

BIOACCUMULATION OF METALS IN THE
KUILS RIVER, WESTERN CAPE

AUPAKI MICHAEL MELATO

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**BIOACCUMULATION OF METALS IN THE KUILS RIVER,
WESTERN CAPE**

by

AUPAKI MICHAEL MELATO

**Dissertation submitted in fulfilment of the requirements for the
degree**

Master of Technology: Environmental Health

in the Faculty of Applied Science

at the

CAPE PENINSULA UNIVERSITY OF TECHNOLOGY

Supervisor: Prof JP Odendaal

Co-supervisor: Prof RG Snyman

Cape Town

April 2011

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DECLARATION

I, Aupaki Michael Melato, declare that the "Bioaccumulation of metals in freshwater snails of the Kuils River, Western Cape" is my own unaided work, and the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed



Date

21 April 2011

ABSTRACT

World wide urban rivers are the most utilised and degraded. A variety of everyday sources of metal pollution exist that is entrenched in the modern way of life. Lately there has been a tremendous growth in the establishment and development of human settlements, both formal and informal in the Cape Town area. The surroundings of the Kuils River are not excluded from this. There are various communities in close proximity to the Kuils River. Due to this, more industries are also being established. This has caused an increased production of potential environmental pollutants, including metals.

The aim of the study was firstly, to identify potential sources of metal pollution along the entire length of the Kuils River, in order to identify sampling sites. Secondly, to identify the metals contaminating the water and sediment of the Kuils River. Thirdly, to determine the bioaccumulation of metals in freshwater snails (*Physa acuta*).

Four sampling sites were identified along the Kuils River. Freshwater snails (*P. acuta*), sediment and water were collected every 2 months for a period of one year. The following metals were investigated: Aluminium (Al), Cadmium (Cd), Cobalt (Co), Chromium (Cr), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni) and Zinc (Zn). Samples were digested with 55% nitric acid. The Inductively Coupled Plasma – Atomic Emission Spectrometer (ICP-AES) were used for metal analyses. The results were statistically analysed by means of ANOVA on ranks using the Sigmastat statistical package.

Results revealed that most metals found in water, sediment and snails had significantly higher concentrations at site 1. This is possibly due to input from the surrounding urban area and nearly agricultural activities. Water concentrations of Al, Cu, Mn and Zn were higher than the DWAF (1996) guidelines. Sediment was mostly contaminated with Al, Fe, Pb and Zn, while the snails contained significant levels of Cu, Fe, Mn and Zn. Further investigations involving toxicity testing should be conducted to determine the toxicity of these metals to *Physa acuta*.

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DEDICATION

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Last but not least, JEHOVAH, the foundation of my life.

Proverbs 3: 5&6

“Trust in the Lord with all thine heart; and lean not unto thine own understanding. In all thy ways acknowledge him, and he shall direct thy paths.” King James Version.

Hebrew 10:23

“Let us hold fast the profession of our faith without wavering; (for he is faithful that promised;)”. King James Version.

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GLOSSARY

Terms/Acronyms/ Abbreviations	Definition/Explanation
CCT	City of Cape Town
CCME	Canadian Council of Ministers of the Environment
CSQG	Canadian Sediment Quality Guidelines
DWAF	Department of Water Affairs and Forestry
ICP-AES	Inductively Coupled Plasma-Atomic Emission Spectrometer
ISQG	Interim Sediments Quality Guidelines
PPM	Parts Per Million
PVC	Polyvinyl Chloride
SD	Standard Deviation
SoE	State of Environment
RHP	River Health Programme
NSoER	National State of Environmental Resources
Invertebrates	Are the animals that do not have a backbone. Invertebrates are cold-blooded; their body temperature depends on the temperature of their environment (Scherman <i>et al.</i> 2003).
Bioavailability	Is the degree of ability of chemicals to be absorbed and ready to interact in organism metabolism (EPA 1994).
Bioaccumulation	This refers to the accumulation of contaminants in the bodies of organisms (EPA 1994).
Ionic Liquids	Salts composed of organic cation and any of a variety of anions that have melting points of less than 100 C°. e.g. (Imidazolium, pyridinium, quaternary ammonium and a quaternary phosphonium salt (Bernot <i>et al.</i> 2005).

Permeable	Ability of water to move between, into, and out of space (Chapman PM 1981).
Phytoremediation	Technique that can help to remove metals from polluted and contaminated water and soil by using plants to clean up (Qoko 2003).
Water Quality Standards	The designation of water bodies for desirable uses and the narrative and numerical criteria considered necessary to protect those uses (Kolbe & Luedke 2005).
Water Pollution	The addition of harmful or objectionable materials, such as sewage or industrial wastes, to a water body in concentrations or quantities that cause the degradation of water quality (Kolbe & Luedke 2005).

Chapter 1

Introduction

1.1 POLLUTION OF FRESHWATER SYSTEMS IN SOUTH AFRICA

The supply of fresh water is limited in South Africa and urban rivers are the most utilised and degraded worldwide. The demands on freshwater resources are greater than ever. Due to urban development and population increases, industries are growing and agricultural activities brought about the degradation of rivers through a deterioration of water quality (Davies & Day 1998, RHP 2005). According to Van Vuuren (2006) the country's main rivers are heavily utilized and regulated to improve water security for socio-economic use and there are widespread water transfer schemes across the country to cater for areas where water requirements exceed the natural water availability. In South Africa about 84 % of the ecosystems of main rivers are threatened, 44 % of them critical. Palmer *et al.* (2004) stated that the challenges of water supply are those associated with water quality, which is also frequently impacted. The decline of both water quality and quantity are worsened by natural variability and changing of climatic conditions. Also, increased flooding and loss of ecological functioning affect water quality (RHP 2005). Water quality is the key factor that will ultimately secure or adversely affect the survival of aquatic organisms, e.g. fish (Mulder 1986).

Mining activities have a high impact on water quality in rivers during low flow (increasing in sulphate, electrical conductivity, iron, zinc, arsenic and cyanide, and a decrease in pH) (Heath & Claassen 1999). Acid drainage from mines is a recognised problem, increasing sulphate, suspended solids and metals (manganese, aluminium, iron, amongst others) and decreasing pH of the

receiving water resources (Wingrove *et al.* 1998). Water pollution is a cosmopolitan problem that needs urgent attention and preventative measures.

South Africa has lately been focusing on the managing of aquatic ecosystems; mainly method development focusing primarily on rivers, since rivers are by far the most dominant freshwater systems in this country (Rabie & Day 1992). South Africa's National Water Act (No. 36 of 1998) emphasises the importance of the establishment of a monitoring programme to provide appropriate data and information necessary to assess the health of aquatic ecosystems (RSA 1998). Agricultural runoff, including nutrients, pesticides, a high poverty level and inadequate sanitation may become one of the greatest localised pressures on water quality in South Africa (NSoER 1999). This report further states that the scarcity of water is exacerbated by pollution of the surface- and water resources. Typical pollutants of South Africa's freshwater aquatic environment include industrial effluents, domestic and commercial sewage, acid mine drainage, agricultural runoff and litter. Marais *et al.* (2004) stated that the litter loads from informal settlements located on the banks of an open canal or river is approximately 6000 kg/ha.yr.

The rivers of Cape Town are also not excluded from surrounding activities that may lead to pollution. Generally, only the minority of the upper reaches of the rivers in the greater Cape Town area are still in a natural or good ecological state. Development in the lowland areas has modified the rivers, resulting in their poor ecological state. Long stretches of most Cape Town rivers have been canalised including certain portions of the Kuils River, resulting in poor water quality, modified flows and abundant alien fish and plant life (RHP 2005). According to Dallas and Day (1993) the ability of a stream to self-purify depends on the biotic component, a reduction in which would reduce this ability. These authors further stated that clearing of riparian vegetation is often associated with canalisation and it may lead to changes in stream temperature regime. For instance, the higher temperature reduces the solubility of dissolved oxygen in

water, decreasing its concentration and thus availability to aquatic organisms. The higher temperatures also favour the growth of sewage fungus and the rate of purification of sludge deposits. This reduces the environmental quality of the water as well as affecting its suitability as drinking water and for recreation (Dallas & Day 1993).

1.2 METALS AS ENVIRONMENTAL CONTAMINANTS IN FRESHWATER SYSTEMS

Ten metals were chosen for this study. There is a lack of evidence to indicate whether or not the selected metals are a threat to the Kuils River. Furthermore, no South African studies were found on the bioaccumulation of metals in *Physa acuta*.

1.2.1 Aluminium

Aluminium is one of the more toxic of the metals and probably not an essential nutrient in organisms (Dallas & Day 1993). In the earth's crust, Al is the third most abundant trace element after oxygen and silicon (Davies & Day 1998). It is widely distributed and constitutes approximately 8% of the earth's surface layer. Aluminium is a very reactive element and it is not a free metal in nature (Dallas & Day 2004, ATSDR 2006). Aluminium is redistributed in the environment by natural and human activities. Mining and processing of its ore by the production of Al metal, alloys and compounds are regarded as the main causes of high levels in the environment. When acid rain falls, Al compounds in the soil may dissolve and enter lakes and streams (ATSDR 2006). Cathalifaud *et al.* (1997) and Dallas & Day (2004) found that Al in soluble form in acidic water draining from mines and in natural waters is affected by acid rain. In waters naturally acidic because of the presence of acidic organic compounds, Al is also present even though not available because it is adsorbed by organic molecules. An increase in movement of Al through soil and into water bodies is regarded as one

of the significant ecological consequences. Due to this effect the balance of aquatic communities may be disturbed (Cronan & Scholfield 1979).

The results from Cronan & Scholfield (1979) showed that non-calcareous watersheds exposed to long term acid precipitation may have accelerated Al leaching. The factors that may play a role are: (i) seasonal variations in the atmospheric deposition of mineral acids to the soil, (ii) the addition rates of mineral acids to the soil, (iii) the neutralisation kinetics and acid-buffering capacity of the vegetation and soil, and (iv) the size of the watershed drainage area. According to Dallas & Day (1993) the solubility Al is strongly pH-dependent. Its toxicity depends on the chemical species involved. In relation to proteins and other numerous organic molecules in water, this can exist as either bases or acids, depending on pH. It also determines the chemical species of metals and in this way alters availability and toxicity. For instance, metals such as Al occurs as unavailable hydrated hydroxides at alkaline pHs but as pH declines below neutral, they form the available and highly toxic aqua-Al³⁺ ion. When water Al concentrations are high, normally pH is low. It is therefore identified as a toxic agent to freshwater invertebrates (Rosseland *et al.* 1990, Dallas *et al.* 1998). According to Herrmann (1987) Al can accumulate in the bodies of invertebrates living in acidic water. Acidic precipitations are regarded as the most prominent reason for Al effects in the environment (Rosseland *et al.* 1990). In an acidified environment, Haines *et al.* (1987) observed increased Al load in fresh water. This is also accompanied with higher bioavailable concentrations of other metals. Acidification has generally been accompanied by declining numbers of benthic invertebrates (Otto & Svensson 1983; Øckland & Øckland 1986). At very low pH, high concentrations of Al can have an ameliorating effect on, for example on mayfly nymphs (*Heptogenia sulphurea*) (Herrmann 1987). The findings of Cronan & Scholfield (1979) indicated that the Adirondack lakes, water with Al concentrations above 0.2 mg/L, showed a specific toxic response to Al in the pH range 4.4 to 5.9. In a study by Skogheim & Rosseland (1986), the pH of water ranged from 4.5 to 5.3. Under these conditions Al concentrations

between 0.025 and 0.075 mg/L is toxic. The guideline by the former Department of Water Affairs and Forestry is set at a range of 0.005 – 0.01 mg/L for Al in aquatic ecosystems (DWAF 1996c). Davies & Day (1998) found that aquo Al ion, Al^{3+} may be highly toxic and soluble when the pH falls to less than about 5. Davies & Day (1998) stated that it is difficult to ascertain the actual effects of trace metals in water. However, pH is regarded as one of the major factors that could contribute to toxic stress due to pollution.

1.2.2 Cadmium

Cadmium is one of the most toxic non-essential elements in the fresh water environment (Wong & Rainbow 1986, DWAF 1996c). This element accumulates in living organisms and has a high toxic potential (Pourreza & Zavvar Mousavi 2004), even when present in very low concentrations (Wong & Rainbow 1986). Cadmium is an element that occurs naturally in the earth's crust, at an average concentration of 0.2 mg/kg (DWAF 1996c). It is a soft, silverwhite metal (ATSDR 1999). Cadmium may change form but it does not disappear from the environment (ATSDR 1999). Cadmium is a by-product of zinc alloying and is present in fertilizers that enter the soil when fertilizers are applied to crops. It can also enter soil or water from spills at hazardous waste sites if large amounts of dissolved Cd are present at the site (ATSDR 1999).

pH, water temperature, ligands and coexisting metal cations influence the hardness of water and chemical speciation. These factors influence the toxicity of cadmium (DWAF 1996c). The guideline by the Department of Water Affairs and Forestry is set at the range 0.00015 – 0.0004 mg/L for Cd in aquatic ecosystems (DWAF 1996c).

1.2.3 Lead

Lead is a common and toxic metal (Dallas & Day 1993). It is a heavy, low melting point, bluish-grey metal that occurs naturally in the Earth's crust. However, it is rarely found naturally as a pure metal. It is usually found combined with two or more other elements to form Pb compounds (Dallas & Day 1993, ATSDR

2005a). Environmental levels of Pb have increased more rapidly over the past three centuries as a result of human activity. Most Pb used in the industry comes from mined ores or from recycled scrap metal (ATSDR 2005a). Other inputs of Pb into the environment are from used dry cell batteries, from sewage effluent, runoff of waste and atmospheric deposition (Stoeppler 1991). High loads of Pb have been found to enter False Bay from stormwater runoff from low-income, high-density settlements in the Western Cape (Mackay 1994). In the past Pb was used in petrol, house paint, and pesticides. Small amounts of Pb may enter rivers, lakes, and streams when soil particles are moved by rainwater. Movement of Pb from soil particles into groundwater is unlikely unless the rain falling on the soil is acidic or "soft". Drinking water in houses containing Pb pipes may contain Pb, especially if the water is acidic or "soft" (ATSDR 2005a). The concentration of Pb in natural water has been reported to be as high as 0.4 to 0.8 mg/L, mostly from natural sources, such as galena deposits (DWAF 1996a). The guideline by the Department of Water Affairs and Forestry is set at the range of 0.0002-0.0012 mg/L for Pb in aquatic ecosystems (DWAF 1996c).

1.2.4 Cobalt

Cobalt is an essential micronutrient, required for some metabolic activities in organisms. It is also toxic in fairly small quantities (Dallas & Day 1993, Teo & Chen 2001). Cobalt rarely occurs in natural waters in concentrations sufficient to affect plants or animals. It may sometimes occur in effluents and its presence in waters is likely to result from contamination with such effluents. Consequently, the element is to be expected in association with other metals whenever it is found in water. For this reason, when a method suitable for the determination of Co in water is required, attention has to be given to the possibility of interference by those metals likely to occur with Co (Benford *et al.* 1967).

Cobalt is not required by plants. There is no evidence as yet available on its function in plants. Ahmed *et al.* (1981) reported some irregular uptake of Co in rape and pea. The Co uptake by both rape and pea was retarded by the

application of phosphate and or lime. No guideline set was by the Department of Water Affairs and Forestry for Co in aquatic ecosystems unlike some other metals (DWAF 1996c).

1.2.5 Chromium

Chromium is a naturally occurring element found in rocks, plants, soil and in volcanic dust and gases (ATSDR 2000). Elevated concentrations are attributed to anthropogenic activities (Jordao *et al.* 1997). Chromium is one of the least toxic of the metals at low concentrations and is in fact essential for fat and carbohydrate metabolism in mammals, forming part of the "glucose tolerance factors". It occurs in several oxidation states (-2 to +6), of which Cr⁶⁺ is the most toxic. For some reason as yet unexplained, it is accumulated up to 4000 times by some algae. At higher concentrations it is genotoxic (causing chromosomal aberrations), teratogenic (causing foetal abnormalities), as well as mutagenic and carcinogenic in mammals (Dallas & Day 2004).

Chromium toxicity to aquatic biota is influenced by abiotic variables such as temperature, pH and biological factors such as species, life stage, and potential differences between local populations (Eisler 1986, Kimbrough *et al.* 1999). Most of the Cr in water binds to sediment and other materials and settles to the bottom; a small amount may dissolve in the water. Most of the Cr in soil does not dissolve easily in water and can attach strongly to the soil. A very small amount of the Cr in soil, however, will dissolve in water and can move deeper in the soil to underground water (ATSDR 2000). The level of Cr in air and water is generally low. The concentration of total Cr in air (both Cr (III) and Cr (VI)) generally ranges between 0.01 and 0.03 µg/m³. Chromium concentrations in drinking water (mostly as Cr (III)) are generally very low (2 ppb). Contaminated well water may contain Cr (VI). Refining processes used to make white bread or sugar can decrease Cr levels. Chromium (III) is an essential nutrient for humans. Chromium-containing consumer products are household utensils, wood

preservatives, cement, cleaning products, textiles, and tanned leather (Föstner & Wittmann 1981, ATSDR 2000).

According to Eisler (1986) most authorities agree on the eight points of recommendations shown below that includes the proposed criteria of sensitive species of wildlife and aquatic organisms:

- (a) Chromium levels are elevated in soil, air, water and biota in the vicinity of electroplating and metal finishing industries, publicly owned municipal treatment plants, tanneries, oil drilling operations and cooling towers;
- (b) Hexavalent Cr (Cr^{6+}) is the most biologically active Cr chemical species, although little is known about the properties of organochromium compounds, water soluble species, or their interactions in complex mixtures;
- (c) Chromium chemistry is imperfectly understood and existing analytical methodologies are inadequate for quantification of Cr species and ionic states;
- (d) Chromium is an essential trace element in humans and some species of laboratory animals, but the data base is incomplete for other groups of organisms;
- (e) At high environmental concentrations, Cr is a mutagen, teratogen and carcinogen;
- (f) No biomagnification of Cr has been observed in food chains and concentrations are usually highest at the lowest trophic levels;
- (g) Toxic and sublethal properties of Cr are modified by a variety of biological and abiotic factors; and
- (h) Sensitivity to Cr varies widely, even among closely related species.

The guideline by the Department of Water Affairs and Forestry is set at 0.012 mg/L for Cr in aquatic ecosystems (DWAf 1996c).

1.2.6 Copper

Copper is a micronutrient (Avenant-Oldewage & Marx 2000) and plays a vital role in metabolic activities of organisms (Teo & Chen 2001, Grosell *et al.* 2007). However, this metal at elevated levels can be toxic (Spear 1981, Csuros & Csuros 2002). Copper is a reddish metal that occurs naturally in rock, soil, water, sediment and in air. This metal is used world wide (Monteiro *et al.* 1995). Copper is frequently found near mines, smelters, industrial settings and waste disposal sites. In the soil it is possible for copper to be attached to the organic material and other components (e.g. clay and sand). It can enter the environment through combustion of fossil fuels and waste, waste dumps, wood production, phosphate fertilizer production, domestic waste water and natural sources (e.g. decaying vegetables, forests fires) (ATSDR 2004).

Normally Cu compounds are used in agriculture to treat diseases in plants, like mildew, or for water treatment and preservatives for wood, leather and fabrics (ATSDR 2004). Fungicides are used in fish farming in order to prevent epidemic diseases such as fin erosion. Fungicides and algaecides are used in the paper industry for pulp making, in order to protect paper from mould development; these preparations contain copper compounds (Spencer & Green 1981, Ramelow *et al.* 1992).

According to Dallas & Day (1993) Cu in water is transportable and at low pH is soluble; it precipitates in alkaline environments and is under these conditions not toxic. In humic waters, it may occur at fairly high concentrations but since it is bound to organic molecules it does not exert significant toxic effects. Winner & Gauss (1986) also observed reduced metal toxicity in hard water for daphnids but it was noticed that the existence of humic acid, it complicates the matters in this relationship. Clements *et al.* (1988) demonstrated how water quality, particularly hardness and alkalinity, affect Cu toxicity. The guideline by the Department of Water Affairs and Forestry is set at the range of 0.0003 – 0.0014 mg/L for Cu in aquatic ecosystems (DWAF 1996c).

1.2.7 Iron

Iron is an essential micronutrient for all organisms. Iron is the fourth most abundant element in the earth's crust (DWAF 1996a, Dallas & Day 1993). According to Csuros & Csuros (2002) it is toxic in high concentration. At high concentrations Fe in aquatic environments can cause oxygen depletion (Dallas & Day 1993). In domestic water it can also cause staining of laundry and porcelain and also cause water to have a bittersweet sharp taste (Csuros & Csuros 2002). Human activities can release Fe into the environment, mostly from the burning of coal, acid mine drainage, mineral processing, sewage, landfill leachates and the corrosion of Fe and steel (DWAF1996d, Csuros & Csuros 2002).

During acidification of surface waters the solubility of several metals increases, resulting in acute or chronic toxic effects in aquatic invertebrate fauna. No guideline is set by the Department of Water Affairs and Forestry for Fe in aquatic ecosystems unlike other metals (DWAF 1996c). Depending on the pH and redox potential of the water, Fe appears as the dissolved ions Fe^{2+} and Fe^{3+} (Iron (II) salts are generally light green, and Iron (III) salt solutions usually range from yellow to brown according to Csuros & Csuros (2002), or as precipitates of both species. Shifts between pH 4.5 and 5.0 cause changes in the redox state of Fe, which then changes its solubility (McKnight & Bencala 1990).

1.2.8 Manganese

Manganese is an essential element in biological functioning when present in micro quantities (Bryan & Ward 1965). According to Dallas & Day (2004) it is an essential micronutrient. However, Mn can also be toxic. Although it is less toxic than most metals, it can still pose a threat to aquatic life when present in high concentrations (Föstner & Prosi 1979). Mn is a very brittle metallic element resembling Fe, but harder (Csuros & Csuros 2002). It is widely distributed in the earth's crust, but does not occur naturally in its pure state. In 1980 the production of Mn ores was estimated to be 26,7 million tonnes worldwide (Adriano 1986).

Mn is mostly used in metallurgical processes where it is an important ingredient in steel. It is used mainly for applications in the electrical industry and ship propellers, and its compounds are used in matches, ceramics, batteries, electrical coils, welding rods, glass, dyes, paints, drying industries and fertilizers (Greenwood & Earnshaw 1984, Friberg *et al.* 1986). Mn plays an important role in antioxidant defences, as it is a component of mitochondrial enzymes, such as superoxide dismutase (MnSOD) and activates a large number of other enzymes (Cotzias 1958). High concentrations are toxic, leading to disturbances in various metabolic pathways. Mn is normally present in natural waters (Bryan & Ward 1965). The guideline by the Department of Water Affairs and Forestry is set at 0.18 mg/L for Mn in aquatic ecosystems (DWAF 1996c).

1.2.9 Nickel

Nickel is an essential trace element in animals, although the functional importance of nickel, still uncertain (Dallas & Day 2004, ATSDR 2005 b). Nickel ranks 24th in order of abundance in the earth's crust, with an average concentration of 0.0086%. In the environment, it is primarily found combined with oxygen or sulfur as oxides or sulfides (ATSDR 2005b). It is a silver-white, malleable, ductile substance with high electric and thermal conductivity (Csuros & Csuros 2002). Nickel compounds are used for nickel plating, to colour ceramics and to make some batteries. Nickel is released into the atmosphere during nickel mining and by industries that make or use nickel, nickel alloys, or nickel compounds. These industries also may discharge nickel in waste water (Csuros & Csuros 2002, ATSDR 2005b).

Most nickel released into the environment ends up in soil or sediment where it attaches to particles containing iron or manganese. Under acidic conditions, nickel is more mobile in soil and might leak into groundwater (ATSDR 2005b). Nickel ions tend to be soluble at pH values less than 6.5. Above a pH of 6.7 this metal mostly forms insoluble Ni hydroxides. About half of the Ni present in most

fresh water is in the ionic form and about half in the form of stable organic complexes, many of which readily adsorb onto clay particles (Dallas & Day 2004). According to the study done by the ATSDR (2005b) Nickel does not bioaccumulate in fish. However, some plants can take up and accumulate nickel. Also, it has been shown that nickel does not accumulate in small animals living on land that has been treated with nickel-containing sludge. No guideline was set by the Department of Water Affairs and Forestry for Ni in aquatic ecosystems (DWAF 1996c).

1.2.10 Zinc

Zinc is an essential micronutrient (Dallas & Day 2004) and in organisms Zn is required for metabolic processes (Teo & Chen 2001). It is fairly abundant in nature (Kelly 1998). Zinc occurs in rocks and ores (Friberg *et al.* 1974, DWAF 1996c). According to Csuros & Csuros (2002), Zn is mostly used in battery manufacturing, soap and detergent industries, ethanol distilleries, chemical industries, paint manufacturing and electroplating plants. It is usually a constituent of industrial effluents (Hellawell 1988). In a study done by Ramessur & Ramjeawon (2002) in Mauritius, it was found that rivers indirectly receive Zn from wastewater discharges by means of road and urban runoff.

Timmermans (1993) found that in most freshwater invertebrates, Zn does not appear to be toxic. In contrast, Phillips (1980) found that at elevated levels it can become toxic as was found in the Germiston Lake. Alabaster & Lloyd (1980) extensively assessed organisms, like fish, where Zn was also found to be extremely toxic. In finer-grained soil fractions elevated levels are generally related with pollution (Kindler & Savim 1990).

The guideline established by the previously known Department of Water Affairs and Forestry is set at 0.002 mg/L for Zn in aquatic ecosystems (DWAF 1996c). In aquatic ecosystem a variety of interactions affects the toxicity of Zn. In hard

water the toxicity is reduced (DWAF 1996c). Dallas & Day (2004) stated that Zn is frequently linked with Cd in natural conditions. In animals Zn is a metabolic antagonist of Cd and its toxicity is reduced in the presence of Zn.

1.3 BIOACCUMULATION OF METALS IN FRESHWATER ORGANISMS

It is vital to monitor the bioaccumulation of metals in an aquatic system due to the potential harmful effects of metals on aquatic ecosystems. This will give an indication of the temporal and spatial extent of metal accumulation, as well as an assessment of the potential impact on human health and organism health (if they have been exposed to elevated levels of a pollutant or if consumed by predators) (Kotze *et al.* 1999).

Organisms can accumulate metals to levels that may be above that which are required for normal physiological functioning. The measurement of metal concentrations in these organisms provides the basis for use of bioaccumulative indicators of the degree of metal pollution in various aquatic ecosystems (Coetzee *et al.* 2002). Invertebrates and fish are mostly used as test organisms in aquatic toxicology (Dallas *et al.* 1998). However, fish are also used, e.g. *Salmo gairderi* (Calamari *et al.* 1980), *Oreochromis mossambicus* and *Clarias gariepinus* (Kotze *et al.* 1999) and *Salmo trutta* (Lamas *et al.* 2007).

The use of invertebrates is wide spread and organisms such as the water flea *Daphnia magna* (Gillis *et al.* 2006), the amphipod *Gammarus pulex* (Duddridge & Wainwright 1980), the isopod *Asellus aquaticus* (Van Hattum *et al.* 1993) and chironomids (Desrosiers *et al.* 2008) are commonly used as bioindicators of water quality. In South African rivers, the water quality is continually deteriorating (Wepener *et al.* 2000). Other organisms are also increasingly used in aquatic toxicological tests, e.g. freshwater crabs (Snyman *et al.* 2002, Thawley *et al.* 2004), molluscs (Palmer *et al.* 2004) and snails (De Kock & Wolmarans 2007). The effect of a substance on an organism depends on the exposure

concentration and duration of exposure. The accumulation potential of toxic substances within the tissues of organisms increases the significance of these pollutants, which may be present in water (Hellowell 1988).

Small invertebrates are functionally important in many terrestrial and aquatic ecosystems (Freshman *et al.* 1997). Benthic species perform a variety of functions in freshwater food webs. Firstly, benthic invertebrates provide important ecosystem services by accelerating detritus decomposition. Dead organic matter is one of the main sources of energy for benthic species in shallow-water habitats (Van de Bund *et al.* 1994). Secondly, they release bound nutrients into solution by their feeding activities, excretion and burrowing into sediments (Covich *et al.* 1999). Thirdly, many benthic invertebrates are predators that control the numbers, locations and sizes of their prey (Crowl & Covich 1994). Fourthly, they supply food for both aquatic and terrestrial vertebrate consumers e.g. fishes, turtles and birds (Covich *et al.* 1999). Lastly, benthic organisms accelerate nutrient transfer to overlying open waters (Clarke *et al.* 1997).

The field guide of Gerber and Gabriel (2002) were used for identification of snails (*Physa acuta*). The family name is Physidae. The size can vary from 12-20 mm. The physiological structure has (i) the shell opening to the left, (ii) shell smooth, glossy and (iii) slender tentacles. The colour of this species is brown and has a slow gliding movement. *Physa acuta* (Pouch snails) occur in large and stable environments (Facon *et al.* 2007). According to the field guide of Gerber and Gabriel (2002), the snails can be found in gravel beds, or on aquatic vegetation.

1.4 STATEMENT OF THE RESEARCH PROBLEM

In recent years there has been a growth in the establishment and development of human settlements, both formal and informal, in the Cape Town area. The area around the Kuils River is not excluded from this. Various sources of pollution exist in close proximity from the river. These include a number of communities and industries along the length of the river. Some of the pollutants could include metals, which may be toxic to freshwater organisms at elevated concentrations. Pollutants may result in a decline of water and sediment quality of the river, with negative consequences for aquatic life and human health. Freshwater snails (*Physa acuta*) are abundant in this river system and may possibly be used as biomonitors of metal pollution in this river.

1.5 RESEARCH AIMS

- To identify potential sources of metal pollution along the entire length of the Kuils River, in order to identify sampling sites.
- To identify the metals contaminating the water and sediments of the Kuils river.
- To determine the bioaccumulation of metals in freshwater snails (*Physa acuta*). This will give us an idea of the bioavailability of these metals.

Chapter 2

Materials and Methods

2.1 GENERAL DESCRIPTION OF THE KUILS RIVER

The Kuils River has its source in the Durbanville hills and flows through industrial and residential areas in Bellville. It also flows under the N1 freeway and then flows parallel to the R300 road and through Kuilsrivier (Fig. 2.1). Below the point where the Bottelary River joins the Kuils River, the latter flows in a concrete channel until below the town of Kuilsrivier (Murray & Shand 1994). Further downstream the Mfuleni township is located within the river plain (Wiseman 1990). The river drains a large area of the Cape Flats, crossing the N2 freeway south of Drift Sands Nature Reserve and skirting the eastern boundary of the high-density urban area of Khayelisha (Ninham 1993).

2.2 VEGETATION

Large amounts of native riparian vegetation have been removed from the Kuils River. This resulted in the invasion of alien plants (kikuyu, river gum, long-leaf wattle) (RHP 2005).

2.3 PHYSICAL CHARACTERISTICS OF SAMPLING SITES

Four sites were selected along the length of the river. Sampling took place every two months for a year (October 2005 to October 2006).

2.3.1 Description of site 1

The Kuils River originates in the Durbanville hills. Site 1 is located close to the source of the river (Fig. 2.2). This site is surrounded by thick vegetation. To the east of site 1 some agricultural activity is taking place. One kilometre downstream a golf course is located. Some illegal dumping of solid waste was also noted at this site. Municipal drainage pipes also dispose its content into the river. This site has relatively slow flowing water. The water seemed clear and without odour. New construction development took place close to upstream of this site at the time of sampling.

2.3.2 Description of site 2

This site is located in Brackenfell. The distance from sampling site 1 to this site is approximately 2.5 km. The river is narrow with a width of approximately 1.5 – 2 m, with relative fast flowing water. Between sampling site 1 and towards sampling site 2, the river flows under the N1 freeway and then flows parallel with the R300 road (Fig. 2.2). This site is dominantly covered by aquatic vegetation. At the time of sampling, there was an illegal residential occupation right next to the river and these people washed their clothes in the river. Municipal pipes were also disposing their content into the river.

2.3.3 Description of site 3

The river passes through an industrial area and the residential area of Kuilsrivier (Town). This sampling point was downstream from the industrial area next to a residential area (Fig. 2.2). At this sampling site, water is mostly slow flowing and was greyish in colour with a slight odour. At time of sampling, the stream was surrounded by vegetation. There was rubble disposal at some spots along the river banks. The construction of a new residential development was taking place next to the upstream at the time of sampling. Runoff from the road was also washed into the river.

2.3.4 Description of site 4

Sampling site 4 was positioned in Kuilsrivier town (Fig. 2.2). Just upstream of this sampling point, the river is canalised. This sampling site was about 500 m from the Stellenbosch Arterial Road. This site is in an open area. On the river banks materials such as papers, rags, plastic and miscellaneous large objects were noticed. The water appeared to be oily, greyish to black in colour and had a slight odour. The water always flowed slowly at this site. There were livestock drinking and community members fishing on several occasions during sampling.

