5.0 Methodologies

There were two aspects of this investigation which needed to be monitored in order to link the physio-chemical processes in the dam with the inflow characteristics from the catchment. These included the monitoring of water quality variables within the dam and on the major tributary of the catchment. Suitable sites first had to be identified. Following this sampling commenced.

5.1 Malpas Dam Monitoring

5.1.1 Site selection

Four distinct regions within Malpas Dam were identified as being possible sites for sampling. These regions included the shallow elongated northern arm (maximum depth 8m), the shallow shorter western region (maximum depth 6m), the deeper main body of the dam (maximum depth 12m) and the region immediately surrounding the destratification system and the offtake points. Each of these regions varied in depth and local water residence time such that it could be expected to result in variation in physical and chemical water quality characteristics between locations. Site 1 was chosen as the site of sampling due to its proximity to the offtake tower and its greater likelihood of representing the water being treated by Armidale City Council (Figure 2.1). At this site the water depth was approximately 20m and was situated midway between the destratification unit and the offtake tower. Water sampling began at this site on January 14th 1998

5.1.2 Water sample collection

Firstly, a marking buoy with a concrete weight attached by rope was placed at Site 1 to facilitate mooring of the boat whilst obtaining samples. Sampling within the dam was carried out from a 6m inboard boat.

Three 1L samples where taken at designated depths. These depths were (depth permitting); water surface, 6m below the water surface, and at approximately 1m above the bottom sediments. These samples were collected weekly in summer and fortnightly during the colder months (May - August). These depths were selected based on observation of historical records which indicated that thermal and oxygen stratification often appeared at depths of 5-10m below the water

surface. Sample collection was undertaken using 1L clear polyethylene bottles and a jinx bottle. Surface samples where taken by submerging the sample bottles to just below the surface while all other depth samples where taken using the 2L jinx bottle. Once taken all samples were securely stored in a container away from direct sunlight and transported to the University of New England, Armidale for analysis.

5.1.3 Parameters of Interest

When selecting the parameters to be monitored, the lifecycle of cyanobacteria was taken into account. Particular emphasis was placed on their nutritional and physical requirements for growth and bloom. As a result the following parameters were selected:

- dissolved oxygen,
- water temperature,
- secchi depth ,
- total phosphorus,
- dissolved reactive phosphorus,
- total kjeldhile nitrogen,
- total filtrable iron, manganese, and copper,
- pH,
- chlorophyl-*a*,
- turbidity,
- total suspended solids and
- algal counts and identification.

The time at which sampling began at each site was recorded along with general weather characteristics such as wind direction/speed, and cloud cover. Sampling typically took 4 hours (from 8.30 am to 12.30 pm) on calm clear days and required the use of equipment listed in Appendix A.

5.1.4 Sample Analysis and Preservation

Dissolved Oxygen, Temperature and Secchi Depth

Dissolved oxygen and temperature profiles at each site where measured insitu using a hand held YSI Dissolved Oxygen Meter whilst secchi depth was also measured insitu using a standard black and white (40cm) secchi disk.

Plankton

Surface plankton samples where taken using a 63μm plankton net. The plankton net was cast several times over the windward side of the boat and dragged in. The contents where then placed into a plastic jar containing lugol's solution.

Chlorophyll-a

To determine the chlorophyll-*a* concentration at each sample depth 50ml of sample was filtered through Whatman 047 GF/C filter papers using a syringe and a field filtering apparatus. The filter papers where then folded in half and frozen in petri dishes to await batch determinations by the spectrophotometric method (Standard Methods, 1992). Approximately 200 samples were analysed for Chl-*a* over the period of January 1998 to April 1999.

Determination of Total KN, Total P, Total Fe, Total Mn and Total Cu

For each sample a 25ml aliquote was prepared and analysed in accordance with the methods outlined in Table 5.1 (Standard Methods, 1992).

Table 5.1 Methods used for preparation and analysis of water samples.

Variable	Method
TKN	Digestion and colourmetric determination
Total P	Digestion and colourmetric determination
Total Fe	Digestion and spectrometric determination
Total Mn	Digestion and spectrometric determination
Total Cu	Digestion and spectrometric determination

Samples which were not analysed immediately were stored at 4°C in a refrigerator until analysis. Over 600 samples were prepared for TKN and TP analysis. Results however, were exceptionally variable, and after one year fundamental flaws with the analysing machine were identified by the

manufacturer, hence results were abandoned. Likewise, continued problems with equipment rendered the total metal data unreliable.

Total Oxidized Nitrogen, Ortho-phosphorus and filterable metals

For each sample a 30ml aliquote was filtered through 45μm nitrate filter papers into clear 50ml narrow necked PVC bottles. These were then analysed in accordance with the methods list in Table 5.2.

Table 5.2 Methods used for preparation and analysis of water samples (bioavailable elements).

