# Appendix B – Mixing Zone Study

# 1. Flow Rate Analysis

This Appendix summarises the results obtained for the mixing zone study conducted following the methodology outlined in GHD (2012a).

## 1.1 Available Flow Data

The best source of flow rate data for the site is a long term gauging station on the Edith River between the Stuart Highway crossing and the Vista Gold mine site (Site ID: G8140152). A record of flow from June 1962 at this site is available. This record is not continuous with the gaps between measurements extending up to four years (Figure 1). These gaps, although significant in length, do not prevent the use of this data to obtain a reasonable range of flows for mixing zone analysis.

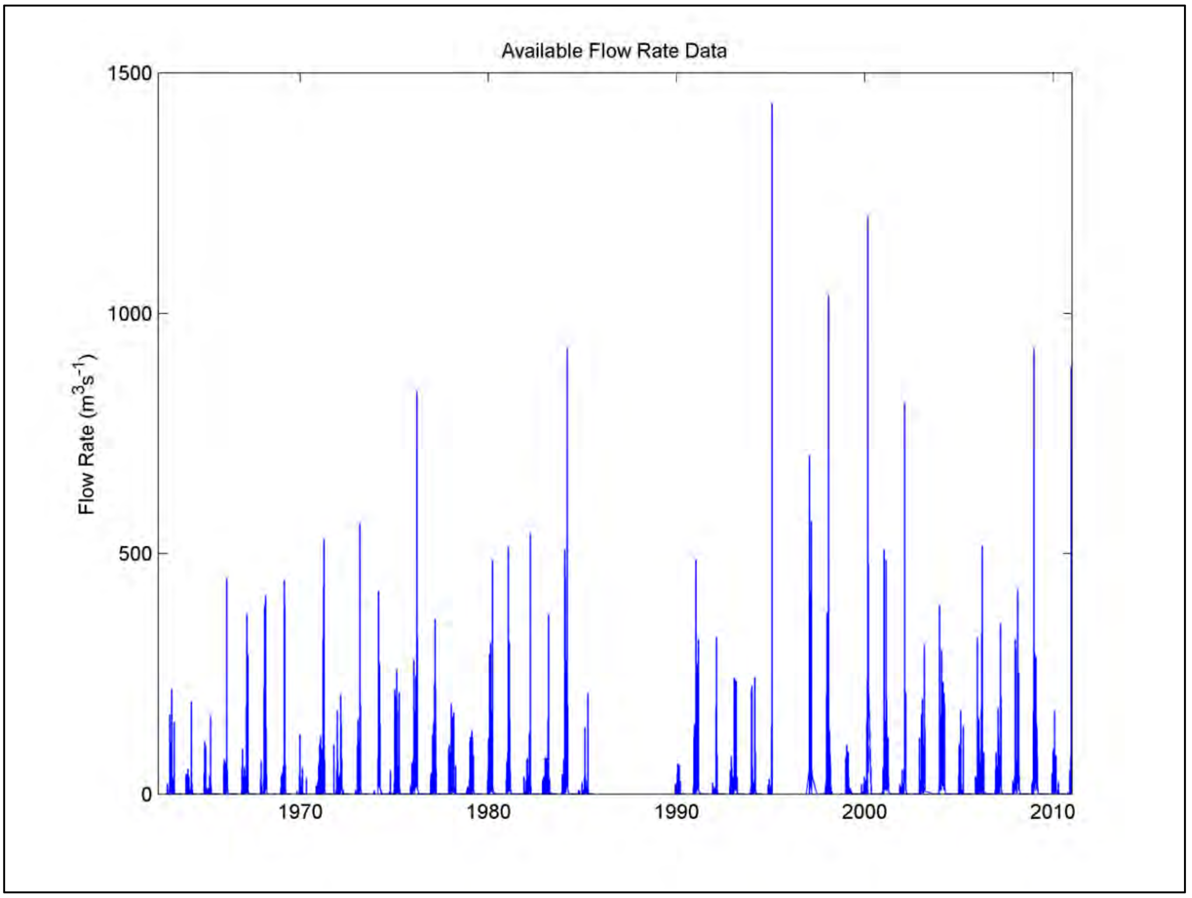


Figure 1 Available Flow Rate Data

Some flow can be expected to enter the Edith River between the long term monitoring station and the Vista Gold site. This has been estimated as 15% of the total flow (Austin Brandis, pers. Comms) and largely enters the creek through a tributary that discharge to the river around 500 m upstream of the gauging site.