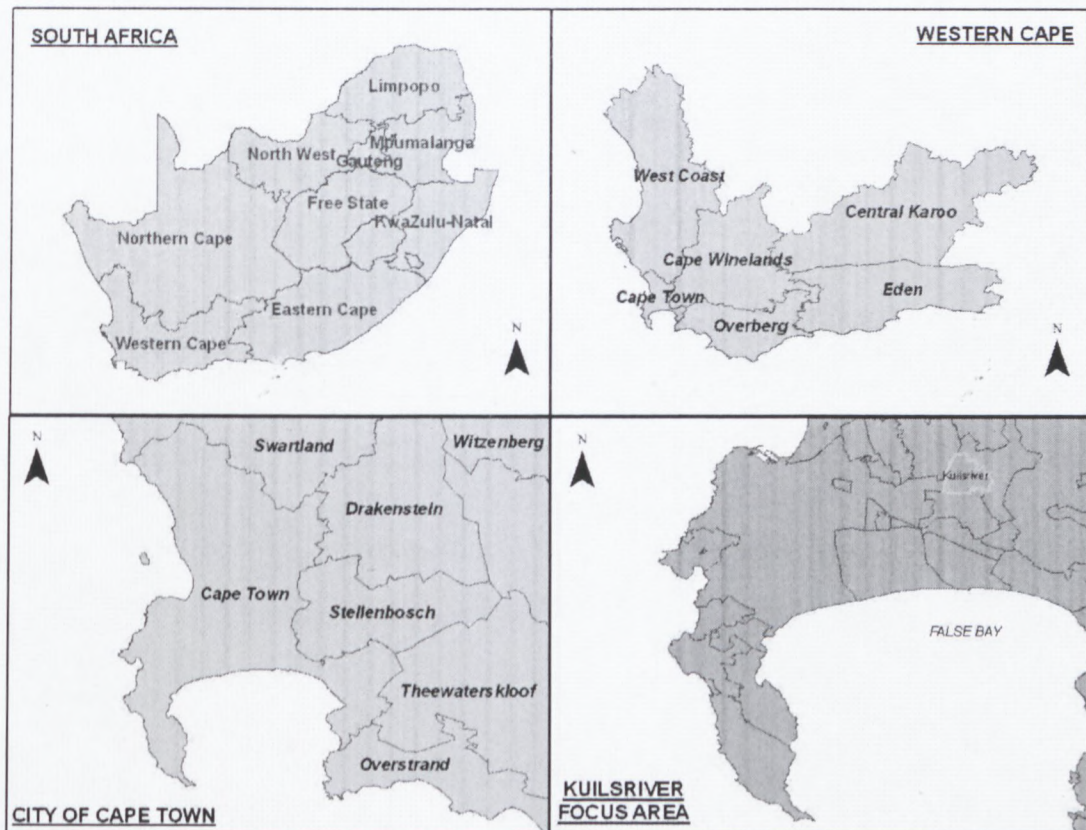


Figure 2.1: The geographical position of Kuilsrivier within the South African region. (Source: Department of Environmental Affairs and Development Planning, Western Cape)

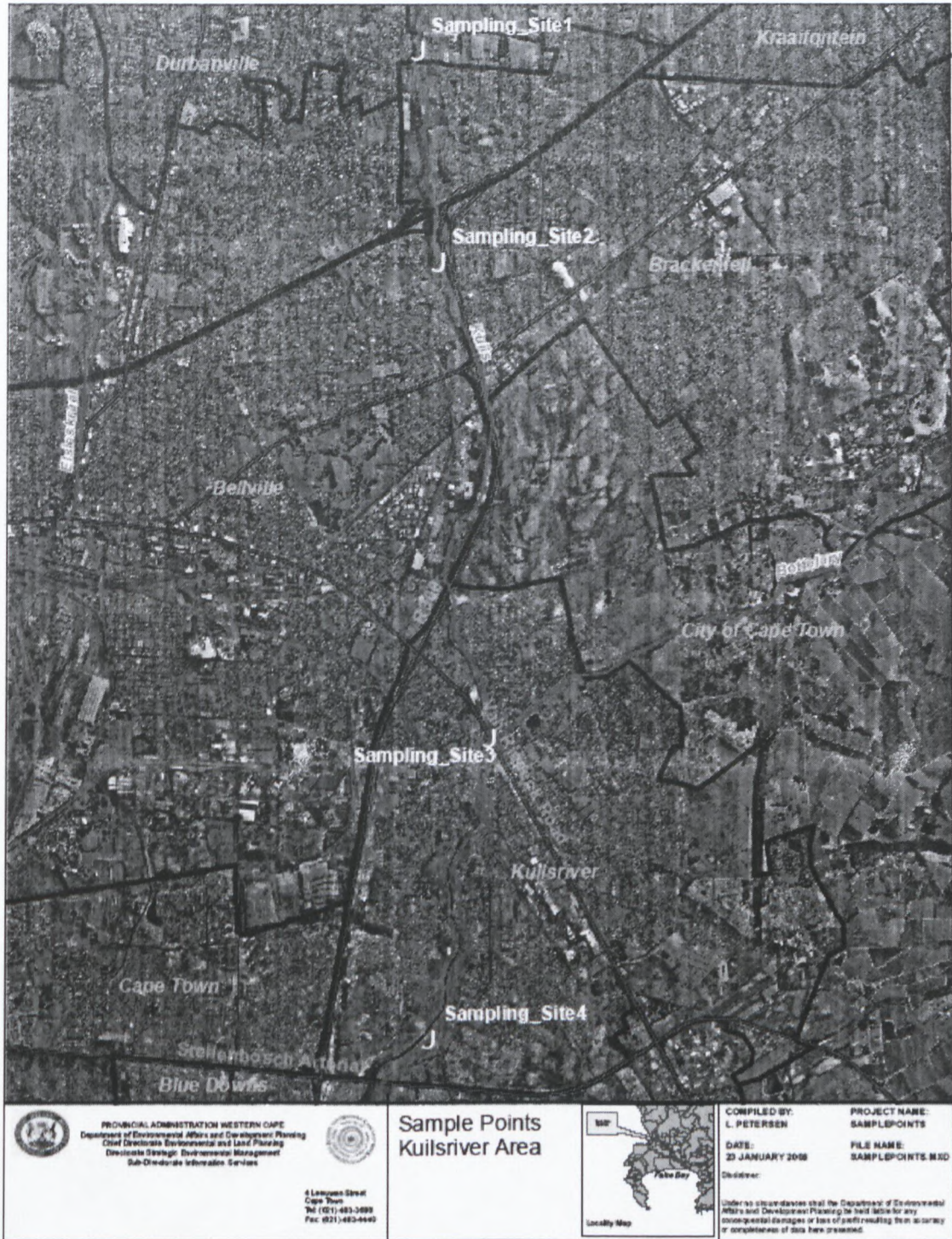


Figure 2.2: The geographical position of Kuils River sampling sites (1, 2, 3 and 4) within the City of Cape Town. (Source: Department of Environmental Affairs and Development Planning, Western Cape)

2.4 RAINFALL AND PHYSICO-CHEMICAL PARAMETERS OF RIVER WATER

2.4.1 RAINFALL

The rainfall data was provided by the South African Weather Services, for their station at the Cape Town International Airport. The average monthly rainfall measured during the sampling months ranged between 0 and 56.2 mm (Table 2.1).

Table 2.1: Average rainfall (mm) recorded in the area of the sampling sites, Kuils River (October 2005 to October 2006). Sampling occasions are indicated by an asterisk (*)

Months	Average rainfall (mm)
*October2005	13.5
November 2005	20.1
*December 2005	1.2
January 2006	0
*February 2006	13
March 2006	4.7
*April 2006	30.1
May 2006	121.8
*June 2006	34
July 2006	71.4
*August 2006	56.2
September 2006	20
*October 2006	37.2

2.4.2 PHYSICO-CHEMICAL PARAMETERS

2.4.2.1 pH

The measurement of the hydrogen ion activity in solution is called pH. Normally pH of river water range from 4 (acidic) to 11 (alkaline), with 7 being neutral in the surface water. In South Africa pH of most fresh water ranges between 6 and 8. The pH may be influenced by factors such as water temperature, the concentrations of inorganic and organic ions and biological activities (DWA 1996c). Generally a lower pH results in a higher level of toxicity (Skogheim & Rosseland 1986).

According to the South African Water Quality Guidelines, the water pH for agricultural irrigation is in the Target Water Range from 6.5 to 8.4; for domestic use it is 6.0 to 9.0 and 6.5 to 8.5 for recreation (DWAF 1996a, b & d). All obtained pH values from the Kuils River fell within these ranges.

The pH of the river water was measured *in situ* during each sampling occasion by making use of a portable pH / Temp Meter MI 105.

2.4.2.2 Temperature

Temperature is an important parameter because it not only influences the metabolic activity and behaviour of organisms, which may affect their exposure to a pollutant, but it may also alter the physical and chemical state of pollutants. In general it can be stated that toxicity will increase with increasing temperature (Mason 1996).

Temperatures of river water were measured *in situ* during each sampling occasion by making use of a portable pH / Temp Meter MI 105. Temperature unit is measured in °C (DWAF 1996c).

2.4.2.3 Electrical Conductivity

Total Dissolved Salts (TDS) is a measure of all salts and organic material dissolved in water. Its concentration is usually directly proportional to the electrical conductivity (EC) of water. Since EC is easier to measure, it is routinely used as an estimate of TDS concentration (Dallas *et al.* 1998).

A portable multi-range EC Meter MI 305 was used to measure electrical conductivity *in situ* during each sampling occasion. The measured unit is milli-Siemens per metre (mS m^{-1}) (DWAF 1996c).

2.4.3 CALIBRATION OF INSTRUMENTS

2.4.3.1 pH/Temperature Meter

The following procedures were followed for the calibration of the pH/Temperature meter as stipulated in the martini instrument manual (User Manual 2004a). The following buffer solutions were firstly being prepared as part of the process for calibration. Three beakers were used. One beaker was for rinsing and the other two beakers for buffer solutions. The first buffer solution was pH 7.01 (MA 9007) and the second pH 4.01 (MA 9004).

For the calibration process, the "On/Off" button was pressed and held until the LCD of the portable pH/Temperature meter showed "TEMP". The same button was pressed again and "BUFF" appeared on the screen. The required buffer of "7.01 pH BUFF" was set with a "SET" Key in the meter. Then, the "On/Off" key was pressed again to exit. After this, the probe was taken out and being immersed in a beaker of first buffer of pH 7.01. The "On/Off" key was pressed and held until "CAL" message was displayed on the lower LCD. When releasing the button, the message "7.01 pH USE" will appear. The meter after recognising the buffer value, required the second buffer. The probe was placed in the distilled water for rinsing. This was for minimising of the cross contamination between the solutions.

The meter showed the "pH 4.01 USE" message as an indication for the second solution. Then the probe was immersed in the buffer solution of pH 4.01. After the recognition of this buffer the meter displayed the "OK 2" message. After this message, few seconds later the meter will return to normal mode, as a complete calibration procedure.

2.4.3.2 Multi range EC Meter

The following procedures were followed for the calibration of MI 305 portable – multi range EC meter. These procedures were stipulated in the martin instrument manual (User Manual 2004b). The calibration process was based on monthly unless after the battery was replaced, of which calibration will immediately be necessary. The probe was cleaned with alcohol and was let to dry. The meter was turned on, and the battery compartment cover on the rear of the meter was removed. The probe was immersed in a conductivity calibration solution. The whole in the in the probe were completely submerged in the solution. The solution for calibration was MA 9060 (12880 $\mu\text{S}/\text{cm}$ calibration solution, 230 ml bottle). For this conductivity solution range key of “19.99 mS” was pressed. The meter was let for few seconds until the thermal equilibrium was reached and the reading was stable. The screw driver was used to adjust the calibration trimmer until the display shows 12.88 mS/cm. Then the battery compartment was attached again. The calibration was completed for the use.

2.5 FIELDWORK AND ANALYTICAL TECHNIQUES

2.5.1 Field collection of water samples

A plastic container attached to a 2 m long stick was used to collect water samples. Plastic containers were used to store water samples. The samples were placed into a cooler bag and transported to the laboratory within 5 hours. These were temporarily stored approximately for 3-4 days depending on the availability of the laboratory. The samples were stored at -10°C . The water samples were defrosted before digestion procedures commenced. From each sampling site, 5 replicates were collected.

2.5.2 Field collection of sediment samples

A small plastic spade was used to take surface sediment samples. A plastic container was utilised to store these samples. The jars were first cleaned with water and a cleaning agent and then rinsed with distilled water. These jars were filled up with sediment and temporarily kept in a cooler bag until placed in freezer in the laboratory. From each sampling site, 5 replicates were collected.

2.5.3. Field collection of snails

Pouch snails were found in the sediment of the Kuils River. A plastic spade was used to dig up shallow sediment. The sediment was placed in a small sieve. River water from the same sampling location was used to rinse the sediment to uncover the snails. From each sampling site, six snails were collected. These snails were collected and stored in 10 mL plastic vials. The vials were labelled appropriately. The collected snails were kept in a plastic cooler bag and immediately taken to the laboratory and freezeed in the freezer at -10°C until the time they were prepared for metal analysis.

2.5.4 Acid digestion and filtration

A syringe was used to measure 10 mL of water sample, which was poured into a test tube. Five mL of 55% nitric acid were added to each of the five test tubes with water samples. The samples were heated, using a dry block heater, to a temperature of 40°C for 1 hour. The temperature was then raised up to 120°C for 3 hours. After this period, the solutions were allowed to cool down. The filtration process is described later in this section.

The sediment samples were put in Petri dishes and dried in an oven at a temperature of 60°C for a period of 48 hours. The dried sediment samples were crushed and sieved to get rid of large objects (stone particles, plant fragments, etc). Each of the sediment samples were subsequently weighed and put into test tubes. Ten millilitres of 55% nitric acid were added to each test tube for digestion. The samples were placed in a dry block heater and heated to 40°C for 1 hour

and then 120°C for 3 hours (Odendaal & Reinecke 2004). The solutions were consequently left to cool down. The filtration process is described later in this section.

The collected snails were placed in Petri dishes and dried in an oven at a temperature of 60°C for a period of 48 hours. The masses of the dried snails were measured in grams (g). The snails with shells were then put in test tubes for digestion. Five millilitres of 55% nitric acid were added to each test tube. The samples were heated to 40°C for 30 minutes and then 120°C for an hour (Odendaal & Reinecke 2004). The solutions were allowed to cool down for the filtration process.

2.5.5 Filtration procedures

A blank digestion was also performed together with each set of digestions. This helped to keep a check on possible contamination (Odendaal & Reinecke 2004). Cooled solutions were filtered through Whatman No. 6 (90mm) filter paper. Each solution was made up to 20 mL in volumetric flasks by adding distilled water. They were subsequently filtered through a cellulose nitrate membrane filter paper with a pore size of 0.45 µm (Ebdon 1982) using a needle and syringe. The samples were temporarily stored in a refrigerator (5°C) in 30 mL plastic vials until they were analysed for metals.

2.6 METAL ANALYSIS

Metal concentrations were determined using Inductively Coupled Plasma - Atomic Emission Spectrometer (ICP-AES) analysis according to the procedure outlined in Saleh *et al* (2000). The results from the ICP-AES were converted using the following formula:

(i) Formula used for sediment and snail sample metal calculations.

$$= \left[\frac{(\text{ICP Value} - \text{Blank}) \times \text{dilution factor (20)}}{\text{Mass of sample (g)}} \right]$$

= mg/kg

- (ii) Formula used for water sample calculations:
- $$= (\text{ICP Value} - \text{Blank}) \times 2$$
- $$= \text{mg/L}$$

2.7 STATISTICAL ANALYSIS

The results of this study were statistically analysed by using the Sigmastat 3.5 computer software programme. The sigmastat programme ran an automatic normality distribution test everytime the data was analysed. In most of the cases the data was indicated as not normally distributed. The data were tested with the Kruskal-Wallis One Way Analysis of Variance on Ranks test. A multiple comparison procedure (Student-Newman-Keuls method) (Odendaal & Reinecke 1999) was used to identify differences between different groups.

2.8 SEDIMENT CHARACTERISATION

Grain size of sediment is a basic physical parameter necessary for environmental assessment. According to Blatt *et al.* (1972), Folk (1974) and Syvitski (1991) more explain the uses this parament:

- 1) Grain size is generally primary property and descriptive measure of sediment.
- 2) Grain size distributions are attribute of sediment deposited in certain environment.
- 3) Community structures are frequently associated to grain size distributions, because many benthic organisms exhibit likeness for specific sediment textures.
- 4) Contaminations are often associated with fine-grained sediment because of adsorption onto the charged surface of clay minerals and the large surface area available for adsorption.

In order to precisely determine grain size distributions for Kuils River, particle size analysis was performed on 4 selected samples. The method for the sediment characterisation analysis was that of Folk (1954). A sieve and Andreasen pipette were used, according to standard procedures (Folk 1968). Samples were maginalized to determine whether they were sandy or clay. For analysis to take place, the sample was placed in a pre-weighed 100 ml beaker, weighed, and dried in an oven set at 80 °C. When the sample was dried, they were taken out to cool and and after that weighed. There was a decline in weight due to water loss from the sample being dried. The weight of the sample and beaker less the weight of the beaker, gave the sample weight.

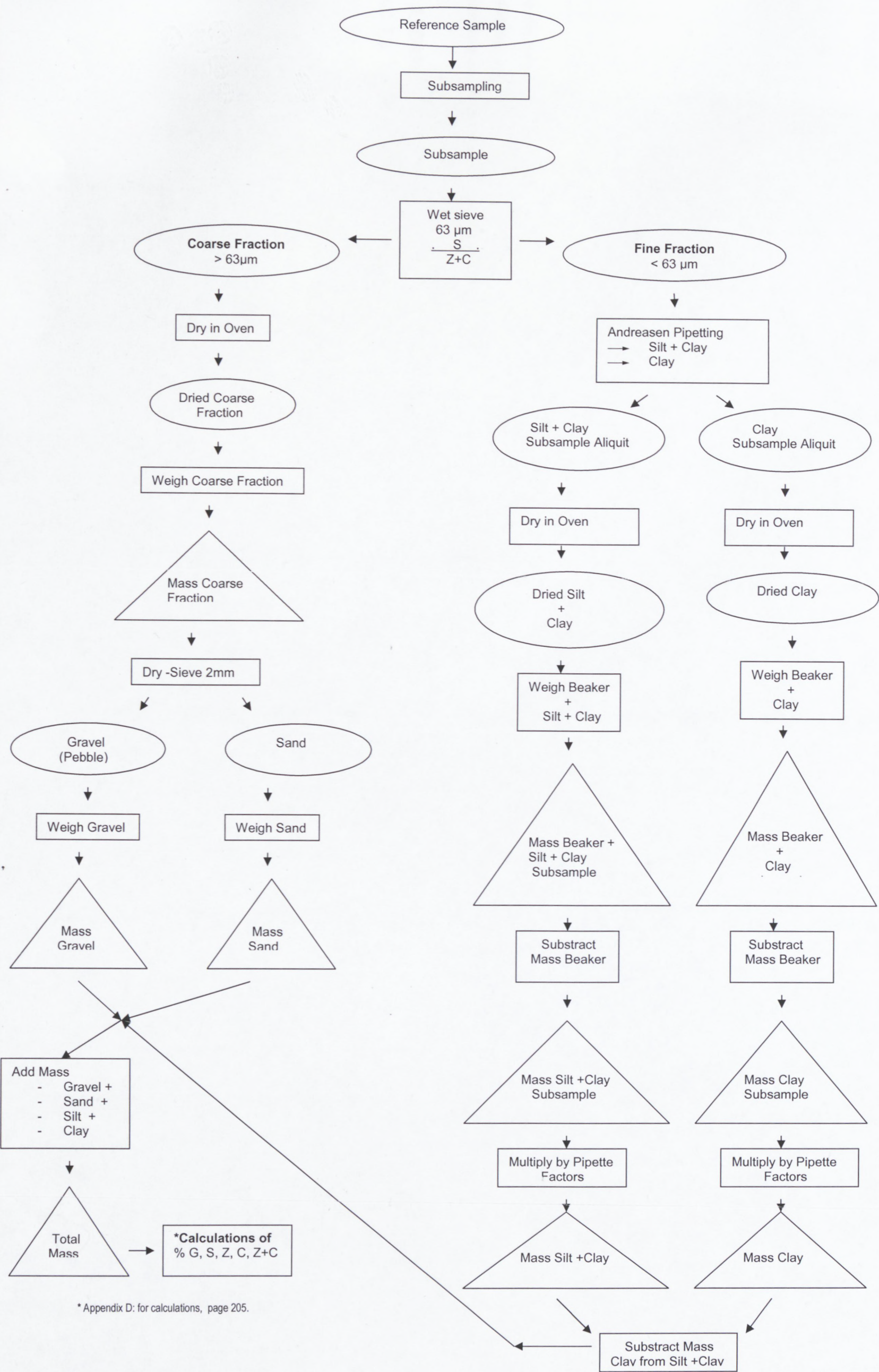
The sample was divided in half using a V-profile chute splitter. This process was for backup purposes. In the occasion of loss or damage to other half this may be used for the grain size analysis after further preparation (de Villiers 1988).

At sampling site 1 and site 4 of sediment, special treatment of unwanted particle had to be applied. Then both sites weeds were removed. The following procedure was used for the removal of weeds: Two beakers with coarse fraction were placed in the fume cabinet at the water bath. Hydrogen peroxide was used to float up substances in the beaker. This solution was occasionally stirred. Floating substances were removed. Salt was removed from the sediment samples overnight by dialysis in cellophane tubing in a bathtub of water. The removal of salt is necessary to avoid flocculation during grain analysis (de Villiers 1988).

A measuring sieve of 63 µm was used. Samples were placed on the sieve and splashed with distilled water to separate the course and fine fractions. Under this sieve was a bowl to receive fine fraction (< 63 µm in size). Splashing with water was done several times until was only coarse fraction (>63 µm in size) left. This coarse fraction was reintroduced into the pre-weighed beaker. The coarse fraction was dried overnight in an oven at 80 °C. The course weight fraction is

equal to the weight of the sand plus gravel. Similar application to fine fraction: The weight fines (silt and clay) can also be calculated by subtracting the coarse weight from the sample weight. The coarse fraction was dry sieved through 2.0 mm sieve. Thus was done in order to separate the sand and gravel. Sand and gravel fractions were weighed using an electronic balance to obtain the weight of sand and gravel. The supernatant water above the settled silt and clay was then transferred to a measuring cylinder and made up to a volume of one litre. An Andreasen Pipette was used to determine the size distribution of silt and clay (Folk 1968). The full process of sediment characterization is shown in figure 2.3.

○ = Sample or Subsample □ = Operation △ = Final Results



* Appendix D: for calculations, page 205.

Figure 2.3: A flow diagram for processing of sediments for characterisation

Chapter 3

Water results: Physico-chemical parameters and metal concentrations

3.1 PHYSICO-CHEMICAL PARAMETERS

3.1.1 pH

Table 3.1: pH values measured in the water at various sites in the Kuils River over a period of one year. SO= Sampling occasion

SO	Sampling Date	pH values			
		Site 1	Site 2	Site 3	Site 4
1	October 2005	6.8	7.3	7.2	7.2
2	December 2005	7.2	7.3	8.2	7.2
3	February 2006	7.2	7.3	7.3	8.1
4	April 2006	6.7	7.9	7.9	8.5
5	June 2006	7.4	7.0	7.1	7.4
6	August 2006	6.5	7.4	7.6	7.5
7	October 2006	7.4	7.7	7.8	7.3

The pH values in the water samples ranged between 6.5 and 8.5. The lowest pH observed value was mostly measured at site 1 and the mostly highest pH measured were at site 3 & 4 (Table 3.1).

3.1.2 TEMPERATURE

Table 3.2: Temperatures measured in the water at various sites in the Kuils River over a period of one year. SO= Sampling occasion

SO	Sampling Date	Temperature (°C)			
		Site 1	Site 2	Site 3	Site 4
1	October 2005	15	16.3	17.3	20.7
2	December 2005	18.7	20	22.6	29.6
3	February 2006	21.6	22.6	24.5	28.1
4	April 2006	18.9	20.4	22.1	28.4
5	June 2006	11.5	11	15	22.1
6	August 2006	13	13.8	14.5	16.3
7	October 2006	13.8	17.3	16.1	22.4

The water temperature ranged from 11 to 29.6°C. The highest water temperature observed throughout the year was at site 4 (Table 3.2). This site had less vegetation cover, which exposed this site to the sun that could have contributed to high temperatures. According to Dallas & Day (1993), when the water in the river is exposed to direct solar radiation, this leads to higher temperature and the greater temperature ranges and fluctuation. Therefore, it could be possible that the direct sunlight was cause of higher temperature at site 4. Conversely, site 1 had the lowest temperatures measured (Table 3.2). There was much more vegetation coverage at this site. Providing more shade and consequently keeping temperatures lower.

3.1.3 ELECTRICAL CONDUCTIVITY

Table 3.3: Electrical Conductivity (mS m^{-1}) measured in the water at various sites in the Kuils River over a period of one year. SO= Sampling occasion

SO	Sampling Date	ElectricalConductivity (mS m^{-1})			
		Site 1	Site 2	Site 3	Site 4
1	October 2005	Not Measured	Not Measured	Not Measured	Not Measured
2	December 2005	206	145	137	111
3	February 2006	141	170	115	108
4	April 2006	89	170	118	96
5	June 2006	192	108	104	109
6	August 2006	55	48	49	75
7	October 2006	80	82	81	84

The levels of electrical conductivity varied between 48 and 206 mS m^{-1} in the water samples. The highest value observed was at site 1 and the lowest at site 2 (Table 3.3).

3.2 METALS IN WATER

No graphs were plotted for metals in water, due to low concentrations. Also, some of the metals were not detected.

3.2.1 ALUMINIUM

3.2.1.1 Comparisons of total Al concentrations measured in water, at a particular site over the 12 month sampling period

In pairwise multiple comparisons made at sites 1 to 4, during occasions 1 to 7, occasion 6 revealed the highest Al concentrations at all sites compared to all the other occasions ($P < 0.05$). The highest measured Al concentration of 1.56 ± 0.18 mg/L was found at site 2 during sampling occasion 6 (Table 3.4).

3.2.1.2 Comparisons of total Al concentrations measured in water per sampling occasion over the length of the river

On sampling occasion 1, site 2 had the lowest Al water concentrations compared to the other sites ($P < 0.05$) (Table 3.4). On occasion 2, site 1 had the highest concentration compared to any of the other sites ($P < 0.05$). The results of occasion 3, at site 4 showed the lowest mean concentration of 0.27 ± 0.04 mg/L compared to the other sites on this occasion ($P < 0.05$). During sampling occasions 4, 5 and 7, there were no statistically significant differences ($P > 0.05$) for all comparisons made from site 1 to 4 (Table 3.4). Pairwise multiple comparisons for sampling occasion 6 ($P < 0.05$) revealed the highest mean concentration at site 2 (1.56 ± 0.18 mg/L) (Table 3.4).

3.2.2 LEAD

3.2.2.1 Comparisons of total Pb concentrations measured in water, at a particular site over the 12 month sampling period

No statistically significant differences were found for Pb ($P > 0.05$) (Table 3.5).

3.2.2.2 Comparisons of total Pb concentrations measured in water per sampling occasion over the length of the river

No statistical differences were found for occasions 1-6 at any site ($P>0.05$). In pairwise multiple comparisons made for occasion 7, site 1 had the highest concentration of Pb compared to the other sites ($P<0.05$) (Table 3.5).

3.2.3 COBALT

3.2.3.1 Comparisons of total Co concentrations measured in water, at a particular site over the 12 month sampling period

No statistically significant differences ($P>0.05$) were observed for Co (Table 3.6).

3.2.3.2 Comparisons of total Co concentrations measured in water per sampling occasion over the length of the river

No statistically significant differences ($P>0.05$) were observed for Co (Table 3.6).

3.2.4 COPPER

3.2.4.1 Comparisons of total Cu concentrations measured in water, at a particular site over the 12 month sampling period

At site 1, occasion 2 had the highest mean concentration of Cu compared to the other occasions ($P>0.05$). Sites 2 and 4, both on sampling occasion 3, had the highest Cu concentrations compared to the other sites ($P<0.05$). At site 3, no statistical significant differences were found for Cu in all occasions ($P>0.05$) (Table 3.7).

3.2.4.2 Comparisons of total Cu concentrations measured in water per sampling occasion over the length of the river

No statistically significant differences ($P>0.05$) were found for Cu (Table 3.7).

3.2.5 IRON

3.2.5.1 Comparisons of total Fe concentrations measured in water, at a particular site over the 12 month sampling period

At sites 1, 2 and 3 during sampling occasion 2, the results revealed the highest mean Fe concentrations ($P < 0.05$) in comparison to other occasions (Table 3.8). Occasion 5 (Site 4) revealed the highest concentrations compared to other sampling occasions at site 4 ($P < 0.05$). The highest mean concentration of Fe was 48.48 ± 9.09 mg/L at site 1 during sampling occasion 2 (Table 3.8).

3.2.5.2 Comparisons of total Fe concentrations measured in water per sampling occasion over the length of the river

Pairwise multiple comparisons of Fe concentrations on occasions 1, 4, 5 and 7, revealed no statistical significant differences ($P > 0.05$). During sampling occasion 2, site 1 revealed the highest mean concentration compared to any of the other sites ($P < 0.05$) (Table 3.8). On occasions 3 and 6, site 2 had the highest Fe concentrations compared to the other sites ($P < 0.05$) (Table 3.8).

3.2.6 MANGANESE

3.2.6.1 Comparisons of total Mn concentrations measured in water, at a particular site over the 12 month sampling period

At sites 1 and 2, during occasion 3, both sites had the highest Mn concentrations compared to other sites ($P < 0.05$). Pairwise comparisons made for sites 3 and 4, both on occasions 6, revealed the highest concentration of Mn ($P < 0.05$) (Table 3.9).

3.2.6.2 Comparisons of total Mn concentrations measured in water per sampling occasion over the length of the river

During sampling occasions 1 to 4, 6 and 7, statistical significant differences were observed for all site comparisons ($P < 0.05$). All these occasions revealed the

lowest mean concentrations of Mn at site 4 ($P < 0.05$). The mean concentrations of these occasions ranged between 0.00 and 0.59 mg/L at all compared sites. No statistical significant differences ($P > 0.05$) were found on occasion 5 when the different sites were compared (Table 3.9).

3.2.7 NICKEL

3.2.7.1 Comparisons of total Ni concentrations measured in water, at a particular site over the 12 month sampling period

No statistical significant differences were found for Ni ($P > 0.05$) (Table 3.10).

3.2.7.2 Comparisons of total Ni concentration measured in water per sampling occasion over the length of the river

No statistical significant differences were found for Ni ($P > 0.05$) (Table 3.10).

3.2.8 ZINC

3.2.8.1 Comparisons of total Zn concentrations measured in water, at a particular site over the 12 month sampling period

At sites 1, 3 and 4 of occasion 7, the mean Zn concentrations were found to be higher than at any of the other occasions ($P < 0.05$) (Table 3.11). Sampling site 2 had the highest concentration of Zn on occasion 3 compared to the other sites ($P < 0.05$) (Table 3.11).

3.2.8.2 Comparisons of total Zn concentration measured in water per sampling occasion over the length of the river

The results of occasion 1, compared over all sites, showed that site 2 had the lowest mean concentration of 0.07 ± 0.07 mg/L ($P < 0.05$). No statistical significant differences were found for occasions 2, 5 and 6 ($P > 0.05$). On occasions 3 and 7,

site 1 had the highest mean concentration of Zn compared to the other sites ($P < 0.05$). During sampling occasion 4, site 4 had the highest mean concentration compared to the other sites ($P < 0.05$) (Table 3.11).

Cadmium and Cr were not detected in any of the water samples that were analysed.

Table 3.4: Mean aluminium concentrations (mg/L) (\pm SD), measured in the water samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	b,c,d,e,f,g 0.23 (\pm 0.27) ^b	b,c,d,e,f 0.07 (\pm 0.07) ^{a,c,d}	e,f,g 0.27 (\pm 0.12) ^b	f 0.34 (\pm 0.16) ^b
2	a,d,e,f,g 0.45 (\pm 0.07) ^{b,c,d}	a,b,d,e,f,g 0.36 (\pm 0.05) ^{a,d}	e,f,g 0.35 (\pm 0.05) ^{a,d}	f 0.23 (\pm 0.06) ^{a,b,c}
3	a,d,e,f,g 0.56 (\pm 0.25) ^d	a,b,d,e,f,g 0.78 (\pm 0.46) ^d	e,f,g 0.44 (\pm 0.13) ^d	f 0.27 (\pm 0.04) ^{a,b,c}
4	a,b,c,e,f,g 0.34 (\pm 0.06)	a,b,c,d,f,g 0.32 (\pm 0.04)	e,f,g 0.40 (\pm 0.08)	f 0.27 (\pm 0.05)
5	a,b,c,d,f,g 0.16 (\pm 0.089)	ND	ND	f 0.12 (\pm 0.27)
6	a,b,c,d,e,g 0.68 (\pm 0.11) ^{b,c,d}	a,b,c,d,e,g 1.56 (\pm 0.18) ^{a,c,d}	a,b,c,d,e,g 1.24 (\pm 0.17) ^{a,b,d}	a,b,c,d,e,g 1.00 (\pm 0.00) ^{a,b,c}
7	a,b,c,d,e,f 0.02 (\pm 0.02)	b,c,d,e,f 0.05 (\pm 0.07)	ND	f 0.01 (\pm 0.01)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Table 3.5: Mean lead concentrations (mg/L) (\pm SD), measured in the water samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	ND	0.01 (\pm 0.02)	0.02 (\pm 0.03)	0.01 (\pm 0.02)
2	0.01 (\pm 0.02)	ND	ND	ND
3	ND	0.01 (\pm 0.02)	0.03 (\pm 0.03)	0.03 (\pm 0.03)
4	ND	ND	ND	ND
5	0.01 (\pm 0.03)	0.02 (\pm 0.03)	0.01 (\pm 0.03)	0.01 (\pm 0.03)
6	ND	0.02 (\pm 0.03)	0.02 (\pm 0.03)	0.01 (\pm 0.02)
7	0.05 (\pm 0.00) ^{b,c,d}	0.01 (\pm 0.02) ^a	ND	ND

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Table 3.6: Mean cobalt concentrations (mg/L) (\pm SD), measured in the water samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	ND	ND	ND	ND
2	ND	0.01 (\pm 0.01)	ND	ND
3	ND	ND	0.00 (\pm 0.01)	ND
4	ND	ND	ND	ND
5	ND	ND	ND	ND
6	ND	ND	ND	ND
7	ND	ND	ND	ND

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 No statistical significant differences were found ($P > 0.05$).