Variable	Method
Ortho-P	Molybdate blue (Murphy & Riley 1962)
TON	Cadmium-copper reduction (Wood et al. 1967)
Filterable Fe	Spectrometric determination (Raymond & Higginson 1992)
Filterable Mn	Spectrometric determination (Raymond & Higginson 1992)
Filterable Cu	Spectrometric determination (Raymond & Higginson 1992)

5.2 Inflow Monitoring

The primary focus of monitoring the inflow was to quantify the load of bioavailable nutrients and sediments entering Malpas Dam as well as other representative variables such as turbidity, water temperature, and metal content. The timing of these loads was also an important aspect of their delivery to Malpas Dam under investigation. To this end total oxidised nitrogen and ortho-phosphate were measured as well as the filterable forms of iron, copper and manganese. Each of these was analysed in similar ways as those in Section 5.1.4.

5.2.1 Sampling Site Selection

A preliminary investigation was undertaken of Malpas Catchment in which the catchment was divided into sub-catchments based on drainage area, land use, geographical location and ease of access for sampling in an effort to determine the optimum location for monitoring catchment inputs to the dam. There were

10 sites selected for initial evaluation (Appendix D). Following this one general site was identified as being suitable for further monitoring. This was located at 'Willow Glen' on the Gara River by which 70% of flow entering Malpas Dam passed (Figure 2.1).

Further investigation within the general locality on Gara River revealed a number of possibilities for sampling. In order to select the optimum location a number of sites in the immediate area around 'Willow Glen' were chosen for monitoring to assess the variation in measured parameters due to the influence of site characteristics. Of particular interest was the impact that discharge, river morphology and benthic plant communities in the area had on variability of the parameters between sites (Appendix B). Following this the existing DIPNR site was chosen as the permanent location for sampling on Gara River. This site was around 5 km upstream from the dam on the Guyra-Ebor road (Plate 5 & 6).

Plate 5 Willow Glen sampling site during high flow.

Plate 6 Willow Glen locality during low flow.

5.2.2 Water Sample Collection and River Gauging

It was desirable to collect samples during 'base flow' conditions, during rainfall events and following these rainfall events. As a result both manual and automatic sampling were adopted for Gara River.

Manual Sampling

Manual samples were collected on average every month with some consideration given to rainfall history. Sampling involved the collection of 3 x 1L replicates at each site using an extendable arm and clear 1L polyethylene bottles. These samples were placed in a container similar to that used for dam samples and then returned to the laboratory for immediate treatment, analysis and preservation.

Automatic Sampling

Automatic sampling of Gara River was initiated in February 1998. This involved a Gammit Autosampler set to take 500ml of sample when the rate of rise of Gara River exceeded 5mm in any 15min period and thereafter at 0.4, 0.5, 0.6, 0.8, 1.0, 1.2, 1.5, 2.0, 2.5m on the rising and falling hydrograph.

The rate of rise value used as a trigger for the autosampler was deduced by trial and error over a six month period from Jan 1998 until June 1998. It was found that given this rate of rise there was noticeable visual change in water quality of Gara River. Gauge height information was recorded on a logger and downloaded every 2 months or when samples were taken.

5.2.3 Sample Preparation and Analysis

Manual samples were analysed within 24 hours of collection or otherwise preserved with 1ml concentrated sulphuric acid and frozen for a latter date. All chemical and physical analysis were undertaken in accordance with the appropriate methods listed in Section 5.1.4.

5.2.4 Hydrograph Analysis

Runoff was calculated by analysis of the hydrograph information provided by the gauging station. The response of the hydrograph was measured by deducting the base flow from total flow and then relating that to the rainfall measured in the immediate period prior and during the flow event.

In the case of multiple peaks in the hydrograph due to localised storms or multiple events runoff was attributed to each event where hydrograph separation was possible or if not, treated as one major rainfall event.

6.0 Malpas Dam Results

6.1 Water Quality in Malpas Dam

6.1.1 Water Temperature

Water temperature varies throughout the year from maximum in the month of February (~25°C) and minimum in July (~7°C)(Figure 6.1). The water column is typically well mixed except in the spring and summer months where stratification[20] may occur (Figure 6.2).

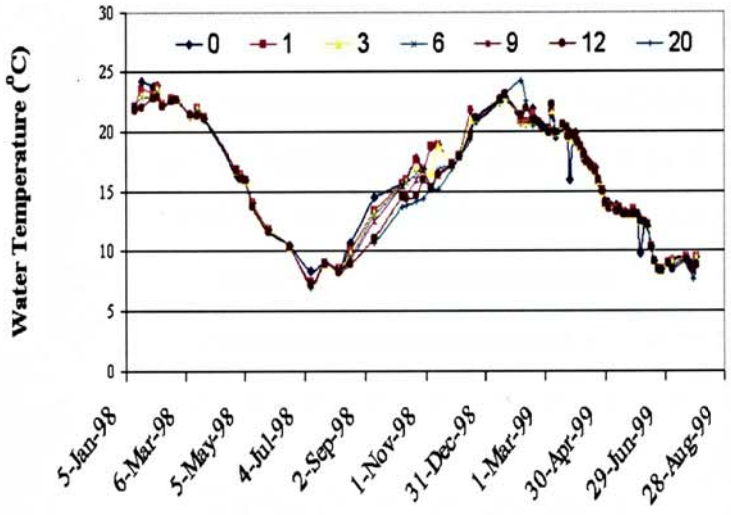

Figure 6.1 Temporal variation in water temperature at Site 1 in Malpas Dam (from the surface to a depth of 20m).