## 1.2 Selection of Mixing Zone Analysis Flows

The instantaneous extent of the mixing zone is dependent on the effluent quality, flow rate, and the flow rate of the river and can be expected to change over time. The mixing zone (from an environmental management perspective) is the maximum of the instantaneous mixing zone extents. As such, the size of the mixing zone must be evaluated over a range of flows.

In order to calculate an appropriate range of flows, an analysis of the available flow rate data was undertaken. The wet season data (November to April, inclusive) was extracted from the full record and flow values corresponding to specific percentile exceedence values were calculated. The flow rate in terms of percentage exceedence is shown in Figure 2 (note the logarithmic vertical scale) and selected values are tabulated in Table 1.  This data can be interpreted according to the following example: the flow is higher than 0.006 $m^3s^{-1}$ 99% of the time, but higher than 400 $m^3s^{-1}$ only 1% of the time.

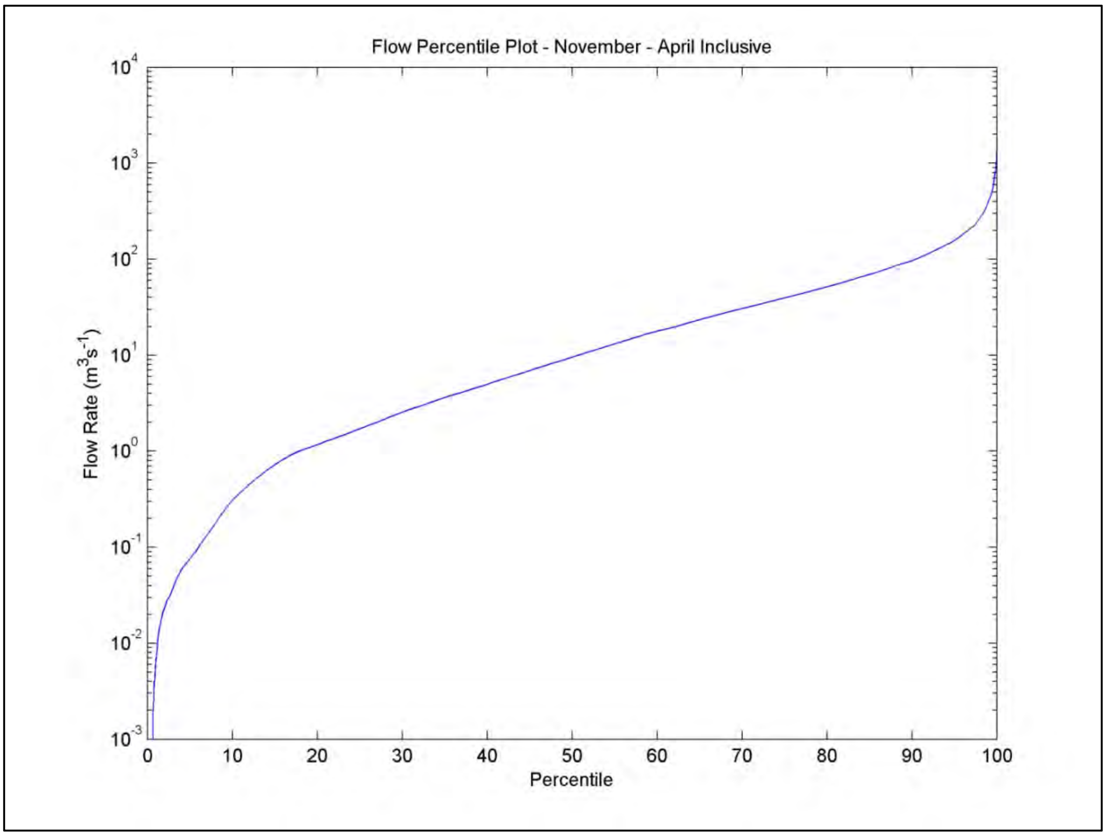


Figure 2    Wet Season Flow Exceedance Plot at Station G8140152

The estimated flow rate at station SW4 is also shown in Table 1.  As previously discussed, the flow at station SW4 is assumed to be 85% of that measured at station G8140152.

Table 1    Selected Percentage Exceedance Values

| Percentage Exceedance | Flow Rate (m3s-1) G8140152 | Flow Rate (m3s-1) SW4 Estimate |
|---|---|---|
| 99 | 0.0060 | 0.0051 |
| 95 | 0.076 | 0.064 |
| 90 | 0.31 | 0.24 |
| 80 | 1.2 | 0.99 |
| 65 | 3.6 | 3.1 |
| 50 | 9.5 | 8.1 |
| 35 | 23 | 19 |
| 20 | 52 | 44 |
| 10 | 97 | 82 |
| 5 | 160 | 130 |
| 1 | 400 | 340 |

## 1.3 Physical River Conditions

Transverse mixing in rivers is controlled by a number of factors, including the width and depth of the river, flow velocity, and river turbulence. In order to calculate the transverse mixing characteristics, an understanding of the way that these parameters change with river flow is required.