Table 3.7: Mean copper concentrations (mg/L) (\pm SD), measured in the water samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	ND	ND	ND	ND
2	^{c,g} 0.13 (\pm 0.25)	^{c,g} 0.02 (\pm 0.04)	ND	^{c,g} 0.02 (\pm 0.05)
3	^{a,b,d,e,f} 0.09 (\pm 0.05)	^{a,b,d,e,f} 0.10 (\pm 0.04)	0.13 (\pm 0.04)	^{a,b,d,e,f} 0.11 (\pm 0.02)
4	ND	ND	0.03 (\pm 0.05)	ND
5	^{c,g} 0.00 (\pm 0.01)	^{c,g} 0.02 (\pm 0.02)	0.02 (\pm 0.04)	^{c,g} 0.01 (\pm 0.01)
6	ND	ND	0.00 (\pm 0.01)	^{c,g} 0.01 (\pm 0.02)
7	^{a,b,d,e,f} 0.05 (\pm 0.03)	^{a,b,d,e,f} 0.09 (\pm 0.04)	0.12 (\pm 0.05)	^{a,b,d,e,f} 0.12 (\pm 0.06)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND = Not Detected.

Table 3.8: Mean iron concentrations (mg/L) (\pm SD), measured in the water samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	b,c,d,f,g 2.63 (\pm 2.31)	b,c,d,g 2.98 (\pm 1.78)	d 2.95 (\pm 2.62)	c,d,g 1.36 (\pm 0.92)
2	a,c,d,e,f,g 48.48 (\pm 9.90) ^{c,d}	a,c,d,e,f,g 42.58 (\pm 9.22) ^{c,d}	d 4.36 (\pm 4.47) ^{a,b}	c,d,f 1.08 (\pm 1.43) ^{a,b}
3	a,b,d,e,f,g 14.95 (\pm 6.54) ^{c,d}	a,c,d,e,f,g 15.01 (\pm 3.09) ^{c,d}	d 0.66 (\pm 1.47) ^{a,b}	a,b,e,f 0.14 (\pm 0.32) ^{a,b}
4	ND	ND	ND	ND
5	b,c,d,f,g 4.73 (\pm 4.81)	b,c,d,g 4.66 (\pm 3.27)	d 2.15 (\pm 1.40)	c,d,g 1.38 (\pm 1.13)
6	a,b,c,e 0.14 (\pm 0.09) ^{b,c,d}	b,c,d,g 2.00 (\pm 0.47) ^{a,c,d}	d 1.01 (\pm 0.21) ^{a,b}	c,d,g 1.15 (\pm 0.87)
7	ND	a,b,c,d,e,f 0.66 (\pm 0.38)	d 0.59 (\pm 0.33)	ND

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND = Not Detected.

Table 3.9: Mean manganese concentrations (mg/L) (\pm SD), measured in the water samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	b,c,d,e 0.03 (\pm 0.03) ^d	b,c,d,e,f,g 0.01 (\pm 0.00) ^d	b,e,f,g 0.01 (\pm 0.01) ^d	ND
2	a,d,e,f,g 0.13 (\pm 0.03) ^{c,d}	a,c,d,e,f,g 0.14 (\pm 0.03) ^{c,d}	a,c,d,e,f,g 0.02 (\pm 0.01) ^{a,b,d}	c,d,e,f,g 0.01 (\pm 0.00) ^{a,b,c}
3	a,d,e,f,g 0.31 (\pm 0.19) ^{c,d}	a,b,d,e,f,g 0.59 (\pm 0.49) ^{c,d}	b,e,f,g 0.01 (\pm 0.01) ^{a,b}	a,b,d,e,f 0.01 (\pm 0.01) ^{a,b}
4	a,b,c,f,g 0.08 (\pm 0.03) ^{a,c,d}	b,c,e,g 0.02 (\pm 0.03) ^{a,b}	b,e,f,g 0.01 (\pm 0.01) ^{a,b}	ND
5	ND	ND	ND	ND
6	b,c,d,e 0.04 (\pm 0.02) ^{b,c,d}	a,b,c,e 0.08 (\pm 0.01) ^{a,d}	a,b,c,d,e,g 0.10 (\pm 0.01) ^{a,d}	a,b,c,d,e,g 0.06 (\pm 0.00) ^{a,b,c}
7	b,c,d,e 0.02 (\pm 0.01) ^{b,c}	a,b,c,d,e 0.09 (\pm 0.00) ^{a,c,d}	a,b,c,d,e,f 0.06 (\pm 0.00) ^{a,b,d}	a,b,d,e,f 0.02 (\pm 0.00) ^{b,c}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND = Not Detected.

Table 3.10: Mean nickel concentrations (mg/L) (\pm SD), measured in the water samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	ND	ND	ND	ND
2	ND	ND	ND	ND
3	ND	ND	ND	ND
4	ND	ND	ND	ND
5	ND	ND	ND	ND
6	0.03 (\pm 0.05)	0.05 (\pm 0.04)	0.01 (\pm 0.02)	0.01 (\pm 0.02)
7	ND	ND	ND	ND

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 No statistical significant differences were found (P>0.05).

Table 3.11: Mean zinc concentrations (mg/L) (\pm SD), measured in the water samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^{b,c,g} 0.23 (\pm 0.27) ^b	^{b,c,d,g} 0.07 (\pm 0.07) ^{a,c,d}	^{b,d} 0.27 (\pm 0.12) ^b	^{b,c,d,e,t,g} 0.34 (\pm 0.16) ^b
2	ND	ND	ND	ND
3	^{a,b,d,e,t} 0.60 (\pm 0.16) ^{c,d}	^{a,b,d,e,t,g} 0.52 (\pm 0.11) ^{c,d}	^{e,b} 0.13 (\pm 0.13) ^{a,b}	^{a,b,g} 0.06 (\pm 0.09) ^{a,b}
4	^{b,c,g} 0.05 (\pm 0.02) ^{b,d}	^{a,b,c,e,t,g} 0.02 (\pm 0.01) ^{a,d}	^{a,b,g} 0.04 (\pm 0.02) ^d	^{a,b,g} 0.09 (\pm 0.03) ^{a,b,c}
5	^{b,c,t} 0.19 (\pm 0.11)	^{b,c,d,g} 0.12 (\pm 0.09)	^{b,c} 0.09 (\pm 0.04)	^{a,b,g} 0.13 (\pm 0.10)
6	^{b,c,g} 0.08 (\pm 0.03)	^{b,c,d,g} 0.07 (\pm 0.03)	^b 0.09 (\pm 0.03)	^{a,b,g} 0.12 (\pm 0.04)
7	^{a,b,d,e,t} 1.31 (\pm 1.15) ^{b,c,d}	^{a,b,c,d,e,t} 0.30 (\pm 0.11) ^{a,d}	^{b,d} 0.34 (\pm 0.09) ^{a,d}	^{a,b,c,d,e,t} 0.53 (\pm 0.14) ^{a,b,c}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.
 Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Chapter 4

Sediment results: Characterisation and metal concentrations

4.1 SEDIMENT CHARACTERISATION

Table 4.1 (a): Comparative percentages of the various soil fractions in sediment samples collected from the four sampling sites in the Kuils River.

	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Mean size (phi) Φ
Site 1	0.00	33.13	50.83	16.04	2.63
Site 2	0.06	98.99	0.80	0.16	1.89
Site 3	0.00	99.06	0.63	0.32	1.55
Site 4	0.31	86.81	9.78	3.09	1.85

Sediment particles are a consequence from a mixture of material inputs from diverse sources. They consist of a range of components. Sediment is normally categorized according to size. In broad terms, sediment are categorized as coarse (sand and coarse material less than 62 μm in diameter) and fine (silt and clays greater than 62 μm). The coarse fraction is composed primarily of stable, inorganic silicate materials that are noncohesive and generally not associated with chemical contamination. The fine fraction consists of particles with a relatively large surface area to volume ratio and frequently, surface electric charges that cause these particles to be more chemically and biologically reactive than coarser sands and that increase the likelihood of sorption and desorption of contaminants (Power & Chapman 1992).

Sediment has been generally used as environmental indicators and their ability to trace contamination sources and monitor contaminants is mostly recognized (Kolbe & Luedke 2005). Gravel and sands are most permeable. Muds are least permeable (Chapman 1981).

The percentage of clay, silt, sand and gravel were determined (Table 4.1(a)). This table shows the various fractions of sampled sediment according to each site. Site 1 was classified as sandy mud, site 2 was slightly gravelly sand, site 3 was identified to be sandy and site 4 was slightly gravelly muddy sand. Generally, the Kuils River has sandy sediment.

Table 4.1 (b): Grain size equivalent of metric and phi scales, giving parameters for size class classification. Source: Friedman and Sanders (1978), Davis (1983).

mm	Φ Units		Size class
4	-2	very fine	Pebble
2	-1	Very coarse	
1	0	Coarse	Sand
2^{-1}	+1	Medium	
4^{-1}	+2	Fine	
8^{-1}	+3	Very fine	
16^{-1}	+4	Very coarse	Silt
32^{-1}	+5	Coarse	
64^{-1}	+6	Medium	
128^{-1}	+7	Fine	
256^{-1}	+8	Very fine	Clay
512^{-1}	+9		

4.2 METALS IN SEDIMENT

4.2.1 ALUMINIUM

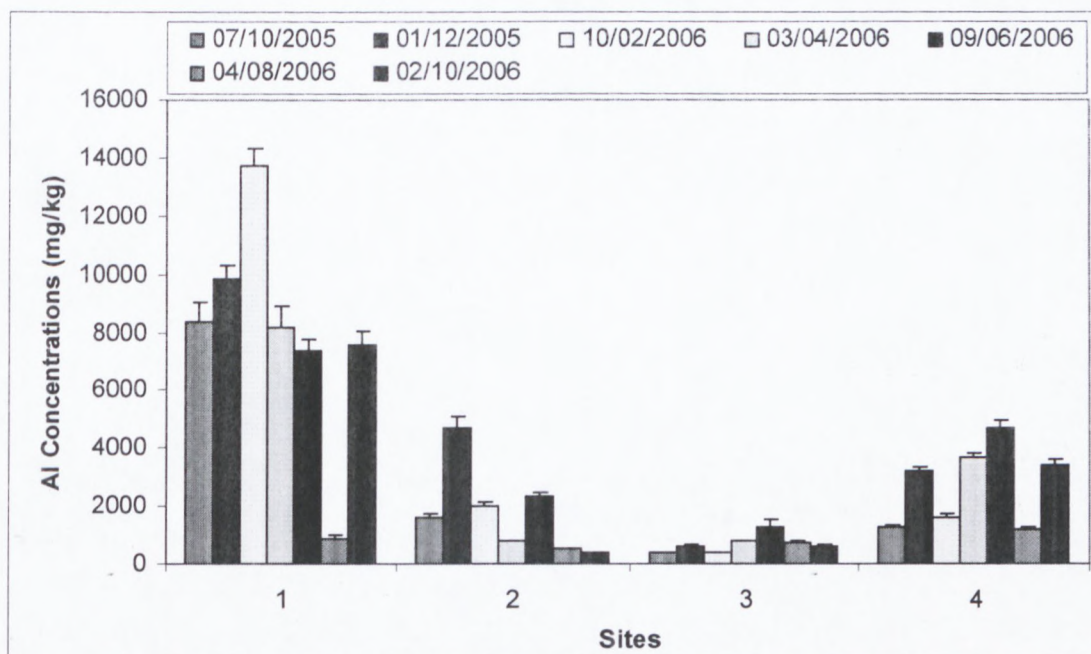


Figure 4.1: Mean concentrations of total aluminium (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: No quality guideline found.

4.2.1.1 Comparisons of total Al concentrations measured in sediment, at a particular site over the 12 month sampling period

At site 1, comparisons of occasions 1 to 7, revealed that occasion 3, had the highest concentrations compared to other sampling occasions at this site ($P<0.05$) (Fig. 4.1). Pairwise multiple comparisons made between sediment Al concentrations on all sampling occasions at site 2, showed that occasion 2, had the highest concentrations ($P<0.05$) of all the occasions. The results of site 3 revealed that occasion 5 had the highest concentrations ($P<0.05$) compared to other occasions. At site 4, sampling occasion 5 had the highest concentrations ($P<0.05$) compared to the other occasions. The lowest Al concentrations measured were 381.52 ± 17.29 mg/kg at site 3 during occasion 1. The highest mean Al concentrations measured were 9845.20 ± 461.14 mg/kg at site 1 during the 3rd sampling occasion (Fig. 4.1, Table 4.2).

4.2.1.2 Comparisons of total Al concentrations measured in sediment per sampling occasion over the length of the river

The Al sediment concentrations measured on occasion 1, at site 1 were statistically significantly higher than those of any of the other sites on the first sampling occasion ($P < 0.05$). On occasion 2, site 1 revealed statistically higher Al concentrations ($P < 0.05$) in comparison to sites 2, 3 and 4 of the same occasion. On occasion 3, site 1 had the highest mean concentration of 13727.14 ± 594.61 mg/kg for this particular sampling occasion ($P < 0.05$). On occasion 4 the comparison of sites 2 vs 3 revealed no statistical difference ($P > 0.05$). The measured concentrations at sites 2 and 3 were significantly lower than at sites 1 and 4 on occasion 4 ($P < 0.05$). For occasions 5, 6 and 7 all site comparisons (sites 1-4) were found to be statistically significant ($P < 0.05$) (Fig. 4.1, Table 4.2).

4.2.2 CADMIUM

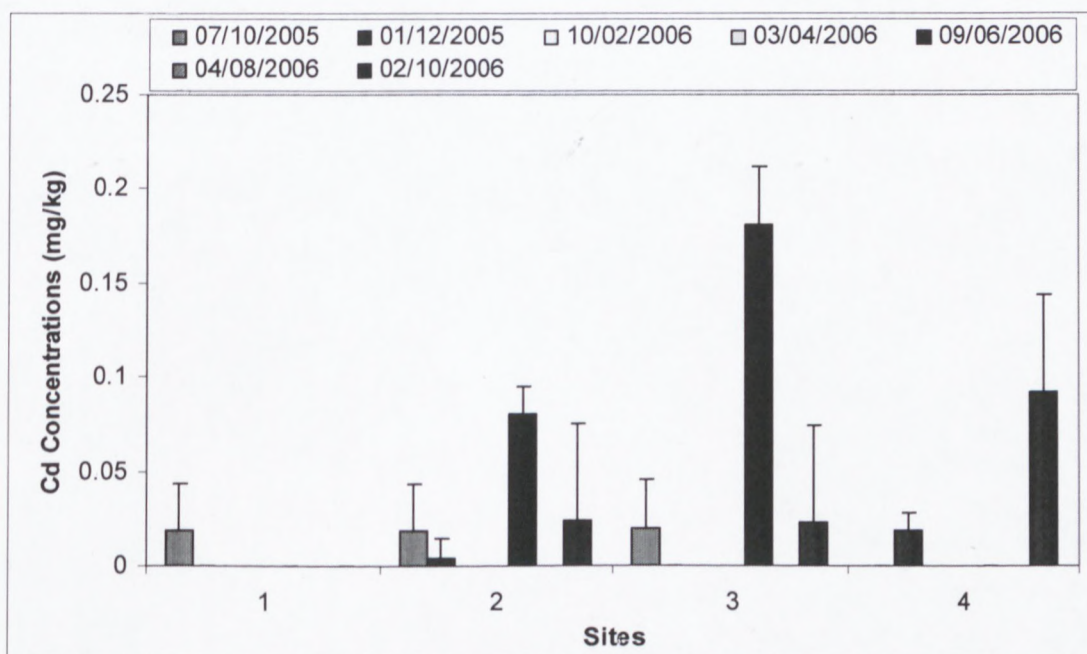


Figure 4.2: Mean concentrations of total cadmium (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: Quality guideline is 0.6 mg/kg (CCME, 2001).

4.2.2.1 Comparisons of total Cd concentrations measured in sediment, at a particular site over the 12 month sampling period

No statistical significant differences were found for Cd ($P>0.05$) (Fig 4.2, Table 4.3).

4.2.2.2 Comparisons of total Cd concentrations measured in sediment per sampling occasion over the length of the river

No statistical significant differences were found for Cd ($P>0.05$) (Fig 4.2, Table 4.3).

4.2.3 LEAD

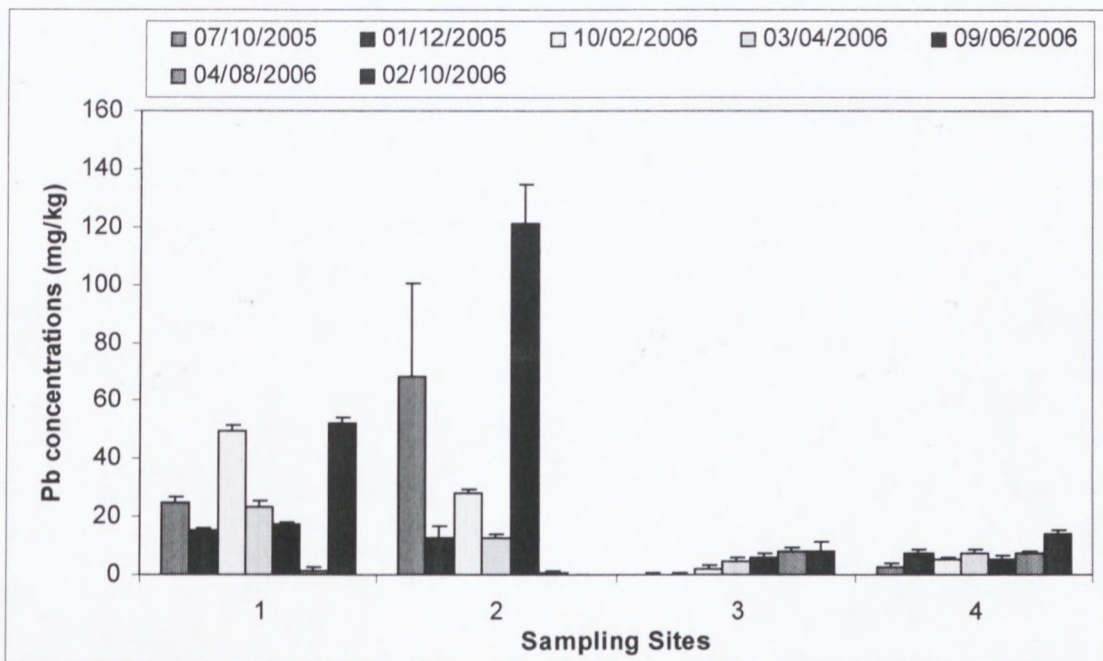


Figure 4.3: Mean concentrations of total lead (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: Quality guideline is 35.0 mg/kg (CCME, 2001).

4.2.3.1 Comparisons of total Pb concentrations measured in sediment, at a particular site over the 12 month sampling period

The results from sites 1 and 4 revealed that sampling occasion 7 had the highest Pb concentrations compared to any of the other occasions ($P<0.05$). At site 2 sampling occasion 5 had the highest mean Pb concentration compared to the

other sampling occasions ($P < 0.05$). At site 3, occasion 4 had the highest concentrations compared to other sampling occasions at this site ($P < 0.05$). The lowest Pb concentration of 0.23 ± 0.51 mg/kg was measured at site 3, on occasion 1. The highest mean Pb concentration of 121.11 ± 13.36 mg/kg was measured at site 2 during the 5th sampling occasion (Fig. 4.3, Table 4.4).

4.2.3.2 Comparisons of total Pb concentrations measured in sediment per sampling occasion over the length of the river

On sampling occasions 1, 3, 4 and 7, all site comparisons revealed statistical significant differences ($P < 0.05$). On occasion 2, only sites 1 and 2 was found not to be statistically different from each other ($P > 0.05$). On occasion 5, only the site 3 vs 4 comparison revealed no statistical difference from each other ($P > 0.05$). The highest Pb concentration of 121.11 ± 13.36 mg/kg was found at site 2 on occasion 5. During sampling occasion 6, only two site comparisons showed no statistical differences from each other ($P > 0.05$): 3 vs 4 and 1 vs 2 (Fig. 4.3, Table 4.4).

4.2.4 CHROMIUM

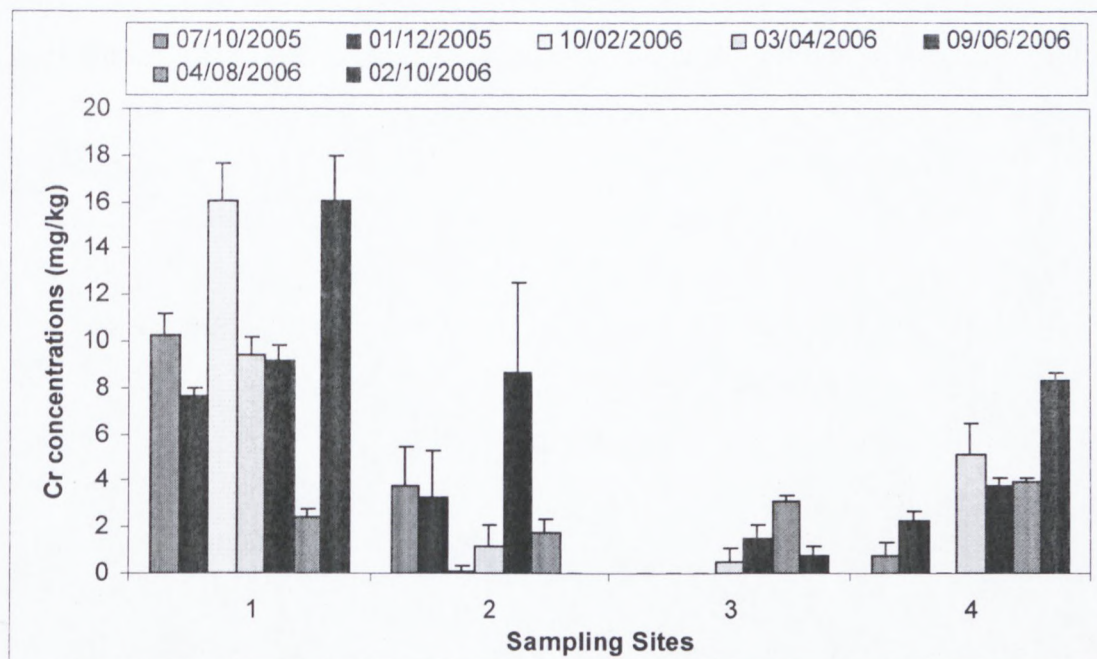


Figure 4.4: Mean concentrations of total chromium (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: Quality guideline is 37.3 mg/kg (CCME, 2001).

4.2.4.1 Comparisons of total Cr concentrations measured in sediment, at a particular site over the 12 month sampling period

At site 1 both occasion 3 and 7 had the same Cr concentrations that were significantly higher when compared to other occasions ($P<0.05$). On occasions 3 and 7, at site 2 the lowest Cr concentrations were found ($P<0.05$). At site 3 on occasion 6, the highest concentrations were found compared to any of the other occasions ($P<0.05$). At site 4, occasion 7 had the highest concentrations compared to any of the other occasions ($P<0.05$). The lowest Cr concentration measured was 0.11 ± 0.24 mg/kg at site 2 during occasions 3. The highest mean Cr concentrations measured were 16.06 ± 1.96 mg/kg at site 1 during the 3rd and 7th sampling occasions (Fig. 4.4, Table 4.5).

4.2.4.2 Comparisons of total Cr concentrations measured in the sediment per sampling occasion over the length of the river

During sampling occasion 1, site 1 had higher Cr concentrations compared to sites 2, 3 and 4 ($P < 0.05$). Results from occasion 2 revealed that the site 2 vs 4 comparison showed no statistical difference ($P > 0.05$). However, the rest of the compared sites were statistically difference from each other ($P < 0.05$). On occasion 2, site 1 had the highest mean concentration of 7.61 ± 0.36 mg/kg. On occasion 3 statistical differences were found for site comparisons, 1 vs 2, 1 vs 3 and 1 vs 4 ($P < 0.05$). Comparisons of Cr concentrations measured during sampling occasion 4 indicated statistical significant differences ($P < 0.05$) between all sites, except between sites 2 and 3 ($P > 0.05$). Similar results were found at occasion 5. Only sites 1 and 2 were not statistically significantly different from each other ($P > 0.05$). Pairwise multiple comparisons made for occasions 6 and 7 showed statistical differences ($P < 0.05$) between all sites. The highest Cr concentration measured was found on occasion 7 at site 1 (16.06 ± 1.96 mg/kg) (Fig. 4.4, Table 4.5).

4.2.5 COBALT

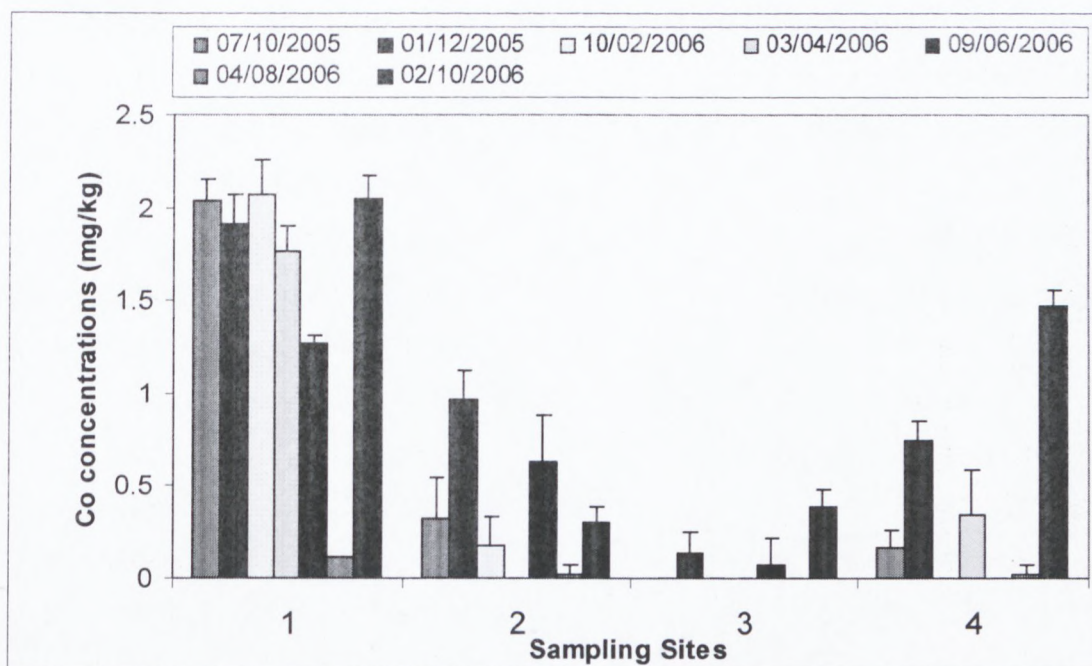


Figure 4.5: Mean concentrations of total cobalt (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: No quality guideline found.

4.2.5.1 Comparisons of total Co concentrations measured in sediment, at a particular site over the 12 month sampling period

At site 1, comparisons made from occasions 1 to 7, revealed that occasion 6 had the lowest concentration compared to the other sampling occasions ($P<0.05$) (Table 4.6). At sampling site 2, occasion 2 had the highest mean concentration (0.97 ± 0.16 mg/kg) compared to any of the other sampling occasions at this site ($P<0.05$). All comparisons made at site 3, from occasions 1 to 7, revealed no statistical significant differences ($P>0.05$). At site 4, occasion 7 had the highest concentrations ($P<0.05$). The lowest Co concentrations measured were 0.02 mg/kg both at sites 2 and 4 during occasion 6. The highest mean Co concentration measured were 2.07 ± 0.20 mg/kg at site 1 during the 3rd sampling occasion (Fig. 4.5, Table 4.6).

4.2.5.2 Comparisons of total Co concentrations measured in sediment per sampling occasion over the length of the river

The results on occasion 1, revealed that only the comparison of site 2 vs 4, showed no statistical significant difference ($P>0.05$). On occasion 2, all site comparisons revealed statistical significant differences ($P<0.05$). During occasion 3, site comparisons 2 vs 3, 2 vs 4 and 3 vs 4 revealed no statistical significant differences ($P>0.05$). On occasion 4, site 1 had the highest Co concentration compared to any of the other sites ($P<0.05$). On occasion 5, only the site 3 vs 4 comparison showed no statistical significant difference ($P>0.05$), while the rest of the site comparisons revealed statistical significant differences ($P<0.05$). No statistical differences were found during sampling occasion 6 ($P>0.05$). During sampling occasion 7, site 1 had the highest mean Co concentration of 2.05 ± 0.12 mg/kg ($P<0.05$) (Fig. 4.5, Table 4.6).

4.2.6 COPPER

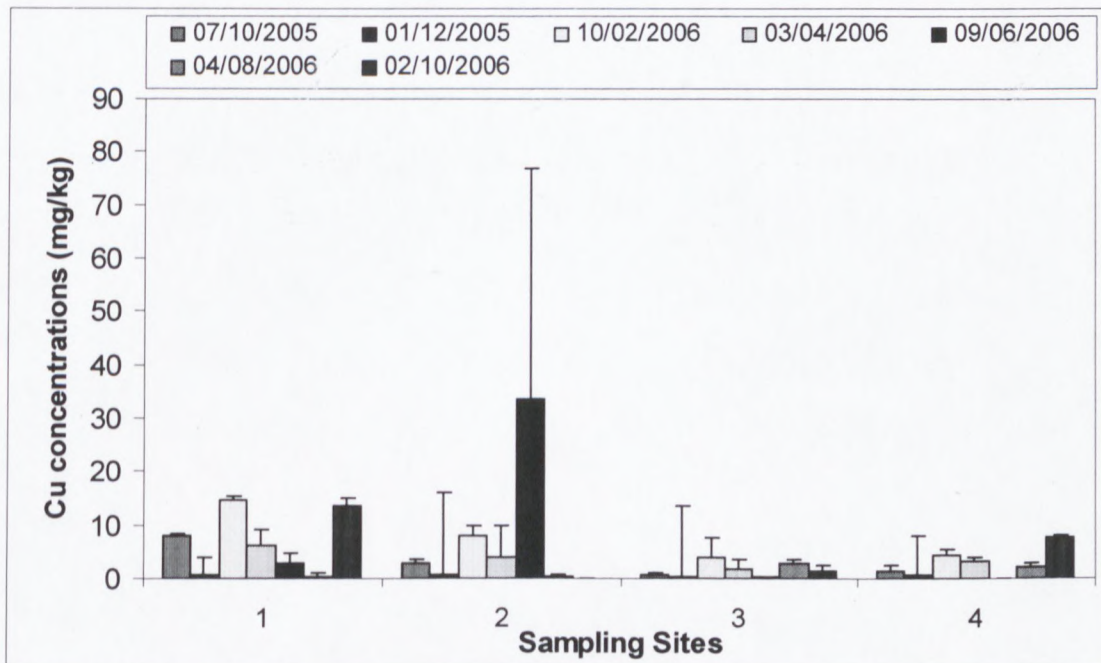


Figure 4.6: Mean concentrations of total copper (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuls River in a period of 12 months (Oct '05 - Oct '06), $n=5$: Quality guideline is 35.7 mg/kg (CCME, 2001).

4.2.6.1 Comparisons of total Cu concentrations measured in sediment, at a particular site over the 12 month sampling period

At site 1, occasion 3 revealed the highest concentrations compared to other sampling occasions at this site ($P < 0.05$). In pairwise comparisons made for site 2, occasion 5 had the highest concentration compared to the other occasions ($P < 0.05$). At site 3, sampling occasion 5 had the lowest mean Cu concentration ($P < 0.05$) in comparison to any of the other sampling occasions. At site 4, occasion 7 revealed the highest Cu concentration compared to any of the other occasions ($P < 0.05$). The lowest Cu concentration measured was 0.18 ± 0.25 mg/kg, during occasion 5 at sites 3. The highest mean Cu concentration measured was 33.75 ± 43.22 mg/kg at site 2 during the 5th sampling occasion (Fig. 4.6, Table 4.7).

4.2.6.2 Comparisons of total Cu concentrations measured in sediment per sampling occasion over the length of the river

Comparisons made between Cu concentrations at each site during sampling occasion 1 showed statistical significant differences ($P < 0.05$) for all sites except for site 3 vs 4. No statistical significant differences were found between sites for Cu on occasions 2 and 4 ($P > 0.05$). On sampling occasion 3, statistical differences ($P < 0.05$) were found for the following site comparisons: 1 vs 3, 1 vs 4 and 1 vs 2. During sampling occasion 5, all compared sites showed statistical differences ($P < 0.05$) from each other, except sites 3 and 4. On occasion 5, site 2 had the highest mean Cu concentration of 33.75 ± 43.22 mg/kg (Fig. 4.6, Table 4.7). On occasion 6, site 1 vs 2 and site 3 vs 4, were the only two site comparisons with no statistical differences ($P > 0.05$). Pairwise multiple comparisons for sampling occasion 7 showed statistical differences ($P < 0.05$) for all site comparisons (Fig. 4.6, Table 4.7).