The use of a "Bubble Plume" destratification unit is employed sporadically however from August 1998 until February 1999 it was not used and subsequently significant thermal stratification occurred. During period temperature varied within the water column by as much as 4°C. Reverse stratification was noted on the 5th of February as the water column became hotter with the depth. On this day the hypolimnion was around 4°C warmer than the epilimnion. Likewise on the 26th of March and 8th of June 1999 surface water temperatures were significantly less than the rest of the water column.

[20] Thermal stratification was defined by a greater then 2°C variation in water temperature between the epilimnion and the hypolimnion.

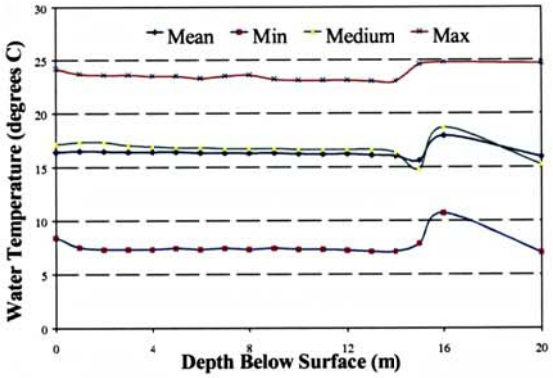

Figure 6.2 Variation in water temperature at Site 1 during the period 1998 to 2001.

6.1.2 pH

The pH at Site 1 fluctuated between 7.34 and 9.48 with a mean of 8.22 and standard deviation[21] of 0.36. Notable occasions where pH exceeded the mean of the water column pH by 2 standard deviations include April, November and December of 1998 and March, April and May of 1999 (Figure 6.3).

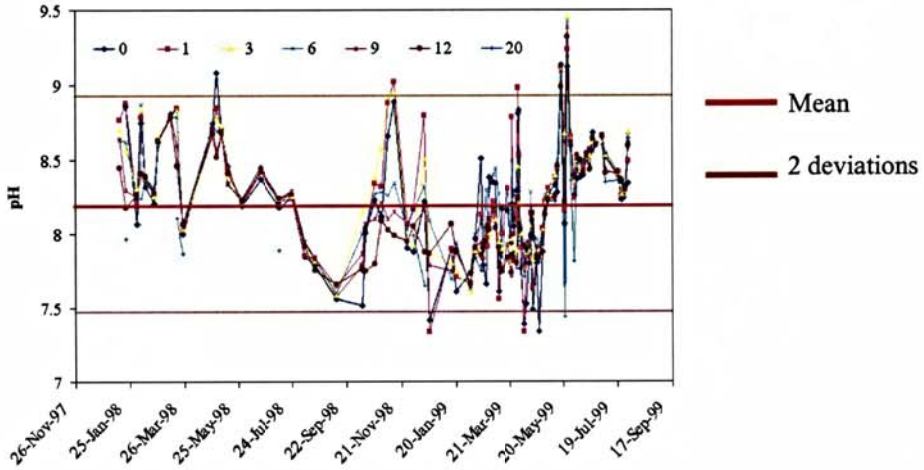

Figure 6.3 *pH* as measured at Site 1 in Malpas Dam over the period 1997-1999.

6.1.3 Dissolved Oxygen

The dissolved oxygen profile at Site 1 demonstrated similar mean values at all depths over the period January 1998 to July 1999 of approximately 7.2mg/L

(Figure 6.4). There were however frequent occasions when extremes[22] were detected and oxygen profiles exhibited stratification.

One such period was January – May 1998 which was characterized by very low dissolved oxygen concentrations at most depths but in particular the deeper depths (>6m). The maximum difference between surface dissolved oxygen levels and those at greater depths for this period was 6mg/L on the 21st January and 5.5mg/L on the 6th of February.

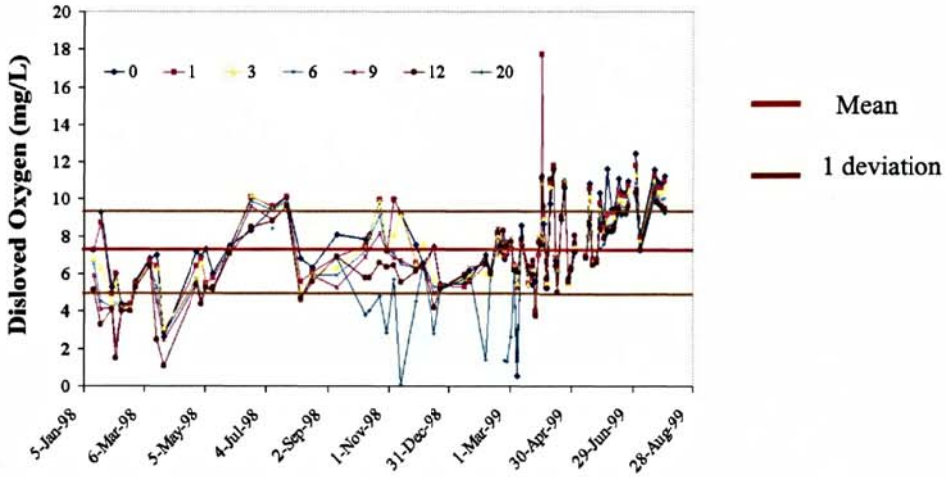

Figure 6.4 Dissolved oxygen profile at Site 1 in Malpas Dam.

