



Wiluna Gold Mine

Monitoring of Lake Way During Mining Operations

September, 2006

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Document Control for Job Number:

Document Status	Reviewer	Signature	Date of Issue
Draft Report	Melanie Ward	MJW	10-10-06
Final Report	Veronica Campagna	VC	20-04-07

Executive Summary

Outback Ecology was engaged by Agincourt Resources Ltd to undertake physico-chemical and biological monitoring of the Williamson Pit Project Area in Lake Way over a three-year period. The 2006 assessment was undertaken to comply with conditions of the Notice of Intent (NOI) for the Williamson Pit, specifically:

During the operational phase, monitoring should:

- Summarise water and sediment quality, and ecological status of the aquatic community on Lake Way during mining, in relation to dewatering discharge effects, and compared to baseline data
- Determine the nature and level of impact caused by dewatering discharge, to biotic and abiotic parameters
- Document environmental fluctuations/conditions and their affect on the aquatic ecosystem
- Document bird visitation/use of Lake Way

Field work was undertaken opportunistically in April 2006, as Lake Way was drying after a major rainfall event.

Surface Water and Sediment Quality

Surface water was present and collected from the Wiluna Discharge sites (LWPipe1 and LWPipe2) and control sites LW2 and LW3. No water was present at control site LW9, so a substitute site close to LW9 was sampled (LW9A). The Williamson Pit discharge sites did not contain sufficient surface water for samples. Sediments were collected from all sites.

Metals and metalloids were tested in water where present, and in sediment at all sites. The data was compared to:

- ANZECC marine water guidelines (‘default’ reference for water quality),
- ANZECC Interim Sediment Quality Guidelines (ISQG, ‘default’ reference for sediment quality), and/or
- More relevant, site-specific background data ranges for Lake Way (both water and sediment quality), which are still being developed through regular monitoring.

In terms of surface water, all inundated sites were classified as hypersaline and there was an increase in the surface water salinity from previous assessments, though there was little variation in pH which remained slightly alkaline. Assessment of dissolved metals showed that Cu and Zn concentrations exceeded the ANZECC marine water guidelines at the Wiluna Discharge site(s), but did not exceed background data ranges. In addition, the alkaline pH and hypersalinity of surface water probably restricted bioavailability of detectable dissolved metal concentrations.

Similarly for sediment chemistry, total concentrations of As and Cr in sediment exceeded the ANZECC ISQG at Wiluna Discharge sites, and total Ni concentrations exceeded the ANZECC ISQG at both the Wiluna Discharge and control sites. No total metal concentrations exceeded the background data ranges for Lake Way, and concentrations were similar between control and discharge sites. Assuming the validity of the control sites, this result indicates that detectable concentrations of metals such as Ni were more likely related geological setting than dewatering discharge, and that dewatering discharge had no discernible impact on sediment chemistry at the time of sampling.

Aquatic Biota

In surface water, a total of five taxa comprising of four Bacillariophyceae (diatoms) and one Chlorophyceae (green algae) were identified. The species observed were all characteristic of saline environments, and Chlorophyceae was the only true phytoplankton. Wiluna Discharge sites LWPipe1 and LWPipe2 recorded the highest diversity (three and four species respectively). Phytoplankton recorded from the control sites (LW2, LW3 and LW9A) was limited in comparison to the discharge sites, with diatoms (*Amphora coffeaeformis* and *Navicula* species) being the only taxa identified. These differences were related to differences in water chemistry and habitat (creek vs playa environment).

In sediments, a total of 11 diatom taxa representing seven genera were identified from the Benthic Microbial Communities (BMCs), an increase from 2005. Dominant genera included *Amphora*, *Navicula* and *Hantzschia*, following previous studies on the surface sediments from the lake. In general, diatom communities were similar between the discharge and control sites, and dominated by well-known salt-tolerant species. The abundance of diatoms from each site was also high, in comparison to previous years. These results also indicate that the discharge was most likely not affecting diatom assemblages in the BMCs during the 2006 assessment.

Four invertebrate taxa were identified from five sites during the Lake Way May 2006 monitoring program. Species diversity was typically low. Diversity in Lake Way is naturally depauperate and since the 2004 assessment by OES, only three different taxonomic groups have been identified from the samples. However, in optimal conditions, Lake Way is likely to be productive in terms of live invertebrates. The Williamson Pit sites did not record any live invertebrates but this was due to the absence of surface water.

Avian Fauna

The avian fauna recorded in 2006 were restricted to the plovers, stilts and avocets. These are all nomadic species that prefer the shallow waters of the playas and feed primarily on invertebrates such as the brine shrimp. Their presence, coupled with the invertebrate data for April 2006 indicates that productivity and subsequent bird visitation of the lake has not been compromised by the Wiluna and Williamson dewatering discharges to Lake Way.

In summary, the Wiluna Discharge and Williamson Pit discharges do not appear to be having a direct impact on the biota on the Lake Way playa as at April 2006. However, these discharges appear to be contributing to increasing salinity levels, particularly along the southern section of the Causeway.

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1.0 INTRODUCTION

In early 2005, Agincourt Resources Ltd began feasibility studies for their proposed Williamson Pit, to be located on the Lake Way playa. Lake Way, located 17km south of Wiluna, is a large temporary salt lake with an area of approximately 270 km^2. The lake forms part of an extensive chain of salt lake systems known as the Salinaland, and is a surface expression of the Lake Carey Palaeoriver.

During the stakeholder consultation process for the Williamson Pit development, the Department of the Environment (DoE) raised a number of environmental concerns relating to the project. In response, Agincourt Resources Ltd commissioned Outback Ecology to develop an investigative monitoring program to address the concerns raised (**Table 1**), which formed part of the mines commitments within the Williamson Notice of Intent.

This report describes the work component 2 of the monitoring program: operational monitoring in the Williamson Pit project area. Field work was conducted in April 2006 following a cyclonic rainfall event, and during the drying phase of the hydric cycle, to meet the objectives of the monitoring program, which are:

- Summarise water and sediment quality, and ecological status of the aquatic community on Lake Way during mining, in relation to dewatering discharge effects, and compared to baseline data
- Determine the nature and level of impact caused by dewatering discharge, to biotic and abiotic parameters
- Document environmental fluctuations/conditions and their affect on the aquatic ecosystem.
- Document bird visitation/use of Lake Way.

Table 1 Summary of monitoring program for Williamson Pit area, Lake Way, 2005 - 2007

Work Component	Items Addressed by Work Outcomes
1a. Baseline monitoring *April and May 2005*	▪ Collect available information on water and sediment chemistry of Lake Way, and collate to provide a set of site-specific guidelines ▪ Identify the likely aquatic microflora and invertebrate communities present in Lake Way near the discharge points ▪ Determine productivity near the Williamson and Wiluna discharges ▪ Provide avian management plan using existing data
1b. Hatching trial *April and May 2005*	▪ Observe salt crust development in the lab, and attempt to estimate likely crust development *in situ* on Lake Way ▪ Identify salinity tolerances of invertebrates present in Lake Way
2. Operational Monitoring: *May 2006**	▪ Summarise water and sediment quality, and ecological status of the aquatic community on Lake Way during mining, in relation to dewatering discharge effects, and compared to baseline data ▪ Determine the nature and level of impact caused by dewatering discharge, to biotic and abiotic parameters ▪ Document environmental fluctuations/conditions and their affect on the aquatic ecosystem ▪ Document bird visitation/use of Lake Way
3. Post-Closure Monitoring: *May 2007**	▪ Demonstrate level of 'recovery' of the ecosystem after mining (preferably after a rainfall event) ▪ Attempt to determine indicators of recovery ▪ Comment on residual impact, likelihood of mitigation, and conditions required for mitigation

2.0 MATERIALS & METHODS

2.1 Site Locations

Sample sites were chosen to represent both potentially-impacted and control areas in Lake Way. Potentially-impacted sites were established and sampled near the discharge points of the existing Wiluna operation (LWPipe1 and LWPipe2) and the proposed Williamson Pit project (WP1 – WP7) (**Figure 1**). For the Williamson Pit Project area, new sites were established within the proposed dewatering discharge footprint, previously identified by KH Morgan and Associates (**Figure 2**). Sites WP2, WP3, WP4, WP6, and WP7 were sampled during the 2006 assessment; unfortunately because of difficulties in accessing the sites, WP1 and WP5 were not sampled.

Previously-established control sites were also sampled (LW2, L3 and LW9) for comparison. During the 2006 sampling period LW9 was dry and an extra site, LW9A approximately 100m NW towards LW2, was sampled surface water parameters as the lake water had accumulated there. The different elevation points in the playa and the prevalence of a southerly wind often results in much of the surface water accumulating in the north western section of the lake, impeded by the Causeway. Access to the previously-established sites is often difficult as many of the access bridges across the channel have been removed.

Table 2 Location of sampling points, Williamson Pit project area, Lake Way, sampled April 2006

Site	Eastings	Northings	Description
LW2	230326	7036599	Along causeway, North
LW3	230376	7036599	Along causeway, South
LW9	231907	7035853	Along causeway, South twds Williamson Pit
LWPIPE2	227811	7041601	Creek where (WD) discharge enters playa
LWPIPE1	225694	7041340	Wiluna operations discharge point (WD)
WP1	231958	7035810	Williamson Pit Discharge point
WP2	231805	7035617	Williamson Pit Discharge sites
WP3	231585	7035474	Williamson Pit Discharge sites
WP4	231902	7035614	Williamson Pit Discharge sites
WP5	231794	7035335	Williamson Pit Discharge sites
WP6	232021	7035581	Williamson Pit Discharge sites
WP7	232049	7035335	Williamson Pit Discharge sites

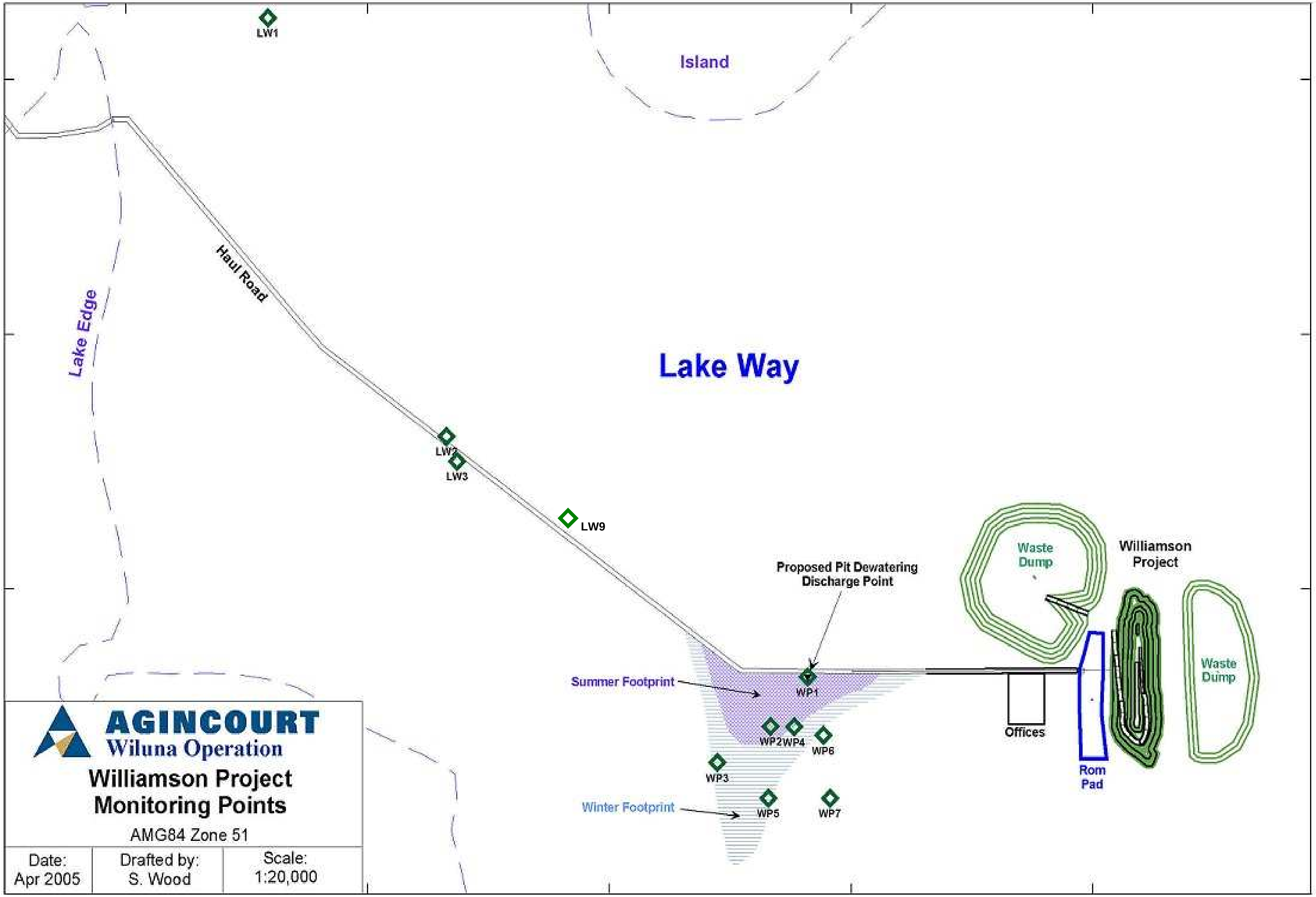

Figure 1 Location of monitoring points on Lake Way, April 2006 (LWPipe1 -2 not on map)

2.2 Climate

The climate of the Wiluna region can be described primarily as desert, with the area typically experiencing low rainfall and extreme temperatures (Beard, 1990). The mean rainfall is around 250mm per year, with occasional above-average rainfalls from tropical cyclones (Shire of Wiluna online, 2005). In the months prior to the assessment rainfall was above average, and reached a maximum of 128.8 mm in January 2006. This was attributed to a number of ex-tropical cyclones that moved through the area in the early part of 2006, causing some sections of Lake Way to become flooded, continuing into the current sampling period.