4.2.7 IRON

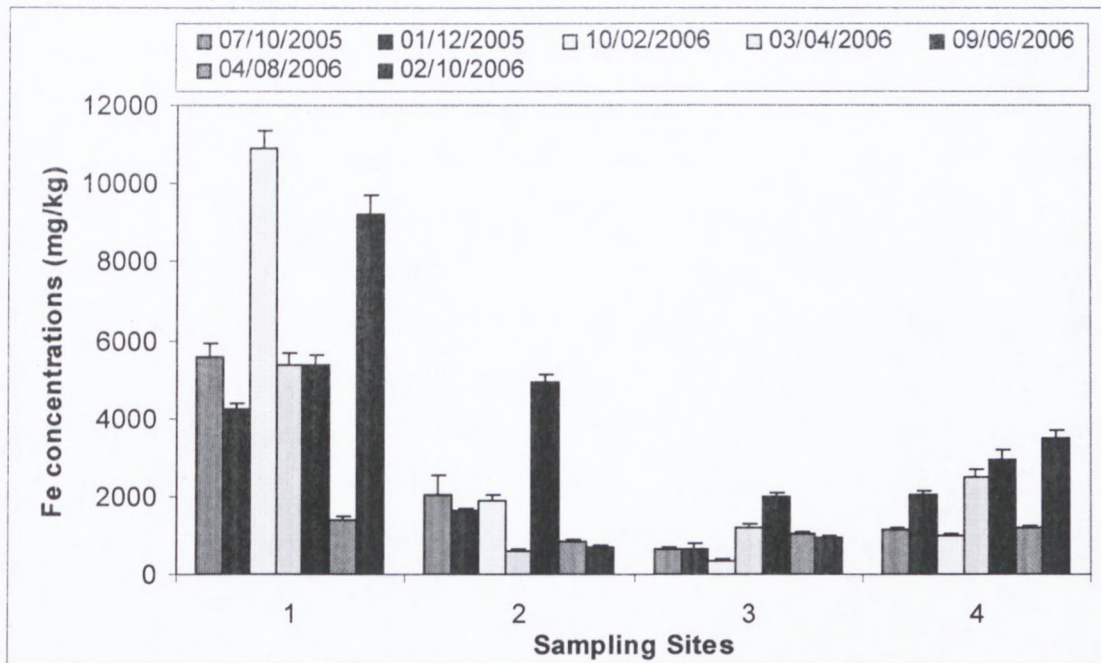


Figure 4.7: Mean concentrations of total iron (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: No quality guideline found.

4.2.7.1 Comparisons of total Fe concentrations measured in sediment, at a particular site over the 12 month sampling period

At site 1, during sampling occasion 3, the results revealed the highest mean Fe concentration ($P<0.05$) in comparison to any of the other sampling occasions. At site 2, occasion 5 had the highest concentrations compared to other sampling occasions at this site ($P<0.05$). All occasion comparisons at sites 3 and 4 were found to be statistically significantly different from each other ($P<0.05$) (Fig. 4.7, Table 4.8)

4.2.7.2 Comparisons of total Fe concentrations measured in sediment per sampling occasion over the length of the river

On occasions 1 to 7 all site comparisons revealed statistical significant differences ($P<0.05$). The highest mean Fe concentration of 10899.75 ± 442.36 mg/kg was found at site 1 on occasion 3 (Fig. 4.7, Table 4.8).

4.2.8 MANGANESE

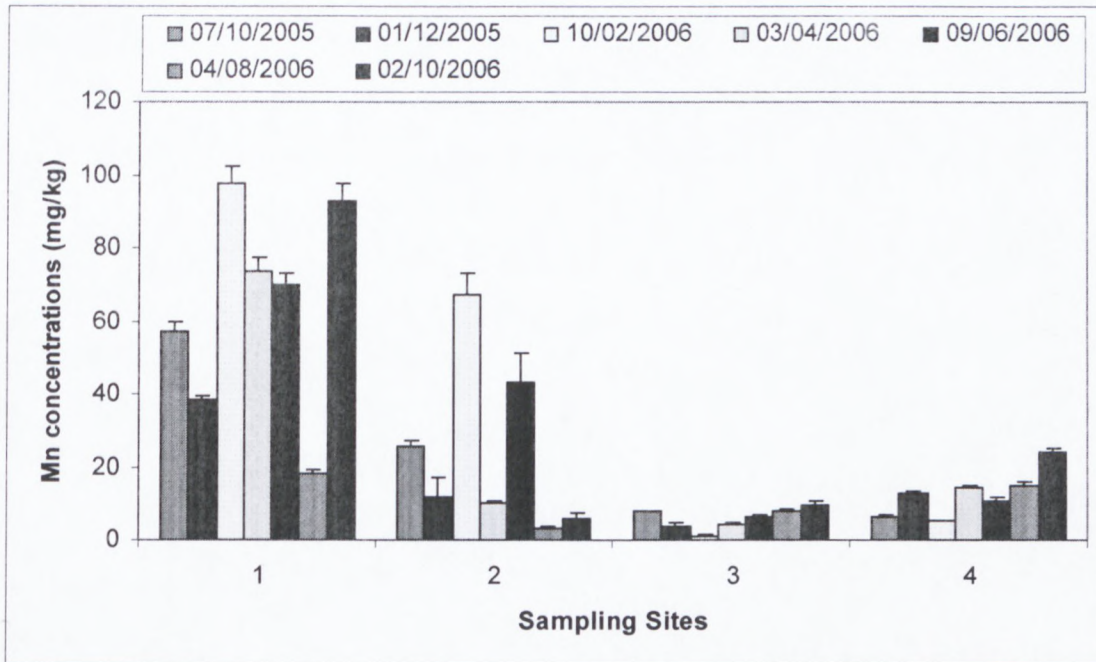


Figure 4.8: Mean concentrations of total manganese (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: No quality guideline found.

4.2.8.1 Comparisons of total Mn concentrations measured in sediment, at a particular site over the 12 month sampling period

In pairwise multiple comparisons made during occasions 1 to 7 at sites 1 and 2, the following results were obtained. Occasion 3 had higher Mn concentrations than any of the other sampling occasions at sites 1 and 2 ($P<0.05$). At sites 3 and 4, occasion 3 had the lowest concentrations compared to any of the other occasions ($P<0.05$). The highest Mn concentration was 97.83 ± 4.46 mg/kg at site 1 during the 3rd sampling occasion (Fig. 4.8, Table 4.9).

4.2.8.2 Comparisons of total Mn concentrations measured in sediment per sampling occasion over the length of the river

On occasions 1 to 7 all site comparisons revealed statistical significant differences ($P<0.05$). The highest mean Mn concentration of 97.83 ± 4.46 mg/kg was found at site 1 on occasion 3 (Fig. 4.8, Table 4.9).

4.2.9 NICKEL

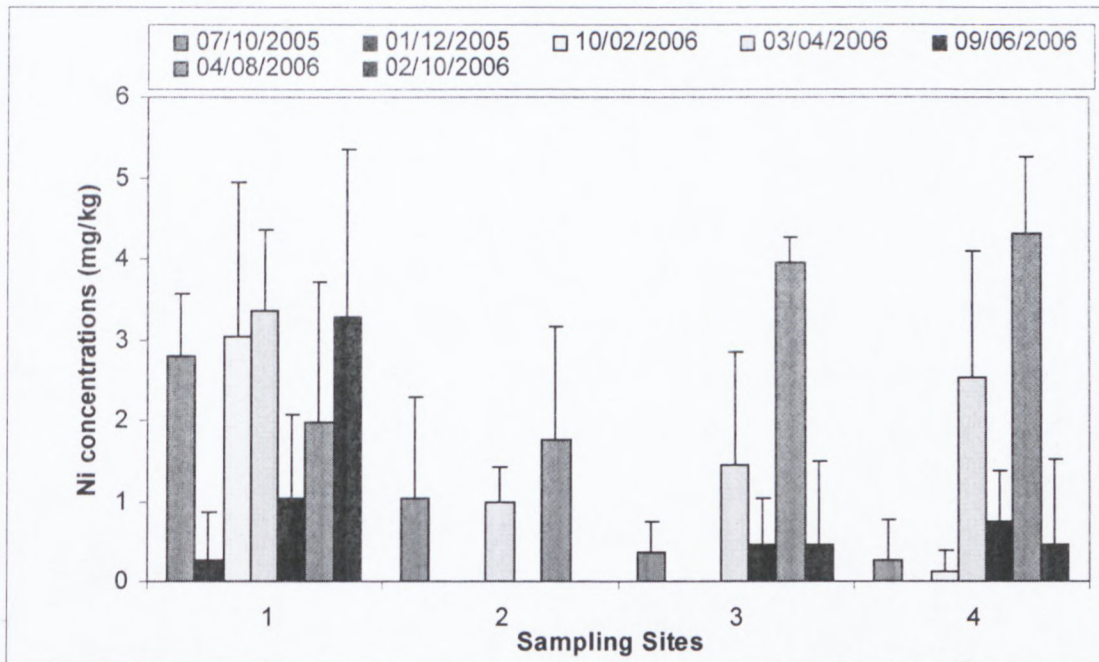


Figure 4.9: Mean concentrations of total nickel (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: No quality guideline found.

4.2.9.1 Comparisons of total Ni concentrations measured in sediment, at a particular site over the 12 month sampling period

The results at site 1 on occasion 2, had the lowest concentration which was statistically significantly higher ($P<0.05$), than any of the occasions. No statistical difference ($P>0.05$) were found at all comparisons made for any occasion at site 2. At site 3 and 4 both on occasion 6, had the highest concentration than any of the compared occasions in their respective sites, ($P<0.05$). In general, the highest mean Ni concentrations measured were 4.30 ± 0.94 mg/kg at site 4 during the 7th sampling occasion (Fig. 4.9, Table 4.10).

4.2.9.2 Comparisons of total Ni concentration measured in sediment per sampling occasion over the length of the river

On sampling occasions 1, 3, 4, 6 and 7, all site comparisons revealed statistical significant differences ($P<0.05$). During sampling occasions 2 and 5, the results revealed no statistical differences ($P>0.05$). The highest mean Ni concentration

measured was found at site 1 on occasion 1 (2.80 ± 0.76 mg/kg) (Fig. 4.9, Table 4.10).

4.2.10 ZINC

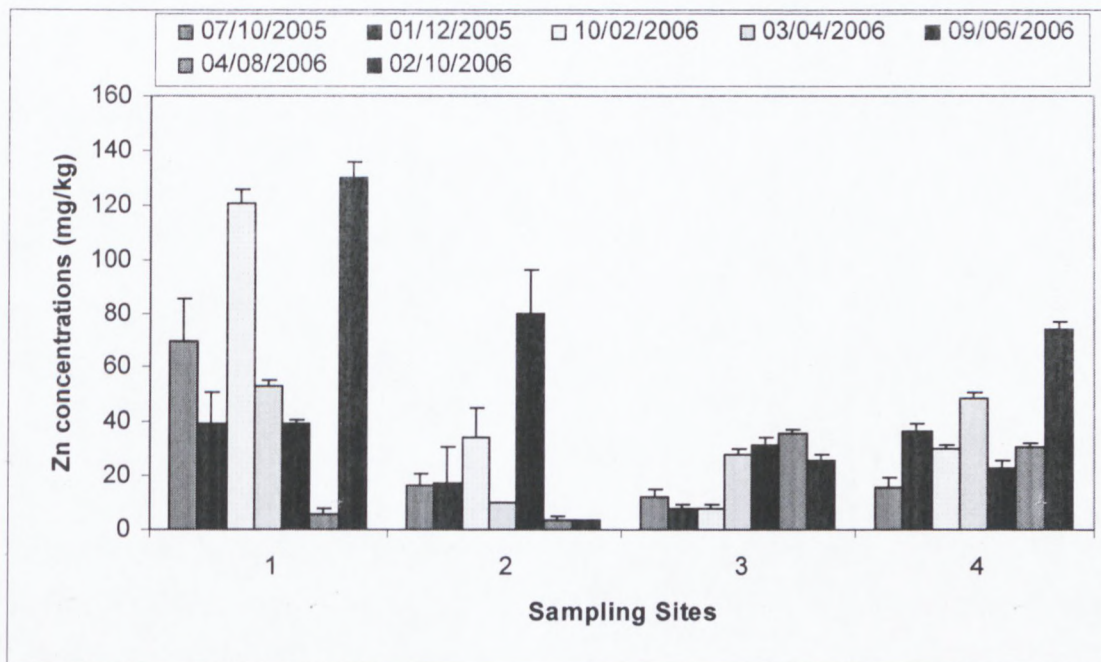


Figure 4.10: Mean concentrations of total zinc (mg/kg) (\pm SD) in sediment samples collected from four sites (1-4) of the Kuils River in a period of 12 months (Oct '05 - Oct '06), $n=5$: Quality guideline is 123.0 mg/kg (CCME, 2001).

4.2.10.1 Comparisons of total Zn concentrations measured in sediment, at a particular site over the 12 month sampling period

In pairwise multiple comparisons made during occasions 1 to 7 at sites 1 and 4, the following results were obtained. Occasion 7 had the highest Zn concentrations of all the sampling occasions for sites 1 and 4 ($P < 0.05$). At site 2, occasion 7 had the lowest concentration compared to any of the other occasions ($P < 0.05$). No statistical significant differences were found between occasions for Zn at site 3 ($P > 0.05$). The lowest Zn concentration measured were 3.23 ± 0.34 mg/kg at site 2. The highest mean Zn concentration measured were 129.55 ± 6.08 mg/kg at site 1 during the 7th sampling occasion (Fig. 4.10, Table 4.11).

4.2.10.2 Comparisons of total Zn concentration measured in sediment per sampling occasion over the length of the river

On sampling occasions 1 to 7, the results showed statistical significant differences ($P < 0.05$) for all site comparisons. The highest mean Zn concentration of 129.55 ± 6.08 mg/kg was detected at site 1 on occasion 7. The same occasion recorded the lowest mean concentrations (3.23 ± 0.34 mg/kg) of Zn at site 2 (Fig. 4.10, Table 4.11).

Table 4.2: Mean aluminium concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	b,c,f 8398.11 (\pm 609.42) ^{b,c,d}	b,c,d,e,f,g 1586.60 (\pm 164.78) ^{a,c,d}	b,d,e,f,g 381.52 (\pm 17.29) ^{a,b,d}	b,c,d,e,g 1302.37 (\pm 64.76) ^{a,b,c}
2	a,c,d,e,f 9845.20 (\pm 461.14) ^{b,c,d}	a,c,d,e,f,g 4712.15 (\pm 402.42) ^{a,c,d}	a,c,d,e,f 583.57 (\pm 65.91) ^{a,b,d}	a,c,d,e,f 3181.94 (\pm 169.38) ^{a,b,c}
3	a,b,d,e,f,g 13727.14 (\pm 594.61) ^{b,c,d}	ab,d,e,f,g 1990.09 (\pm 137.81) ^{a,c,d}	b,d,e,f,g 388.85 (\pm 25.97) ^{a,b,d}	ab,d,e,f,g 1601.78 (\pm 140.44) ^{a,b,c}
4	b,c,f 8180.85 (\pm 734.79) ^{b,c,d}	ab,c,e,f,g 786.14 (\pm 44.62) ^{a,d}	ab,c,e,g 776.44 (\pm 37.61) ^{a,d}	ab,c,e,f,g 3690.20 (\pm 146.02) ^{a,b,c}
5	b,c,f 7356.26 (\pm 381.07) ^{b,c,d}	ab,c,d,f,g 2347.66 (\pm 108.12) ^{a,c,d}	ab,c,d,f,g 1268.04 (\pm 274.48) ^{a,b,d}	ab,c,d,f,g 4657.87 (\pm 287.69) ^{a,b,c}
6	a,b,c,d,e,g 901.19 (\pm 77.45) ^{b,c,d}	ab,c,d,e,g 518.09 (\pm 48.91) ^{a,c,d}	ab,c,e,g 747.28 (\pm 46.32) ^{a,b,d}	b,c,d,e,g 1220.69 (\pm 77.90) ^{a,b,c}
7	b,c,f 7570.01 (\pm 459.42) ^{b,c,d}	ab,c,d,e,f 408.41 (\pm 20.05) ^{a,c,d}	a,c,d,e,f 622.10 (\pm 42.26) ^{a,b,d}	a,c,d,e,f 3384.07 (\pm 213.16) ^{a,b,c}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND = Not Detected.

Table 4.3: Mean cadmium concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	0.02 (\pm 0.02)	0.02 (\pm 0.02)	0.02 (\pm 0.03)	ND
2	ND	ND	ND	0.02 (\pm 0.01)
3	ND	ND	ND	ND
4	ND	ND	ND	ND
5	ND	0.08 (\pm 0.01)	0.18 (\pm 0.03)	ND
6	ND	ND	ND	ND
7	ND	0.02 (\pm 0.05)	0.02 (\pm 0.05)	0.09 (\pm 0.05)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

No statistical significant differences were found (P>0.05).

ND = Not Detected.

Table 4.4: Mean lead concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kulis River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	b,c,e,fg 24.65 (\pm 2.26) ^{b,c,d}	b,c,d,e,fg 68.13 (\pm 32.15) ^{a,c,d}	c,d,e,fg 0.23 (\pm 0.51) ^{ab,d}	b,c,d,e,fg 2.56 (\pm 1.61) ^{ab,c}
2	a,c,d,e,fg 15.52 (\pm 0.68) ^{c,d}	a,c,e,fg 12.50 (\pm 4.39) ^{c,d}	c,d,e,fg 0.33 (\pm 0.56) ^{ab,d}	a,c,e,g 7.12 (\pm 1.54) ^{ab,c}
3	ab,d,e,fg 49.39 (\pm 1.91) ^{b,c,d}	ab,d,e,fg 27.88 (\pm 1.56) ^{a,c,d}	ab,d,e,fg 2.00 (\pm 1.24) ^{ab,d}	ab,d,fg 5.62 (\pm 0.47) ^{ab,c}
4	b,c,e,fg 23.66 (\pm 1.49) ^{b,c,d}	a,c,e,fg 12.57 (\pm 1.40) ^{a,c,d}	ab,d,e,fg 4.35 (\pm 1.50) ^{ab,d}	a,c,e,g 7.64 (\pm 0.88) ^{ab,c}
5	ab,c,d,fg 17.36 (\pm 0.87) ^{b,c,d}	ab,c,d,fg 121.11 (\pm 13.36) ^{a,c,d}	ab,c,d 6.21 (\pm 1.10) ^{ab}	ab,d,e,fg 5.57 (\pm 0.91) ^{ab}
6	ab,c,d,e,g 1.67 (\pm 1.17) ^{c,d}	ab,c,d,e,g 0.92 (\pm 0.51) ^{c,d}	ab,c,d 8.26 (\pm 1.12) ^{ab}	a,c,e,g 7.26 (\pm 0.86) ^{ab}
7	ab,c,d,e,f 52.00 (\pm 2.22) ^{b,c,d}	ND	ab,c,d,f 7.94 (\pm 3.73) ^{ab,d}	ab,c,d,e,f 14.02 (\pm 1.69) ^{ab,c}

Sampling Occasions: 1 = Oct. '05; 2 = Dec. '05; 3 = Feb. '06; 4 = Apr. '06; 5 = Jun. '06; 6 = Aug. '06; 7 = Oct. '06
 Letters on the left side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the right side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Table 4.5: Mean chromium concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kulis River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	b,c,f,g 10.25(\pm 0.95) ^{b,c,d}	c,d,f,g 3.80(\pm 1.64) ^{a,c,d}	ND	b,c,d,e,fg 0.72(\pm 0.63) ^{ab,c}
2	a,c,f,g 7.61(\pm 0.36) ^{b,c,d}	c,d,e,f,g 3.25(\pm 2.07) ^{ac}	ND	a,c,d,e,f,g 2.30(\pm 0.43) ^{ac}
3	ab,c,d,e,f 16.07(\pm 1.57) ^{b,c,d}	ab,d,e,g 0.11(\pm 0.24) ^a	ND	ND
4	b,c,f,g 9.39(\pm 0.81) ^{b,c,d}	ab,c,e,g 1.19(\pm 0.88) ^{ad}	e,fg 0.47(\pm 0.65) ^{ad}	ab,c,e,fg 5.12(\pm 0.39) ^{ab,c}
5	b,c,f,g 9.14(\pm 0.72) ^{c,d}	ab,c,d,fg 8.66(\pm 3.83) ^{c,d}	ab,c,d,fg 1.48(\pm 0.61) ^{ab,d}	ab,c,d,g 3.80(\pm 0.36) ^{ab,c}
6	ab,c,e,g 2.40(\pm 0.39) ^{b,c,d}	ab,c,d,e,g 1.75(\pm 0.57) ^{a,c,d}	ab,c,d,e,g 3.10(\pm 0.25) ^{ab,d}	ab,c,d,g 3.91(\pm 0.19) ^{ab,c}
7	ab,d,e,f 16.06(\pm 1.96) ^{b,c,d}	ND	ab,c,d,e,f 0.75(\pm 0.43) ^{ab,d}	ab,c,d,e,f 8.35(\pm 0.34) ^{ab,c}

Sampling Occasions: 1 = Oct. '05; 2 = Dec. '05; 3 = Feb. '06; 4 = Apr. '06; 5 = Jun. '06; 6 = Aug. '06; 7 = Oct. '06
 Letters on the left side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the right side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Table 4.6: Mean cobalt concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^{e,f} 2.04 (± 0.11) ^{b,c,d}	^{b,d,e,f} 0.33 (± 0.22) ^{a,c}	ND	^{b,g} 0.17 (± 0.09) ^{a,c}
2	^{e,f} 1.91 (± 0.16) ^{b,c,d}	^{a,b,c,d,e,f} 0.97 (± 0.16) ^{a,c,d}	0.13 (± 0.12) ^{a,b,d}	^{a,c,d,e,f,g} 0.74 (± 0.11) ^{a,b,c}
3	^{e,f} 2.07 (± 0.20) ^{b,c,d}	^{b,d,e,f} 0.18 (± 0.16) ^a	ND	ND
4	^{e,f} 1.76 (± 0.13) ^{b,c,d}	ND	ND	^{b,g} 0.35 (± 0.24) ^a
5	^{a,b,c,d,e,g} 1.27 (± 0.05) ^{b,c,d}	^{a,b,c,d,f,g} 0.63 (± 0.25) ^{a,c,d}	0.07 (± 0.16) ^{a,b}	ND
6	^{a,b,c,d,e,g} 0.12 (± 0.00)	^{a,b,c,e,g} 0.02 (± 0.05)	ND	^{b,g} 0.02 (± 0.05)
7	^{e,f} 2.05 (± 0.12) ^{b,c,d}	^{b,d,e,f} 0.31 (± 0.08) ^{a,d}	0.38 (± 0.10) ^{a,d}	^{a,b,c,d,e,f} 1.47 (± 0.09) ^{a,b,c}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Table 4.7: Mean copper concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^{c,e,f,g} 7.87 (± 0.69) ^{b,c,d}	^{c,e,f,g} 2.88 (± 0.88) ^{a,c,d}	^e 0.76 (± 0.33) ^{a,b}	^{b,c,d,e,g} 1.56 (± 0.82) ^{a,b}
2	^{c,e,f,g} 0.69 (± 3.44)	^{c,e,f,g} 0.88 (± 15.39)	^e 0.33 (± 13.28)	^{a,e,f,g} 0.82 (± 7.40)
3	^{a,b,d,e,f} 14.64 (± 0.56) ^{b,c,d}	^{a,b,d,f,g} 8.20 (± 1.74) ^a	^e 4.03 (± 3.56) ^a	^{a,e,f,g} 4.26 (± 1.29) ^a
4	^{c,e,f,g} 6.28 (± 2.95) ^{b,c,d}	^{c,e,f,g} 4.11 (± 5.71)	^e 1.90 (± 1.75)	^{a,e,f,g} 3.27 (± 0.90)
5	^{a,b,c,d,f,g} 3.03 (± 1.85) ^{b,c,d}	^{a,b,d,f,g} 33.75 (± 43.22) ^{a,c,d}	^{a,b,c,d,f,g} 0.18 (± 0.25) ^{a,b}	ND
6	^{a,b,c,d,e,g} 0.36 (± 0.81) ^{c,d}	^{a,b,c,d,e,g} 0.28 (± 0.41) ^{c,d}	^e 2.80 (± 0.97) ^{a,b}	^{b,c,d,g} 2.11 (± 0.74) ^{a,b}
7	^{a,b,d,e,f} 13.37 (± 1.65) ^{b,c,d}	ND	^e 1.62 (± 0.76) ^{a,b,d}	^{a,b,c,d,e,f} 7.65 (± 0.49) ^{a,b,c}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Table 4.8: Mean iron concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	b,c,f,g 5592.45 (\pm 316.11) ^{b,c,d}	d,e,f,g 2061.42 (\pm 486.12) ^{a,c,d}	c,d,e,f,g 663.83 (\pm 30.38) ^{a,b,d}	b,c,d,e,g 1126.81 (\pm 70.25) ^{a,b,c}
2	a,c,d,e,f,g 4212.85 (\pm 151.68) ^{b,c,d}	d,e,f,g 1658.25 (\pm 38.69) ^{a,c,d}	c,d,e,f,g 659.39 (\pm 127.40) ^{a,b,d}	a,c,d,e,f,g 2023.39 (\pm 104.28) ^{a,b,c}
3	a,b,d,e,f,g 10899.75 (\pm 442.36) ^{b,c,d}	d,e,f,g 1895.75 (\pm 128.12) ^{a,c,d}	a,b,d,e,f,g 350.59 (\pm 68.01) ^{a,b,d}	a,b,d,e,f,g 1009.25 (\pm 42.66) ^{a,b,c}
4	b,c,f,g 5399.37 (\pm 290.72) ^{b,c,d}	a,b,c,e,f 605.57 (\pm 36.11) ^{a,c,d}	a,b,c,e,g 1175.66 (\pm 105.51) ^{a,b,d}	a,b,c,e,f,g 2491.00 (\pm 189.43) ^{a,b,c}
5	b,c,f,g 5376.44 (\pm 247.11) ^{b,c,d}	a,b,c,d,f,g 4921.97 (\pm 196.04) ^{a,c,d}	a,b,c,d,f,g 1995.06 (\pm 116.64) ^{a,b,d}	a,b,c,d,f,g 2924.14 (\pm 243.57) ^{a,b,c}
6	a,b,c,d,e,g 1380.53 (\pm 91.94) ^{b,c,d}	a,b,c,d,e,g 838.14 (\pm 63.72) ^{b,c,d}	a,b,c,e,g 1045.55 (\pm 53.55) ^{a,b,d}	b,c,d,e,g 1199.02 (\pm 65.38) ^{a,b,c}
7	a,b,c,d,e,f 9223.26 (\pm 465.13) ^{b,c,d}	a,b,c,e,f 683.77 (\pm 76.97) ^{a,c,d}	a,b,c,d,e,f 933.24 (\pm 49.35) ^{a,b,d}	a,b,c,d,e,f 3508.12 (\pm 151.63) ^{a,b,c}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Table 4.9: Mean manganese concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	b,c,d,e,f,g 56.98 (\pm 2.78) ^{b,c,d}	b,c,d,e,f,g 25.50 (\pm 1.44) ^{a,c,d}	b,c,d,e,g 7.82 (\pm 0.23) ^{a,b,d}	b,c,d,e,f,g 6.38 (\pm 0.63) ^{a,b,c}
2	a,c,d,e,f,g 38.15 (\pm 1.49) ^{b,c,d}	a,c,e,f,g 11.81 (\pm 5.48) ^{a,c}	a,c,e,f,g 3.69 (\pm 1.18) ^{a,b,d}	a,c,d,e,f,g 12.74 (\pm 0.77) ^{a,c}
3	a,b,d,e,f 97.83 (\pm 4.46) ^{b,c,d}	a,b,d,e,f,g 67.15 (\pm 5.79) ^{a,c,d}	a,b,d,e,f,g 1.31 (\pm 0.55) ^{a,b,d}	a,b,d,e,f,g 5.37 (\pm 0.23) ^{a,b,c}
4	a,b,c,f,g 73.36 (\pm 4.05) ^{b,c,d}	a,c,e,f,g 9.94 (\pm 0.59) ^{a,c,d}	a,c,e,f,g 4.35 (\pm 0.29) ^{a,b,d}	a,b,c,e,g 14.29 (\pm 0.85) ^{a,b,c}
5	a,b,c,f,g 69.86 (\pm 3.10) ^{b,c,d}	a,b,c,d,f,g 43.14 (\pm 7.96) ^{a,c,d}	a,b,c,d,f,g 6.32 (\pm 0.60) ^{a,b,d}	a,b,c,d,e,g 10.57 (\pm 1.13) ^{a,b,c}
6	a,b,c,d,e,g 17.92 (\pm 1.15) ^{b,c,d}	a,b,c,d,e,g 3.33 (\pm 0.53) ^{a,c,d}	a,b,c,d,e,g 8.06 (\pm 0.61) ^{a,b,d}	a,b,c,e,g 15.08 (\pm 0.96) ^{a,b,c}
7	a,b,d,e,f 92.97 (\pm 4.88) ^{b,c,d}	a,b,c,d,e,f 6.04 (\pm 1.19) ^{a,c,d}	a,b,c,d,e,f 9.70 (\pm 0.85) ^{a,b,d}	a,b,c,d,e,f 24.24 (\pm 1.04) ^{a,b,c}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Table 4.10: Mean nickel concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^b 2.80 (\pm 0.76) ^{b,c,d}	1.05 (\pm 1.25) ^a	^f 0.36 (\pm 0.38) ^a	^{d,f} 0.27 (\pm 0.50) ^a
2	^{a,b,d,e,f,g} 0.27 (\pm 0.60)	ND	ND	ND
3	^c 3.03 (\pm 1.91) ^{b,c}	ND	ND	^{d,f} 0.12 (\pm 0.27) ^c
4	^b 3.34 (\pm 1.02) ^{b,c,d}	0.98 (\pm 0.44) ^a	^f 1.45 (\pm 1.38) ^a	^{a,b,c,e,f,g} 2.54 (\pm 1.56) ^a
5	^b 1.03 (\pm 1.04)	ND	^f 0.46 (\pm 0.58)	^{d,f} 0.74 (\pm 0.63)
6	^b 1.97 (\pm 1.74) ^{c,d}	1.75 (\pm 1.41) ^{c,d}	^{a,b,c,d,e,g} 3.94 (\pm 0.32) ^{ab}	^{a,b,c,d,e,g} 4.30 (\pm 0.94) ^{ab}
7	^b 3.29 (\pm 2.05) ^{b,c,d}	ND	^f 0.46 (\pm 1.03) ^a	^{d,f} 0.47 (\pm 1.04) ^a

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

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Table 4.11: Mean zinc concentrations (mg/kg) (\pm SD) measured in the sediment samples from four Kuils River sites, per sampling occasion (n=5).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^{b,c,d,e,f,g} 69.62 (\pm 15.75) ^{b,c,d}	^{c,d,e,f,g} 16.68 (\pm 4.23) ^a	^{b,c,d,e,f,g} 12.50 (\pm 2.92) ^a	^{b,c,d,e,f,g} 16.12 (\pm 3.18) ^a
2	^{a,c,d,f,g} 39.40 (\pm 11.30) ^c	^{c,d,e,f,g} 17.48 (\pm 13.06) ^c	^{a,d,e,f,g} 8.20 (\pm 1.07) ^{abd}	^{a,c,d,e,f,g} 36.56 (\pm 2.57) ^c
3	^{a,b,d,e,f,g} 120.63 (\pm 4.98) ^{b,c,d}	34.62 (\pm 10.69) ^{ac}	^{a,d,e,f,g} 7.87 (\pm 1.76) ^{abd}	^{a,b,d,e,g} 30.38 (\pm 1.12) ^{ac}
4	^{a,b,c,e,f,g} 53.31 (\pm 2.25) ^{b,c,d}	^{a,b,c,d,f,g} 9.72 (\pm 0.57) ^{acd}	^{a,b,c,e,f} 27.89 (\pm 2.56) ^{abd}	^{a,b,c,e,f,g} 48.50 (\pm 2.43) ^{abc}
5	^{a,c,d,e,f,g} 39.74 (\pm 1.47) ^{b,c,d}	^{a,b,c,d,f,g} 79.82 (\pm 16.39) ^{acd}	^{a,b,c,d,f,g} 31.78 (\pm 2.94) ^{abd}	^{a,b,c,d,f,g} 23.28 (\pm 2.57) ^{abc}
6	^{a,b,c,d,e,g} 6.02 (\pm 1.79) ^{b,c,d}	^{a,b,c,d,e} 3.80 (\pm 0.89) ^{acd}	^{a,b,c,d,e,g} 35.53 (\pm 1.97) ^{abd}	^{a,b,d,e,g} 30.56 (\pm 2.00) ^{abc}
7	^{a,b,c,d,e,f} 129.55 (\pm 6.08) ^{b,c,d}	^{a,b,c,d,e,g} 3.23 (\pm 0.34) ^{bcd}	^{a,b,c,e,f} 25.61 (\pm 2.38) ^{abd}	^{a,b,c,d,e,f} 74.23 (\pm 2.47) ^{abc}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. ND =Not Detected.

Chapter 5

Snail results: Metal concentrations

Snails were not found at sampling site 2, during occasions 3, 4, 6 and 7 for all metals (Fig.5.1-10, Table 5.10).