Further extreme lows occurred between October 1998 and March 1999 and were once again evident in the deeper depths. For this period the smallest dissolved oxygen concentrations measured were 0.7 and 1.3mg/L on the 13th of November 1998 and March 8, 1999 respectively. On these days the difference between the epilimnion and the hypolimnion was 8.45 and 4mg/L respectively.

Following this period of low hypolimnion dissolved oxygen levels there was a gradual increase in DO in late March 1999, which culminated in the extremely high levels on the 1st of April. At a depth of 1m the DO level was 17.75mg/L. At all depths however DO was significantly higher than mean levels. High DO levels continued sporadically to appear throughout the remainder of the sampling period. At the same time there was little difference in DO levels between depths. This period was characterized by uniformly mean to high levels of DO.

[22] Extreme values are those beyond one standard deviation of the water column mean value over the sampling period.

Other notable occasions which exhibited high DO levels included two short periods between October 1998 and March 1999. On the 23rd of October, 6th of November and 13th of November 1998 DO levels reached 9.90, 10.04, and 9.15mg/L respectively. Further high levels were present at most depths on the 10th and 24th of July 1998.

6.1.4 *Turbidity*

Turbidity at Site 1 had a mean of 4.05NTU and a median of 2.2NTU over the entire water column. For individual depths these figures were comparable. The higher mean is a reflection of the extremely high readings on five occasions and high readings on another 3 occasions during the sampling period.

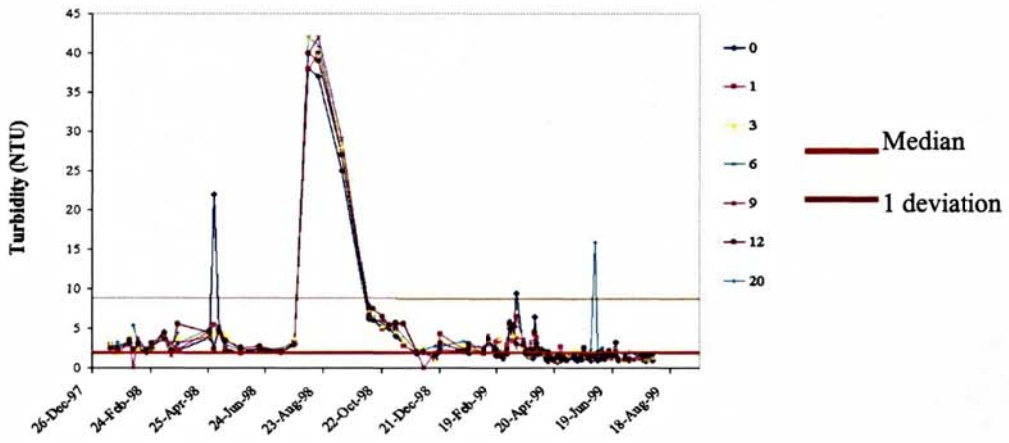

Figure 6.5 Site 1 turbidity over depth below water surface and time.

In general turbidity seemed to increase with depth with the exception of six sampling occasions. On May 1st 1998 the surface turbidity was 22.0NTU whilst at 1m below the water surface it was only 5.5NTU. The mean for the remaining water column was approximately 3.3NTU. On March 12th and March 29th 1999 surface turbidity was approximately 4NTU greater than that at depth whilst on April 1st, June 22nd 1998 and February 5th 1999 turbidity varied by less than 2NTU between the surface and 20m below the water surface.

The highest recorded level of turbidity was on August 7th and 18th 1999 at 3m, 6m and 9m below the water surface respectively (42.0NTU). These days also

had the highest mean water column turbidity of 40NTU. Whilst the lowest water column turbidity was on July 23rd 1999 which registered 0.82NTU at 9m below the water surface. From April to August 1999 turbidity was consistently below the medium level at all depths with the exception of June 1st which measured 15.9NTU at 20m below the water surface.

6.1.5 Colour

Colour at Site 1 ranged from a minimum of $16m^{-1}$ on April 3rd 1999 to $446m^{-1}$ on August 18th 1999 (Figure 6.6). There were 7 sampling days on which the colour at one or more depths exceeded the sampling period mean value of the water column by more than one standard deviation. These included March 11th, March 25th, May 1st, August 7th and 18th and September 11th 1998 and then again on June 1st 1999.

