7.3.2 Autosample Collection

Automatic sampling included the measurement of water temperature as well as the acquisition of water samples.There were 5 significant discharge events captured by the Gammit Autosampler. These occurred from the 29th July to 16th of August 1998, 8th December to 20th December 1998, 1st January to 3rd February 1999, 8th June to 5th July 1999, and 27th January to 25th of March 2000.

This first event monitored was from the 29th of July to the 16th of August 1998[37]. 20 samples were taken during this event, which followed an earlier event in the week. For this period the total rainfall was 91mm which yielded 6313.2ML. Maximum TON concentrations for this event was 302.5μg/L which translates into a total load of TON for this event entering Malpas Dam of 845.48kg[38]. Turbidity was likewise high with a maximum of 50NTU. All variables were normally distributed with a mild correlation between turbidity and TON evident (0.42). TON was independent of discharge whilst turbidity and TON showed only a very weak correlation (0.15)[39]. A feature of this event was the rapid increase in discharge from 1289ML/Day to 3591ML/day over 5 hours. This was in conjunction with an increase in river height of only 0.30m. The hydrograph returned to its original position 11 hours after the peak.

The second event captured by the autosampler was during the period December 8th to December 20th of 1998. Total rainfall for this event was 30.8mm which contributed to a peak discharge for the period of 3ML/Day. All variables were normally distributed (Wilk-Shapiro) with numerous mild to strong relationships between variables. Turbidity was strongly correlated to discharge (0.953) whilst both Ortho-p and TON were mildly negatively correlated (-0.50 and –0.49 respectively). Although on first inspection it appears that these nutrients decrease with increasing discharge this may not be the case. It is evident from

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[37] Event were taken as the point at which the hydrograph began to rise in response to rainfall until it returned to its approximate original level or until it once again began to rise due to another rainfall event. Total discharge was calculated as the amount of water that flowed past the sampling station in this period.

[38] This estimate was based on the point concentration of TON multiplied by the mean discharge between successive points. This method was used as it resulted in close agreement between actual discharge and estimated discharge and assumes a linear relationship between water quality and discharge.

[39] Due to equipment malfunction ortho-P was not measured on these samples.

Figure 7.14 that TON increased shortly prior to peak discharge and the again shortly after (although only minor). Ortho-P resembles this trend.

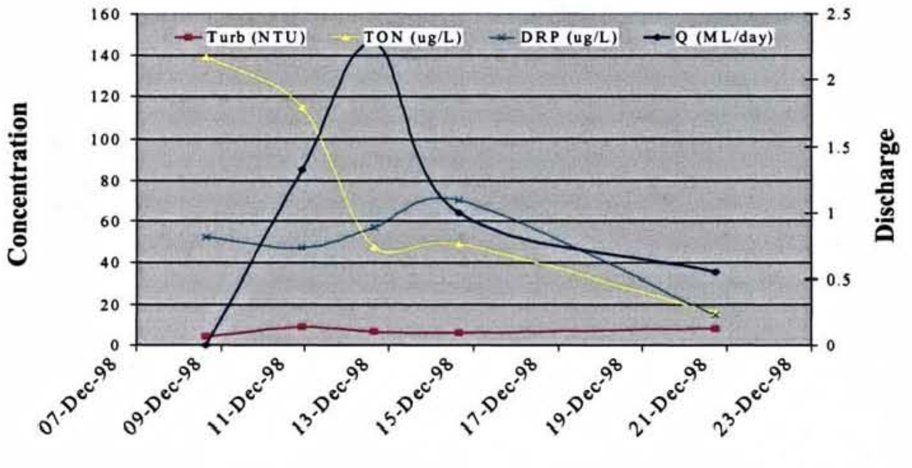

Figure 7.14 Sample Characteristics for the Period December 8th to December 20th 1998

This event yielded 16ML of runoff over approximately 12 days. As such it was not a high intensity storm. Given the low rainfall intensity the erosive capacity of the storm and hence potential for sediment transport overland would be diminished. Nutrient transport would still occur without the mass movement of sediment. Possible sources of the nutrient would be from fertiliser which may have been added during this time or animal faeces. The slight increase in river level could also result in minor stream bank erosion, which added to the minor catchment input would result in an overall increase in turbidity and nutrients. During this event approximately 0.8kg of ortho-P and 0.96kg of total oxidised nitrogen (TON) were transported past 'Willow Glen Station'.