5.1 ALUMINIUM

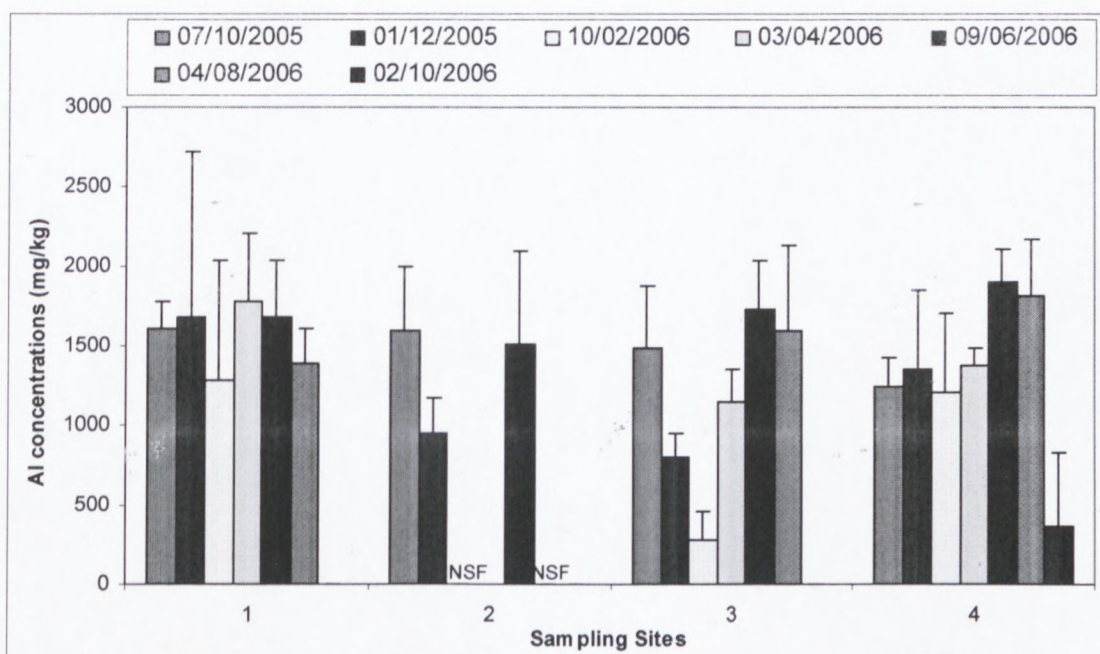


Figure 5.1: Mean concentrations of total aluminium (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.1.1 Comparisons of total Al concentrations measured in snails, at a particular site over the 12 month sampling period

In comparisons made between Al concentrations of each sampling occasion at site 1, occasion 4 had the highest concentration compared to any of the other occasions ($P<0.05$). There were no statistical differences found at site 2 in any of the occasion comparisons ($P>0.05$). At sites 3 and 4, sampling occasion 5 had

the highest Al concentrations compared to any of the other occasions at these sites ($P < 0.05$). At sites 1 and 3 the lowest Al concentrations were measured on occasion 7. The highest mean Al concentrations of 1903.43 ± 200.90 mg/kg were found at site 4 during occasion 5 (Fig. 5.1, Table 5.1).

5.1.2 Comparisons of total Al concentrations measured in snails per sampling occasion over the length of the river

The pairwise multiple comparisons of results of occasions 1, 3, 5, 6 and 7 revealed no statistical significant differences when the sites were compared to each other ($P > 0.05$). During sampling occasion 2, site 1 had the highest Al concentration in snail samples compared to the other sites ($P < 0.05$) (Fig.5.1, Table 5.1).

5.2 CADMIUM

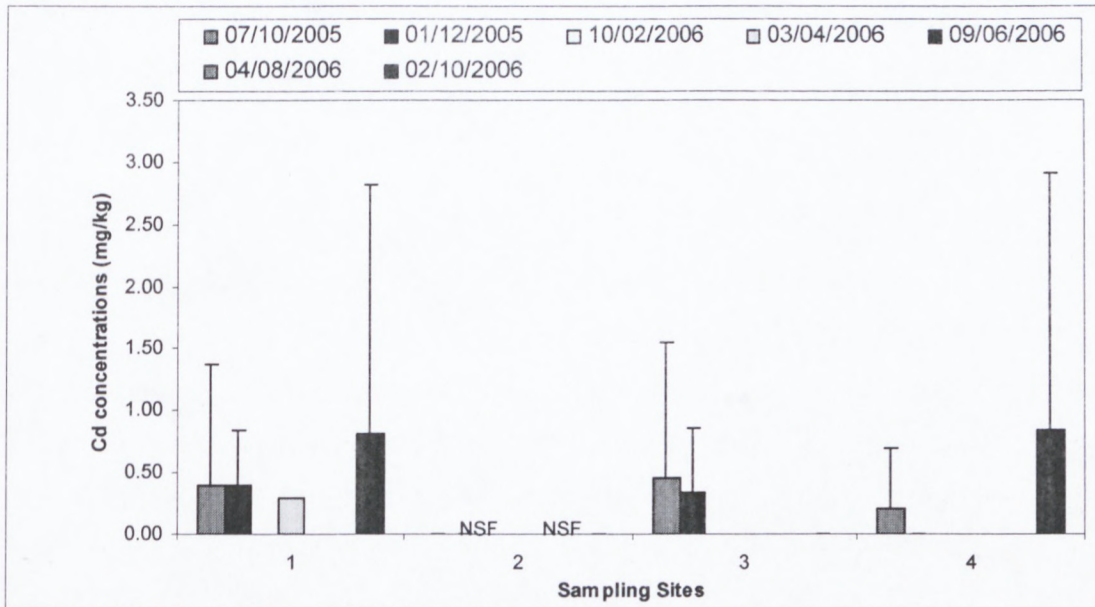


Figure 5.2: Mean concentrations of total cadmium (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.2.1 Comparisons of total Cd concentrations measured in snails, at a particular site over the 12 month sampling period

No statistical significant differences were found for Cd ($P>0.05$) (Fig.5.2, Table 5.2).

5.2.2 Comparisons of total Cd concentrations measured in snails per sampling occasion over the length of the river

No statistical significant differences were found for Cd ($P>0.05$) (Fig.5.2, Table 5.2).

5.3 LEAD

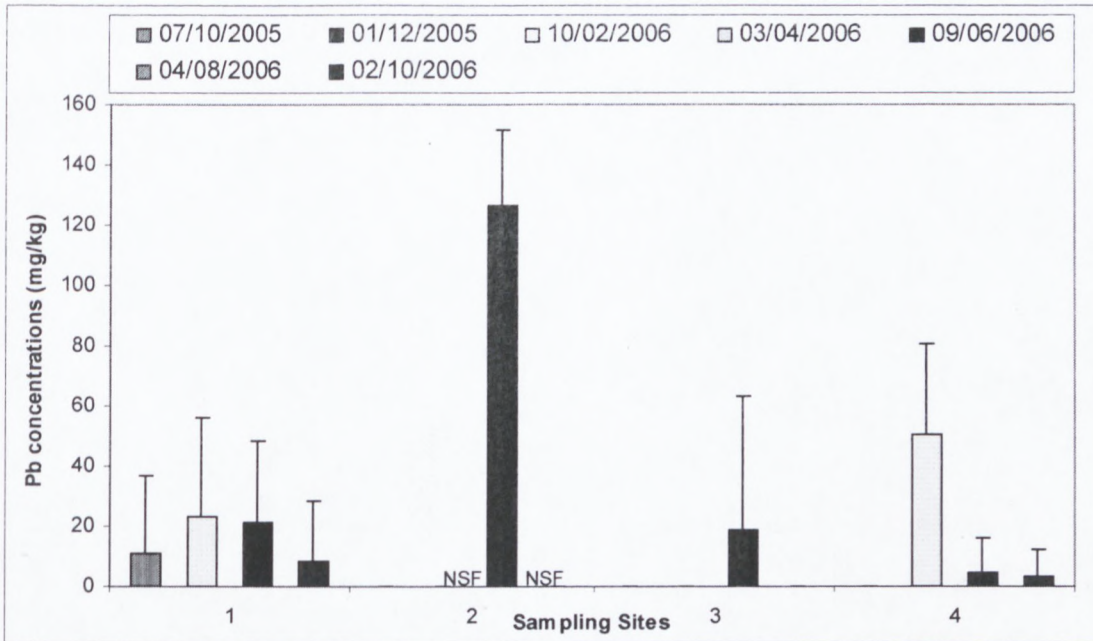


Figure 5.3: Mean concentrations of total lead (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.3.1 Comparisons of total Pb concentrations measured in snails, at a particular site over the 12 month sampling period

Comparisons made between Pb concentrations at site 4 revealed that occasion 3 had the highest concentration when compared to any of the other occasions ($P < 0.05$). The highest recorded mean Pb concentration in snails was 126.50 ± 25.13 mg/kg recorded at site 2 on occasion 5 (Fig. 5.3, Table 5.3).

5.3.2 Comparisons of total Pb concentrations measured in snails per sampling occasion over the length of the river

No statistical differences were found in any of the site comparisons for Pb concentrations measured in snails found on sampling occasions 1 to 7 ($P > 0.05$), except for occasion 3. Sites 1, 3 and 4 differed from each other on occasion 3 ($P < 0.05$) (Fig. 5.3, Table 5.3).

5.4 CHROMIUM

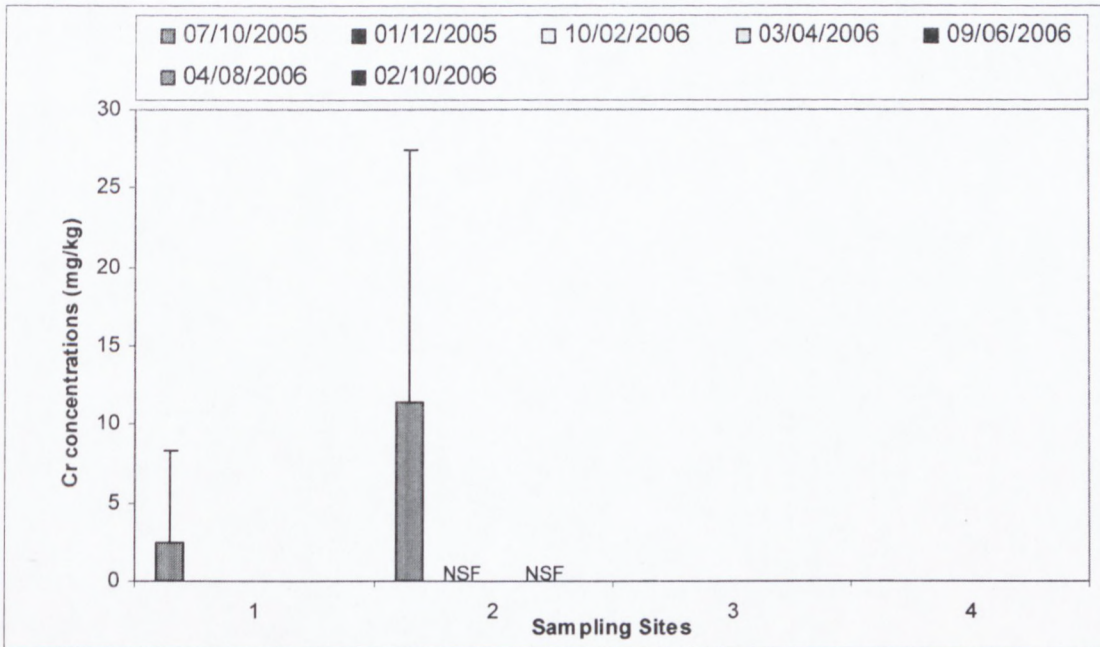


Figure 5.4: Mean concentrations of total chromium (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.4.1 Comparisons of total Cr concentrations measured in snails, at a particular site over the 12 month sampling period

No statistical significant differences were found for Cr ($P>0.05$) (Fig.5.4, Table 5.4).

5.4.2 Comparisons of total Cr concentrations measured in the snails per sampling occasion over the length of the river

No statistical significant differences were found for Cr ($P>0.05$) (Fig.5.4, Table 5.4).

5.5 COBALT

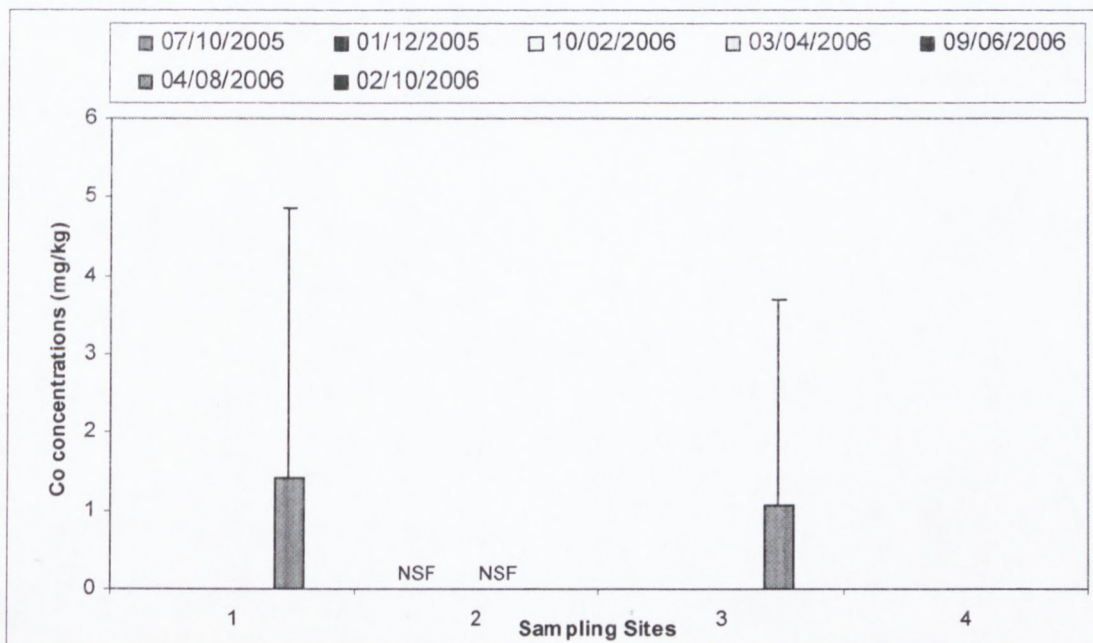


Figure 5.5: Mean concentrations of total cobalt (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.5.1 Comparisons of total Co concentrations measured in snails, at a particular site over the 12 month sampling period

No statistical significant differences were found for Co ($P>0.05$) (Fig.5.5, Table 5.5).

5.5.2 Comparisons of total Co concentrations measured in snails per sampling occasion over the length of the river

No statistical significant differences were found for Co ($P>0.05$) (Fig.5.5, Table 5.5).

5.6 COPPER

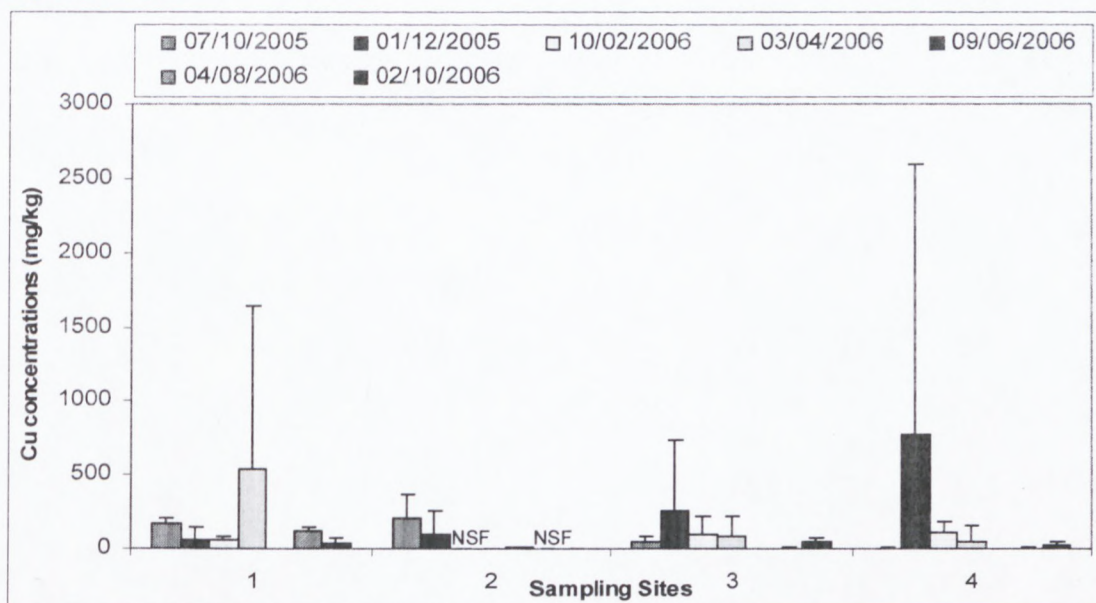


Figure 5.6: Mean concentrations of total copper (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.6.1 Comparisons of total Cu concentrations measured in snails, at a particular site over the 12 month sampling period

In pairwise multiple comparisons made for Cu concentrations in snails at site 1, occasion 4 revealed the highest Cu concentrations compared to any of the other occasions ($P < 0.05$). No statistical differences ($P > 0.05$) were found at sites 2 and 3 between the different occasions. Pairwise multiple comparisons revealed that Cu concentrations in snails of occasion 3 were statistically significantly different from those of other occasions at site 4 ($P < 0.05$) (Fig. 5.6, Table 5.6).

5.6.2 Comparisons of total Cu concentrations measured in snails per sampling occasion over the length of the river

No statistical significant differences ($P > 0.05$) were found between sites for snail Cu concentrations measured on occasions 1, 2, 3, 4, 5 and 7. The highest mean concentration of Cu in snails on occasion 6 was found at site 1 ($P < 0.05$) (Table 5.6).

5.7 IRON

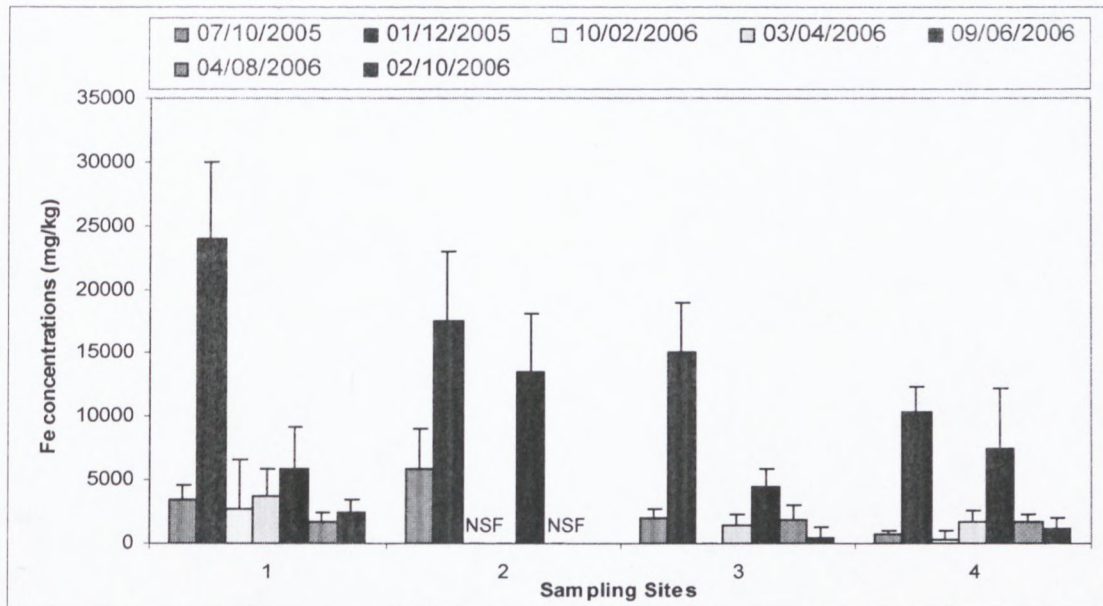


Figure 5.7: Mean concentrations of total iron (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.7.1 Comparisons of total Fe concentrations measured in snails, at a particular site over the 12 month sampling period

In pairwise multiple comparisons made for Fe concentrations in snails at sites 1, 3 and 4, it was shown that sampling occasion 2 had the highest mean Fe concentration ($P < 0.05$) compared to the other occasions. At site 2 there were no statistical differences ($P > 0.05$) between any of the occasions compared to each other. The highest mean Fe concentration measured was 24023.20 ± 5914.25 mg/kg at site 1 during the 2nd sampling occasion (Fig. 5.7, Table 5.7).

5.7.2 Comparisons of total Fe concentrations measured in snails per sampling occasion over the length of the river

No statistical significant differences ($P > 0.05$) were found between sites for snail Fe concentrations measured on occasions 1, 3, 5 and 6. On occasions 2, 4 and 7, site 1 had the highest mean concentrations of Fe in snails ($P < 0.05$) (Fig. 5.7, Table 5.7).

5.8 MANGANESE

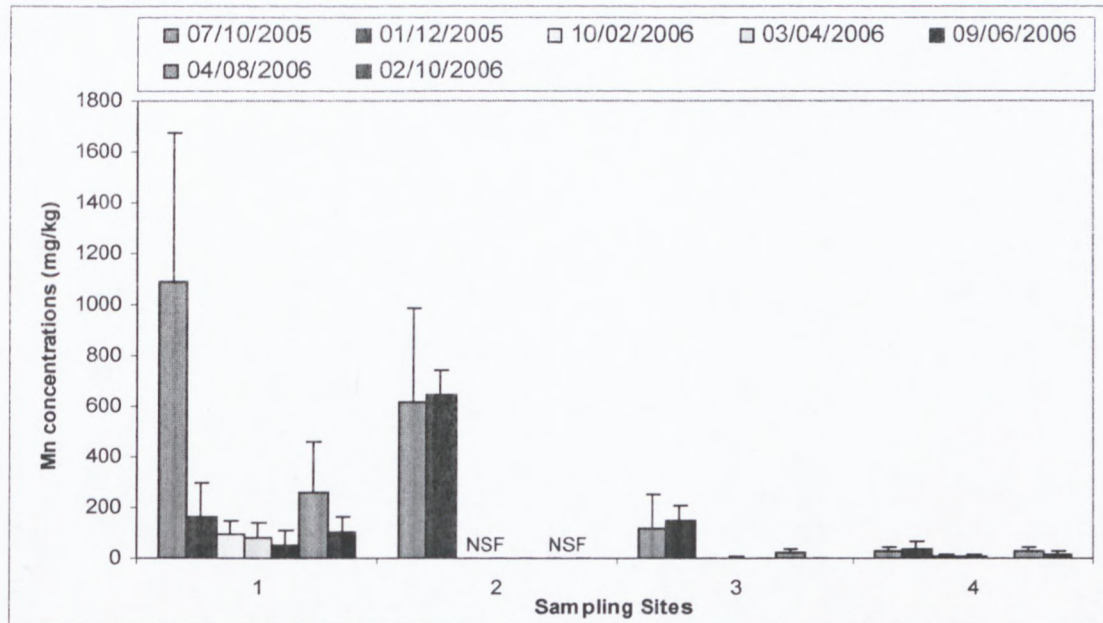


Figure 5.8: Mean concentrations of total manganese (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06, $n=6$ (Except site 2). NSF = No Snails Found.

5.8.1 Comparisons of total Mn concentrations measured in snails, at a particular site over the 12 month sampling period

At site 1, the highest Mn mean concentration in snails was found on occasion 1 ($P<0.05$). No statistical significant differences were found between occasions at site 2, concerning Mn concentrations in snails ($P>0.05$). At sampling sites 3 and 4 it was found that occasion 2 had the highest concentrations ($P<0.05$) when compared to the other sampling occasions (Fig. 5.8, Table 5.8).

5.8.2 Comparisons of total Mn concentrations measured in snails per sampling occasion over the length of the river

Comparisons made for sampling occasions 1, 3, 4, 6 and 7 showed that site 1 had the highest mean Mn concentrations compared to any of the other sites on the aforementioned occasions ($P<0.05$). On occasion 2, site 2 had the highest mean Mn concentration compared to any of the other sites ($P<0.05$). (Fig. 5.8, Table 5.8).

5.9 NICKEL

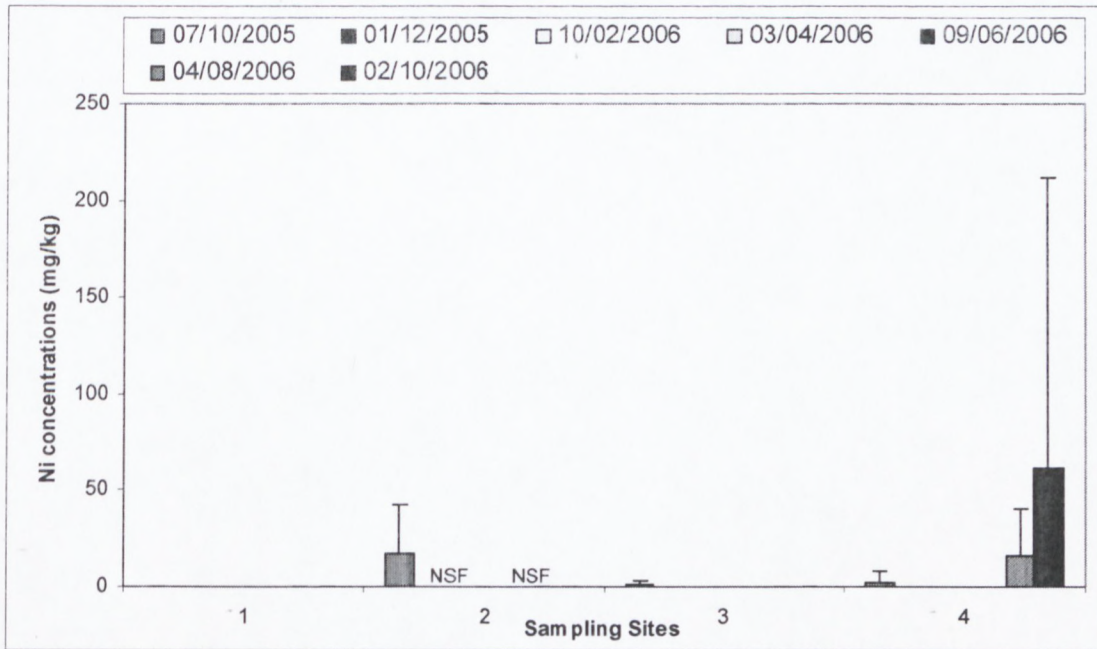


Figure 5.9: Mean concentrations of total nickel (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.9.1 Comparisons of total Ni concentrations measured in snails, at a particular site over the 12 month sampling period

No statistical significant differences were found for Ni ($P>0.05$) (Fig.5.9, Table 5.9).

5.9.2 Comparisons of total Ni concentration measured in snails per sampling occasion over the length of the river

No statistical significant differences were found for Ni ($P>0.05$) (Fig.5.9, Table 5.9).

5.10 ZINC

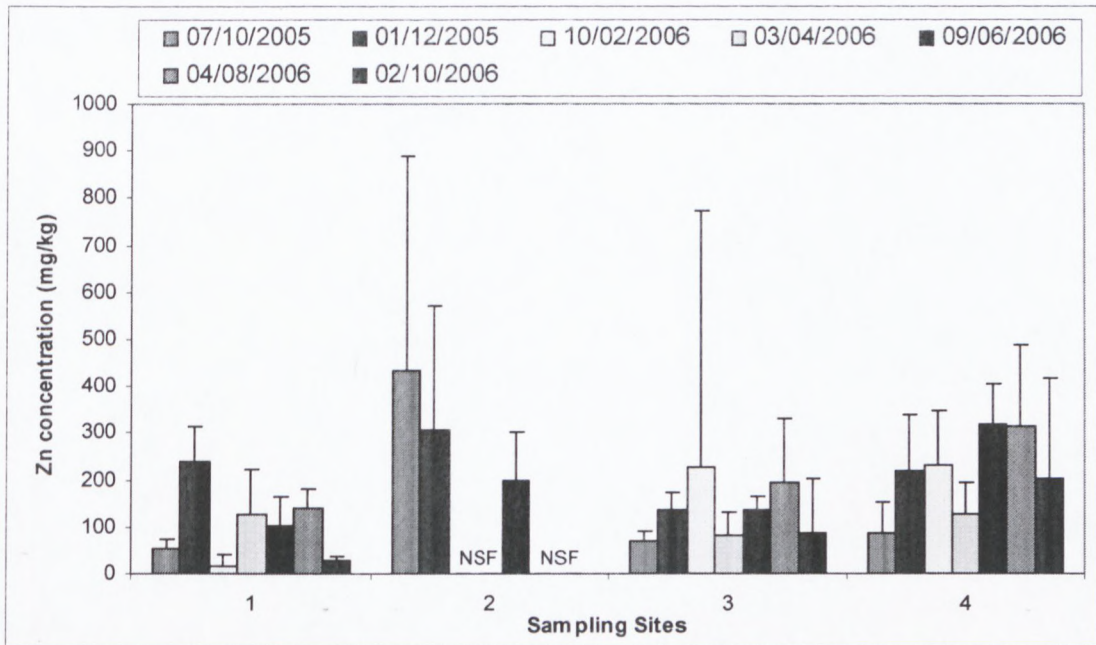


Figure 5.10: Mean concentrations of total zinc (mg/kg) (\pm SD) in snail samples collected from four sites (1-4) of the Kuils River in a period of 12 month (Oct '05 - Oct '06), $n=6$ (Except site 2). NSF = No Snails Found.

5.10.1 Comparisons of total Zn concentrations measured in snails, at a particular site over the 12 month sampling period

At sampling site 1, occasion 2 had the highest Zn concentration when compared to the other occasions ($P<0.05$). No statistical significant differences between occasions were found at sites 2 and 3 ($P>0.05$). At site 4, occasion 1 had the lowest concentration compared to the concentrations measured on the other occasions ($P<0.05$) (Fig.6.10, Table 6.10).

5.10.2 Comparisons of total Zn concentration measured in snails per sampling occasion over the length of the river

No statistical significant differences were found for Zn concentrations ($P>0.05$) (Fig.6.10, Table 6.10).

Table 5.1: Mean aluminium concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	⁹ 1604.89 (\pm 169.56)	1595.48 (\pm 406.82) n=2	b,c,d,g 1491.19 (\pm 385.97)	e,f,g 1243.13 (\pm 183.54)
2	⁹ 1688.39 (\pm 1025.61) ^{b,c}	955.72 (\pm 219.83) ^{a,d,c}	a,c,d,e,f,g 799.04 (\pm 151.22) ^{a,b,d}	e,f,g 1359.38 (\pm 499.51) ^{b,c}
3	⁹ 1285.44 (\pm 746.51)	NSF	a,b,d,e,i,g 276.59 (\pm 189.13)	e,f,g 1207.56 (\pm 495.66)
4	⁹ 1775.06 (\pm 429.37) ^{c,d}	NSF	a,b,c,e,i,g ¹ 143.13 (\pm 215.80) ^a	e,f,g 1382.29 (\pm 110.15) ^a
5	⁹ 1683.42 (\pm 350.25)	1509.99 (\pm 584.32) n=3	b,c,d,g 1736.98 (\pm 294.01)	a,b,c,d,g 1903.43 (\pm 200.90)
6	⁹ 1388.06 (\pm 225.88)	NSF	b,c,d,g 1599.83 (\pm 537.04)	a,b,c,d,g 1822.44 (\pm 343.18)
7	ND	NSF	ND	a,b,c,d,e,f 367.22 (\pm 461.10)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. (NSF= No Snails Found; ND = Not Detected).

Table 5.2: Mean cadmium concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	0.40 (\pm 0.97)	ND	0.45 (\pm 1.10)	0.20 (\pm 0.49)
2	0.40 (\pm 0.44)	ND	0.33 (\pm 0.52)	ND
3	ND	NSF	ND	ND
4	0.29 (\pm 0.00)	NSF	ND	ND
5	ND	NSF	ND	ND
6	ND	NSF	ND	ND
7	0.82 (\pm 2.00)	NSF	ND	0.84 (\pm 2.06)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Sampling site 1 = a, 2 = b, 3 = c, 4 = d. (NSF= No Snails Found; ND = Not Detected).

No statistical significant differences were found (P>0.05).

Table 5.3: Mean lead concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	10.68 (\pm 26.17)	ND	ND	ND
2	ND	ND	ND	ND
3	23.12 (\pm 33.00) ^{d,c}	NSF	ND	^{a,b,d,e,f,g} 50.35 (\pm 30.59) ^{a,c}
4	ND	NSF	ND	ND
5	21.13 (\pm 27.30)	126.50 (\pm 25.13) n=3	18.39 (\pm 45.05)	^c 4.72 (\pm 11.55)
6	ND	NSF	ND	^c 0.00 (\pm 0.00)
7	8.17 (\pm 20.01)	NSF	ND	^c 3.50 (\pm 8.58)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.
 Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. (NSF= No Snails Found; ND = Not Detected).

Table 5.4: Mean chromium concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	2.42 (\pm 5.93)	11.36 (\pm) n=2	ND	ND
2	ND	ND	ND	ND
3	ND	NSF	ND	ND
4	ND	NSF	ND	ND
5	ND	ND	ND	ND
6	ND	NSF	ND	ND
7	ND	NSF	ND	ND

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 NSF= No Snails Found; ND = Not Detected.
 No statistical significant differences were found (P>0.05).

Table 5.5: Mean cobalt concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	ND	ND	ND	ND
2	ND	ND	ND	ND
3	ND	NSF	ND	ND
4	ND	NSF	ND	ND
5	ND	ND	ND	ND
6	1.41 (\pm 3.45)	NSF	1.07 (\pm 2.62)	ND
7	ND	NSF	ND	ND

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 NSF= No Snails Found; ND = Not Detected.
 No statistical significant differences were found (P>0.05).