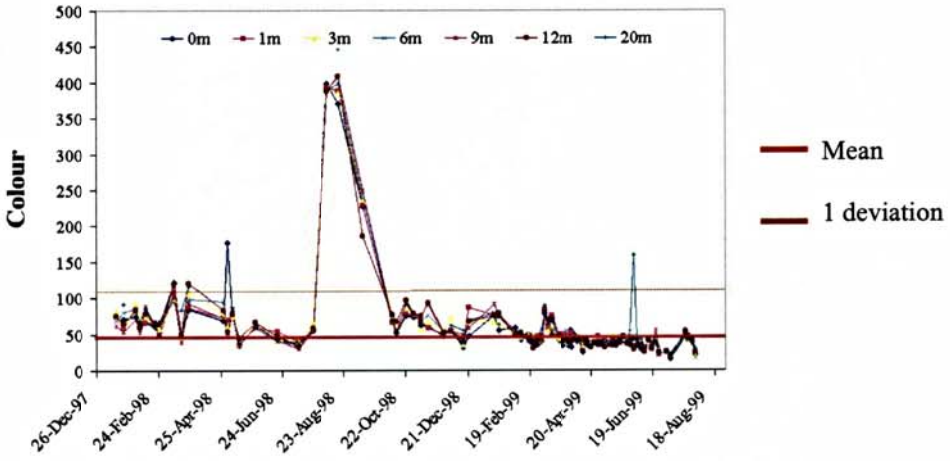

Figure 6.6 Site 1 colour over depth and time.

On the majority of these days there was not an appreciable variation between depths. However disparity between depths did occur on May 1st 1998 and June 1st 1999. On these days the colour at the surface on May 1st was 177 units at and 1 m below water surface only 70 units whilst on June 1st the colour at 20m below water surface was 159 units compared to 28 units at 12m below water surface. Noticeable variation between depths was also evident on January 21st, February 11th, March 18th, March 25th, October 23rd, November 13th, December 16th and 22nd of 1998. On all of these days colour appeared to increase with depth.

6.1.6 Total Suspended Sediments

Total Suspended Sediments (TSS) at Site 1 varied between 0.5 and 26.5mg/L with a mean of 3.4 and median of 2.5mg/L (Figure 6.7). On approximately 26% of occasions TSS noticeably decreased with depth with the largest difference being 19mg/L on the 1st of May 1998 between the surface and m below the water surface.

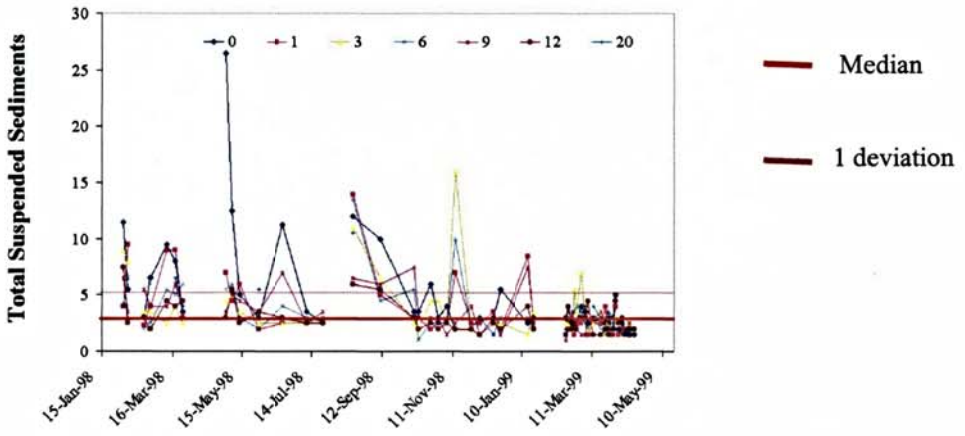

Figure 6.7 Total suspended solids at Site 1 over time and depth.

High TSS levels were recorded regularly in the period January to June 1998 and again from August to October 1998. November 13th had the second highest level for the sampling period of 16mg/L at 3m below the water surface whilst most readings taken in 1999 hovered around the medium value.

6.1.7 Secchi Depth

The early period of the sampling (January–February 1998) was dominated by secchi depths significantly less than the mean for the water column over the entire period (Figure 6.8). May 1st and 6th also had low transparency however August and September had the lowest secchi depths for the sampling period. A minimum of 0.25m was recorded on September 11th and 0.4m on August 7th and 18th. The clearest water occurred on December 16th 1998 which had a secchi depth of 3.6m. Transparency remained good for the remainder of the sampling period with July 1999 having consistently high secchi depths.

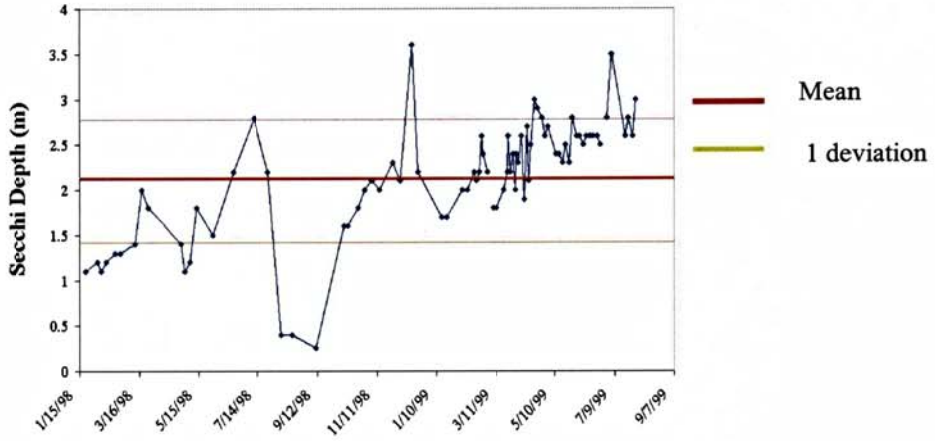

Figure 6.8 Site 1 secchi depth over time.