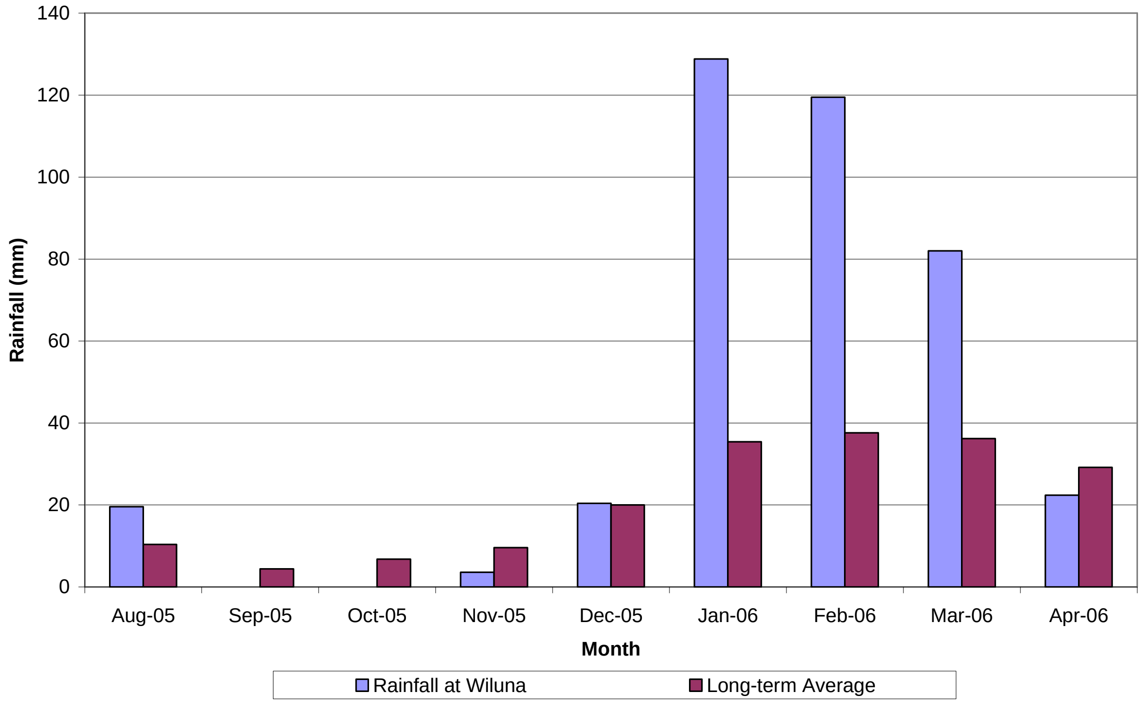

Figure 2 Monthly rainfall recorded at the Wiluna weather station in comparison to the long-term average for Wiluna (BOM, 2006).

2.3 Surface Water Chemistry

At sites with sufficient surface water, basic parameters such as Dissolved Oxygen (DO), Electrical Conductivity (EC), pH, temperature and depth were measured *in situ* using hand held meters. Surface water samples were collected for chemical analyses using bottles provided by ALS Environmental Perth (NATA Accredited Laboratory). Samples were kept chilled until transported to the laboratory (ALS).

Water samples were analysed in the laboratory for the following: pH, EC, Total Dissolved Solids (TDS), total anions and cations, Nitrite-Nitrate, Total Phosphorous (TP), total silica (SiO2). Dissolved metals and metaloids were analysed from the water samples and included the following: Aluminium (Al), Antimony (Sb), Arsenic (As), Barium (Ba), Boron (B), Bromine (Br), Cadmium (Cd), Chromium

(Cr), Copper (Cu), Fluoride (Fl), Lead (Pb), Manganese (Mn), Mercury (Hg), Selenium (Se), Silver (Ag), Strontium (Sr), Tellurium (Te), Tin (Sn), Tungsten (W), Uranium (U), and Zinc (Zn).

Surface water chemistry was compared with:

- ANZECC marine water guidelines for 95% protection of species ('default' reference for anions, cations and metals),
- More relevant, site-specific background data ranges for Lake Way, which are being developed through a regular monitoring program.

2.4 Surface Sediment Chemistry

Sediment samples were collected by scraping the surface sediment into a sterilised glass jar (125mL), excluding as much air from the sample as possible. The samples were then sent to Australian Laboratory Services Environmental (ALS) for analysis. The following analytes were assessed: pH, major anions and cations, total soluble salts (TSS, equivalent of salinity), total Kjeldahl nitrogen (TKN), total nitrogen (TN), total phosphorous (TP), total organic carbon (TOC), nitrite-nitrate, and moisture content (MC).

Total metals and metalloids at all sites were analysed from the sediment samples and included the following: Aluminium (Al), Antimony (Sb), Arsenic (As), Barium (Ba), Boron (B), Cadmium (Cd), Chromium (Cr), Copper (Cu), Fluoride (Fl), Iron (Fe), Lead (Pb), Manganese (Mn), Mercury (Hg), Nickel (Ni), Selenium (Se), Silver (Ag), Strontium (Sr), Tellurium (Te), Tin (Sn), Tungsten (W), Uranium (U), and Zinc (Zn).

Sediment chemistry was compared with:

- ANZECC Interim Sediment Quality Guidelines 'high' trigger value (ISQG, 'default' reference for sediment quality), and
- More relevant, site-specific background data ranges for Lake Way, which are being developed through a regular monitoring program.

2.5 Microalgae

Microalgae were sampled in the form of phytoplankton (free-floating) where water was present and benthic microbial communities (BMCs) in the absence of surface water. Comparisons were then made between the 2006 assessment and those from 2004 and 2005.

2.5.1 Phytoplankton

Phytoplankton was collected using a 500 mL plastic bottle and preserving with Lugol's solution (potassium iodide) for later assessment. Samples were observed under a light microscope and the abundance and diversity was recorded using a calibrated Lund cell. Specimens were identified using available literature.

2.5.2 Benthic Microbial Communities (BMCs)

BMCs samples were taken from each site by inserting a 50mL vial (with a hole drilled into the base) into the sediment and removing the core. The top 5mm of the core was digested and prepared for diatom frustule enumeration according to John (1983). Permanent diatom slides (3 replicates for each site) were made from each sample. Each slide was examined and up to 100 diatom frustules (cells) were counted. In very sparse samples the total area of all three slides were examined and as many frustules as possible were recorded. The total diatom abundance and diversity was recorded, and specimens were identified using relevant literature.

2.6 Aquatic Invertebrates

Aquatic invertebrates were sampled from each site by isolating a known volume of water within a cylinder (diameter of 46cm), and removing the invertebrate population using a 150 µm net. The invertebrates collected were placed in a plastic container and preserved with 70% ethanol for later identification. The aquatic invertebrates were counted under magnification. Sub-samples were counted using a Sedgwick-Rafter Counter (1mL samples) under higher magnification. The macroinvertebrates (specimens greater than 500µm) were counted by placing the entire volume in counting dishes. The abundance was then calculated as number of individuals per litre. Specimens were identified using relevant literature.

2.8 Statistical Analysis

2.8.1 Univariate Statistics – Minitab (v14.0)

Univariate and multivariate statistical methods were adopted to analyse the data. A 95% confidence interval was used for all statistical tests.

Univariate statistics were performed using the Minitab v14 statistical package, as follows;

- Sites were grouped according to their classification;
    - WD – Wiluna Discharge (LWPipe sites)
    - WP – Williamson Pit sites (WP1 - 7)
    - C – Control sites (LW2, 3 and 9/A)
- One-way ANOVA were used to determine if there was any significant difference between sites in relation to a specific factor. A *post hoc* test using Fisher’s LSD was then applied to each significant ANOVA result to determine which groups were different.

2.8.2 Multivariate Statistics - Primer

Multivariate analysis of data was performed using the PRIMER (v6) package.

- Principal Component Analysis (PCA) was used to look at the similarity between the sediment chemistry at each site. PCA produces a graph on which samples with similar chemistry are located close together, while those with markedly different chemistries are located further apart.

- Multi-dimensional scaling (MDS) plots were also used for looking at similarities between the data. Unlike PCA the MDS ranks the similarities within the data (Clarke and Warwick, 2001). To determine if there was a significant difference between the Control and Discharge sites, an ANOSIM (Analysis of similarities hypothesis for differences between groups) was then performed on the MDS data.

3.0 RESULTS AND DISCUSSION

3.1 Site Descriptions

Wiluna Discharge

Wiluna discharge sites, LWPipe1 and LWPipe2 are located in the north-west section of Lake Way along the Wiluna Operations discharge creek line. These sites have water all year as a result of the discharge water from the mine operations.

Site LWPipe1 is located upstream along the creek line (**Plate 1**). The creek line was fringed with a sparse *Halosarcia* community along the floodplain. The clayey surface sediment was not compact with a fine silt layer that was readily disturbed, the subsurface layer with a strong anoxic smell and black in colour. Several roosting sites were present at this site and ten Red-capped plovers observed foraging on the sandbank and fringes. While there was a large number of dead *Parartemia* washed along the edges of the creek line, there were still obvious signs of breeding activity.

Plate 1 LWPipe1, Wiluna discharge site, upstream

Site LWPipe2 (**Plate 2**) was downstream closer to the mouth of the creek opening onto the Lake Way playa. Similar to LWPipe2 the sediment contained a black subsurface layer and when disturbed released a very strong organic odour (rotting). *Parartemia* were active in the water and plover prints observed along the beaches. Sections of the *Halosarcia* community fringing the creek were dead.

Plate 2 LWPIPE2, Wiluna discharge site, downstream toward playa

Williamson Pit Sites

The Williamson Pit sites radiate from the discharge point on the edge of the Causeway along the proposed summer and winter footprints from the mine water discharge on the playa (**Figure 1**). During the 2006 assessment no water was present at these sites. Despite this again the lake bed was very difficult to walk on and the clayey sediment very sticky. There was a fine halite crust on the surface of the lake which appeared thicker in sections. The elevation levels in this section of the lake are lower than those along the Causeway and consequently these sites often are dry or with only a slight surface layer of water. Sites WP2, WP3, WP4, WP6, and WP7 were sampled during the 2006 assessment; unfortunately because of difficulties in accessing the sites, WP1 and WP5 were not sampled. A very strong odour was evident during the sampling and may be attributed to decomposing organic matter as there were large strands of dead *Parartemia* along the edges of the playa. A flock of approximately 60 Black-winged stilts flew over the Causeway towards the west of the lake.

Plate 3 Williamson Pit Sites, facing SSW from the causeway

Lake Way Control Sites

Three control sites LW2, LW3 and LW9 were re-assessed in 2006 (**Figure 1**). Sites LW2 and LW3 were established during the 2004 baseline survey conducted by OES. In 2005 an additional site, LW9 was established to increase the number of control sites along the Causeway. Initial observations indicated much of the biota and productivity appeared to be located on the north western shore of Lake Way. This may be the result of a number of factors, particularly the elevation of the playa – it is slightly lower along the north-west sections and because of the prevailing winds, the water tends to accumulate in these areas. The Causeway would also act as a barrier and contain many of the aquatic species that are distributed to this area by wind, and trapped.

Site LW2 (Plate 4) was located on the northern side of the causeway opposite LW3. The water level at this site was approximately 8cm along the edges of the causeway. There was a fine, clay-silty layer over the surface of the lake with a depth of 29cm before solid sediment reached. This site contained a large number of dead *Parartemia*, though there were also living *Parartemia* in the water column, and this may have been where the smell originated from. This odour disappeared a few days later (K. Bond *pers comm*. 2006)

Plate 4 Site LW2, facing north east from the Williamson Pit Causeway facing the island.

Site LW3 (**Plate 5**) was located on the southern side of the Causeway, approximately 300m west from the Williamson Pit discharge point and opposite site LW2. The sediment was similar to LW3 and again a strong odour. Dead *Parartemi*a were scattered the shoreline, though there were live ones present in the water.

Plate 5 Site LW3 facing south west toward the edge of the playa from the Williamson Pit Causeway.

Site LW9 and LW9A were located on the northern side of the Williamson Pit Causeway. Site LW9 was the original control site selected during the 2005 assessment though was dry during the April 2006 assessment (**Plate 6**), probably because of the higher elevation of this site. It was chosen as a control site as it was directly across from the Williamson Pit discharge point on the southern side of the Causeway. The sediment was fairly compacted with a fine speckled crust on the surface.

Further west from LW9, surface water was present due to the prevailing wind and lower elevation of the playa bed. Samples were collected at this control site for comparisons and the site was subsequently named LW9A (**Plate 7**). The substrate was much firmer and the unpleasant odour was not apparent. The water was clear and there were *Parartemia* in the water.

Plate 6 Site LW9 facing south along Causeway towards Williamson Pit

Plate 7 Site LW9A facing the NNW shoreline of Lake Way from the Williamson Pit Causeway

3.1 Surface Water Chemistry

During the 2006 April sampling of the Lake Way sites, surface water was only found at the Wiluna Discharge sites (LWPipe1 and LWPipe2), and the Control sites (LW2, LW3 and LW9A) which allowed *in situ* measurements to be taken (**Table 3**). The Williamson Pit sites (WP) contained no surface water. The elevation levels of the playa bed and the wind movement resulted in the surface water amass on the western shoreline and against the causeway for the control sites. The Wiluna Discharge sites were within a flowing creek and not influenced by the same factors.

The water depth on the playa (control sites) was typically shallow for inland water with an average depth of 10 cm (**Table 3**). The Wiluna Discharge creek bed was shallow along the edges but appeared deeper toward the centre of the creek. Because of difficulty of sampling of these sites, only the peripheral margins of the creek could be safely sampled.

The concentration of dissolved oxygen is considered one of the most important parameters in limnology (Hammer 1986) and is highly dependent on temperature, salinity, and biological activity (ANZECC 2000) Dissolved oxygen concentrations should not fall below approximately 6 mg/L to sustain life (ANZECC 2000) though for saline system it may go as low as 2 mg/L (Williams 1985). The shallow nature of our inland waters means that stratification is not an issue and therefore dissolved oxygen concentrations are not really a problem with the wind action constantly mixing surface water. At depth of 10 cm Lake Way is not affected by hypoxia (low oxygen concentrations) as has been observed in larger, more permanent systems. The DO concentrations in surface water ranged from 9.4-9.9 mg/L in the Wiluna Discharge sites within the creek, and 4.4 – 7.7 mg/L at the control sites on the playa. While 4.4 mg/L at control site LW2 was low, it was not below the critical 2 mg/L. This may also have been an abnormality, i.e. possibly slightly anoxic sediment dislodged at time of measurement, as the rest of the playa sites recorded normal DO concentrations for saline systems.