The third event occurred between the 1st of January and the 3rd of February of 1999 in response to 54.2mm of rainfall. This event progressed from a low flow of 0.05ML/Day to 248ML/Day. The subsequent change in water quality throughout the 21 samples retrieved was also dramatic (Figure 7.15). Turbidity peaked at 23NTU whilst ortho-phosphate and TON recorded maximums of 608.5 and 952.5μg/L respectively.

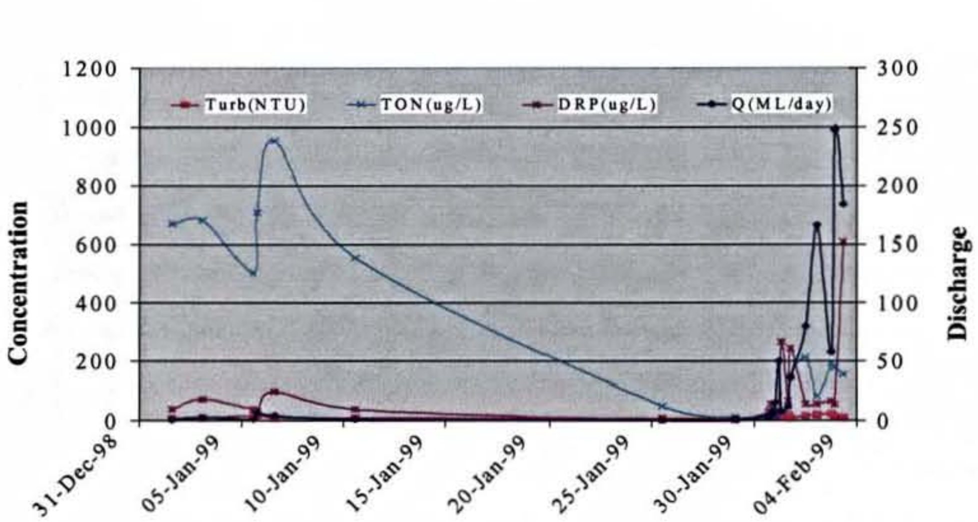

Figure 7.15 Sample characteristics for the period January 1st to February 3rd 1999.

The statistical relationships between the variables measured were mild after some data was modified. Turbidity was normally distributed (0.954) however ortho-P, TON and discharge required log transformation in order to normalise the data and qualify relationships between the variables. However, once again there was very little correlation between variables. The strongest relationship existed between turbidity and Log(discharge) (0.401). Total discharge for this event was 120.5ML which carried an estimated 46.82kg of ortho-P and 61.04kg of TON. Total suspended sediment was also determined for each sample such that the overall TSS load for the event was approximately 14,700kg (Table 7.2). The lack of direct correlation between variables may in part be attributed to the apparent delayed response of the nutrient parameters to increased discharge.

Table 7.2 Automatic Sampling at Willow Glen Station between January 1st and February 3rd 1999.

1st Jan – 3rd Feb 1999	DRP (μg/L)	Q (ML/d)	Turbidity (NTU)	TON (μg/L)
N	21	21	21	21
MEAN	92.205	42.267	13.929	250.32
SD	136.09	70.538	4.7532	294.04
C.V.	147.6	166.89	34.126	117.47
MINIMUM	0	0.05	7.4	8.787
MAXIMUM	608.5	248	23	952.5

From the 8th June to the 5th of July 1999 ten (10) samples were taken. This was a minor event in that discharge increased only 1 order of magnitude from 1.4 to 26.4ML/day in response to 18.6mm of rainfall (Table 7.3). Although the increase in discharge was relatively minor a change in water quality was apparent during the event (Figure 7.16). Mean turbidity for the event exceeded the previously stated base flow condition of 3 NTU whilst Ortho-p was significantly higher in one sample during the period. This indicates that rainfall events of this magnitude and duration have the capacity to affect the water quality in Gara River.