Table 5.6: Mean copper concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^{b,c,d,e,f,g} 167.68 (\pm 39.00)	207.76(\pm 161.39) n=2	47.37(\pm 37.55)	^h 4.37(\pm 6.74)
2	^{a,e,f} 59.17(\pm 91.34)	99.44(\pm 163.65)	255.52(\pm 478.93)	^c 769.47(\pm 1821.00)
3	^{a,e,g} 64.31(\pm 27.01)	NSF	102.49(\pm 115.83)	^{a,b,d,e,f,g} 105.22(\pm 75.30)
4	^{a,e,f} 538.13(\pm 1106.42)	NSF	85.02(\pm 134.33)	^c 45.13(\pm 110.54)
5	ND	11.11(\pm 19.25) n=3	2.30(\pm 5.63)	^c 3.14(\pm 7.70)
6	^{a,b,c,d,e,g} 121.03(\pm 25.57) ^{c,d}	NSF	1.92(\pm 4.71) ^a	^c 2.03(\pm 4.98) ^a
7	^{a,e,f} 37.44(\pm 38.88)	NSF	43.74(\pm 31.12)	^c 25.97(\pm 20.21)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.
 Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. (NSF= No Snails Found; ND = Not Detected).

Table 5.7: Mean iron concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^b 3456.35(\pm 1142.99)	5815.89 (\pm 3253.65) n=2	^{b,c,e,g} 1980.91(\pm 802.92)	^{b,c,d,e,f,g} 740.93(\pm 333.57)
2	^{a,c,d,e,f,g} 24023.20(\pm 5914.25) ^{b,c,d}	17434.37 (\pm 5525.48) ^{a,d}	^{a,c,d,e,f,g} 15114.12(\pm 3793.06) ^{a,d}	^{a,c,d,f,g} 10309.29(\pm 1979.23) ^{a,b,c}
3	^{b,e} 2774.87(\pm 3861.09)	NSF	ND	^{a,b,d,e,f,g} 327.54(\pm 683.06)
4	^b 3792.84(\pm 2060.36) ^{c,d}	NSF	^{b,c,e,g} 1463.43(\pm 804.23) ^a	^{a,b,c,e} 1723.86(\pm 902.48) ^a
5	^{b,c,f,g} 5936.13(\pm 3216.15)	13552.16 (\pm 4481.90) n=3	^{a,b,c,d,f,g} 4454.18(\pm 1360.10)	^{a,c,d,f,g} 7444.08(\pm 4816.37)
6	^{b,e} 1760.90(\pm 646.37)	NSF	^{b,c,e,g} 1905.89(\pm 1146.00)	^{a,b,c,e} 1675.57(\pm 685.68)
7	^{b,e} 2443.84(\pm 953.28) ^{c,d}	NSF	^{a,b,c,d,e,f} 478.46(\pm 867.52) ^a	^{a,b,c,e} 1128.86(\pm 834.07) ^a

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06
 Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. (NSF= No Snails Found; ND = Not Detected).

Table 5.8: Mean manganese concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^{b,c,d,e,f,g} 1090.68 (\pm 585.83) ^{b,c,d}	617.27 (\pm 369.23) ^a n=2	^{c,d,e,f,g} 119.06 (\pm 134.33) ^a	^{c,d,e,g} 31.57 (\pm 16.21) ^a
2	^{a,f} 160.95 (\pm 135.05) ^{b,d}	645.44 (\pm 98.94) ^{a,c,d}	^{c,d,e,f,g} 144.65 (\pm 62.22) ^{b,d}	^{c,d,e,g} 34.85 (\pm 31.94) ^{a,b,c}
3	^{a,f} 93.65 (\pm 58.14) ^{c,d}	NSF	ND	^{a,b,f,g} 4.73 (\pm 7.44) ^a
4	^{a,f} 82.27 (\pm 60.47) ^{c,d}	NSF	^{a,b,f} 1.86 (\pm 2.56) ^a	^{a,b,f,g} 6.19 (\pm 6.91) ^a
5	^{a,f} 53.89 (\pm 59.30)	ND	ND	ND
6	^{a,b,c,d,e,g} 260.36 (\pm 201.73) ^{c,d}	NSF	^{a,b,c,d,e,g} 22.47 (\pm 16.61) ^a	^{c,d,e,g} 32.81 (\pm 14.09) ^a
7	^{a,f} 102.07 (\pm 62.00) ^{c,d}	NSF	ND	^{a,b,c,d,e,f} 13.04 (\pm 13.10) ^{a,c}

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. (NSF= No Snails Found; ND = Not Detected).

Table 5.9: Mean nickel concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	ND	17.50 (\pm 24.75) n=2	0.93 (\pm 2.27)	2.38 (\pm 5.82)
2	ND	ND	ND	ND
3	ND	NSF	ND	ND
4	ND	NSF	ND	ND
5	ND	ND	ND	ND
6	ND	NSF	ND	15.81 (\pm 24.76)
7	ND	NSF	ND	61.38 (\pm 150.35)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. (NSF= No Snails Found; ND = Not Detected).

Table 5.10: Mean zinc concentrations (mg/kg) (\pm SD) measured in the snail samples from four Kuils River sites, per sampling occasion (n=6).

Sampling Occasion	Site 1	Site 2	Site 3	Site 4
1	^{b,d,e,f,g} 55.37 (\pm 18.55)	432.74 (\pm 457.36) n=2	71.20 (\pm 19.60)	^{b,c,d,e,f,g} 88.01 (\pm 66.63)
2	^{a,c,d,e,f,g} 239.77 (\pm 73.47)	305.97 (\pm 263.28)	135.42 (\pm 39.45)	^{a,e,f} 219.13 (\pm 121.69)
3	^{b,d,f} 17.93 (\pm 22.91)	NSF	225.46 (\pm 547.12)	^{a,f} 229.79 (\pm 118.65)
4	^{a,b,c,g} 126.98 (\pm 95.54)	NSF	83.89 (\pm 48.47)	^{a,b,c,e,f,g} 129.50 (\pm 65.29)
5	^{a,b,g} 102.19 (\pm 63.87)	200.24 (\pm 99.64) n=3	135.47 (\pm 29.69)	^d 316.43 (\pm 87.69)
6	^{a,b,c,g} 140.99 (\pm 40.72)	NSF	194.33 (\pm 137.79)	^{a,b,c,d,g} 312.82 (\pm 174.72)
7	^{a,b,d,e,f} 28.66 (\pm 9.20)	NSF	88.78 (\pm 111.68)	^{a,e,f} 204.11 (\pm 212.57)

Sampling Occasions: **1** = Oct. '05; **2** = Dec. '05; **3** = Feb. '06; **4** = Apr. '06; **5** = Jun. '06; **6** = Aug. '06; **7** = Oct. '06

Letters on the **left** side indicate statistical differences at a particular site over the 12 month sampling period. Statistical significant difference from sampling occasion 1 = a, 2 = b, 3 = c, 4 = d, 5 = e, 6 = f and 7 = g.

Letters on the **right** side indicate statistical differences per sampling occasion over the length of the river. Statistical significant difference from sampling site 1 = a, 2 = b, 3 = c, 4 = d. (NSF= No Snails Found; ND = Not Detected).

Chapter 6

Water Discussion: Metal concentrations

Table 6.1: Recommended safe metal concentrations as stipulated by the Department of Water Affairs and Forestry (1996c) and the Australian and New Zealand Environmental Conservation Council (ANZECC 1992) Water Quality Guidelines Targets as well as the present study's mean metal concentrations.

Metals	*TWQR - DWAF 1996c (mg/L)	ANZECC 1992 (mg/L)	Present study's mean metal concentration range (mg/L)
Al	0.005 – 0.01	0.05	0.01 (± 0.01) – 1.59 (± 0.18)
Cd	0.00015 – 0.0004	0.0004	ND
Pb	0.0002-0.0012	0.0034	0.01 (± 0.02) – 0.03 \pm (0.03)
Co	No guideline	No guideline	(0.00) – 0.01 (± 0.01)
Cr	0.012	0.001	ND
Cu	0.0003- 0.0014	0.0014	0.00 (± 0.01) – 0.13 (± 0.25)
Fe	No guideline	No guideline	0.14(± 0.09) – 48.48 (± 9.90)
Mn	0.18	1.90	0.01 (± 0.00) – 0.31 (± 0.19)
Ni	No guideline	0.011	0.01 (± 0.02) - 0.05 (± 0.04)
Zn	0.002	0.008	0.02(± 0.01) - 1.31 (± 1.15)

*TWQR = Target Water Quality Range.

According to Roux *et al.* (1994) there is inadequate knowledge and data on metal concentrations in South African waters. However, since 1994 there has been a considerable improvement in research on metals in South Africa (eg. Wepener *et al.* 2000, Reinecke *et al.* 2003, Jackson *et al.* 2007).

Apart from the comparisons drawn from guideline concentrations, the metal results will also be compared with previous studies on metal contamination in South Africa and abroad.

Cadmium and Cr were not detected in any of the water samples. There are no guidelines for Co and Fe in the DWAF and ANZECC guidelines available. Only the ANZECC guidelines have a guideline for Ni. Most of the metal concentrations discussed in this study were higher than the guideline concentrations of DWAF and ANZECC.

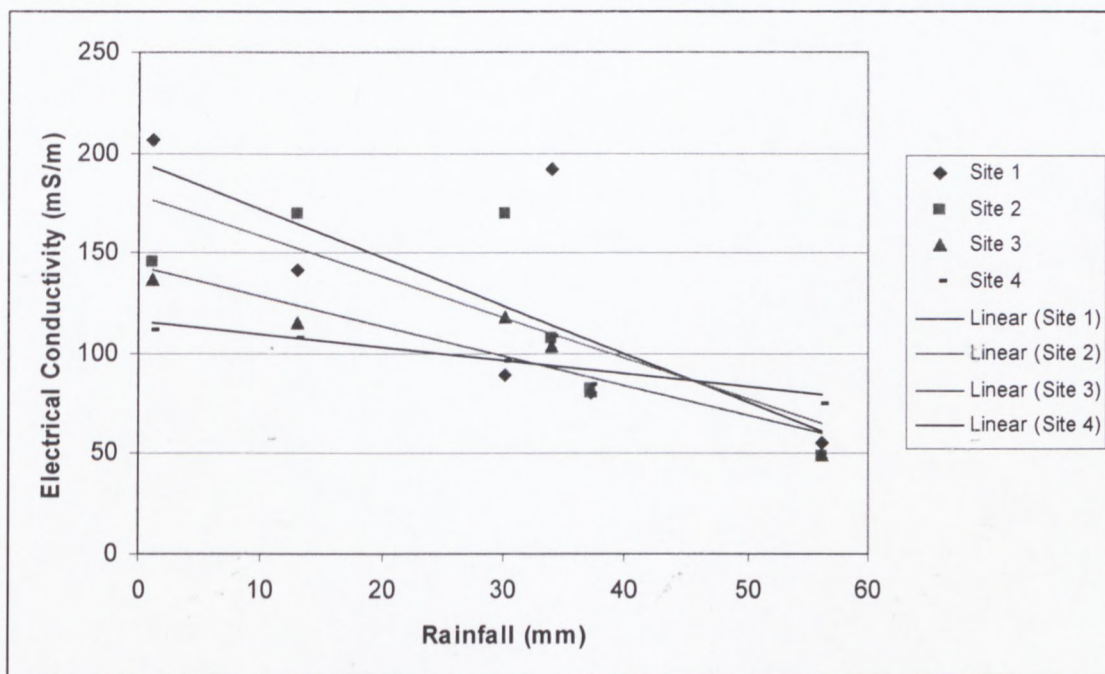


Figure 6.1: The relationship between electrical conductivity and rainfall in the study period.

6.1 Site 1

At site 1 the mean Al concentration (0.68 ± 0.11 mg/L) was found to be statistically significantly higher ($P < 0.05$) on sampling occasion 6 (August 2006) than any of the other occasions (Table 3.4 and Table 6.1). This concentration was above the DWAF and ANZECC water guidelines (Table 6.1). During the same month of August 2006 the pH was 6.5 (Table 3.1.1), which was the lowest value obtained in this investigation. This gives an impression that the lower the pH, the higher the metals like Al accumulate. The study conducted by Macdonald *et al.* (2004),

illustrates the close association between pH and metal concentrations. It was discovered in a spot measurement of water quality in Tanglewood drainage that metals ion (Fe and Al) increases while pH decreases. According to Mishra *et al.* (2008) an increased pH resulted in decreased metal concentrations in mining effluent. Okonkwo & Mothiba (2005) reported that the pH of the Dzindi and Mvudi Rivers in South Africa were marginally within the acidic range of 6.4-6.9. This was associated with elevated water metal concentrations.

In the present study the mean water concentrations of Pb, Cu and Fe were found to be higher during December 2005 (Table 3.5, 3.7 and 3.8). The highest concentrations of the metals were 0.13 mg/L for Cu in December 2005, 48.48 mg/L for Fe in December 2005 and 0.1 mg/L for Pb in December 2005 and June 2006. Lead showed a very low mean concentration in water throughout the entire length of the river. The concentrations of these metals (Pb and Cu) were higher than DWAF and ANZECC water guidelines. Unfortunately, there are no guidelines available for Fe (Table 6.1) (DWAF 1996c, ANZECC 1992, ANZECC & ARMCANZ 2000).

In the study done by Okonkwo & Mothiba (2005) on the Madanzhe River, the Pb concentration in water was high (20.1 mg/L) relative to the Pb concentration (0.1 mg/L) found at site 1 in this study. Also, Cu concentrations from the same study on the Mvuzi River were found to be 2.3 mg/L, which was also higher than the highest Cu concentrations (0.13 and 0.09 mg/L) in the present study. According to Okonkwo & Mothiba (2005) Pb emissions from motor vehicles produced elevated concentrations of this element in roadside vegetation and soil. In the study conducted by Akbar *et al.* (2003), in Pakistan, lead in the roadside soil was elevated. Lead binds strongly to soil particles, and remain in the soil. Lead may enter rivers, when soil particles are moved by rain water (ATSDR 2005a). In the present study Pb concentrations in water, even though it was found to be low, could be coming from contaminated soil, as well as from motor vehicle parts and domestic waste that were disposed of in close proximity to the sampling location

(upstream). Lead may leach from improper disposal of vehicle batteries and contaminate soil, ground water and surface water (EFS 1999). According to Bouazza & Van Impe (1998), waste disposal has been a sensitive issue since the 1980's. Domestic waste is one of the concerns as it is often dumped in unauthorized sites posing contamination of soil and ground water.

Copper in the Tawe River in Wales (Viviant & Massie 1977) was also found to be higher (3.1 mg/L) than in the present study, ranging from 0.5-0.13 mg/L at site 1 (Table 3.7). The cause of pollution in the Tawe River was the mining industry. Copper can also be released to the environment through decaying vegetation and household waste (ATSDR 2004). It is therefore possible that the concentrations of Cu found in water in the present study could be due to decaying vegetation or domestic waste, which was observed at this sampling site.

During the month of February 2006, the highest mean concentration of Mn was recorded at site 1 (0.31 ± 0.19 mg/L) (Table 3.9). This mean concentration was higher than the South African water guidelines (Table 6.1) (DWAF 1996c), however, below the ANZECC guidelines (Table 6.1) (ANZECC 2000). In the study conducted by Ma (2005) Mn mean concentrations in water ranged from 0.006 to 0.021 mg/L in the Bottelary River in the Western Cape, South Africa. This was attributed to runoff from the farming area. It is therefore possible that the relative high concentration of Mn in the present study was due to agricultural runoff, since there was agricultural activity close to sampling site 1.

Zinc had a mean concentration of 1.31 ± 1.15 mg/L in water during October 2006 at site 1, which was statistically significantly higher compared to any of the other sampling occasions (Table 3.11). This mean concentration was higher than DWAF and ANZECC water guidelines (Table 6.1) (DWAF 1996c, ANZECC 2000). Zinc concentrations were also compared with the results of Thawley *et al.* (2004). These authors did a study on polluted sites in the Leragane River, North

West Province in South Africa. Zinc concentrations in the present study were found to be higher than those measured in the Leragane River (Thawley *et al.* 2004). In the upper reaches of the Leragane River the water Zn concentration was 0.0000622 mg/L (0.622 ± 0.004 ug m/L) and at the sampling point lower down in the river the water Zn concentration was 0.000135 mg/L (0.135 ± 0.042 ug m/L).

According to Domagalski *et al.* (1997), the first heavy rainfall after application, results in the highest quantity of pesticides in surface waters. There are significant periods in the Western Cape, where runoff-related pollution after usage of chemical products in the environment occurs (October to December) (Schulz 2001a, Schulz 2001b). This phenomenon could explain Zn, Mn and Cu concentrations at site 1, because of fertilizer and pesticide usage in the agricultural area next to this site.

6.2 Site 2

The mean Al concentration in water had increased to 1.56 ± 0.18 mg/L on occasion 6 (August 2006) at site 2 as compared to site 1 (0.68 ± 0.11 mg/L) (Table 3.4). According to Ball *et al.* (1991) brake wear, engine wear and fluid leakage are sources of Al, Cu, Ni and Cr. Vehicular components wear and detachment is a source of Fe, Al, Cr and Zn. Tyre wear is a source of Zn and Cd (Ball *et al.* 1991, Akbar *et al.* 2003). Due to the above sources of metals, it is suggested that in the present study the runoff from the N1 highway (located approximately one km upstream from the sampling site) could be a contributing factor for the elevated concentrations of Al (1.56 ± 0.18 mg/L) and Ni (0.05 ± 0.04 mg/L) at this site (Table 3.4, 3.10). This contribution could also explain Fe concentrations (42.58 ± 9.22 mg/L) as shown in Table 3.8 during December 2005, since there is a high traffic volume during this time of the year due to the holiday season.

The concentrations of Cu, Mn and Zn were found to be relatively high in the month of February 2006 (Tables 3.7, 3.9 & 3.11). The mean concentrations of these metals were: 0.10 mg/L, 0.59 mg/L and 0.52 mg/L for Cu, Mn and Zn, respectively. The concentrations of these metals were higher than DWAF and ANZECC water guidelines (Table 6.1) (DWAF 1996c, ANZECC 2000). Certain pesticides and fertilizers contain Cu, Zn and Mn (Greenwood & Earnshaw 1984, Friberg 1986, De Oliveira-Filho *et al.* 2004). Manganese is present in natural water (Bryan & Ward 1965). Furthermore, manganese is a major element of pesticides such as Mancozeb and Maneb (Acrobat ® 2005). Mancozeb, is a fungicide utilised for the treatment of plant diseases in the Western Cape. Its usage in agricultural quantities to $1\ 343 \times 10^3$ kg/a (Vermeulen *et al.* 2001). There is a golf course between site 1 and site 2, which uses fertilizers and pesticides (enquiry made by researcher). This could have contributed to these metals found at site 2.

6.3 Site 3

The mean Al (1.24 ± 0.17 mg/L) and Mn concentrations (0.10 ± 0.01 mg/L) were found to be the highest on the August 2006 sampling occasion in comparison to the rest of the occasions at site 3 (Table 3.4, Table 3.9). These concentrations were higher than the DWAF and ANZECC water guidelines (Table 6.1) (DWAF 1996c, ANZECC 2000). Al and Mn are signature elements for steel production (Herngren *et al.* 2006). There are steel production industries at Brackenfell. It could be possible that runoff from this industrial area have contributed to the pollution of the water with Al and Mn.

The highest mean Fe concentration (4.36 ± 4.47 mg/L) at site 3 was found during the December 2005 sampling occasion (Table 3.8). However, these concentrations were still significantly lower than those found at sites 1 and 2

during the same sampling occasion. There are no water guidelines provided for Fe by DWAF and ANZECC (Table 6.1) (DWAF 1996c, ANZECC 2000).

The mean Cu concentration (0.13 ± 0.04 mg/L) in water at this site was found to be the highest during February 2006 when compared to other occasions and sites ($P < 0.05$) (Table 3.7). This concentration was higher than the DWAF and ANZECC water guidelines (Table 6.1) (DWAF 1996c, ANZECC 2000). Copper concentrations were also compared with the results of Yi (2005). This author conducted a study in the Bottelary River in Western Cape, South Africa. The mean Cu concentration ranged from 0– 0.0153661 mg/L. This was attributed to runoff from the use of Cu-based pesticides on the farms and the brick field (Yi 2005). The current study still had a high concentration of Cu and the probable source could be residential and industrial runoff as well as atmospheric depositions from industrial sources.

The mean Zn concentration was the highest during the October 2006 sampling occasion (0.34 ± 0.09 mg/L), compared to the other sampling occasions at site 3 (Table 3.11). However, these concentrations were still significantly lower than those found at site 1 during the same sampling occasion. The concentration of Zn at site 3 was higher than the DWAF and ANZECC water guidelines (Table 6.1) (DWAF 1996c, ANZECC 2000). Zinc concentrations were compared with those from the study conducted by Fakoti and Awofolu (2003). The concentrations in the water ranged from 0.009 ± 0.01 mg/L in Keiskamma River to 0.324 ± 0.002 mg/L in Tyume River, Eastern Cape province, South Africa (Fakoti and Awofolu 2003). These levels were below Zn concentrations of the present study on the Kuils River. It could be possible that this Zn concentration is the results of agricultural activities upstream from site 3.

6.4 Site 4

Aluminium (1.00 ± 0.00 mg/L) and Mn (0.06 ± 0.00 mg/L) concentrations on occasion 6 at site 4 were found to be the highest in comparison to other occasions ($P < 0.05$) (Table 3.4, Table 3.9). The mean concentration for Al was higher than water guidelines (DWAF and ANZECC) (Table 6.1). The mean concentration of Mn was lower than DWAF and ANZECC guidelines (Table 6.1) (DWAF 1996c, ANZECC 2000). The Al concentrations were considered as a threat to the aquatic ecosystem. However, there was a decline in Al at this site compared to other sites. According to Dallas *et al.* (1998) Mn in aquatic ecosystems can either increase or decrease the toxicity of other metals when in mixture.

There was a decline in Fe concentrations during December 2005 from site 1 to site 4, which ranged from $48.48 - 1.08$ mg/L ($P < 0.05$) (Table 3.8). There is no guideline set for Fe. However, in the aquatic environment, oxidation- reduction reactions, pH and the availability of co-existing inorganic and organic complexing agents establish the chemical performance of Fe. The Fe concentrations may be affected by the biological interactions in surface waters. The demand for iron during alga blooms can significantly reduce Fe concentration in the water (DWAF 1996c). This could explain the decline of Fe concentration in the current study. It could be concluded that the downstream sites are “cleaner” than the sites higher up in the Kuils River with regard to Fe.

Both Cu (0.12 ± 0.06 mg/L) and Zn (0.53 ± 0.14 mg/L) concentrations were found to be significantly higher during October 2006 than on any of the other occasions at this site (Tables 3.7 & 3.11). The measured concentrations were compared with both the DWAF and ANZECC water quality guidelines and were found to be higher than these guidelines (Table 6.1) (DWAF 1996c, ANZECC 2000). In a study done by Gobel *et al.* (2007), Cu (153 mg/L) and Zn (370 mg/L) had the highest concentrations. This was attributed to roof runoff, tiles, cement, bitumen

and down pipes. At sampling site 4 in the present study, a section of the stream was canalised and this stream is bordered by residential areas on both sides of the river of which there were building renovation and expanding of the neighbouring houses in Kuilsriver. Therefore, it could be possible that the sources for Cu and Zn were the same as in the study by Gobel *et al.* (2007).

Chapter 7

Sediment Discussion: Metal concentrations

Table 7.1: Recommended guideline metal concentrations as stipulated by the Canadian Council of Ministers of the Environment Quality Guidelines (2001) and Australian and New Zealand Environment and Conservation Council (ANZECC 1992) Water Quality Guideline targets as well as present study's mean metal concentrations.

Metals	CCME (mg/kg) 2001	ANZECC (mg/kg) 1992	Present Mean Concentration Range (mg/kg) Study's Metal
Al	No values	No Values	381.52 - 13727.14
Cd	0.6	1.5	0.02 - 0.18
Pb	35.0	50	0.23 - 121.11
Co	No values	No values	0.02 – 2.07
Cr	37.3	80	0.11 – 16.06
Cu	35.7	65	0.18 – 33.75
Fe	No values	No values	350.59 – 10899.75
Mn	No values	No values	1.31 – 97.83
Ni	No values	21	0.12 – 3.34
Zn	123	200	3.23 – 129.55

In South Africa no sediment quality guidelines exist to compare with this study's results, in order to determine whether sediment concentrations are below or above certain acceptable limits. Therefore, the Canadian Sediment Quality Guidelines (CSQG) for the protection of aquatic life was used. These guideline values are as follows: Cd (0.6 mg/kg), Cu (35.7 mg/kg), Cr (37.3 mg/kg), Pb (35.0 mg/kg) and Zn (123 mg/kg) (CCME 2001). The Interim Sediment Quality Guidelines (ISQG) of ANZECC (1992) was also included for use in this study. The ISQG for nickel is 21 mg/kg in sediment (ANZECC 1992). The World Shale

component values were used for Al, Co, Fe and Mn comparisons. The component value for aluminium is 8.0 mg/kg, cobalt is 19 mg/kg, Fe is 4.6 mg/kg and Mn is 850 mg/kg (Turekian & Wedepohl 1961).

Metals in aquatic systems are generally primarily associated with sediment (Förstner 1983). The metal sediment concentration is normally a more sensitive and precise indicator of contamination of an aquatic system (Carelli *et al.* 1995). According to Dojlido & Taboryska (1991) large concentrations of metals could represent a great danger to aquatic environment.

7.1 Site 1

At sampling site 1, sediment was classified as sandy mud, with a high percentage of silt, followed by lower percentage of clay and sand (Table 4.1a). Many South African waters are naturally silty, although this silt loads increase noticeably as a result of agricultural malpractices (Davies & Day 1998). Clay minerals have an important adsorption function (Dassenakis *et al.* 1995), which may generally explain the high concentrations of metals which has been discussed below.

Most of the metal concentrations measured on the different sampling occasions at site 1 showed a non-statistical temporal trend. Most of the metals (Al, Co, Cr, Cu, Fe, Mn, Ni and Zn) found in sediment samples revealed common peaks at sampling site 1 (Figs. 4.1-4.10). The highest peaks were found to be on sampling occasion 3 (February 2006) and occasion 7 (October 2006). These metals (Al, Pb, Cr, Co, Cu, Fe, Mn, Zn) showed the lowest sediment concentrations on occasion 6 (August 2006). During the month of February 2006, the concentration of Al was 13727.14 ± 594.61 mg/kg (Fig 4.1; Table 4.2). During the months of February 2006 and October 2006 Fe revealed high mean concentrations of 10899.75 ± 442.36 mg/kg and 9223.26 ± 465.13 mg/kg, respectively (Fig. 4.7; Table 4.8).

According to Watling & Watling (1983) high concentrations of Al and Fe indicate the presence of clay and hydrated iron minerals. Other studies by Modak *et al.* (1992) showed that Al and Fe are naturally included in the clay mineral structure. The present study's highest Al concentration (13727.14 ± 594.61 mg/kg) was much higher than the World Shale component value (8.0 mg/kg) (Turekian & Wedepohl 1961). Steenkamp (1992) reported Fe concentrations of 21650 mg/kg in the Bronkhorstspuit River. This very high concentration was attributed to mining activities in the area. A study by Jackson *et al.* (2007) showed a mean Al concentration of 17448.8 mg/kg and mean Fe concentration of 26473.3 mg/kg in the Berg River in the Western Cape. These levels were found nearby an agricultural area, where pesticides and insecticides are used for the treatment of crops. According to Seachem (2006) agricultural treatment that contains phosguard will increase environmental Al concentrations. Sediment characterisation in the present study showed that site 1 had a clay content of 16.4% (Table 4.1). This could result in high concentrations of these two metals (Al and Fe) in sediment through adsorption, with possible contributions from the agricultural activities nearby this sampling site. In addition, the increased concentrations of Al and Fe could be due to the fact that they are the two most abundant metals in the environment (ATSDR 2005a).

The other metals with common peaks during sampling occasions in February 2006 and October 2006 were Pb and Zn. Sediment had Pb concentrations of 49.39 ± 1.49 mg/kg and 52.0 ± 2.22 mg/kg in February and October 2006 (Fig. 4.3 and Table 4.4). Zinc concentrations were 120.63 ± 4.98 mg/kg and 129.55 ± 6.08 mg/kg in February 2006 and October 2006 (Fig 4.10; Table 4.11). Lead in the present study was found to have similar concentrations as detected by Bradley & Cox (1986), while the Zn concentration found by Bradley & Cox (1986) was higher (145 mg/kg) than in the present study. The high Zn concentrations in the study of Bradley & Cox (1986) were attributed to mining activities. There are no mining activities close to the study area in the present study. Comparisons with

the Canadian sediment guidelines (CCME 2001) showed that Pb and Zn in the present study were far above those guidelines.

However, other metals that were found to be below the limit of the Canadian guidelines during February 2006 and October 2006 were Cu (14.64 ± 0.56 mg/kg and 13.37 ± 1.65 mg/kg) (Fig 4.6; Table 4.7), Cr (16.07 ± 1.57 mg/kg and 16.06 ± 1.96 mg/kg) (Fig 4.4; Table 4.5) and Ni (3.03 ± 1.91 mg/kg and 3.29 ± 2.05 mg/kg, respectively) (Fig 4.9; Table 4.10). These metal concentrations were not a threat to the aquatic environment. Cadmium was not detected at site 1 (Table 5.2).

The possible reasons for the occasion 3 (February 2006) peaks are various. During the months of December 2005 and January 2006 only 1.2 mm rainfall was measured (Table 2.1). Evaporation could concentrate substances in the river (Davies & Day 1998). This could be a possible contribution since water flow was very slow in that time period. According to Davies & Day (1998) most particles settle out of suspension and deposit on the bottom layer of rivers when slow or no movement of water is experienced. It has been suggested that metals and other reactive contaminated material can be adsorbed from the water column onto surfaces of fine grained sediment (Dassenakis *et al.* 1995, Segura *et al.* 2006). The slow stream flow and fine grained sediment could have resulted in more metals accumulating in the sediment.

The peak measured on occasion 7 (October 2006) (Figs. 4.1-4.10) could possibly be due to runoff from residential areas, the nearby agricultural area and illegal waste dumping next to the river. Rainfall could have triggered the runoff to the river, since the average rainfall measured was 37.2 mm (Table 2.1). During rain events the surface contaminants can be washed off to the river (Sartor *et al.* 1974, Fuchs *et al.* 1997). According to Segura *et al.* (2006) farming activities, transport, urbanisation and domestic waste affected the Mapocho River in Chile in terms of metal pollution. Concentrations fell within the range of 17-83 mg/kg for

Pb in the study by Segura *et al.* (2006). Furthermore, large quantities of metals can also be deposited by rain (Moore & Ramamoorthy 1984, ATSDR 2006, Gobel *et al.* 2007). Metal roofs frequently contain Cu, Zn and Pb. Metal gutters and metal down pipes are also found in urban areas. The pollutants, which settle on the roof, wash off and become storm water components (Gobel *et al.* 2007).

A kilometer downstream from site 1 there was building construction that coincided with the sampling period of the present study. Wind could be one of the possible transport agents for pollutants. According to Cowling *et al.* (1996) a distinctive feature of the Cape Peninsula's climate is its strong wind regime. Contaminated soil particles could have been transported by wind to the river from the construction site. Also, cement can release certain toxins into the aquatic environment (Davies & Day 1998). According to the investigations done by Van der Sloot (2000), cement mortars contain all the metals chosen for the present study (Al, Cd, Co, Cr, Cu, Fe, Pb, Mn, Ni and Zn). The land gradient in the surroundings of sampling site 1 of the present study was approximately 15°. When the gradient is relatively steep the erosive power of water is greater (Davies & Day 1998). Table 2.1 shows a rainfall of 37.2 mm for October 2006. Therefore, building construction could be considered as a possible contributor to the peak found during October 2006 for all metals (Figs. 4.1-4.10, Tables 4.1-4.11).

According to Davies & Day (1998) rain determines the degree of dilution of natural chemical constituents and of pollutants. The decrease in metal concentrations (Al, Cr, Co, Cu, Fe, Mn and Zn) observed on occasion 6 (August 2006) could be due to metals being washed downstream since heavy rains were experienced from April 2006 until the collection of August 2006 samples (Table 2.1).

7.2 Site 2

The sediment at site 2 was characterised as slightly gravelly sand (Table 4.1a). A significant increase of Pb, Cu, Fe, Mn and Zn concentrations (Fig.4.3, 4.6, 4.7, 4.8 and 4.10) were revealed during the months of February 2006 and June 2006. The concentration of Pb during June 2006 (121.11 ± 13.36 mg/kg) was higher than the recommended Canadian Sediment Quality Guidelines (Fig. 4.3; Table 4.4). Leaded petrol was banned in 1997 in Guangzhou. The Pb pollution of that soil environment, however, still seems to be a major concern because Pb concentrations of 75-926 mg/kg were still found in that area in 2006 (Duzgoren-Aydin 2007). According to Moore and Ramamoorthy (1984) large quantities of Pb are transported and deposited by rain into rivers. The exact source of Pb in the 2006 part of the present study is not known because leaded petrol was banned in South Africa from January 2006 (Harper *et al.* 2003). In spite of this it seems as if no significant decrease in Pb concentrations were found during the 2006 sampling occasions, as compared to the 2005 sampling occasions.

Major sources of pollution in agricultural wastewater are fertilizers containing metals such as Cd, Pb, Cr, Zn, Cu and Ni (Spencer & Green 1981). It is possible that the golf course upstream from site 2 could have contributed to metal contamination of the river due to the use of fertilizers and pesticides, although it was not proven beyond doubt. Other possible sources could be runoff from surrounding residential areas near this sampling site.