The water temperature appeared to reflect the ambient air morning temperatures measured at the Wiluna Discharge sites (LWPipe1-2) of 15.9 – 22.8 ºC. Those at the control sites on the playa were slightly higher as they were measured later in the day, the average daily temperature was approximately 23.2 – 25.0 ºC.

Table 3 Water quality parameters measured *in situ* Lake Way sites (April, 2006)

	Sites				
	Wiluna Discharge		Control		
Parameter	LWPipe1	LWPipe2	LW2	LW3	LW9A
Depth (cm)	7.5	4.5	8.0	8.0	15.0
Dissolved Oxygen (ppm)	9.9	9.4	4.4	7.7	7.0
Temperature(°C)	15.9	22.8	23.2	25.0	24.0
pH	8.0	7.9	7.7	7.7	8.0
Electrical Conductivity (mS/cm)	175.5	183.3	186.0	180.0	121.0

The physico-chemical parameters measured at the sites (*in situ*) were comparable to those analysed in the laboratory. pH is a measure of the acidity or alkalinity of water and has a scale from extremely acidic (0) to neutral (7) to extremely alkaline (14). It is measured as it may have an adverse effect on biota by interfering with their physiological functioning, but also because it can cause other pollutants such heavy metals to become bioavailable (ANZECC 2000; Parametrix 1995). The pH of the surface water at the Lake Way sites was slightly alkaline to alkaline (**Table 4**). The Wiluna Discharge sites (LWPipe1 – 2) had a pH range of 7.94 to 7.77, respectively. This was slightly less alkaline than the previous year where the pH was 8.03 – 8.04, the difference being minor. The pH at the Control Sites LW2, LW3 and LW9A, ranged from 7.53 to 8.18. There was little difference from the 2005 assessment of the sites LW2 and LW3 with the pH ranges again being circum-neutral. None of the pH values fell outside the ANZECC Guidelines of 6.5 -9.0 (ANZECC 2000). Surface water was not collected at Williamson Pit sites, as they were dry.

Salinity is the concentration of all the ionic components present in the water (Hutchinson 1957 in Hammer 1986). The salinity of surface water can be measured in a number of ways; the two most accepted is as the specific electrical conductance (conductivity) of the water or as the total dissolved solids (TDS) in the water. Electrical Conductivity (EC) measures the total concentration of ionised substances present and, therefore, the ions in the water. All sites sampled with sufficient surface water in Lake Way during the April 2006 sampling period were classified as hypersaline (> 50 000 mg/L or EC = 31 250 µS/cm) according to Hammer (1986). Despite this, no thick salt crusts were observed at the time of sampling.

The Wiluna Discharge sites (LWPipe1 and 2) recorded similar salinities of 195 000 to 204 000 µS/cm, respectively in 2006. This was an increase from the previous assessment in 2005 which recorded 120 000 µS/cm at LWPipe1 and 133 000 µS/cm at LWEPipe2. The control sites, LW2 and LW3 also recorded an increase in surface water salinities in terms of EC and TDS with an increase nearly four times that of the 2005 samples. There was little difference between the control sites in terms of salinity concentrations and the differences in concentrations from the two years may be attributed to the heavy rainfalls in May 2005 prior to the sampling of the sites. In 2006 while there had been above average rainfalls in January through to March, the below average falls in April and warm conditions may have been enough to facilitate the evapoconcentration of the ions in the water and hence the high EC concentrations. There may have been the influence from the Williamson Pit discharge water, though the EC of the control site on either side of the Causeway were also elevated, so this is not likely to be the sole cause of increasing EC.

The difficulties in the development of guidelines for salinity especially in temporary inland waters, which are naturally hypersaline, result in the need to use site-specific evaluations (ANZECC 2000). Comparison of data with the Lake Way control site water quality ranges established by OES show that the April 2006 salinity values were within the control site ranges (**Appendix A**).

The ionic sequence of inland surface waters tends to follow a sodium chloride dominance, in the order of Na>Mg>K><Ca for the cations, and Cl>SO_4>HCO_3.CO_3 for the anions (Williams, 1981; Hammer, 1986). The sequence recorded in the Lake Way water samples was Na>Mg>K>Ca for the cations and the anions Cl>SO_4>HCO_3>CO_3. Often K and Ca interchange in inland waters (Hammer 1986).

Table 4 Water chemistry of the Lake Way sites during the April 2006 assessment.

Parameter	Unit	Sites				
		Wiluna discharge		Control		
		LWPipe1	LWPipe2	LW2	LW3	LW9A
pH Value	pH Unit	7.94	7.77	7.53	7.58	8.18
Electrical Conductivity	µS/cm	195000	204000	209000	210000	172000
Total Dissolved Solids	mg/L	172000	184000	191000	185000	135000
Carbonate Alkalinity as $CaCO_3$	mg/L	<1	<1	<1	<1	<1
Bicarbonate Alkalinity as $CaCO_3$	mg/L	167	177	110	112	126
Total Alkalinity as CaCO3	mg/L	167	177	110	112	126
Sulphate as $SO4^{2-}$	mg/L	25100	20200	20700	21500	17000
Sulphur as S	mg/L	8360	6730	6900	7170	5650
Chloride	mg/L	85400	78000	101000	103000	66200
Calcium	mg/L	748	493	755	735	872
Magnesium	mg/L	4820	3900	5470	5420	3430
Sodium	mg/L	52500	43600	56300	57200	40200
Potassium	mg/L	3880	3140	5090	4770	3150
Nitrite as N	mg/L	<0.010	<0.010	<0.010	<0.010	<0.010
Nitrate as N	mg/L	102	61	4.2	5.4	697
Nitrite + Nitrate as N	mg/L	102	61	4.2	5.4	697
Total Phosphorus as P	mg/L	0.01	0.03	0.02	0.01	<0.01

Nitrogen (N) is an essential nutrient required by all biota and is mostly available in water in the form of nitrite (NO_2^-), nitrate (NO_3^-), and ammonium (NH_4^+). Nitrite-N is an intermediate indicator of nitrogen cycling and decomposition (Hammer 1986) and in the nitrogen cycle gives rise to nitrate-N (Boulton and Brock 1999). Generally, for inland salt lakes the concentration of nitrite is normally 0.02 mg/L or less (Hammer 1986). Concentrations in Lake Way playa and creek were below 0.01 mg/L in April 2006.

The nitrate (NO_3) concentrations in the 2006 assessment were generally higher than the ranges of the previous assessments (**Appendix A**). They were also much higher than most inland waters, and at the LWPipe1 and 2 and LW9A sites, values exceeded both the ANZECC marine water guidelines and the background ranges for Lake Way. The reason for the increase is unknown, but could be related to the use of compounds in blasting at the mine, or to biological processes.

Excess nitrogen in the system can be detrimental in terms of nuisance algal growth leading to anoxia or toxin release, though this is not a factor in Lake Way as it does not have a true phytoplankton population for a bloom to occur. The dissolved oxygen concentrations measured *in situ* did not indicate that there was a problem with anoxia. Nitrate is more bioavailable than nitrite and the high concentrations at the Lake Way sites may be an indication that there is little uptake due to the lack of plants and phytoplankton. Zooplankton and other aquatic invertebrates excrete excess nitrogen as ammonium which can then be converted into nitrite then nitrate. The high numbers of *Parartemia* at these sites may have attributed to the high concentrations of nitrate. Though the values exceed guidelines, it is not toxic to organisms and may eventually be decomposed by the reducing bacteria in the sediment.

Phosphorous is also essential for the growth of biota and is the single most important limiting chemical factor for the growth of phytoplankton (Hammer 1986). It exists in water in both particulate, bound to organic matter and clay, and dissolved such as orthophosphate. The Total Phosphorous concentrations recorded in the water column at all sites were typically low and fell below the control site ranges (**Appendix A**).

The dissolved metals and metalloids suite tested in the surface water for the Lake Way monitoring sites is given in **Table 5**. Unfortunately, there is a lack of information to determine appropriate trigger values for certain metalloids, therefore trigger-value estimates have be made.

Water quality data for Lake Way, collected in April 2006, was compared to both ANZECC marine water guidelines and the background values collected for Lake Way (**Appendix A**).

Compared to the ANZECC marine water quality guidelines:

Wiluna Discharge

- Cu exceeded the trigger values at both LWPipe1 and 2
- Zn exceeded the trigger values at LWPipe2

Control Sites

- Cu exceeded the trigger values at all sites
- Zn exceeded the trigger values at LW2 and LW3

Compared to the background ranges for Lake Way, all metals and metalloids were within or below the ranges.

Cu is an essential element for biota and can bioaccumulate in aquatic organisms, though it is commonly regulated by them (ANZECC 2000). Toxicity of Cu decreases with increased salinity. Zinc is an essential trace element required by all organisms. It is adsorbed by suspended material and it is difficult to ascertain if it subsequently becomes bioavailable. The uptake and toxicity of Zn decreases with increased salinity (ANZECC 2000). For both Cu and Zn, it is likely that the hypersaline conditions in Lake Way may be inhibiting bioavailability.

Table 5 Dissolved Metals and metalloids in water, Lake Way (April, 2006) (units in mg/L)

	Sites				
	Wiluna discharge		Control		
Parameter	LWPipe1	LWPipe2	LW2	LW3	LW9A
Aluminium	<0.10	<0.10	<0.10	<0.10	<0.10
Antimony	0.066	0.072	0.028	0.01	0.022
Arsenic	0.167	0.193	<0.010	<0.010	0.015
Barium	0.199	0.203	0.205	0.238	0.212
Boron	4.44	4.8	2.5	2.94	3.28
Bromine	73.9	80.7	49.6	49	47.8
Cadmium	0.0022	0.0017	0.0021	0.0017	<0.0010
Chromium	0.012	0.014	<0.010	<0.010	0.013
Copper	0.062	0.062	0.041	0.042	0.034
Fluoride	<1.0	<1.0	<1.0	<1.0	1.1
Lead	<0.010	<0.010	<0.010	<0.010	<0.010
Manganese	0.013	<0.010	<0.010	0.038	<0.010
Mercury	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Selenium	<0.050	<0.050	<0.050	<0.050	<0.050
Silica	<0.1	<0.1	2.6	<0.1	<0.1
Silver	<0.010	0.01	0.01	<0.010	0.01
Strontium	17.4	18.5	20.3	20.6	19.4
Tellurium	<0.050	<0.050	<0.050	<0.050	<0.050
Tin	<0.010	<0.010	<0.010	<0.010	<0.010
Tungsten	<0.010	<0.010	<0.010	<0.010	<0.010
Uranium	0.016	0.017	0.022	0.023	0.017
Zinc	<0.050	0.065	0.074	0.056	<0.050

To determine differences between the Wiluna Discharge and control sites in terms of their surface water chemistry, a one-way ANOVA test was performed, $\alpha = 0.05$ (**Appendix C**). Significant differences between sites were recorded for particular water quality parameters, as follows:

- CaCO3 (p=0.005),
- Antimony (p=0.006)
- Copper (p=0.006)
- Strontium (p=0.04)
- Boron (p=0.013)
- Bromine (p=0.002).
- All other factors showed no differences.

A principal component analysis (PCA) plot of the Lake Way sample locations showed that sites closest to dewatering discharge were similar (indicated by grouping of sites on the plot), and were also different the control sites (two groups of sites are separated) (**Figure 3**). Control sites including LW2 and LW3 had similar water chemistry readings for pH, salinity and metal concentrations and were therefore situated within close proximity of each other on the plot. In comparison control site LW9 had a higher pH and lower salinity concentration, and based on these differences was isolated in the analysis.

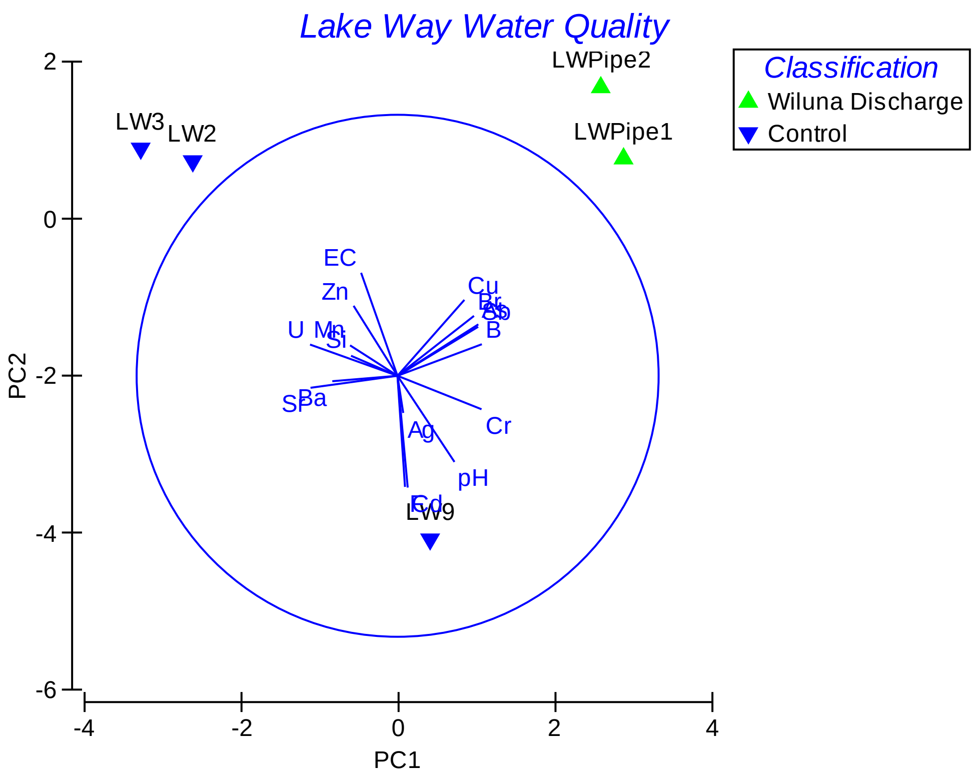

Figure 3 PCA plot of surface water chemistry recorded at the Lake Way sites during the April 2006 assessment. 79.7 % of the variation in the plot is explained by the first two axes indicating a strong relationship between the two dimensional graph and similarity between sites

3.2 Surface Sediment Chemistry

Surface sediment was collected at all accessible sites in 2006. The pH of the sediment varied between sites. The Wiluna Discharge sites were classified as alkaline (8.2 -8.4), as were the control sites (8.4 – 8.6), while the Williamson Pit sites recorded a slightly lower pH of 7.5 to 8.1(**Table 6**). This did not vary greatly from the previous assessment of 2005 where all sites recorded a pH of 8 – 8.5. The relative consistency of the pH at all sites indicates likely consistency in terms of the bioavailability of heavy metals in saline systems, which tend to become toxic at a lower pH (<7) (ANZECC 2000; Parametrix 1995).