Table 7.3 Automatic Sampling at Willow Glen Station between 8th June and 5th July 1999.

8th June – 5th July 1999	DRP (µg/L)	Q (ML/d)	Turbidity (NTU)	TON (µg/L)
N	10	10	10	10
MEAN	11.564	2.925	9.08	8.106
SD	20.362	2.6151	5.7694	7.3631
C.V.	176.08	89.404	63.54	90.835
MINIMUM	0	1.4	6	0
MAXIMUM	66.59	26.4	25	20.44

This event yielded 194.5ML and carried approximately 27.5kg of Ortho-P and 12.8kg of TON. Each of the variables displayed non-normal characteristics, which were adjusted via log transformation. Following this, moderate correlations between TON and ortho-P (0.614), TON and discharge (-0.521), and Ortho-P and discharge (-0.43) were observed.

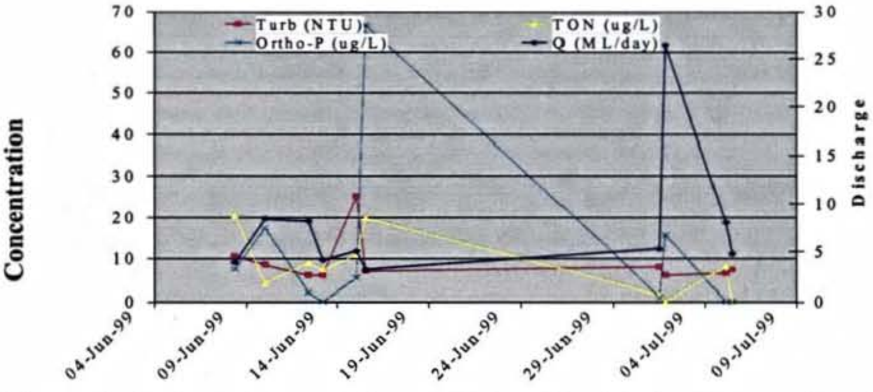

Figure 7.16 Automatic sampling at Willow Glen Station between June 8th and July 5th 1999.

The final event captured occurred between the 27th of January and 25th of March 2000. A total of 150.4mm of rain fell in this period contributing to a modest peak discharge of 31ML/day (Table 7.4). Within the 10,340ML of water transported during the event there was 513kg of Ortho-P and 6,874kg of TON.

Table 7.4 Automatic sampling at Willow Glen Station between the 27th Jan and 25th March 2000.

27th Jan – 25th Mar 2000	DRP (μg/L)	Q (ML/d)	Turbidity (NTU)	TON (μg/L)
N	21	21	21	21
MEAN	69.768	7.5895	5.9	951.08
SD	134.57	9.0038	3.152	1332.4
C.V.	192.89	118.63	53.423	140.09
MINIMUM	7.5	0.05	3	168.4
MAXIMUM	649.8	31	16	6500

There were extremely high concentration of Ortho-P and TON present on the 8th of March (649μg/L and 6500μg/L respectively)[40]. When included in the statistical analysis, the data set had non-normal characteristics. On omission of this sample all parameters where normally distributed[41]. Using the later data set TON and ortho-P were strongly correlated (0.834) whilst turbidity and ortho-P, and turbidity and TON where mildly correlated (0.45 and 0.41 respectively). Discharge was negatively correlated with all parameters measured (very slightly).

7.3.2.1 Autosample Event Summary

During each sampling period, clear relationships between the parameters measured were not evident. However some basic trends were visible. Firstly, total oxidised nitrogen concentrations tended to peak prior to the peak discharge for minor events. This was followed by a small increase after the peak discharge. In contrast to this, Ortho-P tended to follow the shape of the

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[41] Although this sample was omitted it is likely that the high concentrations were valid. Visual inspection of the sample revealed the presence of algae which may have contributed to the nutrient load via release of cell metabolites. It was deemed that this sample was not representative of the overall water quality within the river at this point due to the very localised presence of algae at this site.

hydrograph and was at times correlated with turbidity which invariably increased with discharge.