No rating curve (which relates flow rate to water level) is currently available at station SW4. A flow rating curve is available at station G8140152 downstream. A localised rating curve for SW4 is currently being developed for ongoing operational use however was not available for use in this investigation.

In order to estimate the flow conditions in the area of interest (SW4), a hydraulic model of the site was created using HEC-RAS. This covered the Edith River from station G8140152 at the downstream end to a location approximately two kilometres upstream of the area of interest. River cross sections for the model were created using available LIDAR topographic data for the site and limited observations of the river bathymetry. The rating curve at station G8140152 was used as the downstream boundary condition. The flows described in Table 2 were modelled using HEC-RAS and a rating curve and other river data was extracted at station SW4. This data is summarised in Table 2.

Table 2 Modelled River Conditions at SW4

| Percentage Exceedance | Flow Rate (m3s-1) SW4 | Water Surface Elevation (m AHD) | Main Channel River Flow Velocity (m s-1) | Total River Flow Area ($m^2$) |
|---|---|---|---|---|
| 99 | 0.0051 | 107.474 | 0.00070 | 8.4 |
| 95 | 0.064 | 107.504 | 0.0085 | 9.0 |
| 90 | 0.24 | 107.548 | 0.032 | 9.8 |
| 80 | 0.99 | 107.637 | 0.10 | 12 |
| 65 | 3.1 | 107.825 | 0.23 | 16 |
| 50 | 8.1 | 108.133 | 0.40 | 24 |
| 35 | 19 | 108.563 | 0.63 | 37 |
| 20 | 44 | 109.045 | 0.94 | 55 |
| 10 | 82 | 109.625 | 1.2 | 81 |
| 5 | 130 | 110.162 | 1.5 | 110 |
| 1 | 340 | 111.499 | 2.1 | 230 |

A comparison of the modelled rating curve developed for station SW4 and the existing rating curve for station G8140152 is shown in Figure 3. The flow characteristics with depth for the two sites are similar, with minor variations likely resulting from small differences in river slope and river bank slope between the two sites.

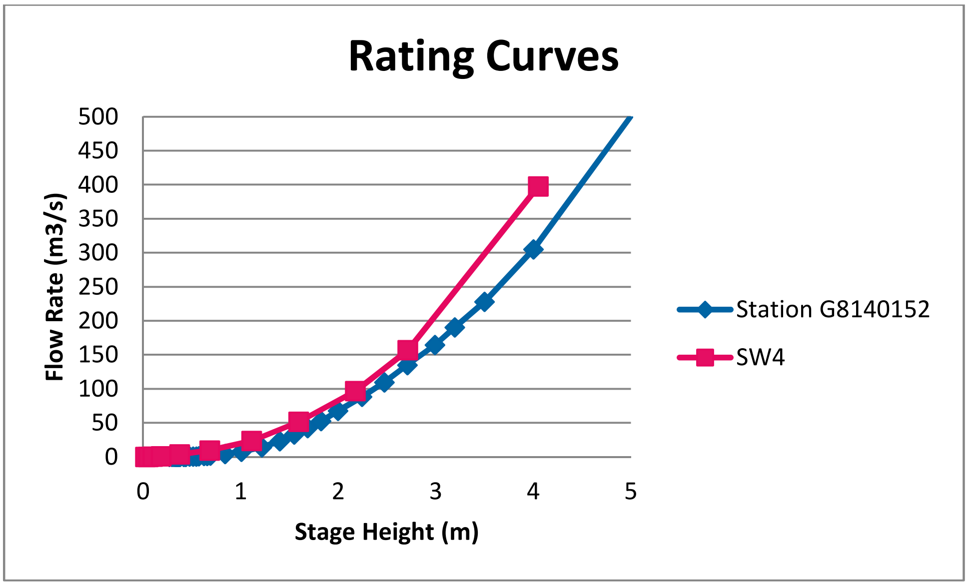


Figure 3 Existing and Modelled Rating Curve Comparison

## 1.4 Mixing Zone Calculations

The longitudinal extent of the mixing zone was calculated using the Gaussian diffusion modelling method described in Fischer et. al., 1979 using parameter values from this reference as well as more recent studies. The first step in this process is the calculation of the shear velocity, a parameter which describes the amount of bed shear:

$$u^* = \sqrt{gdS}$$

Where:

g is acceleration due to gravity

d is the average depth

S is the bed slope

For all cases analysed, an individual depth value was calculated, based upon the HEC-RAS modelling results. The slope used in all calculations corresponds to the overall slope of this section of the Edith River.