The salinity of the sediment measured as EC was relatively low compared to the overlying surface water. The EC at the two Wiluna Discharge sites were similar to each other at approximately 29 000 µS/cm. From 2005, this was an increase of 9000 µS/cm. Sites LW2 and LW9 recorded the lowest EC of the control sites, while LW3 had the highest EC of 40 800 µS/cm. This site is on the same side as the WP sites and because of the direction of the prevailing winds and the fact that it is located against the causeway, the Williamson Pit discharge water may be accumulating at this site. The relevance of LW3 as a control site should be reconsidered, in that context.

The Williamson Pit sites recorded the highest sediment EC ranging from 36500 µS/cm, at WP2, to 53000 µS/cm at WP4. These sites are located within the summer footprint of the discharge, where the discharge water pool and salt concentrates. Sediment salinity decreases with increasing distance from the discharge point, being lowest at site WP7.

The Total Soluble Salts (TSS) measured in the sediment also showed an increase from the previous assessment, and corresponded to the EC. The TSS concentrations exceeded the background data ranges for Lake Way, with the upper range being 150 000 mg/kg and the upper quartile 79 600 mg/kg (**Appendix B**). High TSS were also recorded at the control sites LW2 and LW9 which were on the other side of the causeway. This may indicate that the increase in surface sediment may be due to evapoconcentration of the salts, though site LW3 on the same side recorded high TSS values. This again may indicate an influence form the discharge.

Total nitrogen was the highest at the control sites in the playa with site LW3 recording 460 mg/kg. LW2 also recorded a high TN concentration of 280 mg/kg while LW9 below 20 mg/kg. The differences between the control sites may be due to amount of decomposing invertebrates and faecal matter, particularly at LW3. This site also recorded the highest Total Organic Carbon of 1.6%, which was greater than the normal control ranges for the lake.

Table 6 Sediment chemistry of the Lake Way sites during the April 2006 assessment.

		Sites									
		Wiluna discharge		Williamson Pit discharge					Control		
Parameter	Units	LW Pipe 1	LW Pipe 2	WP2	WP3	WP4	WP6	WP7	LW2	LW3	LW9
pH Value	pH Unit	8.4	8.2	7.5	7.8	7.8	8	8.1	8.4	8.6	8.4
Electrical Conductivity	µS/cm	29400	29800	36500	36900	53000	42300	38700	34800	40800	32500
Total Soluble Salts	mg/kg	95600	96800	119000	120000	172000	137000	126000	113000	133000	106000
Moisture Content	%	42.2	47.6	24.8	16.6	22.9	21.3	20.5	49.2	55.9	24.1
Bicarbonate Alkalinity as $CaCO_3$	meq/kg	62	35	30	22	27	35	84	97	93	164
Carbonate Alkalinity as $CaCO_3$	meq/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Sulphate as $SO4^{2-}$	mg/kg	26800	44000	40600	30600	43800	35800	34300	33900	35200	32400
Sulphur as S	mg/kg	5170	7690	10200	8520	11300	9410	9090	5730	5170	8190
Chloride	mg/kg	66200	70900	87000	54300	89000	67600	48900	86300	135000	52100
Sodium	mg/kg	50600	49900	76400	42100	96600	47200	41600	67600	102000	28500
Potassium	mg/kg	4560	6040	6620	3770	9980	3010	2820	5680	8570	3800
Calcium	mg/kg	3240	205000	68800	108000	12400	112000	109000	3050	3950	24400
Magnesium	mg/kg	21000	20700	16800	15200	22200	12600	11400	15900	19900	20600
Nitrite as N	mg/kg	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Nitrate as N	mg/kg	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Nitrite + Nitrate as N	mg/kg	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00	<1.00
Total Kjeldahl Nitrogen as N	mg/kg	170	120	80	40	70	50	70	280	460	<20
Total Nitrogen as N	mg/kg	170	120	80	40	70	50	70	280	460	<20
Total Phosphorus as P	mg/kg	73	46	53	45	58	46	45	99	114	83
Total Organic Carbon	%	0.87	0.55	0.35	0.22	0.38	0.28	0.33	0.83	1.6	0.22

Sediment quality was compared to both the ANZECC Interim Sediment Quality Guidelines (ISQG) and background data ranges for Lake Way.

Sediments are the ultimate repository for many contaminants that enter aquatic systems and ultimately can have an impact on the biota that live in or on the sediments. ANZECC's ISQG are based on ranked North American data on the effects of contaminants on several benthic organisms and the set that are referred to, are the interim sediment quality trigger values. Concentrations below this value are unlikely to result in biological impacts. These values provide interim guidance until more definitive numbers can be derived. Their application is more in delineating uncontaminated from contaminated sites. One factor that should be taken into account is the availability of contaminants to the biota and that depends on their chemical forms. This is greatly increased if the sediment becomes anoxic and this is usually gauged by a low pH (acidic) (Batley *et al.* 2003).

While excess concentrations of certain metals may be related to anthropogenic factors, they may also be naturally high due to the local geology. In that regard, the background sediment quality ranges for Lake Way, complied by OES, provide a site-specific comparison that takes local conditions into account.

The Arsenic (As) concentrations recorded in Wiluna Discharge sites LWPipe1 and 2, exceeded both the ANZECC ISQG and background data ranges, while the other sites did not exceed either guideline. There was a slight increase from 2005 in the As concentration at WP3, WP4, LW3 and LW9, but the increase was not significant. As has been found to bioaccumulate to some extent in marine organisms but secondary toxicity unlikely (ANZECC 2000).

Chromium at site LWPipe1 exceeded the ISQG but was below the normal ranges for the creek sites. Chromium toxicity decreases with increased salinity.

Cobalt exceeded the background ranges for the creek sites at LWPipe2 but no ISQG values are given for this metal. The other metal that exceeded ISQG values was nickel at both Wiluna discharge sites, Williamson discharge site WP2, and all three control sites. Nickel did not exceed the background ranges at any of these sites, indicating that this metal is naturally high in the Lake Way system, as is typical of many Salinaland playas. Nickel toxicity decreases at higher pH and salinity, and it has been noted that the bioconcentration of Ni is not a significant problem in aquatic environments (ANZECC 2000).

Table 7 Sediment total metal concentrations of the Lake Way sites during the April 2006 assessment.

		Sites									
		Wiluna discharge		Williamson Pit discharge					Control		
Parameter	Units	LW Pipe 1	LW Pipe 2	WP2	WP3	WP4	WP6	WP7	LW2	LW3	LW9
Aluminium	mg/kg	10200	4110	4820	5040	5060	3780	3520	7780	7860	10000
Antimony	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<20	<10
Arsenic	mg/kg	90	196	23	19	12	<10	16	18	38	15
Barium	mg/kg	<100	<100	<100	<100	<100	<100	<100	<100	<200	<100
Boron	mg/kg	<100	<100	<100	<100	<100	<100	<100	<100	<200	<100
Cadmium	mg/kg	<5	<5	<5	<5	<5	<5	<5	<5	<10	<5
Chromium	mg/kg	140	28	40	39	35	32	26	76	47	75
Cobalt	mg/kg	42	234	17	<10	12	<10	<10	<10	<20	12
Copper	mg/kg	29	<10	<10	<10	<10	<10	<10	14	<20	20
Fluoride	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	56	<10
Iron	mg/kg	31000	9190	11500	11200	11300	9500	8370	28600	18100	25200
Lead	mg/kg	<10	<10	<10	<10	<10	<10	11	<10	<20	<10
Manganese	mg/kg	312	555	1600	64	897	215	206	423	169	402
Mercury	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Nickel	mg/kg	45	36	23	13	17	10	<10	27	25	28
Selenium	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<20	<10
Silver	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<20	<10
Strontium	mg/kg	38	1250	395	467	93	498	555	429	134	824
Tellurium	mg/kg	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Tin	mg/kg	<10	<10	<10	<10	<10	<10	<10	<10	<20	<10
Tungsten	mg/kg	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Uranium	mg/kg	18	1.6	2.8	3.4	3	3	2.3	4.5	3.6	9.8
Zinc	mg/kg	34	24	18	<10	13	<10	<10	18	<20	24

A one way ANOVA, plus an LSD *post hoc*, were performed to determine if sites was significantly different from each other in terms of sediment quality, at $\alpha = 0.05$ (**Appendix C**). The differences were as follows:

- The control sites and Wiluna Discharge sites were significantly different in terms of pH (p=0.007)
- The Wiluna Discharge, Williamson Pit and control sites were all significantly different in terms of As concentrations (p=0.041)
- Williamson Pit sites and control sites were significantly different in terms of Co (p=0.023)
- While there was a significant difference amongst sites in terms of Ni concentration, there was no clear difference between the three areas (p=0.001)
- The control and Wiluna Discharge sites differed significantly for Sulphur (p=0.019)
- The control and Williamson Pit sites, and the Wiluna and Williamson Pit sites, showed significant differences for TP (p=0.044)
- The control and Wiluna Discharge sites were significantly different for Zn (p=0.005)

Based on the results of principal component analysis (PCA) of the 2006 Lake Way sediment chemistry, sites were clustered together according to similarity (**Figure 4**). There were clear influences of the two dewatering discharges on sediment chemistry. The Williamson Pit discharge sites appeared to be most similar to each other in terms of sediment chemistry (as shown by the closeness of sites to each other on the plot), followed by the control sites. In contrast, the Wiluna discharge sites were clearly separated from each other, most likely due to the differences in the metals and metalloids.

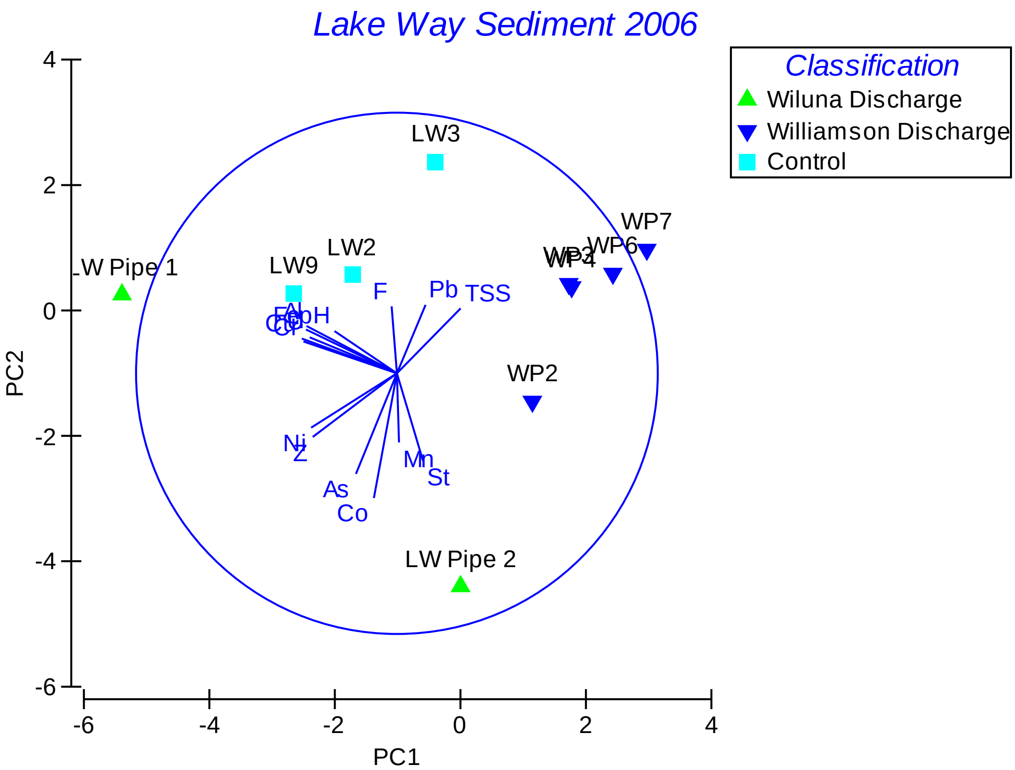

Figure 4 PCA plot of sediment chemistry recorded at the Lake Way sites during the April 2006 assessment. 67.2 % of the variation in the plot is explained by the first two axes indicating a strong relationship between the two dimensional graph and similarity between sites

3.3 Analysis of Historical Water and Sediment Chemistry

Principal component analysis (PCA) was used to determine if there were differences in the sediment and water chemistry of sites in Lake Way over time (2004 – 2006). The resulting PCA plot showed that the sediment chemistry data from 2006 differed markedly from the 2005 and 2004 sampling periods. Reasons for this are possibly related to elevated TSS concentrations and the associated anions and cations measured in the sediments from the current assessment. The 2004 and 2005 sampling periods had similar sediment chemistry, as shown by the overlap in sites. Control sites LW4 and LW6 (from previous assessments) were separated in 2004, and may be based on pH.

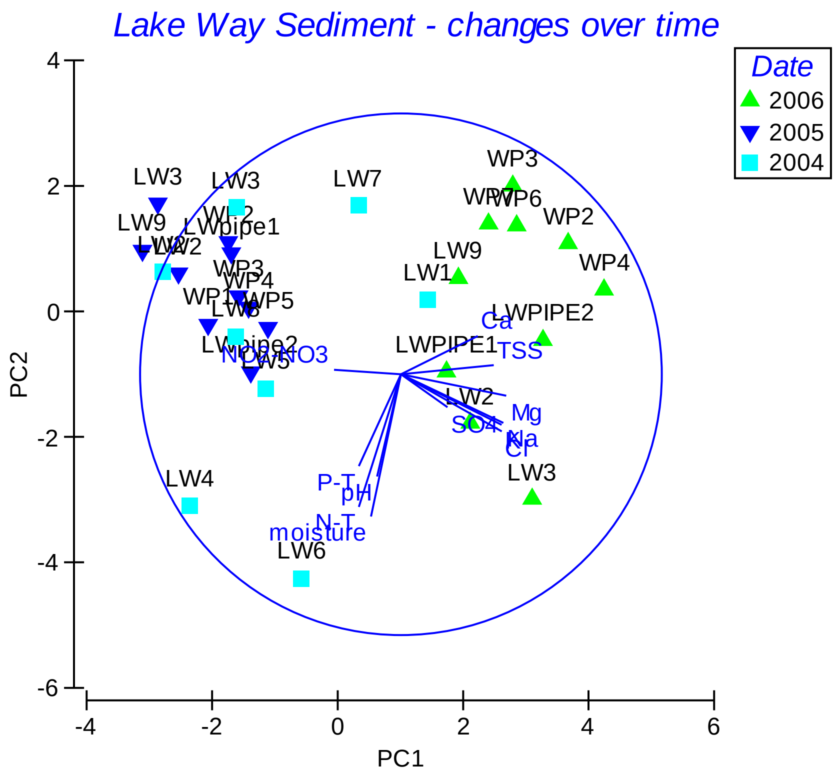

Figure 5 PCA plot of sediment chemistry recorded at the Lake Way sites from 2004 to 2006. 66.4 % of the variation in the plot is explained by the first two axes indicating a strong relationship between the two dimensional graph and similarity between sites

3.4 Microalgae

The term 'microalgae' is relatively general and refers to microscopic algae from a range of different groups including cyanobacteria, green algae and diatoms. They are one of the main primary producers in aquatic systems and can provide valuable information on changing environmental conditions. By monitoring shifts in the diversity and abundance of microalgae the assessment of human impacts such as agriculture and mining can be undertaken.