Correlation analysis of the data provided by the 5 events monitored (Table 7.5) indicates that there is indeed a strong relationship between variables. Both ortho-P and TON loads were strongly correlated with total discharge for each event (>0.98)[42] as to, was turbidity. Rainfall was likewise strongly correlated with all variables (>0.96)[43]. These relationships indicate that it may be possible to estimate loads of nutrients from discharge measurements. Given there a relationship between TSS and turbidity it would also be possible to predict the suspended sediment load being carried by such events.

Table 7.5 Gara River autosample summary data.

Event	Total Discharge (ML)	Rainfall (mm)	Ortho-P Load (kg)	TON Load (kg)
29th July – 16th August 1998	6313.2	91	NA	845.48
8th Dec – 20th Dec 1998	15	30.8	0.81	0.98
1st Jan 1999 – 3 Feb 1999	120.5	54.2	46.82	61.64
8th Jun – 5 Jul 1999	195.5	18.6	27.5	12.8
27th Jan – 25 Mar 2000	10340	150.4	513	6874

7.4 Rainfall – Runoff Relationships

Discharge due to rainfall runoff in the catchment was calculated for each rainfall event greater than 5mm. For the period February 1997 to July 2000 there were 221 such events. When assessing the discharge due to each event, the associated runoff was taken as the flow which occurred between similar points on the hydrograph. In the case of multiple peak hydrographs or when sporadic rainfall occurred on small time scales these were grouped together. Following this method there were 30, 35, 37, and 28 events recorded for 1997, 1998, 1999, and 2000 respectively (Appendix D). Variables of interest measured during these

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[42] Due primarily to the direct relationship between discharge and nutrient load estimation.

[43] Although these findings could be expected the strength of the relationships may be in part due to the small sample size. In this case five (5).

events included the total discharge for the event, the apparent runoff[44] due to rainfall, total rainfall, initial discharge at the beginning of the event, and the 20min and 6min rainfall intensity for each event. Statistical analysis was performed on each of these variables.

It was found that for individual years, the 20min and 6min rainfall intensities were normally distributed (greater than 0.81) whilst all other variables required log transformation to achieve this state. Following this these variables recorded values between 0.89 and 0.98.

Pearson correlation of the variables revealed many associations which persisted throughout the study period (Appendix C). Often the effective runoff was strongly correlated with total rainfall (greater than 0.81) and moderately associated with all other variables measured. Log Effective Discharge was also consistently strongly correlated with Log Total Discharge (above 0.98).

Further analysis of the data involved grouping the information from 1997, 1998 and 1999 and performing similar statistical analysis as those performed on the individual years in Section 7.3.1.2 (Table 7.6) and then using this to construct a simple regression model for the effective runoff for 2000 (Model 1, R^2=0.98).

Table 7.6 Correlation of variables measured at Willow Glen Station for the combined years of 1997, 1998, and 1999.

	Log Effective Discharge	Log Initial Discharge	Log Total Discharge	Log Total Rainfall	20 Minute Rainfall Intensity
Log Initial Discharge	0.4341				
Log Total Discharge	0.9827	0.5384			
Log Total Rain	0.6865	-0.1213	0.6336		
20 Minute Rainfall Intensity	0.1831	-0.1815	0.1669	0.5517	
6 Minute Rainfall Intensity	0.177	-0.1524	0.1627	0.5921	0.9442

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[44] Apparent runoff was that portion of the hydrograph remaining after the baseflow was removed.

Model 1

$$
\begin{aligned}
&Log\ Effective\ Discharge = C_1 + C_2(Log\ Initial\ Discharge) + C_3(Log\ Total\ Discharge) \\
&+ C_4(Log\ Total\ Rainfall) + C_5(20\ Minute\ Rainfall\ Intensity)
\end{aligned}
$$

Where: $C_1 = -0.8644$, $C_2 = -0.1645$, $C_3 = 1.2$, $C_4 = 0.1145$, $C_5 = -0.00154$

When Model 1 was applied to the variables of the Year 2000 there was an extremely high correlation between the model results and the observed results for the Log Effective Discharge (0.99) (Figure 7.17). This is not surprising as it is simply a water budget model where all the major inputs and outputs have been quantified.