6.1.8 Dissolved Reactive Phosphorus (DRP)

DRP at Site 1 ranged from zero to 1570µg/L at a mean of 71µg/L over the entire water column for the sampling period (Figure 6.9). A large standard deviation (SD) of 136.7µg/L and a median value of 55µg/L characterized this data.

Extremely high DRP concentrations were found throughout the initial period from January-February (mean 276.18µg/L, SD 409.2µg/L) followed by generally low levels (mean 20µg/L, SD 28.7µg/L) from 11th March – 24th July 1998. For the remainder of the sampling period from July 1998 until July 1999[23] the concentration of DRP hovered around 64µg/L throughout the water column which also coincided with a relatively small SD of 24.2µg/L.

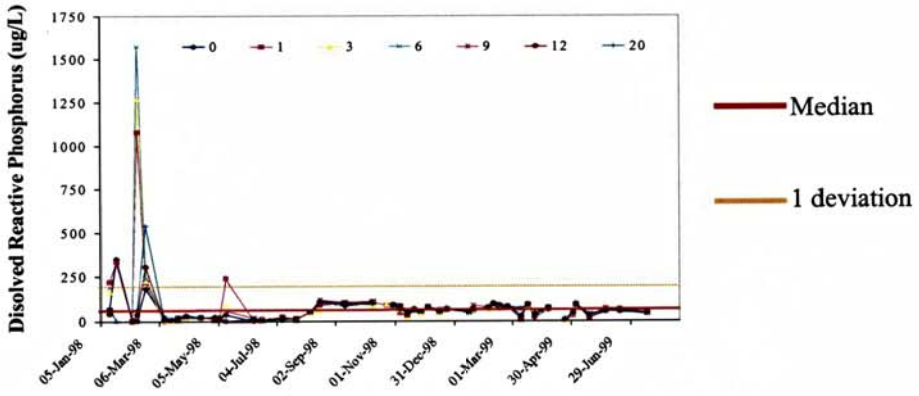

Figure 6.9 Site 1 DRP over depth and time.

[23] With the exception of April 24th 1999.

The highest recorded concentration was found at a depth of 6m below the water surface. Subsequently this particular day (11th February 1998) also had the highest mean water column concentration although at 0m, 12m and 20m below the surface concentrations were found to be only 3, 37 and 67µg/L respectively.

6.1.9 Total Oxidised Nitrogen (TON)

TON concentrations at Site 1 varied dramatically both temporally and spatially for the duration of the sampling (Figure 6.10). However overall the mean and median were relatively similar (132.7µg/L and 100.9µg/L respectively) for the water column.

Generally, moderate levels of TON were recorded for summer–autumn periods, January-April 1998 and October 1998 to February 1999. At these times variation between depths in the water column were also comparatively smaller than those for the remainder of the sampling period, namely the winter and springs season.

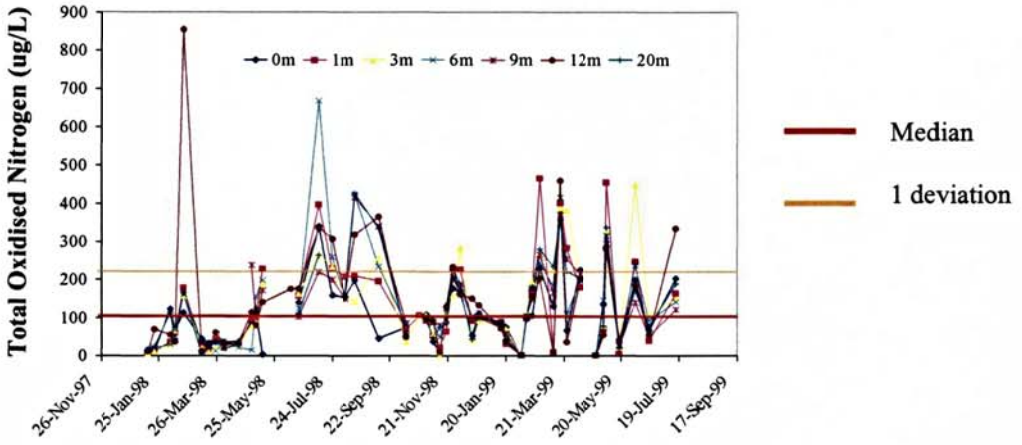

Figure 6.10 Site 1 total oxidised nitrogen over time and depth.