3.4.1 Phytoplankton

Phytoplankton are free-floating microalgae that live suspended in the water column, and can play and important role in the nutrient cycling of wetland systems (Boulton and Brock 1999). In salt lakes phytoplankton are considered to be rare (Borowitzka 1981), however there are some species that are resilient to the harsh environmental conditions found in these areas.

The surface water samples collected from the Lake Way 2006 assessment identified a total of five taxa comprising of four Bacillariophyceae (diatoms) and one Chlorophyceae (green algae). The species observed were all characteristic of saline environments, and Chlorophyceae was the only true phytoplankton, with the remainder probably having been dislodged from benthic communities.

Wiluna discharge sites LW Pipe1 and LW Pipe2 recorded the highest diversity (three and four species respectively) and abundance (1217 cells/L), although these numbers were still relatively low compared to other salt lakes in WA. *Dunaliella viridis* was the dominant species and is a flagellated green algae, indicative of high salinities (Oren 2005). A number of diatoms were also present, including salt tolerant genera such as *Amphora* and *Navicula* (John 2000). However, these are not true phytoplankton and are generally found in the surface sediments.

In comparison phytoplankton observed from the control sites (LW2, LW3 and LW9A) was limited, with diatoms (*Amphora coffeaeformis* and *Navicula* species) being the only taxa identified. This is in contrast to results from 2004, where Site LW2 and LW3 had a high abundance of cells dominated by Bacillariophyceae and Cyanophyta, although as noted above, these groups are normally associated with BMCs in the lake sediments rather than phytoplankton in the water column.

The difference in abundance, diversity and species composition of microalgae in surface water of the Wiluna discharge and control sites was related to differences in water chemistry of the two areas (Figure 3), and also to the differences in habitats (creek versus playa environment).

Table 8 Phytoplankton abundance recorded from Lake Way surface water samples (April, 2006)

	Abundance (cells/L)				
	Wiluna discharge		Control		
Taxa	LW Pipe 1	LW Pipe 2	LW2	LW3	LW9A
Bacillariophyta (Diatoms)					
Bacillariophyceae					
Amphora coffeaeformis	94		94	94	
Hantzschia sp.		94			
Navicula sp.	187	281	94	281	
Navicula sp. aff *salinicola*					94
Nitzschia sp. aff *rostellata*		187			
Chlorophyta (Green)					
Volvocales					
Dunaliella viridis	936	655	187		
Total Abundance	1217	1217	374	374	94
Total Diversity	3	4	3	2	1

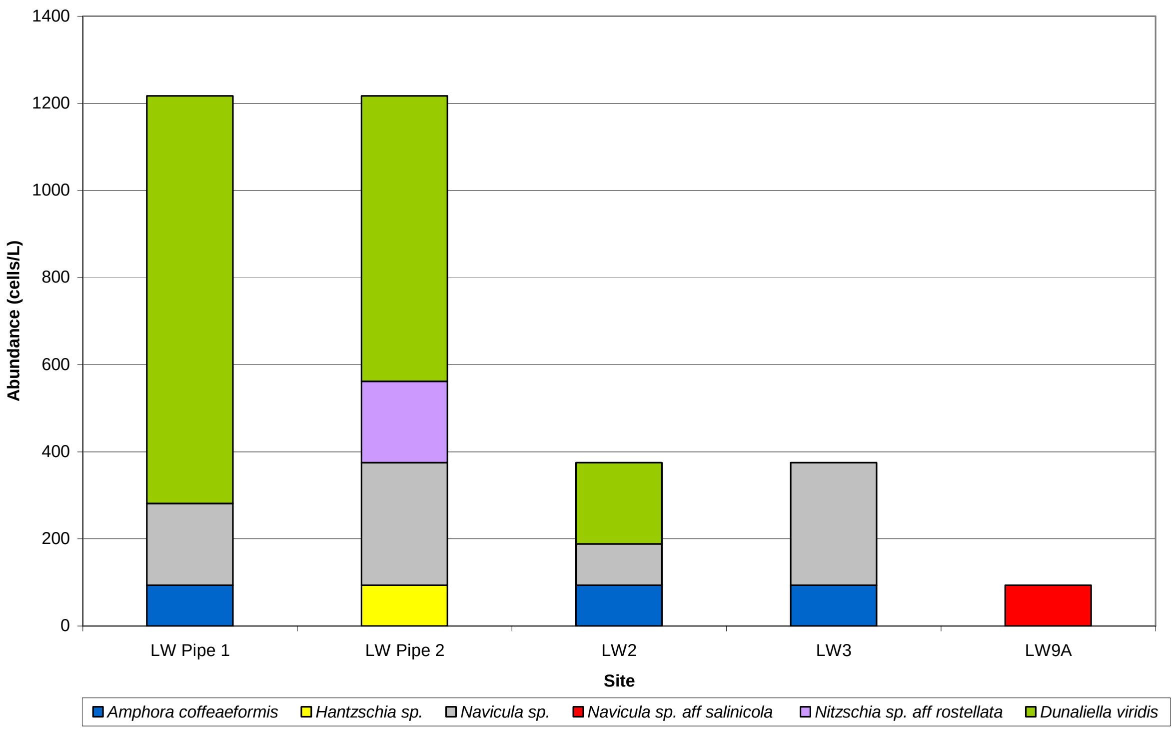

Figure 6 Abundance of phytoplankton taxa recorded in the surface water of Lake Way (April 2006)

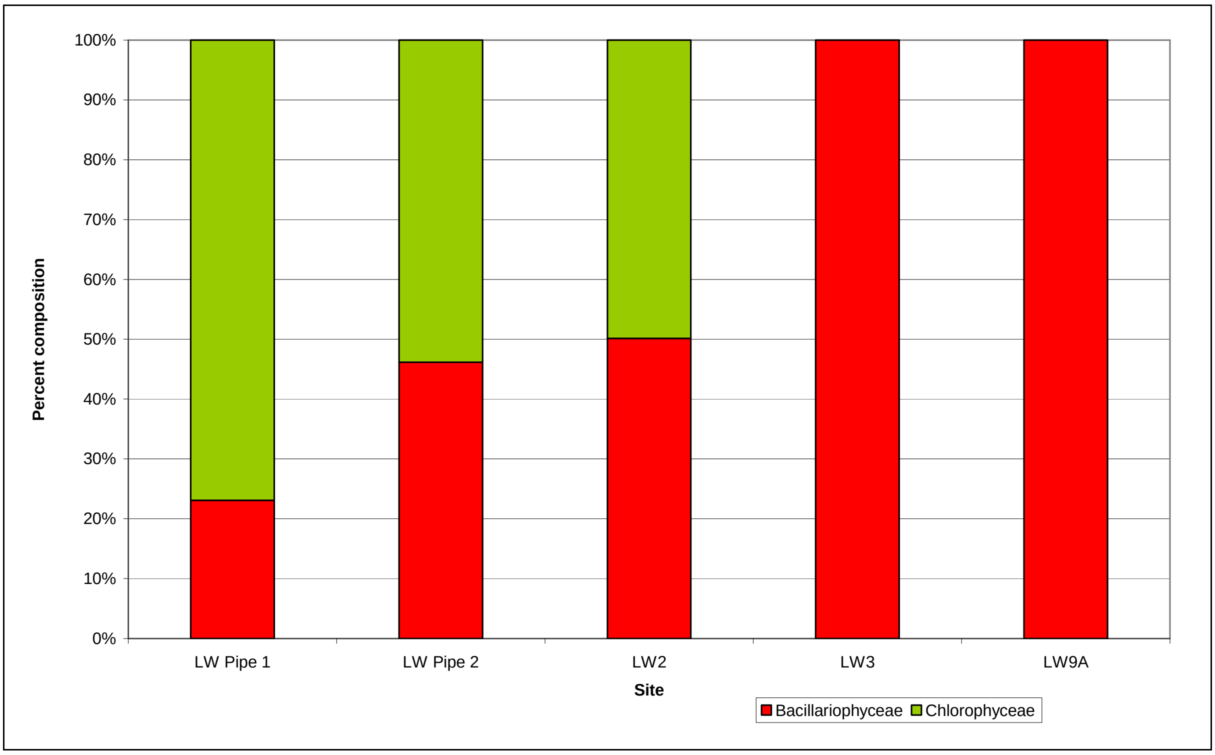

Figure 7 Percentage abundance of phytoplankton groups (phyla) recorded in the surface water of Lake Way (April 2006)

The limited number of phytoplankton observed from the Lake Way sites most likely reflects the extensive benthic microbial communities (BMCs), which restrict the availability of nutrients in the overlying surface waters (Bauld 1986). This is typical of inland salt lakes in this region. Overall, the samples were dominated by saline taxa from Bacillariophyceae, and are commonly found in the sediments from these types of systems. The 2006 data contrasts with the 2004 assessment, when Cyanobacteria (blue-green algae) were the most abundant phytoplankton. Reasons for this include the varying inundation levels and water chemistry of Lake Way, which influence the type of microalgae that dominate the surface waters.

3.4.2 Benthic Microbial Communities (BMCs)

The naturally saline lakes found in the semi-arid and arid zones of Western Australia tend to be shallow and temporary, with much of the productivity occurring in benthic microbial communities (BMCs) in the surface sediments (Borowitzka 1981). BMCs can form extensive mats that may be dominated by the microalgae known as diatoms (Bauld 1981).

Diatoms are unicellular, belonging to the Phylum Bacillariophyta, and have a cosmopolitan distribution in aquatic habitats throughout the world (John 2000). They have a thick cell wall made up of silica with distinct patterns that are characteristic to each species (Cox 1996). This allows them to be easily identified and to survive extended periods of desiccation (John 1998), especially important in the extreme conditions often encountered in inland salt lakes.

Due to the absence of surface water at most of the sample sites from Lake Way in April 2006, diatoms in the BMCs were analysed, with a total of 11 taxa representing seven genera identified. These results were much higher than in previous years, with five species recorded in 2005 and ten species in 2004. Dominant genera included *Amphora*, *Navicula* and *Hantzschia*, following previous studies on the surface sediments from the lake. The majority of taxa classified were classified as halotolerant or able to withstand increases in salinity.

It is important to note that the taxon previously identified as *Navicula durrenbergiana* in the 2004 and 2005 samples from Lake Way (OES, 2004; 2005) has now been separated into *Navicula* sp. aff. *incertata* and *N.* sp. aff*. salinicola*, both of which were found in the current analysis.

The two Wiluna discharge sites were markedly different in species composition, with LWPipe1 recording the highest number of species (seven). In contrast, LWPipe2 had the lowest number of species (three) of all sites assessed in 2006. Both sites featured the salt-tolerant *Amphora coffeaeformis*, one of the most common diatoms found in Western Australian salt lakes (John 1998). However, LWPipe1 had a number of taxa that although saline, may be indicative of the recent rainfall, leading to the highest diversity. Water salinities were lower in LWPipe1 (172 000 mg/L), compared to LWPipe2 (184 000 mg/L), with both readings considered to be of intermediate salinity. As the 2005 assessment did not record any diatoms, the results from the current sampling period suggest that recent rainfall has diluted salts in this region, with the lower salinity allowing for the establishment of a relatively diverse diatom community.

The diversity of the Williamson Pit discharge area was relatively consistent, with four to five species observed at each of the sites (WP2-WP7). Common taxa included *Amphora coffeaeformis*, *Hantzschia* sp. aff. *baltica* and *Navicula* sp. aff. *salinicola*, all of which have been previously documented from saline environments (Taukulis and John 2006; Gell and Gasse 1990). Diatom community structure was a reflection of the high sediment salinities which ranged from 119 000 to 172 000 mg/kg. Once again there was an increase in the productivity at these sites probably related to the higher rainfall than in the 2005 assessment period, and when both the diversity and abundance of diatoms was very low.

All control sites (LW2, LW3 and LW9) showed the same number of species (five) and were dominated by similar diatom assemblages that included *Amphora coffeaeformis* and *Navicula* sp. aff. *salinicola*, found at some of the discharge sites. Although Site LW2 had the highest surface water salinity at 191 000 mg/L, it still displayed a diverse and abundant diatom community, this is most likely due to the presence of water and TN at this site. The control sites recorded consistent species diversity, which in general was higher than that recorded from the 2004 and 2005 sampling events. This indicates that the conditions in the sediments at the control sites were relatively uniform and were conducive to the establishment of diatoms in the BMCs.

Table 9 Diversity and abundance of diatom taxa recorded in the surface sediment of Lake Way (April 2006).