Aluminium, Cr and Fe exhibited their highest concentrations during the month of June 2006 (Figs. 4.1, 4.4, 4.7). The mean concentrations of these metals were 2347.66 ± 108.12 mg/kg for Al, 8.66 ± 3.83 mg/kg for Cr and 4921.97 ± 196.04 mg/kg for Fe. According to Gobel *et al.* (2007) pollutant sources from the road and traffic include road surface abrasion, tyre abrasion, brake pad abrasion, drip loss, fuel, gear, oil, brake fluid amongst others. Ball *et al.* (1991) stated that break wear, engine wear, fluid leakage are sources of Al, Cu, Ni and Cr. Vehicular

component wear and detachment are sources of Fe, Al, Cr and Zn. Tyre wear is a source of Zn and Cd. It was further stated that rainfall runoff from urban pavements frequently contains important quantities of dissolved metal elements, particulate-bound metal elements, suspended, colloidal and unstable fractions of particulates. It is probable that the N1 highway and the runoff from it could have been a major source of metal pollution at site 2, which was only a few hundred metres downstream from where the N1 highway crosses the river.

7.3 Site 3

Sediment at site 3 was found to be sandy (99.06% sand) (Table 4.1a). Generally, most metals revealed a decline in concentrations on all sampling occasions compared to other sites. According to Power & Chapman (1992) the coarse fraction is composed mostly of stable, inorganic silicate materials that are noncohesive and normally not related with chemical contamination. The decline in metal concentrations at site 3 can be explained by the sandy nature of the sediment at this site.

Sediment samples of June 2006 for Al, Cd and Fe (Figs. 4.1; 4.2 & 4.7) and August 2006 for Cr, Ni and Zn (Figs. 4.4; 4.9 & 4.10) had relatively high concentrations compared to the other sampling occasions at site 3. However, site 3 generally had low metal concentrations compared to ANZECC (1992) and CCME (2001) guidelines (Table 7.1).

The following could be considered as reasons of the decline of metal concentrations. At site 3 there were water plants present. Certain plants such as *Eichhornia crassipes* (water hyacinth), *Typha* species and *Phragmites* species (Anon 1997) have the ability to remove, degrade, or immobilize harmful chemicals. According to a study done by Qoko (2003) on the Kuils River, the accumulation of metals in *Eichhornia crassipes* occurred in all organs and was easily harvested because they are free floating plants. This plant was found to have higher concentrations of metals (Cu, Fe, Pb and Zn) than *Typha capensis*,

Phragmites and *Schoenopletus*. Ma (2005) further stated in the investigation done on the Bottelary River that *Typha capensis* and *Phragmites australis* are good biological monitors that accumulated most of the metals. These plants can be regarded as possible candidates for phytoremediation. It could therefore be possible that metal concentrations were reduced in the vicinity of site 3 due to metals being accumulated by aquatic plants in that area.

7.4 Site 4

The sediment at site 4 was found to be gravely muddy sand (Table 4.1a). Apart from Al and Ni (Figs. 4.1 & 4.9), nearly all of the sediment metals (Cd, Co, Cr, Cu, Fe, Pb, Mn and Zn) revealed common peaks during October 2006 at this site (Figs. 4.2 – 4.8 & 4.10). All these metals, except Fe (Fig. 4.7), were below the World Shale value, as well as the Australian and Canadian sediment guidelines (Turekian & Wedepohl 1961, ANZECC 1992, CCME 2001).

There are many possible sources that could have contributed to the pollution of the river with these metals. Since there were livestock drinking water from this sections of the river, animal faeces could be contributed to the metal load of the river. According to Segura (2006) animal excretions could contribute to the pollution of the river with metals. Furthermore, a study by Yi (2005) reported that the water quality in the Bottelary River was also altered by livestock and human waste. Ramessur & Ramjeawon (2002) stated that a river indirectly receives metals from wastewater discharges by means of road and urban runoff, battery manufacturing, soap and detergent industries, ethanol distilleries, chemical industries, paint manufacturers and electroplating plants.

This sampling site is located just downstream of Kuilsrivier (the town), surrounded by residential areas. Approximately 1 km away from the river, one of the residents had a motor car repair business. This could also be a possible source of pollution at this site. The drainage pipe from the road close to this

motor car repair shop could be a mode of transportation of pollution, containing metal particles, into the river. Davies & Day (1988) noted that effluent may be discharged from pipes or storm water drains into rivers. According to Ball *et al.* (1991) motor car services could contribute to Al, Cd, Cr, Cu and Zn pollution. Recycled scrap metal contribute to Pb pollution (ATSDR 2005) and urban runoff according to Wong & Li (2004) is also a major contributor to river pollution.

Chapter 8

Snail Discussion: Metal concentrations

Ten metals were selected (Al, Cd, Co, Cu, Cr, Fe, Pb, Mn, Ni and Zn) for analysis in snail samples. The concentrations of these metals are provided in Figures 5.1-5.10 and Tables 5.1-5.10. Of these ten metals, six (Al, Cu, Fe, Pb, Mn and Zn) are discussed below. The other four metals' (Cd, Co, Cr, Ni) concentrations were very low (Tables 5.2, 5.4, 5.5 & 5.9) and will not be discussed in detail.

In this present study the freshwater snail, *Physa acuta* was used to assess the possible bioaccumulation of metals. Woodard (2005) indicated that *P. acuta* could be an excellent species for aquatic toxicity testing. This organism dwells in large stable lakes and rivers but also in temporary and unstable habitats such as small ponds or irrigation canals (Facon *et al.* 2007). This organism can also deal with harsh environments, including environments that have been polluted (Dillon 2000). Woodard (2005) investigated the usefulness of *Physa acuta* as a model species for environmental toxicology testing. The investigation was purposely for acute and chronic tests of its continued existence and its metabolic, reproductive and behavioral reaction on exposure to a wide concentration variety with a special reference to Cadmium (Cd²⁺). Bernot *et al.* (2005) investigated the effects of several classes of ionic liquids on the survival, movement and feeding behaviour of *P. acuta*. Kefford & Nugegoda (2005) investigated the threshold for growth and reproduction in *P. acuta*. Takimoto *et al.* (1987) investigated the metabolism of fenitrothion in this species. Apart from the study by Woodard (2008) on Cd in *P. acuta*, no literature could be found on metals in this freshwater snail's species. The above authors were included in the study to demonstrate lack of information to support the current study for comparison purposes.

8.1 Site 1

Aluminium, Fe and Zn revealed similar superficial trends from October 2005 to April 2006. Aluminium and Zn continued with this common trend until June 2006 (Figs. 4.1; 5.2 and 5.10). Each of the metals was compared with the corresponding sediment results.

Snail Al concentrations (1688.39 ± 1025.61 mg/kg) were found to be approximately six times lower than the sediment Al concentrations (9845.20 ± 461.14 mg/kg) at site 1 on occasion 2 (Table 5.1, Table 4.2). Many authors agree that Al is one of the most toxic trace metals and is probably not an essential nutrient in any organism (Herrmann 1987, Dallas & Day 1993, Cathalifaud *et al.* 1997). The findings of Rosseland *et al.* (1990) furthermore indicated that increased Al concentrations in streams may cause Al accumulation in terrestrial animals eating prey originating from contaminated streams or rivers or lakes. Snails can also be a vital prey for mammals, birds, and large invertebrates (Symondson and Lidell 1993; Graveland *et al.* 1994). In this regard Al concentration in snails could be considered as a threat to predators. Furthermore, according to Patrick & Loutit (1978) this indirect effect may include the increased accumulation of metals via the contaminated food and the resulting toxic effects on predators.

Snail Fe concentrations of 24023.20 ± 5914.25 mg/kg and snails Zn concentrations of 239.77 ± 73.47 mg/kg at site 1 on occasions 2 (December 2005) were found to be higher than on any of the other occasions ($P < 0.05$) (Fig. 5.7, Table 5.7 and Fig. 5.10, Table 5.10). These metals, when compared with sediment metal concentrations of the same site 1 and on occasion 2 for Fe, the snail Fe concentrations was approximately 5.7 times higher than the corresponding sediment mean concentrations of 4212.85 ± 151.68 mg/kg on occasion 2 at site 1 (Fig. 4.7, Table 4.8). The snail Zn concentrations was approximately 6.1 times higher than the corresponding sediment mean concentration of 39.40 ± 11.30 mg/kg on occasion 2 at site 1 (Fig. 4.10, Table

4.11). Iron and Zn are micronutrients and are required for metabolic activities (DWAF 1996a, Dallas & Day 2004). Their essential role and toxicity in organisms are separated by a very "thin line" (Spear 1981). Their mechanisms of toxicity at the biochemical level are poorly understood (Dallas & Day 2004). According to Timmermans (1993) these metals (Fe and Zn) mostly do not appear to be toxic in freshwater invertebrates but at elevated levels it can become toxic.

During October 2006 (occasion 7) Mn revealed a peak of 1090.68 ± 585.83 mg/kg in snail samples (Fig. 5.8, Table 5.8). Manganese mean concentrations detected in snails were approximately 19 times higher than those of the sediment (56.98 ± 2.78 mg/kg) (Table 4.9). The direct increase of concentration in snails was unknown. According to Bryan & Ward (1965) Mn is an important element in biological processes. Uptake of Mn by aquatic invertebrates increases with increasing temperature and decreases pH (WHO 1981). The mean temperature in the current study was 15°C (Table 3.2) and the pH was 6.8 (Table 3.1). It could be possible that physico-chemical parameters had an effect on the concentrations found in snails.

Snail mean Cu concentrations revealed a peak of 538.13 ± 1106.42 mg/kg during April 2006 (Fig. 5.5). The copper concentrations in snails was approximately 86 times higher than that of the sediment (6.28 ± 2.95 mg/kg) (Table 4.7) of the April 2006 sampling occasion. According to De Oliveira-Filho *et al.* (2004) contamination of water, sediment and soil by Cu can arise from the widespread use of Cu-based products such as fertilizers and fungicides in agriculture. These researchers furthermore reported that the use of Cu compounds is likely to affect a variety of non-target aquatic species. It is therefore possible that agricultural activities next to site 1 contributed to the Cu concentrations found. However, it must also be taken into account that freshwater snails, like other molluscs, have Cu-containing hemocyanin, the oxygen-binding protein, in their hemolymph. Other important proteins in organisms also contain Cu (Moore & Ramamoorthy 1984). Metallothioneins (contain Cu (Kagi *et al.* 1984)), metal binding proteins,

regulate essential metals and detoxify toxic metals (Cd, Hg) (Deb & Fukushima 1999). Therefore, some of the Cu found in the snails' bodies may not be due to environmental pollution.

8.2 Site 2

During sampling visits at site 2 in the months of February 2006, April 2006, August 2006 and October 2006 at site 2, no snails were found (Fig. 5.1-5.10). Snails were only found three times throughout the entire sampling period at site 2 (October 2005, December 2005 and June 2006). This site was characterised by relatively fast flowing water, shade throughout the day caused by trees on both banks. Metals that were detected in snail samples at this site were Al, Pb, Cu, Fe, Mn and Zn. The highest concentrations were found during occasion 5 (Fig. 5.1; 5.3; 5.6, 5.7 and 5.10).

Leaded petrol was completely banned in South Africa from January 2006 (Harper *et al.* 2003). However, lead did not show any decline in snail samples from 2005 to 2006. Indeed, a statistically significant increase ($P < 0.05$) were observed in the month of June 2006 (Table 5.3). This could be partly due to the half life of lead in the environment. The effects of lead may persist long after the source has been removed (Duzgoren-Aydin 2007). There were similar results found for Pb concentrations measured in sediment and snails during June 2006. Both had the highest concentrations measured at site 2 (121.11 ± 13.36 mg/kg and 126.50 ± 25.13 mg/kg, respectively) (Figs. 4.3 & 5.3). Rainfall of 121.8 mm (Table 2.1) was recorded in June 2006. It is known that small amounts of Pb can enter rivers and streams by rainwater (ATDRS 2005). Lead particles could have been transported into the river via storm water pipes in this time period. The main contributor to the relatively high Pb concentrations could probably be the N1 highway, which crosses the Kuils River more or less than 500 metres upstream from sampling site 2. Also, a nearby golf course, as well as some agricultural

activities next to the river may have contributed to the high level of lead, since this metal can occur as impurities in fertilizers and in metal-based pesticides and compost manure (Okonkwo & Mothiba 2005). Lead bioaccumulated to significant levels in freshwater snails during June 2006 relative to October 2005 and December 2005. pH is known to affect bioavailability of metals. However, pH in the present study was relatively neutral to slightly alkaline and probably had a minimal effect on metal accumulation (Table 3.1).

Manganese in snails in December 2005 was compared to October 2005 (Fig. 5.8, Table 5.8) at site 2, and there was no significant difference ($P > 0.05$). Further comparison was made with sediment results (11.81 ± 5.48 mg/kg) of the same site and occasion (Fig. 4.8, Table 4.9). The concentrations of Mn in snails (645.44 mg/kg) were also found to be approximately 55 times higher than that in sediment samples. According to Dallas & Day (2004) Mn is essential for organisms. Since it is a micronutrient, it is not surprising to find Mn in snails. Föstner & Prosi (1979) states that elevated levels of manganese could be toxic to organisms. However, in the present study, the literature did not reveal the actual toxicity of Mn for *Physa acuta*. It is therefore unclear whether or not the snail concentrations are normal or toxic. This should be researched in future studies to determine the level of toxicity of this metal.

The concentration of Al, Cu and Zn in snails (Figs. 5.1, 5.6 & 5.10) decreased over the entire sampling period. At low concentrations, Cu and Zn are important for the effective functioning of an organism (ANZECC 1992, ANZECC & ARMCANZ 2000). These metals' highest concentrations were found during October 2005 (Al = 1595.48 ± 406.82 mg/kg, Cu = 207.76 ± 161.39 mg/kg, Zn = 432.74 ± 457.36 mg/kg).

8.3 Site 3

At site 3 Al (1736.98 ± 294.01 mg/kg) and Pb (18.39 ± 45.05 mg/kg) had their highest concentrations in the snails during the month of June 2006 (Fig. 5.1 & Fig. 5.3). Aluminium concentrations in snails were approximately 1.4 times higher than in the corresponding sediment samples (1268.04 ± 274.48 mg/kg) (Table 4.2). Also, Pb snail concentrations were approximately 3 times higher than in the corresponding sediment samples (6.21 ± 1.10 mg/kg) (Table 4.4). The source responsible for these peaks in metal concentration is not known. The probable source was industrial and residential runoff due to relative high rainfall in this time period. In the present study the pH range was 7.1 (Table 3.1). Aluminium is everywhere in the environment, but its entrance into the food chain is limited by its insolubility (Driscoll & Schecher 1989). It is insoluble in the pH range of 6.0-8.0 due to the formation of polymer, gibbsite (Elangovan *et al.* 1997). It could be possible that this high concentration especially Al, could have been obtained from plants. Ma *et al.* (2001) states that plants, together with species that accumulate aluminium in their leaves, detoxify aluminium internally by forming complexes with organic acids. Sparling & Lowe (1996) stated that a very high level of Al can be accumulated in aquatic invertebrates. A very high level of Al can be accumulated by Aquatic invertebrates; however mainly of this materialize to be through adsorption rather than assimilation. The concentrations of Al may possibly be as high as 5000 mg/kg in insects and greater than 17,000 mg/kg in other invertebrates.

Lead is not known to be essential trace element in animal nutrition (Forster and Wittmann 1981). According to the study by Zödl and Wittmann (2003) it is possible to have a high concentration of Pb in gastropods. The Pb concentrations as well are at variance between species (Ash & Lee 1980).

Copper, Fe and Mn in snails had their highest mean concentrations on the December 2005 sampling occasion. The mean concentrations of these metals

were 255.52 ± 478.93 mg/kg, 15114.12 ± 3793.06 mg/kg and 144.65 ± 62.22 mg/kg, respectively (Fig. 5.6, 5.7 & 5.8). The majority of the authors agree that these metals (Cu, Fe & Mn) are essential for all organisms (DWAF 1996a, Teo & Chen 2001, Dallas & Day 2004, Grosel *et al.* 2007). The water temperature during the sampling occasion of December 2005 was 22.3 °C (Table 3.2). The electrical conductivity was also the highest (131 mSm⁻¹) compared to other occasions at the site (Table 3.3). Mason (1996) stated that, the temperature is an important environmental factor. It influences the metabolic activity and the behaviour of organisms, which may affect their exposure to pollutants. It may also change the physical and chemical state of a pollutant, influencing its bioavailability. According to Felts & Heath (1984) toxicity of metals generally increases with increasing temperature. It is therefore not surprising for Cu, Fe and Mn in the present study to have high mean concentrations.

Manganese showed higher concentrations during the December 2005 sampling occasion than on any of the other occasions at site 3 (Fig. 5.8, Table 5.8). The same was found at sampling site 2. However, site the Mn concentration has decreased from 645.44 ± 98.94 (site 2) to 144.65 ± 62.22 mg/kg (site 3) (Table 5.8). The snail Mn concentrations were approximately 39 times higher than the sediment Mn concentrations of 3.69 ± 1.18 mg/kg (Table 4.9). Aquatic macrophytes take up pollutants via their roots (Salt 1995) and also absorb chemicals from the water column through their leaves (Biernacki *et al.* 1997). The degree of metal uptake by some plants are largely dependent on the type of metal and plant species involved (Mortimer 1985). Qoko (2003) investigated *Eichhornia crassipes*, *T. capensis* and *P. australis* in the Kuils River for accumulation of metals. It could be partially possible for the snails to have high concentrations of metal, due to intake of contaminated plant material for food. According to Russell-Hunter (1983) snails and slugs are essential component of herbivorous and detritivorous fauna in many ecosystems.

Mean Zn concentrations at site 3 revealed the same temporal trends as was found at site 1, except for occasion 3 in February 2006, which was the lowest (Fig. 5.10, Table 5.10). In comparison with sediment at site 1 and 3, especially for occasion 3 (Fig 4.10, Table 4.11), it was noticed that when the concentrations of metals in sediment were high the snails concentrations were low. However, where snail concentrations were high, sediment concentrations were low. This could have been due to spatial and temporal fluctuation in bioavailability in this river.

8.4 Site 4

Aluminium (1943 ± 200.90 mg/kg) and Zn (316.43 ± 87.69 mg/kg) concentrations in snails during June 2006 were high (Tables 5.1 & 5.10). Aluminium sediment concentrations were approximately 2.4 times higher than the snail metal concentrations. However, Zn concentrations in snails were approximately 13.6 times higher than the sediment concentrations during June 2006. Zinc is an important micronutrient for organisms (Friberg *et al.* 1986, Dallas & Day 2004) and it is required for metabolism, while Al is regarded as not essential for any organism (Cathalifaud *et al.* 1997).

Copper, Fe and Mn revealed the highest snail concentrations during December 2005, as were found at site 3 (Figure 5.6, 5.7 and 5.8). These metals are considered important in metabolic activities of organisms (Bryan & Ward 1965, Dallas & Day 1993, Avenant-Oldewage & Marx 2000). It was observed that Cu concentrations in snails had increased gradually down the river and ranged from 59.17 ± 91.34 at site 1 to 769.47 ± 1821.00 mg/kg at site 4 (Fig. 5.6, Table 5.6). Copper is an important metal for organisms according to Spear (1981) and Csuros & Csuros (2002) but can be toxic at increased concentrations.

Iron concentrations (24023.20 ± 5914.25 to 10309.29 ± 1979.23 mg/kg) had decreased in snails from site 1 to site 4 (Fig. 5.6, Table 5.6).

No clear trend was observable for Mn. The range of Mn concentrations in snails was 34.85 ± 31.94 to 645.44 ± 98.94 mg/kg (Fig. 5.8, Table 5.8). At elevated levels Mn can pose a threat to aquatic life when present in high concentration (Föstner & Prosi 1979).

Lead showed the highest concentrations in snails of 50.35 ± 30.59 mg/kg during the February 2006 sampling at site 4, as compared to any of the occasions (Fig. 5.3). This Pb concentration in the snails was much higher than in water and in sediment. According to Mason (1996) temperature could influence the metabolic activity and the behaviour of organisms. According to Cairns *et al.* (1975) the effects of temperature change chemical toxicity in aquatic organisms. It must be noted that the most useful information regarding this relationship has been acquired in laboratory situations. The temperature was found to be 28.1°C during the February 2006 sampling occasion (Table 3.2). Therefore, this can explain the possible metal accumulation in snails which could have enhanced by the relatively high temperature of the water at site 4 as the snails could have been much more active due to the higher water temperature or could have increased bioavailability.

Chapter 9

Conclusion

- In the Kuils River, not all metals measured for in water posed a pollution threat to the river. Metals like Cd, Cr and Co were not detected, while Pb and Ni concentrations were found to be lower than the DWAF (1996 a-d) guidelines. The metal concentrations in water, which were significantly higher than the DWAF (1996 a-d) guidelines were Al, Cu, Mn and Zn. However, they were lower compared to metal concentrations found in other studies on South African rivers.

These metals in the water were significantly higher at site 1 compared to the other sites, probably due to lower pH (Table 3.2), illegal disposal of waste (domestic and other) and agricultural run off at this site. High clay content in sediment, that adsorb and release metals on a constant basis. Iron is not included in the DWAF (1996) guidelines. However, there was a decline in Fe concentrations throughout the length of the river. This gave the impression that the upstream sampling sites were more exposed to sources of Fe contamination than the downstream sites.

- The results showed that the river sediment was also contaminated with metals. Site 1 had significantly higher sediment metal concentrations than the other sites. Some of the metals found in sediment samples (Cd, Co, Cu, Cr, Mn and Ni), when compared to the Canadian Sediment Quality Guidelines (CSQG), the Interim Sediment Quality Guidelines (ISQG) and the World Shale component value, were below the given guidelines. Metals found in sediment which were above these guidelines were Al, Fe, Pb and Zn.

- The majority of sediment metal concentrations were found to be higher at sites 1 and 4. The sediment characterisation showed clay content of 16.4 % at site 1. The flow rate of water at site 1 was also very slow, which gave particles time to settle down. This could result in metals binding to the clay fraction of the sediment. This abovementioned factor of slow flow rate of water could also explain the level of metal accumulation at site 4 for both bioaccumulation and sediment. Agricultural activity and residential areas were also seen as contributing factors to metal contamination, particularly at site 1.
- Generally, metal concentrations in sediment were lower in months when the study area received relatively higher levels of rainfall. Davies & Day (1998) stated that rain determines the degree of dilution of natural chemical constituents and pollutants.
- In most cases concentrations of Cu, Fe, Mn and Zn in snails were much higher than in the corresponding sediment samples. These metals are essential for the metabolic processes in animals. It is therefore not surprising that these metals occurred in high concentrations in snails, relative to the sediment. However, it is difficult to conclusively state whether or not the metal concentrations in snails are normal or bioaccumulated. Further investigations involving toxicity testing should be conducted to determine the toxicity of these metals to *Physa acuta*. But more importantly, data should be compared with those of a reference site and to literature from low polluted sites.
- A similar trend was found for snail Zn concentrations at sampling site 1 and 3, except occasion 3 (February 2006). When comparing the snail Zn results of these two sites with the sediment Zn results, the following can be seen. Where the concentrations of Zn in sediment were high, the concentrations in snails were low, but where snail Zn concentrations were

high, the sediment Zn concentrations were low. It is concluded that this could be due to fluctuation in the bioavailability of Zn in this river over time and along the length of the river.

- In most cases the metal concentrations (Fe, Mn and Zn) in snails were found to be higher at site 1, which indicated that the metal input and bioavailability were higher at this site than at any of the other sites.
- Even though Pb was banned in South Africa since 2006, there were no decline in concentrations of Pb in snails and sediment, in the samples collected in 2006 compared to those collected in 2005. This could be due to the long half-life of Pb in the environment. Further investigations should be considered to evaluate the status of Pb in the Kuils River into the future.
- This study can serve as a baseline for further work on the toxicity of metals in the Kuils River.

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Appendix A

**Table A1: Aluminium concentration in water samples over the entire sampling period at
Kuilis River (2005-2006)**

07-10-2005			
	Conc mg/l	mean (ppm)	SD (ppm)
Control	0.14404		
Water 1A	0.29964		
Water 1B	0.66448		
Water 1C	0.05754		
Water 1D	0.09862		
Water 1E	0.02844	0.229744	0.265166
Water 2A	0.08762		
Water 2B	0.00868		
Water 2C	0.02242		
Water 2D	0.0346		
Water 2E	0.17412	0.065488	0.067688
Water 3A	0.09674		
Water 3B	0.18952		
Water 3C	0.38688		
Water 3D	0.33556		
Water 3E	0.3167	0.26508	0.118864
Water 4A	0.52742		
Water 4B	0.2033		
Water 4C	0.37832		
Water 4D	0.44382		
Water 4E	0.14962	0.340496	0.159925

01-12-2005			
	Conc mg/l	mean (ppm)	SD (ppm)
Control	0.025		
Water 1A	0.52446		
Water 1B	0.44538		
Water 1C	0.35082		
Water 1D	0.43586		
Water 1E	0.51122	0.453548	0.069439
Water 2A	0.341		
Water 2B	0.38222		
Water 2C	0.29866		
Water 2D	0.41776		
Water 2E	0.3711	0.362148	0.044871
Water 3A	0.31648		
Water 3B	0.27968		
Water 3C	0.41524		
Water 3D	0.37544		
Water 3E	0.33612	0.344592	0.052484
Water 4A	0.19652		
Water 4B	0.21082		
Water 4C	0.20518		
Water 4D	0.2045		
Water 4E	0.32552	0.228508	0.05447

10-02-2006			
	Conc mg/l	mean (ppm)	SD (ppm)
Control	0.025		
Water 1A	0.22628		
Water 1B	0.56558		
Water 1C	0.68542		
Water 1D	0.43238		
Water 1E	0.90004	0.56194	0.254473
Water 2A	0.71992		
Water 2B	0.50168		
Water 2C	0.52202		
Water 2D	0.57452		
Water 2E	1.57774	0.779176	0.454487
Water 3A	0.34228		
Water 3B	0.32166		
Water 3C	0.42216		
Water 3D	0.45518		
Water 3E	0.6559	0.439436	0.13296
Water 4A	0.25474		
Water 4B	0.2384		
Water 4C	0.27756		
Water 4D	0.33272		
Water 4E	0.25086	0.270856	0.037367

03-04-2006			
	Conc mg/l	mean (ppm)	SD (ppm)
Control	0.02773		
Water 1A	0.32656		
Water 1B	0.24752		
Water 1C	0.39144		
Water 1D	0.37928		
Water 1E	0.3438	0.33772	0.056812
Water 2A	0.32846		
Water 2B	0.27288		
Water 2C	0.3219		
Water 2D	0.3748		
Water 2E	0.32324	0.324256	0.036119
Water 3A	0.28246		
Water 3B	0.41898		
Water 3C	0.34908		
Water 3D	0.46892		
Water 3E	0.45588	0.395064	0.078293
Water 4A	0.26322		
Water 4B	0.30602		
Water 4C	0.24468		
Water 4D	0.32952		
Water 4E	0.20812	0.270312	0.048363

09-06-2006			
	Conc	Mean	SD
	mg/l	(ppm)	(ppm)
Control	0.1		
Water1A	0.2		
Water 1B	0		
Water 1C	0.2		
Water 1D	0.2		
Water 1E	0.2	0.16	0.089443
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0.6		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0.12	0.268328

04-08-2006			
	Conc	Mean	SD
	mg/l	(ppm)	(ppm)
Control			
Water1A	0.6		
Water 1B	0.6		
Water 1C	0.8		
Water 1D	0.6		
Water 1E	0.8	0.68	0.109545
Water 2A	1.8		
Water 2B	1.6		
Water 2C	1.6		
Water 2D	1.4		
Water 2E	1.4	1.56	0.167332
Water 3A	1.4		
Water 3B	1.4		
Water 3C	1		
Water 3D	1.2		
Water 3E	1.2	1.24	0.167332
Water 4A	1		
Water 4B	1		
Water 4C	1		
Water 4D	1		
Water 4E	1	1	0

02-10-2006			
	Conc	Mean	SD
	mg/l	(ppm)	(ppm)
Control			
Water1A	0		
Water 1B	0		
Water 1C	0.025454		
Water 1D	0.008306		
Water 1E	0.051508	0.017054	0.021885
Water 2A	0.151248		
Water 2B	0		
Water 2C	0.08		
Water 2D	0.014596		
Water 2E	0	0.049169	0.065957
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0.029546		
Water 4D	0		
Water 4E	0	0.005909	0.013213

**Table A2: Cadmium concentration in water samples over the entire sampling period at
Kuilis River (2005-2006)**

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	09-06-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	04-08-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	02-10-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0.005		
Water 3D	0		
Water 3E	0	0.001	0.002236
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

Table A3: Lead concentration in water samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0.05		
Water 2E	0	0.01	0.022361
Water 3A	0.05		
Water 3B	0.05		
Water 3C	0		
Water 3D	0		
Water 3E	0	0.02	0.027386
Water 4A	0		
Water 4B	0.05		
Water 4C	0		
Water 4D	0		
Water 4E	0	0.01	0.022361

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.05		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0.01	0.022361
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0.05	0.01	0.022361
Water 3A	0.05		
Water 3B	0.05		
Water 3C	0.05		
Water 3D	0		
Water 3E	0	0.03	0.027386
Water 4A	0.05		
Water 4B	0.05		
Water 4C	0.05		
Water 4D	0		
Water 4E	0	0.03	0.027386

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0	0	0
Water 3E	0		
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	09-06-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0.06		
Water 1C	0		
Water 1D	0		
Water 1E	0	0.012	0.026833
Water 2A	0		
Water 2B	0		
Water 2C	0.06		
Water 2D	0.06		
Water 2E	0	0.024	0.032863
Water 3A	0.06		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0.012	0.026833
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0.06	0.012	0.026833

	04-08-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0.05		
Water 2D	0.05		
Water 2E	0	0.02	0.027386
Water 3A	0		
Water 3B	0		
Water 3C	0.05		
Water 3D	0.05		
Water 3E	0	0.02	0.027386
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0.05	0.01	0.022361

	02-10-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.05		
Water 1B	0.05		
Water 1C	0.05		
Water 1D	0.05		
Water 1E	0.05	0.05	6.59E-10
Water 2A	0.05		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0.01	0.022361
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

**Table A4: Cobalt concentration in water samples over the entire sampling period at
Kuilis River (2005-2006)**

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0.01	0.002	0.004472
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0.01		
Water 2E	0.018954	0.005791	0.008538
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0.01		
Water 1E	0	0.002	0.004472
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0.01		
Water 3B	0		
Water 3C	0.01		
Water 3D	0		
Water 3E	0	0.004	0.005477
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	09-06-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	04-08-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0.005	0.001	0.002236
Water 3A	0.005		
Water 3B	0		
Water 3C	0.005		
Water 3D	0		
Water 3E	0	0.002	0.002739
Water 4A	0		
Water 4B	0		
Water 4C	0.005		
Water 4D	0		
Water 4E	0	0.001	0.002236

	02-10-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

**Table A5: Copper concentration in water samples over the entire sampling period at
Kuilis River (2005-2006)**

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0.57106		
Water 1B	0.03674		
Water 1C	0		
Water 1D	0		
Water 1E	0.05406	0.132372	0.246359
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0.07816	0.015632	0.034954
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0.00378		
Water 4E	0.1036	0.021476	0.045938

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.14036		
Water 1B	0.1298		
Water 1C	0.09006		
Water 1D	0.04266		
Water 1E	0.05072	0.09072	0.044445
Water 2A	0.09566		
Water 2B	0.11344		
Water 2C	0.05304		
Water 2D	0.0842		
Water 2E	0.16064	0.101396	0.039755
Water 3A	0.07888		
Water 3B	0.103		
Water 3C	0.1134		
Water 3D	0.17224		
Water 3E	0.17184	0.127872	0.04222
Water 4A	0.1351		
Water 4B	0.11604		
Water 4C	0.09826		
Water 4D	0.11144		
Water 4E	0.07268	0.106704	0.023156

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0.10928		
Water 2B	0		
Water 2C	0		
Water 2D	0.03914		
Water 2E	0	0.029684	0.047614
Water 3A	0.00764		
Water 3B	0.00834		
Water 3C	0		
Water 3D	0		
Water 3E	0	0.003196	0.004383
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	09-06-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0.02		
Water 1E	0	0.004	0.008944
Water 2A	0.02		
Water 2B	0		
Water 2C	0.04		
Water 2D	0		
Water 2E	0.02	0.016	0.016733
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0.08	0.016	0.035777
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0.02		
Water 4E	0.02	0.008	0.010954

	04-08-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.02		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0.004	0.008944
Water 2A	0.04		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0.008	0.017889
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	02-10-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.00856		
Water 1B	0.09102		
Water 1C	0.04814		
Water 1D	0.03256		
Water 1E	0.05812	0.04768	0.030605
Water 2A	0.0904		
Water 2B	0.0995		
Water 2C	0.01562		
Water 2D	0.1113		
Water 2E	0.1242	0.088204	0.042515
Water 3A	0.1159		
Water 3B	0.1152		
Water 3C	0.18024		
Water 3D	0.03374		
Water 3E	0.1461	0.118236	0.054257
Water 4A	0.05452		
Water 4B	0.07618		
Water 4C	0.09582		
Water 4D	0.17068		
Water 4E	0.1946	0.11836	0.061059

Table A6: Chromium concentration in water samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0.015054		
Water 1E	0	0	0
Water 2A	0.009664		
Water 2B	0		
Water 2C	0.001686		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0.004106		
Water 3C	0		
Water 3D	0		
Water 3E	0	0.000821	0.001836
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0.02764		
Water 4E	0	0.005528	0.012361