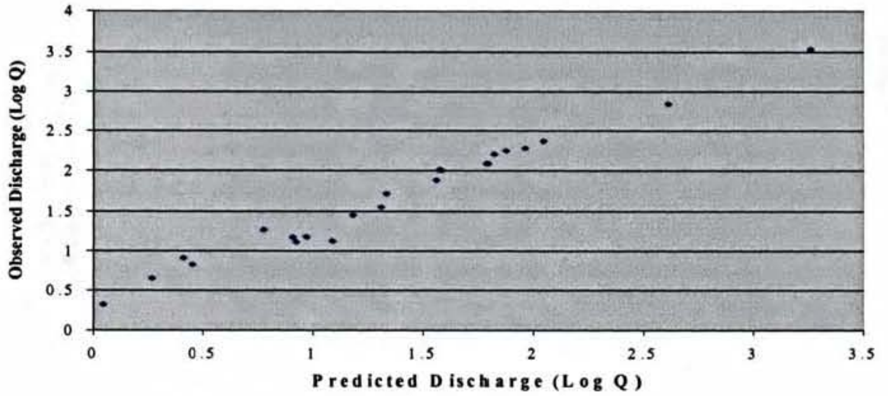

Figure 7.17 **Scatter plot of observed effective discharge Vs predicted effective discharge (Model 1) for year 2000.**

This model allows for the accurate estimation of the amount of runoff that has occurred following a rainfall event. Although this is useful it is limited in its application as a predictive tool. A more useful modelling tool would provide for an estimation of effective runoff (and hence total discharge) from an expected rainfall event. This is the situation expressed in Model 2 (Figure 7.18). This model has a reduced regression coefficient (0.81) compared to Model 1 however it still maintains a hight correlation (0.79) between the predicted effective discharge and the actual effective discharge.

Model 2

$$Log\ Effective\ Discharge = C_1 + C_2(Log\ Initial\ Discharge) + C_3(Log\ Total\ Rainfall) + C_4(20\ Minute\ Rainfall\ Intensity)$$

Where: $C_1 = -0.702$, $C_2 = 0.688$, $C_3 = 2.653$, $C_4 = -0.014$

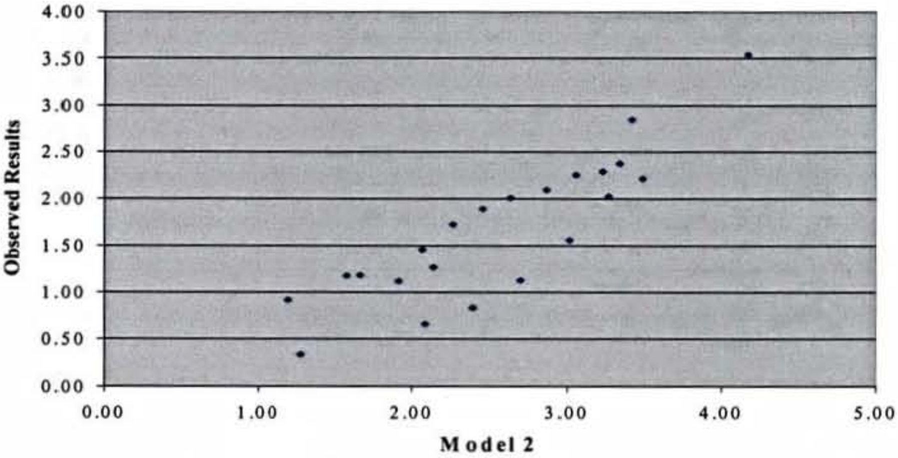

Figure 7.18 Scatter plot of observed effective discharge Vs predicted effective discharge (Model 2) for year 2000[45].

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[45] Both axes are log transformed.