	Sites									
	Wiluna discharge		Williamson Pit discharge					Control		
Taxa	LW Pipe 1	LW Pipe 2	WP2	WP3	WP4	WP6	WP7	LW2	LW3	LW9
Bacillariophyceae										
Luticola mutica								1	1	
Navicula cruciculoides	1									
Navicula sp. 1	4									
Navicula sp. aff. *incertata*		1	9	5	12	6	49	3	9	13
Navicula sp. aff. *salinicola*			35	40	25	4	18	55	38	29
Pinnularia borealis	1									
Amphora coffeaeformis	41	90	30	44	48	4	17	32	49	52
Navicella pusilla			2							
Hantzschia amphioxys	1					3				1
Hantzschia sp. aff. *baltica*	47	9	24	11	15	83	16	9	3	5
Nitzschia sp. aff. *rostellata*	5									
Total	100	100	100	100	100	100	100	100	100	100
Diversity	7	3	5	4	4	5	4	5	5	5

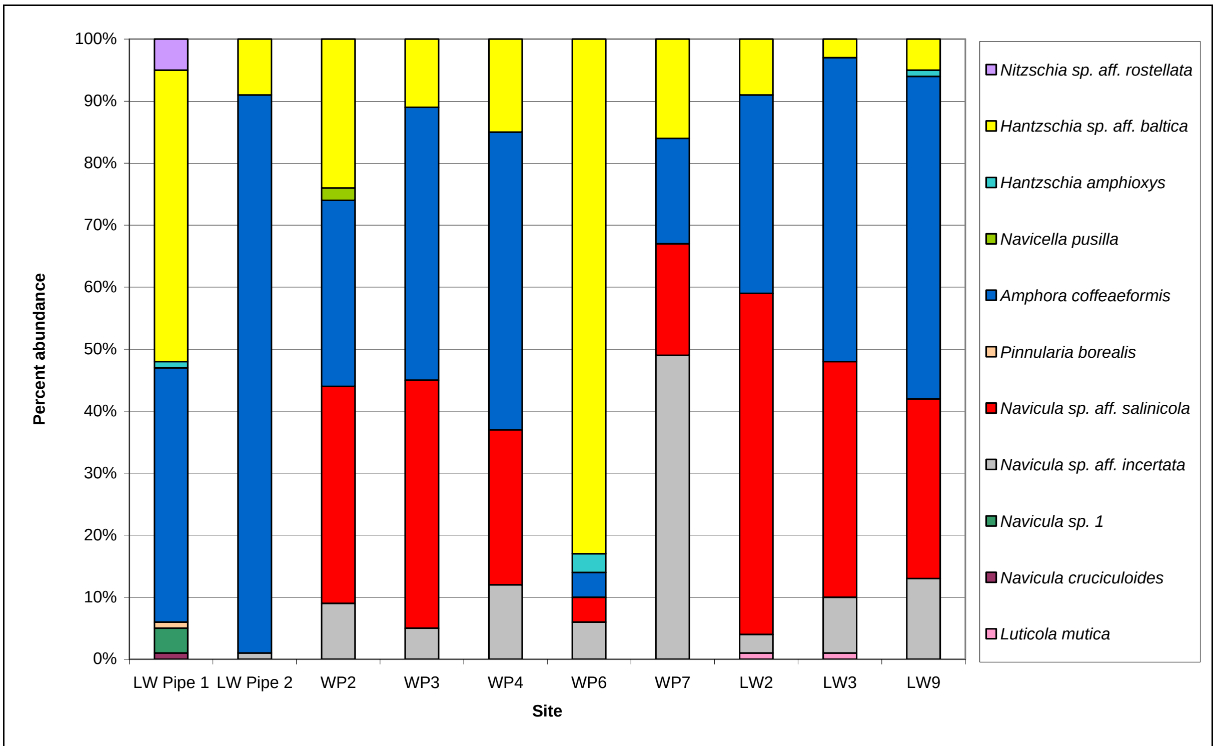

Figure 8 Percentage abundance of diatom taxa recorded in the surface sediment of Lake Way (April 2006)

In general, diatom communities from all sites were very similar, and dominated by well-known salt-tolerant species. The abundance of diatoms from each site was also high, in comparison to previous years assessments in 2004 and 2005, due to an adequate availability of silica and nutrients required for growth and development, and probably also the positive influence of rainfall. These results also indicate that the discharge was most likely not affecting diatom assemblages in the BMCs at the time of sampling in 2006.

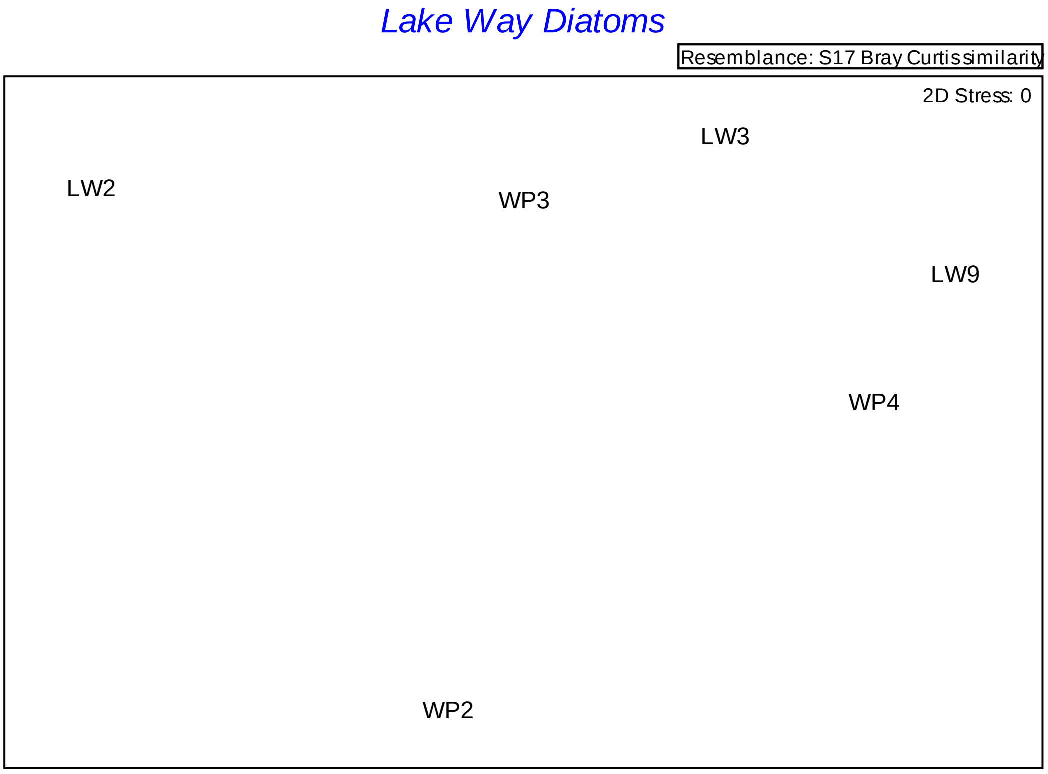

Figure 9 MDS Plot of diatom community structure in Lake Way (April 2006)

An ANOSIM was used to determine if there was a significant difference between discharge and control sites, in terms of diatom assemblages. The results showed no significant differences between sites. This is supported by the MDS plot of the diatom community structure of the sites. It shows differences between the sites in terms of distance between them on the MDS plot (**Figure 9**). There was some intermingling of normally separated sites such as the WP sites. The global r value was 0.14 (close to 1 is very significant) and the significance level is 20.3% ($p = 0.2$), therefore there was no significant difference between sites ($p<0.05$). This result indicates that the diatoms were present at the sites predominantly due to the presence of surface water, irrespective of the quality of water.

3.5 Aquatic Invertebrates

The aquatic invertebrates that inhabit the inland waters of Western Australia are predominantly the Crustaceans (Williams 1998). They are dominated by a restricted number of Branchiopods, in particular the endemic brine shrimp, *Parartemia* (Order Anostraca) and also members of the seed shrimp (Subclass Ostracoda) (De Deckker 1983; Williams 1998).

3.5.1 Live invertebrates

Four invertebrate taxa were identified from five sites during the April 2006 monitoring program in Lake Way. Species diversity was typically low, with only four different taxa from three Subclasses - the Branchiopoda, Ostracoda and Copepoda (**Table 10**). As recorded in many Australian inland waters, all taxa belonged to the Class Crustacea. Because of minimal population, no statistical analyses could be performed on the invertebrate data.

Two species of *Parartemia* were recorded from the Lake Way study sites and had been recorded in the 2005 assessment. *Parartemia* sp. 2 dominated the playa sites (control sites LW2, LW3, LW9A) while *Parartemia* sp. 1 dominated the creek sites (Wiluna Discharge sites, LWPipe1 and LWPipe2). Generally, *Parartemia* do not occur in sympatry with other *Parartemia* species, but because of the distance and differences in habitat between the Wiluna discharge sites and the control sites, the presence of two species is not considered sympatric in Lake Way. Both populations displayed signs of sexual maturity, and amplexing (males attaching to the females to initiate copulation) was obvious. The *Parartemia* population at the playa sites appeared to have undergone a ‘second recruitment’ as there were large stands of dead *Parartemia* along the shoreline at sites LW3, and many of the live females contained brown cysts in their brood pouches indicating sexual maturity and the imminent release of cysts.

Diversity in Lake Way appears to be naturally depauperate, and since the 2004 assessment by OES, only three different taxonomic groups have been identified from the samples. They are consistently the Anostraca, Ostracoda and Copepoda. The high salinities at these sites appear to be the overriding factor limiting diversity of aquatic invertebrates, as both control and discharge sites have the same halobiont species. The Williamson Pit sites did not record any live invertebrates due to the absence of surface water.

In previous assessments there has been a dominance by the Cyclopoid copepods present in Lake Way playa sites though they were absent during the 2006 assessment. The nature of the biota of temporary systems is such that the resting stages emerge at different stages of the hydric cycle allowing each group to benefit and exclude excessive competition. While the species diversity in Lake Way is minimal, the system is productive and provides a valuable food source for many nomadic birds such as the plovers.

Table 10 **Aquatic Invertebrates collected from Lake Way (April, 2006)**

	No/100 Litre				
Taxa	**LWPipe1**	**LWPipe2**	**LW2**	**LW3**	**LW9A**
<u>Crustacea</u>					
Anostraca					
Parartemia sp. 1	2	14			
Parartemia sp. 2			6	3	3
Ostracoda					
Reticypris sp.	6	5	8	14	8
Copepoda					
Harpacticoida	1				
Abundance	**10**	**19**	**14**	**17**	**11**
Diversity	**3**	**2**	**2**	**2**	**2**

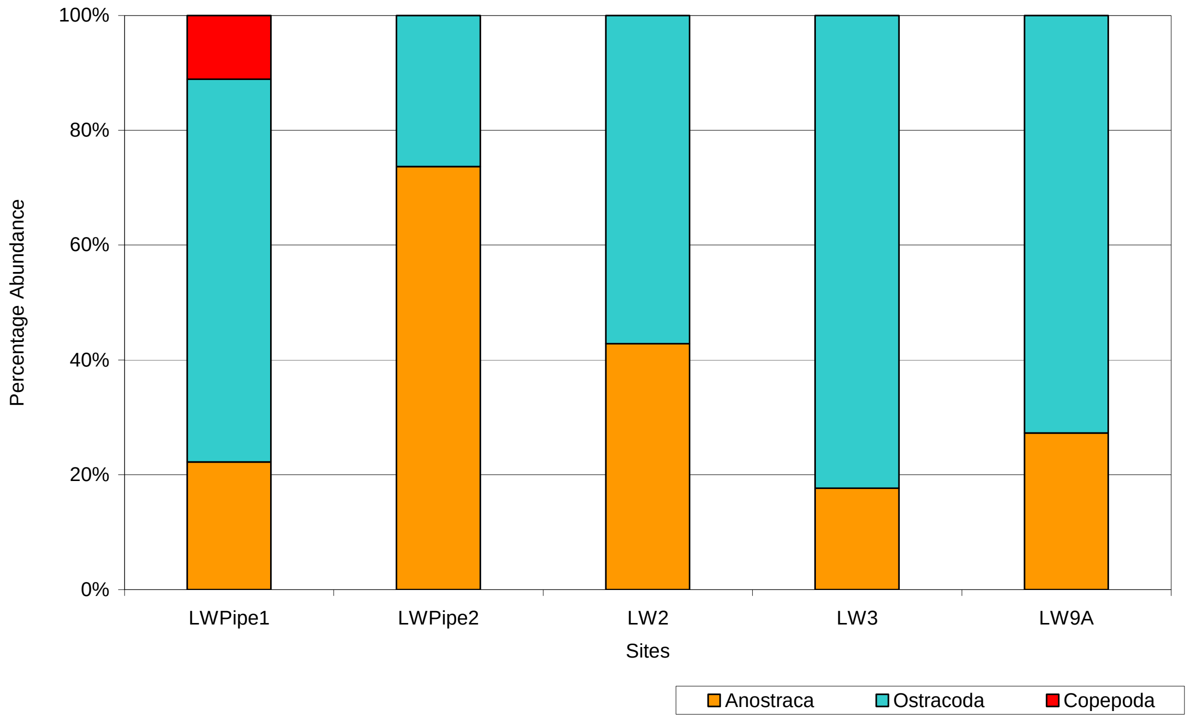

Figure 10 **Percentage abundance of aquatic invertebrates in Lake Way (April, 2006)**

4.0 Avian Fauna

Opportunistic sightings of the avian fauna that visited and used the Lake Way playa were recorded during the 2006 monitoring program. The avian population was mostly restricted to the Red-capped plovers and Black-winged stilts, though the occasional crow and predatory bird such as the falcon were also noted (**Table 11**).

The presence of *Parartemia* and ostracods provide a valuable food source for the smaller shoreline birds such as the plovers and stilts. The activity observed at the Wiluna Discharge sites (presence of guano at roosting sites along the shoreline and large numbers of plover prints) indicate these birds visit the area frequently, though no active nesting or breeding activities were recorded.

Table 11 Avian fauna observations at Lake Way sites (April, 2006)

COMMON NAME	SPECIES	NUMBER	LOCATION	COMMENTS
Red-capped Plover	*Charadrius ruficapillus*	10	LWPipe1	Foraging on sandbank
Falcon		1	LWPipe1	Hovering above Creek
Crows	*Corvus bennetti*		LWPipe2	Calls heard
Black-winged Stilt	*Himantopus himantopus*	62	Lake Way Causeway	Flying over Causeway
Red-necked Avocet	*Recurvirostra novaehollandiae*	2	Lake Way Causeway	Flying over Causeway

Waterbird usage of Lake Way continues to be classified as breeding, feeding or loafing. The presence of the brine shrimp, *Parartemia*, and the seed shrimp, Ostracods, in the playa and the creek sites continue to provide the smaller water birds such as the waders, with ample food.