The notable exception to this is the 20th of February 1998. On this day the water column contained on average 271.4µg/L with the concentration at 12m being 855µg/L.

6.1.10 Filterable Iron, Copper, and Manganese

The most prevalent of the metals monitored was filterable Iron (Fe) (Figure 6.11), which was present in consistently higher concentrations than either

filterable Manganese (Mn) (Figure 6.12) or filterable Copper (Cu) (Figure 6.13)[24]. Over the sampling period the mean water column concentrations for Fe, Mn and Cu were 93.7, 12.2 and 10.2µg/L respectively. However the median value for each was significantly lower: 22, 0.15 and 6µg/L for the respective metals.

The higher mean reflects the influence of a small number of periods, which had high concentrations of these metals and subsequently biased the mean value upwards. Notably May 1st, September 1st and the period October 23rd to November 13th 1998 had very high Fe loads (mean 264.1µg/L) throughout the water column. For the same periods Mn had a mean of 34.02µg/L and maximum of 137.7µg/L whilst Cu recorded a mean of 3.1µg/L and maximum of 10µg/L. Mn also recorded high concentrations throughout the water column of December 23rd 1998 and also below 3m on January 15th 1999.

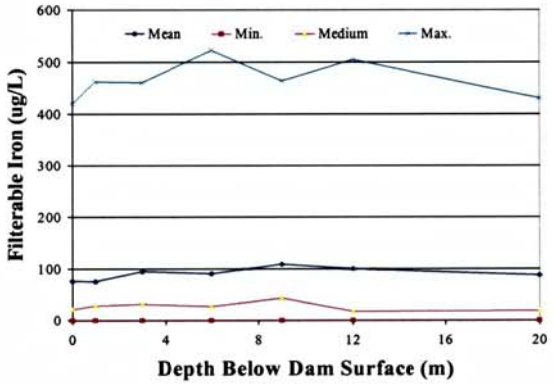

Figure 6.11 Filterable iron concentrations at Site 1 in Malpas Dam.

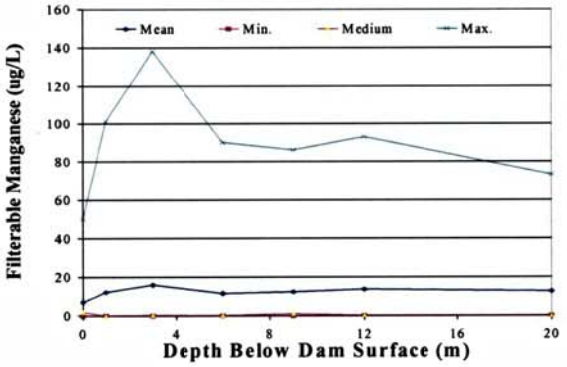

Figure 6.12 Filterable manganese concentrations at Site 1 in Malpas Dam.

[24] Graph format changes due to the fragmented nature of the data available.

Small concentrations (<10μg/L) of Cu were detected on most sampling occasions throughout the sampling period with surface layers generally having higher concentrations than deeper layers (Figure 6.13). The most notable occasion occurred on the 20th of January 1999 whereby at 1m below the water surface the Cu concentration were 354μg/L. At 3m it was 125μg/L and at 6m 26.7μg/L. Other reasonably high measurements were recorded on 20th February 1998. On this day the maximum was 33.5μg/L at the surface.

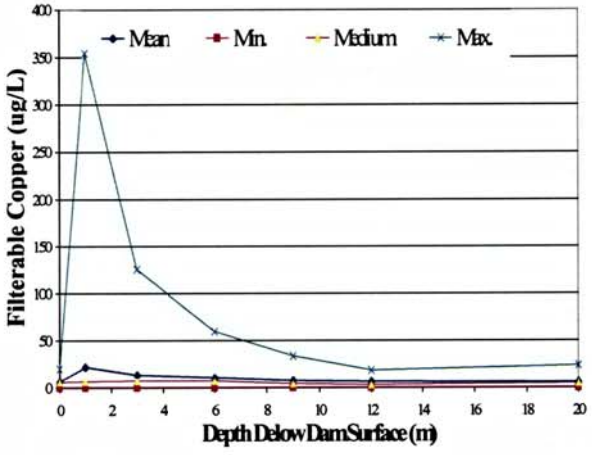

Figure 6.13 Filterable copper concentration measured at Site 1 in Malpas Dam.

6.1.11 Algae

During the sampling period cyanobacteria, green algae and diatoms were recorded. For cyanobactera both anabanea species and microcystis[25] species were noted (Figure 6.14). Ceratim represented diatoms on the 25th of February 1998 (2 and 1 cell at 5m and 6m depths) whilst Ulothrix was in abundance on March 11th and March 18th 1998 with small colonies of Volvox on 6th November and 13th November 1998.

During February 1998 the first evidence of anabaena was detected sporadically in the water column on the 11th and 25th. Following this in March significant numbers throughout the water column were recorded and continued to persist until the middle of June 1998. On March 11th the surface cell count was 10,770 whilst at 1m below the surface it was 1945. Throughout the remainder of the

[25] Three cells of Microcystis were identified on 5th February 1999 at a depth of 1m. On all other occasions it was absent.

water column numbers decreased to the point that 230 cells were detected at a depth of 15m. Anabaena was again detected on March 18th when the surface layers contained significantly more anabaena cells than in the first 1m of water. Anabaena were detected to a depth of 9m on this day.