8.0 Catchment to Dam Interaction and Impact on Cyanobacteria Growth

Sudden and dramatic changes in the physical conditions within Malpas Dam depend largely on inflow characteristics. The main source of inflow is from Gara River, which is subject to extreme annual discharge fluctuations and rapid responses to intense rainstorm events (Figure 8.1). At Site 1 water quality was seen to be directly affected by large events only with smaller events having exerted their influence closer to the inflow locality.

Figure 8.1 clearly shows the response of the catchment to rainfall during this period. From the same data it is evident that discharge increased only after a minimum of 8mm of rainfall had fallen in a 24 hour period. Although the hydrograph response in such cases was minor it represents benchmark conditions after which catchment runoff generally occurs.

During the study period the mean water column turbidity at Site 1 significantly exceeded the mean annual level on 23 occasions. The most notable period of such high readings occurred from July–October 1998. During this time turbidity ranged from 6.8–40NTU (Figure 8.2) and occurred in response to 380mm of rain being delivered. Individual rainfall events ranged from 11mm to 62mm and produced event discharges past 'Willow Glen Station' of 19-4500ML/Day.

When this discharge data is linked to Site 1 water quality results it appears that the discharge due to the event on the 27th of July 1998 as measured at 'Willow Glen' station impacted at Site 1 approximately 10 days later. This resulted in a turbidity of 40NTU, which persisted for another 10 days before gradually declining to lower levels 25 days later (Figure 8.2).

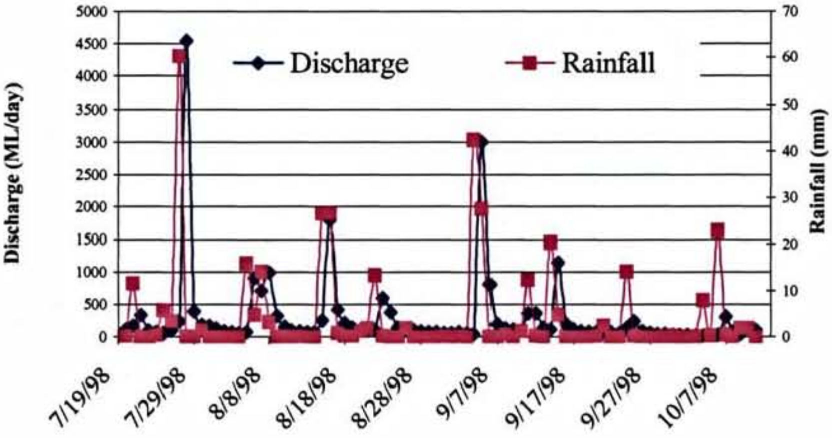

Figure 8.1 Rainfall and discharge measured at 'Willow Glen' station for the period 27th July-13 October 1998.

Given that this was the largest event measured during the study period it is not unreasonable to conclude that there is a maximum travel period of 10 days for water quality associated with a large inflow event to reach Site 1[46]. The numerous associated rainfall events measured at 'Willow Glen' station between the 27th of July and the 13th of October appeared to have had little impact on the turbidity at Site 1[47]. Although these minor events had little obvious impact at Site 1 it is probable that variations in water quality occurred elsewhere in the dam. The area from the inlet of Gara River to Site 1 (northern arm of the dam) would have acted as a buffer zone for the effects of the inflow.

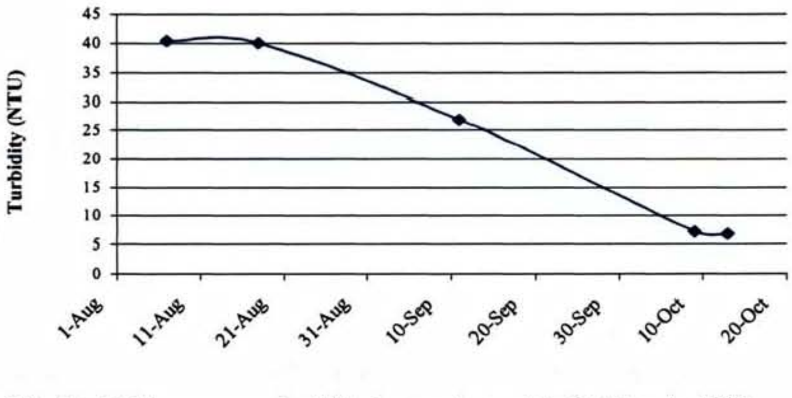

Figure 8.2 Turbidity measured at Site 1 over August to October in 1998.