4.0 CONCLUSION

During the 2006 monitoring of Lake Way surface water was restricted to the Wiluna discharge creek sites, LWPipe1 and LWPipe2 (assessed for comparison to the playa sites) and the control sites LW2, LW3 and LW9 (LW9A was sampled as no water was present at LW9), located in low-lying areas of Lake Way. The surface water was classified as hypersaline and there was an increase in salinity levels at all sites. While higher than average rainfall fell at Wiluna in the early part of the year, concentration of salts probably occurred over the month of drying between rainfall and sampling. Surface water movement across the lake is dictated by the prevailing wind resulting in much of the water concentrated in the south-western sections, trapped by the causeway. Salinity appeared to be the overriding factor in the differentiation of the sites, especially from previous assessment as shown by PCA plots. The control site LW3 recorded increased salinity levels and this may be due to the Williamson Pit discharge water being blown south.

The total soluble salts (TSS) measured in the sediment also showed an increase from the previous assessment and corresponded to the increased EC. The TSS also exceeded the background data ranges for Lake Way, collated by OES. While evapoconcentration and local elevation may be a factor in elevated salinity at some sites, the data suggests that dewatering discharge had caused local increases in sediment salinity during the April 2006 assessment, as was expected. The data shows that the Williamson dewatering discharge has pooled within the expected ‘footprint’, but that wind movement of surface water has caused a slight extension of this footprint to the west of the Williamson discharge point.

Of the metals and metalloids analysed in the water and sediment samples, a few exceeded the ANZECC trigger values and ISQ guidelines, respectively. Because of the lack of available information and being mostly based on marine water, comparisons were also made to the more-relevant background data ranges for Lake Way.

For surface water, the Wiluna Discharge sites (creek) exceeded the ANZECC guidelines for Cu at both LWPipe1 and 2, and Zn at LWPipe2. The control sites showed Cu to exceed the guidelines at all sites, while Zn exceeded the guidelines at LW2 and LW3. All these though were below the background ranges for Lake Way. Comparisons with the Williamson Pit sites could not be made because of lack of surface water.

Sediments are the ultimate repository for many contaminants that enter aquatic systems and ultimately can have an impact on the biota that live in or on the sediments. The Wiluna Discharge sites, LWPipe1 and 2 exceeded the ANZECC ISQG values for As and Cr at LWPipe1. The only other metal that exceeded these guidelines was Ni, at the Wiluna Discharge sites and the control sites (LW2, LW3 and LW9). It should be noted that no metal or metalloid concentrations exceeded the site-specific background data ranges for Lake Way. This indicates that detectable concentrations of metals such as Ni were more likely related to geological setting than dewatering discharge, as the control and discharge sites recorded similar concentrations.

Toxicity and bioavailability of metals and metalloids is affected by salinity and pH. At low pH and salinities the toxicity of many metals increases. Lake Way sediment and surface water was hypersaline and alkaline, the pH having increased from previous assessments. While there appears to be an increase in some elements, the high salinities and alkalinity may be inhibiting bioaccumulation in the food chain.

The surface water samples collected from the Lake Way 2006 assessment identified a total of five taxa comprising of four Bacillariophyceae (diatoms) and one Chlorophyceae (green algae). The species observed were all characteristic of saline environments, and Chlorophyceae was the only true phytoplankton. Wiluna discharge sites LWPipe1 and LWPipe2 recorded the highest diversity (three and four species respectively) and abundance (1217 cells/L). *Dunaliella viridis* was the dominant species. The control sites were comparatively limited in terms of the diversity and abundance of phytoplankton, and the 2006 results were quite different from the 2005 results. These differences were attributed to the timing of sampling within the hydric cycle, and the different habitat provided by the discharge and control sites (creek versus playa).

Due to the absence of surface water at most of the sample sites from Lake Way in April 2006, diatoms in the BMCs were analysed, with a total of 11 taxa representing seven genera identified. These results were higher than in previous years, with five species recorded in 2005 and ten species in 2004. Dominant genera included *Amphora*, *Navicula* and *Hantzschia*, following previous studies on the surface sediments from the lake. The majority of taxa classified were classified as halotolerant or able to withstand increases in salinity. In general, the diatom communities were very similar between all sites, and were dominated by well-known salt-tolerant species. The abundance of diatoms from each site was also high, in comparison to previous years (OES, 2004; 2005), with there being greater availability of silica and nutrients required for growth and development. The data indicates that the discharge was most likely not affecting diatom assemblages in the BMCs during the 2006 assessment, and that the presence of surface water had a greater influence on diatom presence and productivity.

Four invertebrate taxa were identified from five sites during the Lake Way May 2006 monitoring program. Species diversity was typically low, with only four different taxa from three Subclasses - the Branchiopoda, Ostracoda and Copepoda. As is typical of Australian inland waters, all taxa belonged to the Class Crustacea. Two species of *Parartemia* were recorded form the samples, *Parartemia* sp.1 from creek sites and *Parartemia* sp. 2 in the playa. Diversity in Lake Way is naturally depauperate and since the 2004 assessment by OES, only three different taxonomic groups have been identified from the samples. They are consistently the Anostraca, Ostracoda and Copepoda. The high salinities at these sites appear to be the overriding factor as both control and impact sites have the same halobiont species. The Williamson Pit sites did not record any invertebrates but this was due to the absence of surface water.

The avian fauna recorded in 2006 were restricted to the plovers, stilts and avocets. These are all nomadic species that prefer the shallow waters of the playas and feed primarily on invertebrates such as the brine shrimp.

The increase in salinity and certain metals at April 2006 does not appear to have had a detrimental affect on the limited biota in Lake Way. The presence of the dominant crustacean, the endemic brine shrimp, *Parartemia*, was recorded and there appeared to have been a second recruitment. While phytoplankton was less than the previous assessment this may be a result of being consumed by the invertebrates, with the high nitrogen levels possibly supporting this. The decrease in phytoplankton was related to an increase in diatoms, which are an excellent source of food for the sediment feeders such as the ostracods and the brine shrimp.

Avian fauna were present in Lake Way though not in the large numbers sometimes associated with inland salt playas. This may have been related to the time of day, the season and the position of Lake Way in the hydric cycle (drying phase).

While there doesn’t appear to be a negative impact on the biota of Lake Way from the Wiluna and Williamson discharges, an increase in salinity has been recorded, particularly at control site LW3 which is located west of the Williamson discharge point. This site had TSS levels similar to the Williamson Pit sites and therefore the discharge may be accumulating there. The nearby causeway probably acts as a barrier and trap to surface water, and the aquatic invertebrates within it. Similar to other large playas, the level of salinity in Lake Way may be dissipated with adequate rainfall, as no thick salt crusts were observed.

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Appendix A

Lake Way Playa/Creek Water Quality Ranges

Parameter	Units	Control				Creek			
		Min	Max	N	UQ	Min	Max	N	UQ
Aluminium	mg/L	BD	NT	3		NT	NT		
Antimony	mg/L	BD	0.85	19		BD	2.5	69	
Arsenic	mg/L	BD	0.63	24		0.005	2.76	70	0.56175
Barium	mg/L	0.079	0.238	5	0.212	NT	NT		
Beryllium	mg/L	BD		2		NT	NT		
Bicarbonate Alkalinity as $CaCO_3$	mg/L	48	126	10	103.75	160	160	1	160
Boron	mg/L	0.11	9.41	18	3.37	0.1	37.17	59	16.71
Bromine	mg/L	14.3	49.6	4	49.15				
Cadmium	mg/L	BD	0.04	24		BD	1.1	70	
Calcium	mg/L	607	1100	10	1045	860	860	1	860
Carbonate Alkalinity as $CaCO_3$	mg/L	BD	NT	5					
Chloride	mg/L	150 00	103 000	10	58 150	69 000	69 000	1	69 000
Chlorophyll *a*	mg/L	BD	0.0072	5		BD	0	1	
Chromium	mg/L	BD	0.12	23		BD	0.49	70	
Cobalt	mg/L	BD	NT	20		BD	0.96	69	
Copper	mg/L	BD	0.042	23		BD	0.9	70	
Electrical Conductivity @ 25℃	µS/cm	26 000	210 000	10	1 50 250	150 000	150 000	1	150 000
Fe (soluble)	mg/L	BD	4.3	5		1.4	1.4	1	1.4
Fluoride	mg/L	BD	1.1	5					
Hydroxide Alkalinity as $CaCO_3$	mg/L	BD		2					
Iron	mg/L	BD	3.41	2					
Lead	mg/L	BD	0.27	24		BD	13	71	
Magnesium	mg/L	780	5470	10	2997.5	3400	3400	1	3400
Manganese	mg/L	BD	0.132	17		BD	3.6835	69	
Mercury	mg/L	BD	NT	21		BD	0.001	71	
Nickel	mg/L	BD	0.13	21		BD	4.4	69	
Nitrate as N	mg/L	BD	5.4	4					
Nitrite + Nitrate as N	mg/L	BD	5.4	4					
Nitrite as N	mg/L	BD		10		BD	0	1	
pH Value	pH units	5.6	8.82	24	8.045	6.8	9.6	61	8.32
Potassium	mg/L	850	5090	10	2890	3100	3100	1	3100
Selenium	mg/L	BD	0.18	23		BD	1.722	65	
Silica	mg/L	BD	2.6	5					
Silver	mg/L	BD	0.01	5					
Sodium	mg/L	8 700	57 200	10	35 150	46 000	46 000	1	46 000
Strontium	mg/L	7.96	20.6	5	20.3				
Sulphate as SO_4^{2-}	mg/L	4 900	21 500	10	15 725	24 000	24 000	1	24 000
Sulphur as S	mg/L	5650	7170	3	7035				
Tellurium	mg/L	BD		5					
Tin	mg/L	BD		5					
Total Organic Carbon	mg/L	4.8	7.2	5	6.9	16	16	1	16
Total Alkalinity as $CaCO_3$	mg/L	48	126	5	112				
Total Dissolved Solids @180℃	mg/L	10 560	229 800	24	138 750	2700	260 000	60	132 600
Total Kjeldahl Nitrogen as N	mg/L	4.6	5	2	4.9				
Total Nitrogen as N	mg/L	0.61	5	7	2.9	1.7	1.7	1	1.7
Total Phosphorus as P	mg/L	BD	0.36	10		0.1	0.1	1	0.1
Tungsten	mg/L	BD	0	5					
Uranium	mg/L	BD	0.023	5					
Vanadium	mg/L	BD		2					
WAD CN	mg/L	BD	0.02	5		BD		1	
Zinc	mg/L	BD	0.7	19		BD	1	70	0.23

Appendix B

Lake Way Playa/Creek Sediment Quality Ranges

Parameter		Control Min	Control Max	Control N	Control UQ	Creek Min	Creek Max	Creek N	Creek UQ
Alkalinity	meq/kg	93	164	3	130.5				
Aluminium	mg/kg	7 780	10 000	3	8 930				
Antimony	mg/kg	BD		3					
Antimony	mg/kg	BD	8	57		BD	11	107	
Arsenic	mg/kg	2.8	67	62	21.75	BD	85	98	
Barium	mg/kg	BD		6					
Beryllium	mg/kg	BD		3					
Bicarbonate Alkalinity as $CaCO_3$	meq/kg	93	6200	10	4370				
Boron	mg/kg	BD	165	47		23	340	75	185
Cadmium	mg/kg	BD	0.2	63		BD	1.2	97	
Calcium	mg/kg	880	24 400	13	4 400				
Carbonate Alkalinity as $CaCO_3$	meq/kg	BD		3					
Chloride	mg/kg	2 020	13 5000	13	52 100				
Chromium	mg/kg	16	785	62	200	9	1 690	99	186.5
Cobalt	mg/kg	BD	17	69		BD	48	89	
Copper	mg/kg	BD	112	63		5	108	99	32.5
Electrical Conductivity @ 25℃	µS/cm	6 770	40 800	6	34 2 25				
Fluoride	mg/kg	BD	56	3					
Gold	mg/kg								
Iron	mg/kg	12 300	37 600	6	27 750				
Lead	mg/kg	BD	24	61		BD	53	99	
Magnesium	mg/kg	110	20 600	13	4 500				
Manganese	mg/kg	24	525	56	247.5	77	979	99	300
Mercury	mg/kg	BD	0.046	63	0.013	BD	0.152	93	
Moisture Content (dried @ 103℃)	%	17.7	59	23	49.2				
Nickel	mg/kg	5	63	59	27	5	165	95	31
Nitrate as N (Sol.)	mg/kg	BD		6					
Nitrite + Nitrate as N (Sol.)	mg/kg	BD		13					
Nitrite as N (Sol.)	mg/kg	BD		6					
pH Value	pH Unit	7.5	8.6	13	8.4				
Potassium	mg/kg	230	8 570	13	3 800				
Selenium	mg/kg	BD	10	59	10	BD	27	50	
Silver	mg/kg	BD		6					
Sodium	mg/kg	1 420	102 000	13	28 500				
Strontium	mg/kg	134	1 030	6	759.75				
Sulphate as SO_4^{2-}	mg/kg	9 500	43 000	13	32 400				
Sulfur	mg/kg	5 170	8 190	3	6 960				
Tellurium	mg/kg	BD		3					
Tin	mg/kg	BD		6					
Total Kjeldahl Nitrogen as N	mg/kg	BD	460	6	415				
Total Nitrogen as N	mg/kg	BD	460	13	667.5				
Total Organic Carbon	%	BD	1.6	6	1.215				
Total Phosphorus as P	mg/kg	12	350	13	270				
Total Soluble Salts	mg/kg	22 000	133 000	13	110 000				
Tungsten	mg/kg	BD		3					
Uranium	mg/kg	3.6	9.8	3	7.15				
Vanadium	mg/kg	35	107	3	85				
Zinc	mg/kg	BD	61	59	30.25	8	155	99	45
WAD CN	mg/kg	BD		14					

Appendix C

Statistical Analysis (Minitab v14.0) of Water and Sediment Data, April 2006

Normality Test performed on data initially. Johnson's Transformation used to transform data (designed by a "T" in the title). A *post hoc* test using Fisher's Least Significant Difference was performed on samples with more than two groups to determine which was significantly difference ($p \leq 0.05$).