The second parameter calculated using this method is the transverse mixing coefficient, which is calculated as follows:

$$\varepsilon_T = C_T d u^*$$

Where:

$C_T$ is a mixing coefficient

d is the average depth

u* is the friction velocity, calculated previously

The value of $C_T$ is site specific and depends on the cross section and topology of the channel. A study by Rutherford (1994) found that straight, rectangular channels generally had a $C_T$ value of around 0.13, in meandering channels $C_T$ varied from 0.3 to 0.9, and curved channels $C_T$ varied from 1 to 3. Selection of an appropriate value of $C_T$ is the primary source of uncertainty in this analysis and as such a range of values were modelled, for comparative purposes. A midrange value at for meandering rivers (0.6) and midrange curved channel value (2) were selected to form an appropriate range. Results are presented for both the lower and upper bound estimate.

Two distances were calculated for each flow scenario and parameter value case. These correspond to the distance where the maximum transverse concentration is 20% higher than the average concentration (qualitatively described as well mixed) and the distance where the maximum concentration is just 5% higher than the background concentration (qualitatively described as effectively fully mixed). These distances represent the longitudinal extent of the mixing zone under two different mixing criteria. Setting the mixing zone size criteria according to relative effluent concentration means that these results are independent of the final effluent concentration or discharge rate (as long as the volume of the effluent is insignificant compared the flow rate of the river). The results of the mixing zone analysis for the two parameter estimates and mixing criteria are shown in Table 3 and Table 4.

Table 3 Mixing Zone Extent Estimates, $C_T$ = 0.6

| Percentage Exceedance | Flow Rate (m3s-1) SW4 | Mixing Zone Size as defined by 'Maximum 20% Above Average' Criteria (m) | Mixing Zone Size as defined by 'Maximum 5% Above Average' Criteria (m) |
|---|---|---|---|
| 99 | 0.0051 | 7 | 12 |
| 95 | 0.064 | 82 | 134 |
| 90 | 0.24 | 291 | 474 |
| 80 | 0.99 | 810 | 1321 |
| 65 | 3.1 | 1484 | 2419 |
| 50 | 8.1 | 1826 | 2977 |
| 35 | 19 | 1913 | 3119 |
| 20 | 44 | 2146 | 3499 |
| 10 | 82 | 1995 | 3253 |
| 5 | 130 | 2064 | 3366 |
| 1 | 340 | 2194 | 3578 |

Table 4 Mixing Zone Extent Estimates, $C_T$ = 2

| Percentage Exceedance | Flow Rate (m3s-1) SW4 | Mixing Zone Size as defined by 'Maximum 20% Above Average' Criteria (m) | Mixing Zone Size as defined by 'Maximum 5% Above Average' Criteria (m) |
|---|---|---|---|
| 99 | 0.0051 | 2 | 4 |
| 95 | 0.064 | 25 | 40 |
| 90 | 0.24 | 87 | 142 |
| 80 | 0.99 | 243 | 396 |
| 65 | 3.1 | 445 | 726 |
| 50 | 8.1 | 548 | 893 |
| 35 | 19 | 574 | 936 |
| 20 | 44 | 644 | 1050 |
| 10 | 82 | 599 | 976 |
| 5 | 130 | 619 | 1010 |
| 1 | 340 | 658 | 1073 |

The mixing zone distance for the very smallest flows are extremely low, especially the flows with an exceedence less than 90%. At these very low flows it is unlikely that effluent would be discharged, making these results irrelevant. They are included for completeness only.

The results indicate that the size of the mixing zone stabilises at higher flow rates, reaching a plateau around the median flow rate.

In all cases the distance to reach the 5% above average criteria is around double that taken to reach the 20% threshold. The mixing zone results for the larger $C_T$ mixing parameter (around 1000 m to meet the 5% criteria) are significantly smaller than those for the lower bound estimate (around 3500 m to reach the 5% criteria).

Given the curved river path and the variability in channel cross section (both factors that promote transverse mixing) it is possible that mixing could occur more rapidly than predicted in these results. In situ mixing measurements would be required to further refine these mixing zone estimates. This analysis has assumed that the flow is discharged on one bank of the river, which is effectively the worst case scenario for transverse mixing. Improvements to transverse mixing can be made, if needed, through the use of a diffuser.