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[46] The response of dam water quality may be as small as 3 days due to sampling times.

[47] Although some minor influences may have been masked by the impact of the initial event.

Large events provide the bulk of both nutrients and sediments which enter Malpas Dam. However, input from smaller events are still significant as they also contain higher than average concentrations of nutrients and sediment. (Section 7.4). The organic matter transported to the dam via inflow will contribute to the nutrient reserve of the dam following biological and abiotic breakdown. These processes will contribute to various water quality concerns such as decreased dissolved oxygen concentrations and pH fluctuations.

In addition to the deleterious water quality impacts that extreme inflows have on Malpas Dam there are positive aspects. Significantly, there is a direct relationship between inflow water quality and the ability for cyanobacteria growth. During and immediately after large inflows, the high sediment load and subsequent decrease in transparency hinder the growth of algae. However this was not an important mechanism by which they were controlled during this investigation due to the timing of the events. Water temperatures were well below the established threshold of 14°C for cyanobacteria growth in Malpas Dam and no algae were present. The fact that Malpas Catchment is in a transitional rainfall zone (Section 2.1.3) means it may receive summer dominated rainfall and hence large events with similar characteristics as that which occurred in July of 1998 will impact on potential cyanobacteria growth.

9.0 Conclusion and Recommendations

Prediction of the occurrence of algae from the research conducted herein is not feasible, however changes in physical water quality characteristics within Malpas Dam is possible by the use of either of the regression models supplied in Section 7.4. Given the initial river discharge at Willow Glen Station and the total rainfall for the event a reasonable estimation of the amount of runoff can be calculated.

Given that discharge can be estimated it is then possible to estimate the load of nutrients and sediments being transported within the flow. However, although clear relationships seem to exist between discharge, nutrient loads and turbidity within runoff from Malpas Catchment it is not possible to accurately estimate the loads of the nutrients and the degree of change in turbidity from this investigation due to the very small sample size (n=5).

Surface runoff will occur following 8mm of rainfall in a 24-hour period. This will result in changes in the water quality of the Gara River but will not necessarily impact on the water quality at Site 1 in Malpas. Buffering of inflow impacts in the zone between the inlet of Gara River and Site 1 mean that only large events will directly flow through the system. It is apparent from this investigation that the catchment is a major source of nutrients to the dam and will directly impact on water quality in the vicinity of the offtake tower following extreme events. During this investigation this occurred in the period July – October 1998 in response to rainfall in excess of 60mm in 24 hours and maximum daily flow of 4500ML. On these rare occasions the influence of the inflow will be evident between 3-10 days after reaching the dam.

The conditions under which cyanobacteria prospered appeared to be physically regulated rather than chemical as the potentially limiting nutrients (nitrogen and phosphorus) were abundant during the entire period of investigation. Both temperature and water column transparency (turbidity) exerted the largest influence on cyanobacteria growth with their occurrence limited to periods when the temperature was between 14.5-24°C and mean water column turbidity was less than 6NTU. This effectively limits their growth season from September to

May. The impact that extreme events will have on their growth will depend on the timing of such events.

From this research it appears that cyanobacteria will continue to be a problem for ADSC for many years to come. With this in mind it is recommended that ADSC develop/implement water treatment procedures that can consistently overcome the various water quality problems in the dam. Methods of control of the algae should also be investigated. This should be based on ways in which to decrease light availability to the organisms as well as reducing their access to nutrients.

Future research may take the form of experiments involving artificially increasing turbidity in regions of the dam where a bloom may be in existence, removing the nutrient sources through capping of the sediments, construction of wetlands or harvesting of algal cell material.

Destruction of cells/blooms through algicides or sonic means etc. is not advised due to the possibility that the bloom may be toxic. It is also not beneficial in the long-term as it neither removes nutrients form the dam nor prevents the return of algal populations following these treatments