Water Quality

One-way ANOVA: Bicarbonate Alkalinity as CaCO3 versus Classification

```
Source          DF      SS      MS      F      P
Classification   1  3763.2  3763.2  55.89  0.005
Error            3   202.0    67.3
Total            4  3965.2

S = 8.206   R-Sq = 94.91%   R-Sq(adj) = 93.21%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev    +---------+---------+---------+---------
C      3  116.00   8.72    (-----*-----)
WD     2  172.00   7.07                         (-------*------)
                           +---------+---------+---------+---------
                         100       125       150       175
Pooled StDev = 8.21
```

One-way ANOVA: Antimony versus Classification

```
Source          DF         SS         MS      F      P
Classification   1  0.0028812  0.0028812  46.47  0.006
Error            3  0.0001860  0.0000620
Total            4  0.0030672

S = 0.007874   R-Sq = 93.94%   R-Sq(adj) = 91.91%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level  N      Mean     StDev  --------+---------+---------+---------+-
C      3  0.020000  0.009165  (-----*-----)
WD     2  0.069000  0.004243                    (------*------)
                              --------+---------+---------+---------+-
                                    0.025     0.050     0.075     0.100
Pooled StDev = 0.007874
```

One-way ANOVA: Copper versus Classification

```
Source          DF         SS         MS      F      P
Classification   1  0.0006348  0.0006348  50.12  0.006
Error            3  0.0000380  0.0000127
Total            4  0.0006728

S = 0.003559   R-Sq = 94.35%   R-Sq(adj) = 92.47%

                              Individual 95% CIs For Mean Based on
                              Pooled StDev
Level  N      Mean     StDev  --------+---------+---------+---------+-
C      3  0.039000  0.004359  (------*------)
WD     2  0.062000  0.000000                      (-------*-------)
                              --------+---------+---------+---------+-
                                    0.040     0.050     0.060     0.070
Pooled StDev = 0.003559
```

One-way ANOVA: Strontium versus Classification

```
Source          DF     SS     MS      F      P
Classification   1  5.547  5.547  12.02  0.040
Error            3  1.385  0.462
Total            4  6.932

S = 0.6795   R-Sq = 80.02%   R-Sq(adj) = 73.36%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev    -+---------+---------+---------+--------
C      3  20.100  0.624                      (-------*-------)
WD     2  17.950  0.778    (----------*---------)
                           -+---------+---------+---------+--------
                         16.5      18.0      19.5      21.0
Pooled StDev = 0.679
```

One-way ANOVA: Boron versus Classification

Source	DF	SS	MS	F	P
Classification	1	3.523	3.523	28.51	**0.013**
Error	3	0.371	0.124		
Total	4	3.893			

```
S = 0.3515   R-Sq = 90.48%   R-Sq(adj) = 87.31%
                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  --+---------+---------+---------+-------
C      3  2.9067  0.3911  (-------*-------)
WD     2  4.6200  0.2546                      (---------*---------)
                          --+---------+---------+---------+-------
                          2.40      3.20      4.00      4.80
Pooled StDev = 0.3515
```

One-way ANOVA: Bromine versus Classification

Source	DF	SS	MS	F	P
Classification	1	974.70	974.70	117.91	**0.002**
Error	3	24.80	8.27		
Total	4	999.50			

```
S = 2.875   R-Sq = 97.52%   R-Sq(adj) = 96.69%
                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  ----+---------+---------+---------+-----
C      3  48.800  0.917  (----*---)
WD     2  77.300  4.808                        (----*-----)
                         ----+---------+---------+---------+-----
                           48        60        72        84
Pooled StDev = 2.875
```

Sediment Quality

One-way ANOVA: TAs versus Classification

Source	DF	SS	MS	F	P
Classification	2	5.151	2.575	5.21	**0.041**
Error	7	3.459	0.494		
Total	9	8.610			

S = 0.7029   R-Sq = 59.83%   R-Sq(adj) = 48.35%

```
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level  N     Mean   StDev  ---+---------+---------+---------+------
C      3  -0.0129  0.6816     (---------*--------)
WD     2   1.3296  0.2434                (----------*-----------)
WP     5  -0.5692  0.7859  (------*-------)
                           ---+---------+---------+---------+------
                           -1.0       0.0       1.0       2.0
Pooled StDev = 0.7029
```

Fisher 95% Individual Confidence Intervals

All Pairwise Comparisons among Levels of Classification

Simultaneous confidence level = 88.90%

Classification = C subtracted from:

Classification	Lower	Center	Upper
WD	-0.1749	1.3425	2.8598
WP	-1.7702	-0.5563	0.6576

```
Classification  ------+---------+---------+---------+---
WD                           (-------*------)
WP                     (-----*-----)
                ------+---------+---------+---------+---
                   -2.0       0.0       2.0       4.0
```

Classification = WD subtracted from:

Classification	Lower	Center	Upper
WP	-3.2895	-1.8988	-0.5081

```
Classification  ------+---------+---------+---------+---
WP              (------*-----)
                ------+---------+---------+---------+---
                   -2.0       0.0       2.0       4.0
```

One-way ANOVA: TCo versus Classification

Source	DF	SS	MS	F	P
Classification	2	3.331	1.666	6.73	**0.023**
Error	7	1.731	0.247		
Total	9	5.063			

S = 0.4973   R-Sq = 65.80%   R-Sq(adj) = 56.03%

```
                               Individual 95% CIs For Mean Based on
                               Pooled StDev
Level  N     Mean   StDev  ---------+---------+---------+---------+
C      3   0.0447  0.5646   (--------*-------)
WD     2   1.2999  0.4635                (---------*----------)
WP     5  -0.2123  0.4688  (-----*------)
                           ---------+---------+---------+---------+
                                 0.00      0.80      1.60      2.40
Pooled StDev = 0.4973
```

Fisher 95% Individual Confidence Intervals

All Pairwise Comparisons among Levels of Classification

Simultaneous confidence level = 88.90%

Classification = C subtracted from:

Classification	Lower	Center	Upper
WD	0.1817	1.2552	2.3288
WP	-1.1158	-0.2570	0.6018

```
Classification  -------+---------+---------+---------+--
WD                                (------*-------)
```

```
WP                          (----*-----)
                 -------+---------+---------+---------+--
                     -1.5       0.0       1.5       3.0

Classification = WD subtracted from:
Classification    Lower   Center    Upper
WP               -2.4961  -1.5122  -0.5283
Classification   -------+---------+---------+---------+--
WP               (------*-----)
                 -------+---------+---------+---------+--
                     -1.5       0.0       1.5       3.0
```

One-way ANOVA: T_MC versus Classification

```
Source          DF     SS     MS     F      P
Classification   2  4.873  2.437  4.96  0.045
Error            7  3.436  0.491
Total            9  8.309

S = 0.7006   R-Sq = 58.65%   R-Sq(adj) = 46.84%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N     Mean   StDev  -----+---------+---------+---------+----
C      3   0.6877  1.0454              (---------*--------)
WD     2   0.5349  0.1834           (----------*-----------)
WP     5  -0.7656  0.5515  (------*-------)
                           -----+---------+---------+---------+----
                             -1.0       0.0       1.0       2.0
Pooled StDev = 0.7006
```

Fisher 95% Individual Confidence Intervals

```
All Pairwise Comparisons among Levels of Classification
Simultaneous confidence level = 88.90%
Classification = C subtracted from:
Classification    Lower   Center    Upper
WD               -1.6652  -0.1529   1.3594
WP               -2.6631  -1.4533  -0.2434

Classification   --------+---------+---------+---------+-
WD                      (---------*---------)
WP               (-------*-------)
                 --------+---------+---------+---------+-
                      -1.5       0.0       1.5       3.0

Classification = WD subtracted from:
Classification    Lower   Center   Upper
WP               -2.6864  -1.3004  0.0856
Classification   --------+---------+---------+---------+-
WP               (--------*---------)
                 --------+---------+---------+---------+-
                      -1.5       0.0       1.5       3.0
```

One-way ANOVA: Nickel versus Classification

```
Source          DF      SS     MS      F      P
Classification   2  1004.0  502.0  21.12  0.001
Error            7   166.4   23.8
Total            9  1170.4

S = 4.875   R-Sq = 85.79%   R-Sq(adj) = 81.72%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  -+---------+---------+---------+--------
C      3  26.667  1.528            (------*-----)
WD     2  40.500  6.364                        (--------*-------)
WP     5  14.600  5.505  (-----*----)
                         -+---------+---------+---------+--------
                         10        20        30        40
```

```
Pooled StDev = 4.875
```

Fisher 95% Individual Confidence Intervals

```
All Pairwise Comparisons among Levels of Classification
Simultaneous confidence level = 88.90%
Classification = C subtracted from:
Classification    Lower   Center   Upper
WD                 3.310   13.833  24.357
WP              -20.485  -12.067  -3.648

Classification  --------+---------+---------+---------+-
WD                                  (----*----)
WP                       (---*---)
                --------+---------+---------+---------+-
                      -20         0        20        40

Classification = WD subtracted from:
Classification    Lower   Center    Upper
WP              -35.545  -25.900  -16.255
Classification  --------+---------+---------+---------+-
WP              (----*----)
                --------+---------+---------+---------+-
                      -20         0        20        40
```

One-way ANOVA: pH Value versus Classification

```
Source          DF      SS      MS      F      P
Classification   2  0.8173  0.4087  11.06  0.007
Error            7  0.2587  0.0370
Total            9  1.0760

S = 0.1922   R-Sq = 75.96%   R-Sq(adj) = 69.09%

                          Individual 95% CIs For Mean Based on
                          Pooled StDev
Level  N    Mean   StDev  -----+---------+---------+---------+----
C      3  8.4667  0.1155                    (--------*--------)
WD     2  8.3000  0.1414             (----------*---------)
WP     5  7.8400  0.2302  (-----*------)
                          -----+---------+---------+---------+----
                             7.80      8.10      8.40      8.70
Pooled StDev = 0.1922
```

Fisher 95% Individual Confidence Intervals

```
All Pairwise Comparisons among Levels of Classification
Simultaneous confidence level = 88.90%
Classification = C subtracted from:
Classification    Lower   Center    Upper
WD              -0.5816  -0.1667   0.2483
WP              -0.9586  -0.6267  -0.2947
Classification  ---------+---------+---------+---------+
WD                     (--------*-------)
WP              (-----*------)
                ---------+---------+---------+---------+
                      -0.50      0.00      0.50      1.00

Classification = WD subtracted from:
Classification    Lower   Center    Upper
WP              -0.8403  -0.4600  -0.0797
Classification  ---------+---------+---------+---------+
WP                (-------*------)
                ---------+---------+---------+---------+
                      -0.50      0.00      0.50      1.00
```

One-way ANOVA: Sulfur versus Classification

```
Source          DF        SS        MS     F      P
Classification   2  27461823  13730912  7.40  0.019
Error            7  12995587   1856512
Total            9  40457410

S = 1363   R-Sq = 67.88%   R-Sq(adj) = 58.70%
```

```
                       Individual 95% CIs For Mean Based on
                       Pooled StDev
Level  N  Mean  StDev  ---------+---------+---------+---------+
C      3  6363   1607    (--------*--------)
WD     2  6430   1782  (----------*-----------)
WP     5  9704   1079                      (-------*------)
                       ---------+---------+---------+---------+
                             6000      8000     10000     12000
Pooled StDev = 1363
```

Fisher 95% Individual Confidence Intervals

```
All Pairwise Comparisons among Levels of Classification
Simultaneous confidence level = 88.90%
Classification = C subtracted from:
Classification  Lower  Center  Upper
WD              -2875      67   3008
WP                988    3341   5694

Classification      +---------+---------+---------+---------
WD                            (---------*---------)
WP                                         (-------*-------)
                    +---------+---------+---------+---------
                -6000     -3000         0      3000

Classification = WD subtracted from:
Classification  Lower  Center  Upper
WP                578    3274   5970
Classification      +---------+---------+---------+---------
WP                                        (--------*--------)
                    +---------+---------+---------+---------
                -6000     -3000         0      3000
```

One-way ANOVA: T_TP versus Classification

```
Source          DF      SS     MS     F      P
Classification   2   6.351  3.175  5.06  0.044
Error            7   4.391  0.627
Total            9  10.742

S = 0.7920   R-Sq = 59.12%   R-Sq(adj) = 47.44%

                           Individual 95% CIs For Mean Based on
                           Pooled StDev
Level  N     Mean   StDev  -----+---------+---------+---------+----
C      3   1.1389  0.7070                 (---------*----------)
WD     2  -0.0391  0.6942   (-------------*------------)
WP     5  -0.7013  0.8529  (-------*-------)
                           -----+---------+---------+---------+----
                             -1.0       0.0       1.0       2.0
Pooled StDev = 0.7920
```

Fisher 95% Individual Confidence Intervals

```
All Pairwise Comparisons among Levels of Classification
Simultaneous confidence level = 88.90%
Classification = C subtracted from:
Classification    Lower   Center    Upper
WD              -2.8877  -1.1781   0.5316
WP              -3.2079  -1.8402  -0.4725

Classification    -+---------+---------+---------+--------
WD                  (----------*-----------)
WP                (--------*--------)
                  -+---------+---------+---------+--------
                -3.0      -1.5       0.0       1.5

Classification = WD subtracted from:

Classification    Lower   Center   Upper
WP              -2.2291  -0.6621  0.9048
```

```
Classification    -+---------+---------+---------+--------
WP                      (----------*---------)
                  -+---------+---------+---------+--------
                -3.0      -1.5       0.0       1.5
```

One-way ANOVA: Zinc versus Classification

```
Source          DF     SS     MS      F      P
Classification   2  431.4  215.7  12.85  0.005
Error            7  117.5   16.8
Total            9  548.9

S = 4.096   R-Sq = 78.60%   R-Sq(adj) = 72.49%

                         Individual 95% CIs For Mean Based on
                         Pooled StDev
Level  N    Mean  StDev  ---------+---------+---------+---------+
C      3  20.667  3.055            (-------*-------)
WD     2  29.000  7.071                      (--------*---------)
WP     5  12.200  3.493  (-----*------)
                         ---------+---------+---------+---------+
                              14.0      21.0      28.0      35.0
Pooled StDev = 4.096
```

Fisher 95% Individual Confidence Intervals

```
All Pairwise Comparisons among Levels of Classification
Simultaneous confidence level = 88.90%
Classification = C subtracted from:
Classification    Lower  Center   Upper
WD               -0.509   8.333  17.176
WP              -15.541  -8.467  -1.393

Classification  -------+---------+---------+---------+--
WD                               (-----*----)
WP                     (---*----)
                -------+---------+---------+---------+--
                     -15         0        15        30

Classification = WD subtracted from:
Classification    Lower   Center   Upper
WP              -24.904  -16.800  -8.696
Classification  -------+---------+---------+---------+--
WP              (-----*----)
                -------+---------+---------+---------+--
                     -15         0        15        30
```