30.00	30.00	30.00	30.00	30.00	**30.00**
780 +	30.00	30.00	30.00	30.00	30.00	30.00	30.00

Appendix 5: Receiving Water Quality Targets for Ruamahanga River

Parameter	Receiving Water Guideline	Source Document	Water Management Purpose[5]
Filtered BOD (g/m^3)	2.0	MfE Water Quality Guidelines Nº 1 (1992), Biological growths.	To assess compliance with minimum RMA Standard - s107(1)(c) and 3rd Schedule guideline
Visual Clarity - Black disc (m)	1.6	MfE Water Quality Guidelines Nº 2 (1994), Guideline 4: For water managed for contact recreation the horizontal sighting of a 200 mm black disc should exceed 1.6 m.	Contact Recreation & to assess compliance with RMA 3rd Schedule guideline
Visual Clarity change (%)	<33 - 50% change for contact recreation	MfE Water Quality Guidelines Nº 2 (1994), Guidelines for the Management of Waste Colour and Clarity; For water managed for aesthetic purposes the visual clarity should not change by more than 33 - 50%	Aesthetic & to assess compliance with minimum RMA Standard - s107(1)(d)
Colour –Hue (Munsell points)	10 points change	MfE Water Quality Guidelines Nº 2 (1994), Guideline 2: The hue of the water body should not be changed by more than 10 points on the Munsell scale.	To assess compliance with minimum RMA Standard - s107(1)(d)
Ammonia-Nitrogen (g/m^3)	1.61 [a]	ANZECC Guidelines (2000), Table 8.3.7: Effects on aquatic life for "slightly-moderately disturbed" ecosystems, for a 95% level of protection.	Aquatic Ecosystems & to assess compliance with minimum RMA Standard - s107(1)(g)
Nitrate–Nitrogen (g/m^3)	7.2 [b]	ANZECC Guidelines (2000) recalculated value from Table 3.4.1: Effects on aquatic life for "slightly-moderately disturbed" ecosystems.	Aquatic Ecosystems & to asses compliance with minimum RMA Standard - s107(1)(g)
Nitrite–Nitrogen (g/m^3)	9	ANZECC Guidelines (2000), Section 4.3.3.3 for livestock drinking water quality.	To assess compliance with minimum RMA Standard - s107(1)(f)
E.coli (cfu/100mL) (95%ile value)	130	MfE Microbiological Water Quality Guidelines (2003): Guideline value for <0.1% risk of *Campylobacter* infection (from Table H2).	Contact Recreation & to assess compliance with RMA 3rd Schedule
E.coli (cfu/100mL) (median value)	100	ANZECC Guidelines (2000), Section 9.3.3.2 for livestock drinking water quality.	To assess compliance with Minimum RMA Standard - s107(1)(f)
Dissolved Reactive Phosphorus (g/m^3) [c]	0.030	NZ Periphyton Guideline (Biggs, 2000). NIWA (2004) derive these site-specific guidelines.	Contact Recreation & to assess compliance with RMA 3rd Schedule

[a] *At pH of 7.5 (Receiving water monitoring 1994 – 2004 shows that the mean pH upstream of the ponds is 7.5).*

[b] *Refer http://www.mfe.govt.nz/publications/water/anzecc-water-quality-guide-02/anzecc-nitrate-correction-sep02.htm*

[c] *A site-specific guideline was developed for the Ruamahanga River for continuous nutrient exposure (NIWA 2004) (i.e., not applicable to intermittent discharge situation where a narrative "no undesirable biological growths" guideline would be applicable.*