The 25th of March contained cells less than 1000/ml to a depth of 9m. The maximum on this day was 930 cells found at 5m whilst in April and May anabaena numbers increased throughout the water column such that on May 1st a surface bloom of 448,000 cells was recorded. Anabaena were present in lesser numbers to a depth of 14m (1000 cells). One week later the entire water column contained in excess of 20,000 cells/ml. This decreased to 10,000 cells/ml one week later and to approximately 2000 cells a fortnight later.

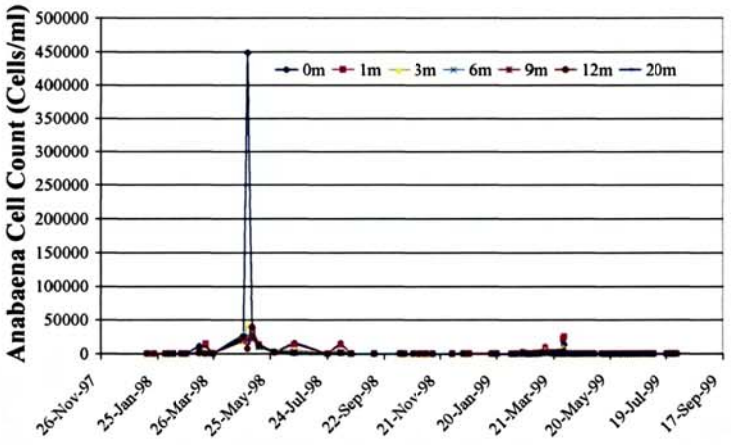

Figure 6.14 Site 1 Anabaena populations over depth and time.

Minor numbers of anabaena were again detected from December 1998 through to February 1999 followed by significant numbers uniformly distributed throughout the water column on the 8th of March 1999. On the 12th March the population was confined to the top 4m of the water column with the surface recording 10,000 cells/ml. Anabaena numbers decreased throughout the water column over the following 3 weeks but once again bloom conditions prevailed on March 31st and April 1st. On these days the surface counts were approximately 20,000 cells/ml and 18,000cells/ml for the top 1m of water respectively.

In conjunction to anabaena blooms significant numbers of Ulothrix were also recorded throughout the water column on the 11th and 18th of March 1998 (Figure 6.15). However they did not appear again during the sampling period.

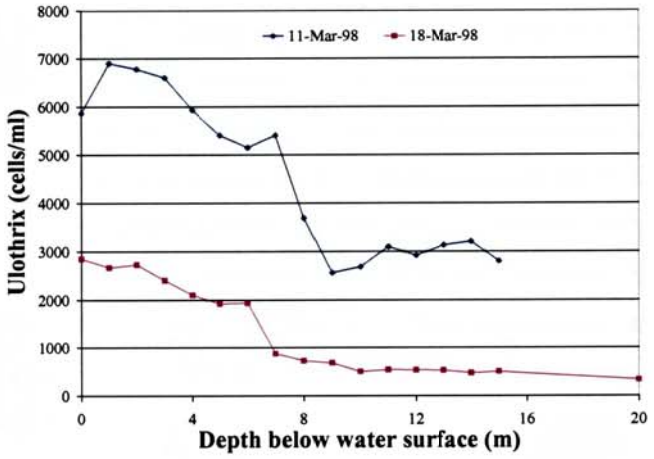

Figure 6.15 Ulothrix cell counts throughout the water column at Site 1 on the 11th and 18th of March 1998.

6.1.12 Chlorophyll a

Chlorophyll a ranged from zero to 38.5µg/L over the sampling period (Figure 6.16). Maximum water column levels occurred during January, February, March and April of 1998 whilst minor levels were recorded on most days when sampling occurred.

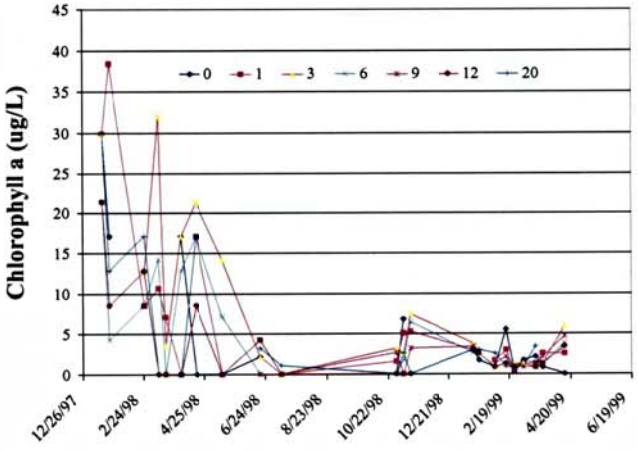

Figure 6.16 Chlorophyll-*a* concentrations at Site 1 in Malpas Dam.