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	09-06-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	04-08-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	02-10-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

Table A7: Iron concentration in water samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	6.3401		
Water 1B	2.5823		
Water 1C	2.82646		
Water 1D	0.8634		
Water 1E	0.51272	2.624996	2.313511
Water 2A	1.978		
Water 2B	1.09658		
Water 2C	4.03846		
Water 2D	5.52928		
Water 2E	2.23944	2.976352	1.783172
Water 3A	0.18534		
Water 3B	6.85366		
Water 3C	1.41986		
Water 3D	2.13092		
Water 3E	4.1787	2.953696	2.61743
Water 4A	1.0851		
Water 4B	0.62866		
Water 4C	2.487		
Water 4D	0.42716		
Water 4E	2.15552	1.356688	0.919721

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	47.29622		
Water 1B	33.27422		
Water 1C	58.58362		
Water 1D	47.29582		
Water 1E	55.95842	48.48166	9.899864
Water 2A	31.23882		
Water 2B	51.55282		
Water 2C	41.16962		
Water 2D	52.26342		
Water 2E	36.65582	42.5761	9.219375
Water 3A	10.5559		
Water 3B	6.59086		
Water 3C	4.46524		
Water 3D	0		
Water 3E	0.18834	4.360068	4.466244
Water 4A	1.7879		
Water 4B	3.2864		
Water 4C	0.097		
Water 4D	0.24684		
Water 4E	0	1.083628	1.431442

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	25.42018		
Water 1B	15.28698		
Water 1C	7.9954		
Water 1D	14.6972		
Water 1E	11.3568	14.95131	6.539871
Water 2A	19.31058		
Water 2B	14.18452		
Water 2C	16.87554		
Water 2D	11.552		
Water 2E	13.149	15.01433	3.085354
Water 3A	3.2786		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0.65572	1.466234
Water 4A	0.71882		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0.143764	0.321466

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	09-06-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	12.6		
Water 1B	4.54		
Water 1C	4.84		
Water 1D	0.78		
Water 1E	0.88	4.728	4.806508
Water 2A	10.16		
Water 2B	3.04		
Water 2C	5.14		
Water 2D	2.84		
Water 2E	2.14	4.664	3.269844
Water 3A	4.38		
Water 3B	2.56		
Water 3C	1.68		
Water 3D	0.76		
Water 3E	1.38	2.152	1.404179
Water 4A	3.4		
Water 4B	0.9		
Water 4C	0.78		
Water 4D	1.06		
Water 4E	0.78	1.384	1.132819

	04-08-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0.22		
Water 1C	0.22		
Water 1D	0.14		
Water 1E	0.1	0.136	0.092087
Water 2A	2.76		
Water 2B	2.1		
Water 2C	1.88		
Water 2D	1.66		
Water 2E	1.58	1.996	0.472737
Water 3A	1.3		
Water 3B	1.1		
Water 3C	0.76		
Water 3D	1.02		
Water 3E	0.88	1.012	0.207171
Water 4A	0.8		
Water 4B	0.82		
Water 4C	0.68		
Water 4D	0.76		
Water 4E	2.7	1.152	0.867018

	02-10-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0.81666		
Water 2C	0.75752		
Water 2D	0.8146		
Water 2E	0.92424	0.662604	0.375281
Water 3A	0.78828		
Water 3B	0.69192		
Water 3C	0		
Water 3D	0.71982		
Water 3E	0.7442	0.588844	0.331069
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

Table A8: Manganese concentration in water samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0.04794		
Water 1B	0.082		
Water 1C	0.02208		
Water 1D	0.01046		
Water 1E	0.00626	0.033748	0.031479
Water 2A	0.0142		
Water 2B	0.00868		
Water 2C	0.01756		
Water 2D	0.01848		
Water 2E	0.01236	0.014256	0.003983
Water 3A	0.0008		
Water 3B	0.01928		
Water 3C	0.0027		
Water 3D	0.00746		
Water 3E	0.01128	0.008304	0.007378
Water 4A	0.00494		
Water 4B	0		
Water 4C	0.00482		
Water 4D	0.00124		
Water 4E	0.00522	0.003244	0.002439

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.12818		
Water 1B	0.08658		
Water 1C	0.14282		
Water 1D	0.1204		
Water 1E	0.15352	0.1263	0.025641
Water 2A	0.10914		
Water 2B	0.16592		
Water 2C	0.14192		
Water 2D	0.16864		
Water 2E	0.12218	0.14156	0.026237
Water 3A	0.03598		
Water 3B	0.0243		
Water 3C	0.02716		
Water 3D	0.01468		
Water 3E	0.01726	0.023876	0.008453
Water 4A	0.00808		
Water 4B	0.0086		
Water 4C	0.00414		
Water 4D	0.00014		
Water 4E	0.00688	0.005568	0.00349

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.06608		
Water 1B	0.28576		
Water 1C	0.4301		
Water 1D	0.22524		
Water 1E	0.56186	0.313808	0.19043
Water 2A	0.6166		
Water 2B	0.29366		
Water 2C	0.28834		
Water 2D	0.33104		
Water 2E	1.43262	0.592452	0.48902
Water 3A	0.01528		
Water 3B	0.00642		
Water 3C	0.01254		
Water 3D	0.01338		
Water 3E	0.02118	0.01376	0.005312
Water 4A	0.01584		
Water 4B	0.0013		
Water 4C	0.01816		
Water 4D	0.0204		
Water 4E	0.01084	0.013308	0.007592

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.05576		
Water 1B	0.05782		
Water 1C	0.1112		
Water 1D	0.10442		
Water 1E	0.08014	0.081868	0.025651
Water 2A	0.01798		
Water 2B	0.02056		
Water 2C	0.02116		
Water 2D	0.0244		
Water 2E	0.01248	0.019316	0.004453
Water 3A	0.00966		
Water 3B	0.02464		
Water 3C	0.01218		
Water 3D	0.01184		
Water 3E	0.0119	0.014044	0.006009
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	09-06-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	04-08-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.02		
Water 1B	0.04		
Water 1C	0.04		
Water 1D	0.06		
Water 1E	0.02	0.036	0.016733
Water 2A	0.1		
Water 2B	0.08		
Water 2C	0.08		
Water 2D	0.08		
Water 2E	0.08	0.084	0.008944
Water 3A	0.1		
Water 3B	0.1		
Water 3C	0.08		
Water 3D	0.1		
Water 3E	0.1	0.096	0.008944
Water 4A	0.06		
Water 4B	0.06		
Water 4C	0.06		
Water 4D	0.06		
Water 4E	0.06	0.06	0

	02-10-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.04018		
Water 1B	0.012		
Water 1C	0.01602		
Water 1D	0.01038		
Water 1E	0.01012	0.01774	0.012764
Water 2A	0.09558		
Water 2B	0.09282		
Water 2C	0.08778		
Water 2D	0.09294		
Water 2E	0.0941	0.092644	0.002938
Water 3A	0.05604		
Water 3B	0.05992		
Water 3C	0.04948		
Water 3D	0.05602		
Water 3E	0.05934	0.05616	0.00415
Water 4A	0.01352		
Water 4B	0.01746		
Water 4C	0.01284		
Water 4D	0.0151		
Water 4E	0.01736	0.015256	0.002131

**Table A9: Nickel concentration in water samples over the entire sampling period at
Kuils River (2005-2006)**

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0		
Water 1B	0		
Water 1C	0.05		
Water 1D	0.05		
Water 1E	0.05	0.03	0.027386
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0.0179		
Water 2E	0	0.00358	0.008005
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	09/06/2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	04/08/2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0.1		
Water 1E	0.05	0.03	0.044721
Water 2A	0.1		
Water 2B	0.05		
Water 2C	0.05		
Water 2D	0		
Water 2E	0.05	0.05	0.035355
Water 3A	0		
Water 3B	0.05		
Water 3C	0		
Water 3D	0		
Water 3E	0	0.01	0.022361
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0.05	0.01	0.022361

	02/10/2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

**Table A10: Zinc concentration in water samples over the entire sampling period at
Kuilis River (2005-2006)**

	07-10-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Control			
Water 1A	0.29964		
Water 1B	0.66448		
Water 1C	0.05754		
Water 1D	0.09862		
Water 1E	0.02844	0.229744	0.265166
Water 2A	0.08762		
Water 2B	0.00868		
Water 2C	0.02242		
Water 2D	0.0346		
Water 2E	0.17412	0.065488	0.067688
Water 3A	0.09674		
Water 3B	0.18952		
Water 3C	0.38688		
Water 3D	0.33556		
Water 3E	0.3167	0.26508	0.118864
Water 4A	0.52742		
Water 4B	0.2033		
Water 4C	0.37832		
Water 4D	0.44382		
Water 4E	0.14962	0.340496	0.159925

	01-12-2005		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0		
Water 1B	0		
Water 1C	0		
Water 1D	0		
Water 1E	0	0	0
Water 2A	0		
Water 2B	0		
Water 2C	0		
Water 2D	0		
Water 2E	0	0	0
Water 3A	0		
Water 3B	0		
Water 3C	0		
Water 3D	0		
Water 3E	0	0	0
Water 4A	0		
Water 4B	0		
Water 4C	0		
Water 4D	0		
Water 4E	0	0	0

	10-02-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.65816		
Water 1B	0.73656		
Water 1C	0.37484		
Water 1D	0.51116		
Water 1E	0.73838	0.60382	0.157874
Water 2A	0.65866		
Water 2B	0.49276		
Water 2C	0.37846		
Water 2D	0.49384		
Water 2E	0.5883	0.522404	0.106445
Water 3A	0.20068		
Water 3B	0.33462		
Water 3C	0.0379		
Water 3D	0.02334		
Water 3E	0.07218	0.133744	0.132285
Water 4A	0.19302		
Water 4B	0.09826		
Water 4C	0		
Water 4D	0		
Water 4E	0	0.058256	0.08652

	03-04-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.07406		
Water 1B	0.06312		
Water 1C	0.0369		
Water 1D	0.04144		
Water 1E	0.03734	0.050572	0.016989
Water 2A	0.04284		
Water 2B	0.00988		
Water 2C	0.01952		
Water 2D	0.02718		
Water 2E	0.01876	0.023636	0.012362
Water 3A	0.03724		
Water 3B	0.08174		
Water 3C	0.02422		
Water 3D	0.03454		
Water 3E	0.02584	0.040716	0.023593
Water 4A	0.11274		
Water 4B	0.11544		
Water 4C	0.05676		
Water 4D	0.0961		
Water 4E	0.05852	0.087912	0.028616

	09-06-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.32		
Water 1B	0.2		
Water 1C	0.28		
Water 1D	0.1		
Water 1E	0.06	0.192	0.111893
Water 2A	0.26		
Water 2B	0.08		
Water 2C	0.1		
Water 2D	0.02		
Water 2E	0.14	0.12	0.089443
Water 3A	0.14		
Water 3B	0.12		
Water 3C	0.06		
Water 3D	0.04		
Water 3E	0.1	0.092	0.041473
Water 4A	0.28		
Water 4B	0.06		
Water 4C	0.04		
Water 4D	0.16		
Water 4E	0.12	0.132	0.095499

	04-08-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	0.04		
Water 1B	0.08		
Water 1C	0.1		
Water 1D	0.12		
Water 1E	0.08	0.084	0.029665
Water 2A	0.12		
Water 2B	0.08		
Water 2C	0.06		
Water 2D	0.06		
Water 2E	0.04	0.072	0.030332
Water 3A	0.08		
Water 3B	0.08		
Water 3C	0.14		
Water 3D	0.08		
Water 3E	0.08	0.092	0.026833
Water 4A	0.08		
Water 4B	0.08		
Water 4C	0.18		
Water 4D	0.12		
Water 4E	0.12	0.116	0.040988

	02-10-2006		
	Conc. mg/l	Mean (ppm)	StDev (ppm)
Water 1A	3.3257		
Water 1B	0.67332		
Water 1C	1.23304		
Water 1D	0.62318		
Water 1E	0.69744	1.310536	1.153395
Water 2A	0.21436		
Water 2B	0.48706		
Water 2C	0.23074		
Water 2D	0.28244		
Water 2E	0.28	0.29892	0.109345
Water 3A	0.28282		
Water 3B	0.3021		
Water 3C	0.4905		
Water 3D	0.27502		
Water 3E	0.32614	0.335316	0.088968
Water 4A	0.28834		
Water 4B	0.49428		
Water 4C	0.60226		
Water 4D	0.62054		
Water 4E	0.62646	0.526376	0.143469

Appendix B

Table B1: Aluminium concentration in sediment samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	7645.01		
Sd 1B	7907.203		
Sd 1C	8504.413		
Sd 1D	9064.302		
Sd 1E	8869.628	8398.111	609.4242
Sd 2A	1812.994		
Sd 2B	1711.17		
Sd 2C	1456.221		
Sd 2D	1492.202		
Sd 2E	1460.413	1586.6	164.776
Sd 3A	405.8664		
Sd 3B	392.041		
Sd 3C	373.9948		
Sd 3D	373.3593		
Sd 3E	362.3212	381.5165	17.28628
Sd 4A	1235.573		
Sd 4B	1326.453		
Sd 4C	1274.7		
Sd 4D	1402.723		
Sd 4E	1272.422	1302.374	64.75917

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	9282.391		
Sd 1B	9973.157		
Sd 1C	10170.93		
Sd 1D	9449.53		
Sd 1E	10350	9845.202	461.1413
Sd 2A	4807.996		
Sd 2B	4910.287		
Sd 2C	5138.731		
Sd 2D	4632.715		
Sd 2E	4071.032	4712.152	402.4173
Sd 3A	550.0641		
Sd 3B	550.5088		
Sd 3C	516.9268		
Sd 3D	619.8087		
Sd 3E	680.5604	583.5738	65.91166
Sd 4A	3101.183		
Sd 4B	3184.504		
Sd 4C	3029.008		
Sd 4D	3467.98		
Sd 4E	3127.012	3181.938	169.3758

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	13841.22		
Sd 1B	13279.81		
Sd 1C	13235.19		
Sd 1D	14695.91		
Sd 1E	13583.57	13727.14	594.6125
Sd 2A	1986.431		
Sd 2B	1926.481		
Sd 2C	2217.587		
Sd 2D	1849.513		
Sd 2E	1970.45	1990.092	137.806
Sd 3A	408.7138		
Sd 3B	380.1114		
Sd 3C	375.3518		
Sd 3D	359.7096		
Sd 3E	420.3407	388.8455	24.96979
Sd 4A	1684.043		
Sd 4B	1592.354		
Sd 4C	1793.953		
Sd 4D	1468.703		
Sd 4E	1469.866	1601.784	140.4431

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	7035.482		
Sd 1B	8221.368		
Sd 1C	8183.015		
Sd 1D	8387.072		
Sd 1E	9077.313	8180.85	734.7936
Sd 2A	722.672		
Sd 2B	801.8622		
Sd 2C	759.431		
Sd 2D	813.2738		
Sd 2E	833.4541	786.1386	44.61955
Sd 3A	822.5246		
Sd 3B	765.2239		
Sd 3C	802.199		
Sd 3D	724.812		
Sd 3E	767.4472	776.4413	37.61464
Sd 4A	3446.925		
Sd 4B	3711.849		
Sd 4C	3689.571		
Sd 4D	3779.679		
Sd 4E	3822.979	3690.2	146.021

	09-06-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control	7261.7988		
Sd 1A	7203.8835		
Sd 1B	7343.2969		
Sd 1C	7993.505		
Sd 1D	6978.8235	7356.262	381.0673
Sd 1E	2446.9067		
Sd 2A	2419.6952		
Sd 2B	2408.9888		
Sd 2C	2252.6072		
Sd 2D	2210.102	2347.66	108.1174
Sd 2E	1308.8884		
Sd 3A	1155.9383		
Sd 3B	1125.2955		
Sd 3C	1724.2189		
Sd 3D	1025.878		
Sd 3E	4459.0781	1268.044	274.4781
Sd 4A	4487.9586		
Sd 4B	4533.7774		
Sd 4C	5155.1095		
Sd 4D	4653.4422		
Sd 4E	7261.7988	4657.873	287.6864

	04-08-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	869.15446		
Sd 1B	968.04511		
Sd 1C	880.62162		
Sd 1D	988.86414		
Sd 1E	799.27749	901.1926	77.44652
Sd 2A	491.11319		
Sd 2B	558.05581		
Sd 2C	496.05934		
Sd 2D	580.57143		
Sd 2E	464.67066	518.0941	48.90787
Sd 3A	682.78805		
Sd 3B	721.48044		
Sd 3C	795.61043		
Sd 3D	784.69363		
Sd 3E	751.84502	747.2835	46.31759
Sd 4A	1253.8737		
Sd 4B	1192.9486		
Sd 4C	1232.4115		
Sd 4D	1317.2805		
Sd 4E	1106.9418	1220.691	77.90458

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	6870.7212		
Sd 1B	7740.562		
Sd 1C	7362.7209		
Sd 1D	7859.558		
Sd 1E	8016.4997	7570.012	459.4161
Sd 2A	390.09566		
Sd 2B	391.50964		
Sd 2C	400.66374		
Sd 2D	428.35558		
Sd 2E	431.40124	408.4052	20.0466
Sd 3A	567.05777		
Sd 3B	632.92856		
Sd 3C	591.01882		
Sd 3D	669.62144		
Sd 3E	649.88426	622.1022	42.25872
Sd 4A	3201.0286		
Sd 4B	3352.5566		
Sd 4C	3161.8178		
Sd 4D	3637.5251		
Sd 4E	3567.4106	3384.068	213.1587

Table B2: Cadmium concentration in sediment samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	0.0468604		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0.0442087		
Sd 1E	0	0.018214	0.024958
Sd 2A	0		
Sd 2B	0.0447127		
Sd 2C	0		
Sd 2D	0.0465008		
Sd 2E	0	0.018243	0.024988
Sd 3A	0.0470256		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0.0487329	0.019152	0.026232
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0		
Sd 1E	0	0	0
Sd 2A	0		
Sd 2B	0.0226091		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0.004522	0.010111
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0.0231965		
Sd 4B	0.0225887		
Sd 4C	0.0223414		
Sd 4D	0		
Sd 4E	0.0226347	0.018152	0.010152

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0		
Sd 1E	0	0	0
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0		
Sd 1E	0	0	0
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	09/06/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0		
Sd 1E	0	0	0
Sd 2A	0		
Sd 2B	0		
Sd 2C	0.404494		
Sd 2D	0		
Sd 2E	0	0.0808989	0.180895
Sd 3A	0.069622		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0.0139243	0.031136
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	04/08/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0		
Sd 1E	0	0	0
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0		
Sd 1E	0	0	0
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0.116659		
Sd 2E	0	0.0233318	0.052171
Sd 3A	0		
Sd 3B	0.114129		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0.0228258	0.05104
Sd 4A	0.115314		
Sd 4B	0.116741		
Sd 4C	0.11534		
Sd 4D	0.113947		
Sd 4E	0	0.0922683	0.051589

**Table B3: Lead concentration in sediment samples over the entire sampling period
at Kuils River (2005-2006)**

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	22.0613871		
Sd 1B	22.397986		
Sd 1C	26.1466459		
Sd 1D	25.6693192		
Sd 1E	26.9656851	24.6482	2.259083
Sd 2A	31.9474961		
Sd 2B	87.5331992		
Sd 2C	46.4585132		
Sd 2D	62.4533829		
Sd 2E	112.256218	68.12976	32.15065
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	1.13999088		
Sd 3E	0	0.227998	0.509819
Sd 4A	2.66746354		
Sd 4B	3.05148795		
Sd 4C	0		
Sd 4D	4.43171402		
Sd 4E	2.65306122	2.560745	1.606135

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	14.5543478		
Sd 1B	15.6030803		
Sd 1C	15.9925011		
Sd 1D	15.1840573		
Sd 1E	16.2703349	15.52086	0.677956
Sd 2A	12.109375		
Sd 2B	10.4386163		
Sd 2C	20.0968842		
Sd 2D	10.8235294		
Sd 2E	9.02059443	12.4978	4.388375
Sd 3A	1.29761905		
Sd 3B	0		
Sd 3C	0.35978836		
Sd 3D	0		
Sd 3E	0	0.331481	0.562108
Sd 4A	6.60496405		
Sd 4B	5.96340637		
Sd 4C	9.83288651		
Sd 4D	6.60768543		
Sd 4E	6.57492078	7.116773	1.542907

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	50.218556		
Sd 1B	47.787264		
Sd 1C	47.335147		
Sd 1D	52.038857		
Sd 1E	49.548326	49.38563	1.905197
Sd 2A	28.458852		
Sd 2B	26.709872		
Sd 2C	27.826337		
Sd 2D	26.218786		
Sd 2E	30.185884	27.87995	1.56396
Sd 3A	1.1550012		
Sd 3B	3.9077715		
Sd 3C	2.6224927		
Sd 3D	1.1767475		
Sd 3E	1.1281588	1.998034	1.242874
Sd 4A	5.4951321		
Sd 4B	5.4521531		
Sd 4C	6.1753555		
Sd 4D	5.9728752		
Sd 4E	4.9871164	5.616526	0.468291

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	21.385505		
Sd 1B	24.129959		
Sd 1C	23.204058		
Sd 1D	24.219551		
Sd 1E	25.366962	23.66121	1.485672
Sd 2A	13.826999		
Sd 2B	14.302835		
Sd 2C	11.597418		
Sd 2D	11.177656		
Sd 2E	11.968	12.57458	1.399071
Sd 3A	5.6349132		
Sd 3B	5.0349813		
Sd 3C	5.0972001		
Sd 3D	1.8373357		
Sd 3E	4.1631461	4.353515	1.502235
Sd 4A	6.3809524		
Sd 4B	7.8276269		
Sd 4C	8.0555689		
Sd 4D	8.7085632		
Sd 4E	7.2063113	7.635805	0.88359

	09/06/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	18.25467		
Sd 1B	17.96117		
Sd 1C	17.39906		
Sd 1D	17.16539		
Sd 1E	16	17.356059	0.873322
Sd 2A	134.8107		
Sd 2B	113.0129		
Sd 2C	126.7416		
Sd 2D	101.9699		
Sd 2E	129.0017	121.10734	13.35674
Sd 3A	7.426317		
Sd 3B	7.252947		
Sd 3C	5.200946		
Sd 3D	6.107588		
Sd 3E	5.083179	6.2141952	1.102892
Sd 4A	4.703669		
Sd 4B	4.501463		
Sd 4C	6.184586		
Sd 4D	5.930657		
Sd 4E	6.534422	5.5709595	0.912441

	04/08/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	1.180916		
Sd 1B	1.174812		
Sd 1C	3.767365		
Sd 1D	1.113586		
Sd 1E	1.128923	1.6731205	1.171075
Sd 2A	1.169317		
Sd 2B	1.125113		
Sd 2C	1.159017		
Sd 2D	1.142857		
Sd 2E	0	0.9192608	0.514155
Sd 3A	8.060692		
Sd 3B	8.432888		
Sd 3C	9.144947		
Sd 3D	9.203197		
Sd 3E	6.457565	8.2598579	1.117043
Sd 4A	7.151371		
Sd 4B	6.761652		
Sd 4C	8.733624		
Sd 4D	7.082153		
Sd 4E	6.566604	7.2590808	0.857925

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	48.07115		
Sd 1B	52.90674		
Sd 1C	53.42629		
Sd 1D	52.6375		
Sd 1E	52.96528	52.001392	2.215314
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	4.462576		
Sd 3B	6.191281		
Sd 3C	6.395594		
Sd 3D	8.584058		
Sd 3E	14.09028	7.9447574	3.734177
Sd 4A	15.28044		
Sd 4B	14.8354		
Sd 4C	11.09481		
Sd 4D	14.80994		
Sd 4E	14.07929	14.019974	1.690994

Table B4: Cobalt concentration in sediment samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	1.8987816		
Sd 1B	1.943958		
Sd 1C	2.0944952		
Sd 1D	2.0875332		
Sd 1E	2.1737649	2.039707	0.114333
Sd 2A	0.4866534		
Sd 2B	0.421641		
Sd 2C	0.2158273		
Sd 2D	0.5231342		
Sd 2E	0	0.329451	0.219188
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0.2151566		
Sd 4B	0.212565		
Sd 4C	0		
Sd 4D	0.2062328		
Sd 4E	0.2040816	0.167607	0.093804

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	1.769348		
Sd 1B	1.945655		
Sd 1C	1.933569		
Sd 1D	1.751411		
Sd 1E	2.139761	1.907948	0.157741
Sd 2A	1.203906		
Sd 2B	0.866697		
Sd 2C	0.790812		
Sd 2D	1.035656		
Sd 2E	0.9462	0.968654	0.159969
Sd 3A	0		
Sd 3B	0		
Sd 3C	0.220459		
Sd 3D	0.22779		
Sd 3E	0.224165	0.134483	0.122793
Sd 4A	0.724843		
Sd 4B	0.725277		
Sd 4C	0.597632		
Sd 4D	0.771001		
Sd 4E	0.900996	0.74395	0.108993

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	2.314108		
Sd 1B	1.958396		
Sd 1C	1.996553		
Sd 1D	2.226194		
Sd 1E	1.84284	2.067618	0.195837
Sd 2A	0.319234		
Sd 2B	0		
Sd 2C	0.266107		
Sd 2D	0		
Sd 2E	0.29979	0.177026	0.162716
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	1.629969		
Sd 1B	1.70679		
Sd 1C	1.935315		
Sd 1D	1.665094		
Sd 1E	1.873153	1.762064	0.13441
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0.291673		
Sd 4B	0.296671		
Sd 4C	0.616575		
Sd 4D	0.532886		
Sd 4E	0	0.347561	0.241467

	09-06-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	1.224399		
Sd 1B	1.334951		
Sd 1C	1.226857		
Sd 1D	1.275806		
Sd 1E	1.294118	1.271226	0.046817
Sd 2A	0.34626		
Sd 2B	0.3517		
Sd 2C	0.786517		
Sd 2D	0.811124		
Sd 2E	0.829974	0.625115	0.252553
Sd 3A	0.348109		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0.069622	0.155679
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	04-08-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0.118092		
Sd 1B	0.117481		
Sd 1C	0.11773		
Sd 1D	0.111359		
Sd 1E	0.112892	0.115511	0.003145
Sd 2A	0.116932		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0.023386	0.052293
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0.11919		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0.023838	0.053303

	02-10-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	1.915337		
Sd 1B	2.231087		
Sd 1C	1.995836		
Sd 1D	2.00319		
Sd 1E	2.110604	2.051211	0.122185
Sd 2A	0.225889		
Sd 2B	0.396889		
Sd 2C	0.294126		
Sd 2D	0.383154		
Sd 2E	0.244102	0.308832	0.078364
Sd 3A	0.343223		
Sd 3B	0.393654		
Sd 3C	0.335888		
Sd 3D	0.554197		
Sd 3E	0.29338	0.384068	0.10155
Sd 4A	1.380673		
Sd 4B	1.61088		
Sd 4C	1.404567		
Sd 4D	1.479262		
Sd 4E	1.457883	1.466653	0.089839

**Table B5: Copper concentration in sediment samples over the entire sampling period
at Kuils River (2005-2006)**

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	7.626523		
Sd 1B	6.861646		
Sd 1C	7.912637		
Sd 1D	8.252431		
Sd 1E	8.681918	7.867031	0.686166
Sd 2A	3.045665		
Sd 2B	2.631791		
Sd 2C	2.467626		
Sd 2D	4.30179		
Sd 2E	1.958236	2.881022	0.884624
Sd 3A	0.950388		
Sd 3B	1.1794		
Sd 3C	0.299715		
Sd 3D	0.70041		
Sd 3E	0.67154	0.76029	0.329917
Sd 4A	1.611762		
Sd 4B	1.380255		
Sd 4C	0.286829		
Sd 4D	2.406508		
Sd 4E	2.13424	1.563919	0.821919

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	12.46565		
Sd 1B	3.463586		
Sd 1C	5.75386		
Sd 1D	6.625168		
Sd 1E	5.020574	6.665768	3.443563
Sd 2A	37.03585		
Sd 2B	1.246213		
Sd 2C	3.050262		
Sd 2D	2.745249		
Sd 2E	3.706815	9.556877	15.38764
Sd 3A	30.3196		
Sd 3B	2.895175		
Sd 3C	0.119048		
Sd 3D	0		
Sd 3E	0.033176	6.673399	13.27596
Sd 4A	3.395036		
Sd 4B	3.500791		
Sd 4C	3.559875		
Sd 4D	4.204647		
Sd 4E	20.19737	6.971545	7.400259

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	15.0373		
Sd 1B	13.99811		
Sd 1C	14.52018		
Sd 1D	15.37966		
Sd 1E	14.28734	14.64452	0.560264
Sd 2A	6.210526		
Sd 2B	7.089895		
Sd 2C	9.852722		
Sd 2D	7.660743		
Sd 2E	10.18728	8.200234	1.743697
Sd 3A	2.086856		
Sd 3B	10.33942		
Sd 3C	3.250394		
Sd 3D	2.073429		
Sd 3E	2.405686	4.031157	3.558754
Sd 4A	3.017153		
Sd 4B	3.249761		
Sd 4C	4.492891		
Sd 4D	6.278481		
Sd 4E	4.262825	4.260222	1.293615

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	5.815918		
Sd 1B	5.160866		
Sd 1C	4.270347		
Sd 1D	11.44749		
Sd 1E	4.698542	6.278633	2.945782
Sd 2A	0.181861		
Sd 2B	0		
Sd 2C	0.292613		
Sd 2D	7.425366		
Sd 2E	12.62824	4.105615	5.710664
Sd 3A	2.228531		
Sd 3B	0.318097		
Sd 3C	2.763032		
Sd 3D	0		
Sd 3E	4.19236	1.900404	1.747862
Sd 4A	2.273516		
Sd 4B	2.490201		
Sd 4C	4.489102		
Sd 4D	3.519309		
Sd 4E	3.587377	3.271901	0.901407

	09-06-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	6.233304		
Sd 1B	2.912621		
Sd 1C	1.784519		
Sd 1D	2.319647		
Sd 1E	1.882353	3.026489	1.847146
Sd 2A	25.39243		
Sd 2B	8.440797		
Sd 2C	18.42697		
Sd 2D	109.8494		
Sd 2E	6.639791	33.74987	43.21827
Sd 3A	0		
Sd 3B	0.453309		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0.462107	0.183083	0.250716
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	04-08-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0		
Sd 1E	1.806277	0.361255	0.807792
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0.914286		
Sd 2E	0.479042	0.278666	0.411439
Sd 3A	3.793267		
Sd 3B	2.342469		
Sd 3C	3.657979		
Sd 3D	1.453136		
Sd 3E	2.767528	2.802876	0.967871
Sd 4A	1.907032		
Sd 4B	2.414876		
Sd 4C	2.911208		
Sd 4D	2.360718		
Sd 4E	0.938086	2.106384	0.743683

	02-10-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	11.80529		
Sd 1B	13.66028		
Sd 1C	12.30211		
Sd 1D	13.04352		
Sd 1E	16.04661	13.37156	1.654071
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	1.520342		
Sd 3B	1.199726		
Sd 3C	1.198715		
Sd 3D	2.959323		
Sd 3E	1.235185	1.622658	0.759256
Sd 4A	7.377306		
Sd 4B	8.398786		
Sd 4C	7.151557		
Sd 4D	7.847311		
Sd 4E	7.452337	7.645459	0.490252

Table B6: Chromium concentration in sediment samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	9.837863		
Sd 1B	9.020578		
Sd 1C	10.85001		
Sd 1D	10.04553		
Sd 1E	11.47968	10.24673	0.948052
Sd 2A	6.053386		
Sd 2B	3.205008		
Sd 2C	3.553957		
Sd 2D	4.55057		
Sd 2E	1.639137	3.800411	1.637451
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0.08941		
Sd 4B	1.332074		
Sd 4C	0		
Sd 4D	0.95967		
Sd 4E	1.195465	0.715324	0.627311

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	7.700304		
Sd 1B	7.643652		
Sd 1C	7.94067		
Sd 1D	6.987192		
Sd 1E	7.757751	7.605914	0.36341
Sd 2A	2.125873		
Sd 2B	6.919602		
Sd 2C	2.524176		
Sd 2D	2.650769		
Sd 2E	2.010172	3.246118	2.070787
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	2.653909		
Sd 4B	2.010075		
Sd 4C	1.740572		
Sd 4D	2.747364		
Sd 4E	2.355093	2.301402	0.42586

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	16.15581		
Sd 1B	15.21981		
Sd 1C	14.63315		
Sd 1D	18.70459		
Sd 1E	15.65538	16.07375	1.573821
Sd 2A	0		
Sd 2B	0		
Sd 2C	0.527561		
Sd 2D	0		
Sd 2E	0	0.105512	0.235932
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	8.127168		
Sd 1B	9.847262		
Sd 1C	9.485397		
Sd 1D	9.188523		
Sd 1E	10.28186	9.386041	0.813765
Sd 2A	2.661506		
Sd 2B	0.8295		
Sd 2C	0.943342		
Sd 2D	1.174451		
Sd 2E	0.341788	1.190117	0.876903
Sd 3A	0.436649		
Sd 3B	0.330364		
Sd 3C	1.58188		
Sd 3D	0		
Sd 3E	0	0.469779	0.651669
Sd 4A	3.846587		
Sd 4B	4.390272		
Sd 4C	4.35588		
Sd 4D	7.267882		
Sd 4E	5.716137	5.115351	1.388041

	09-06-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	9.349955		
Sd 1B	9.708738		
Sd 1C	8.922596		
Sd 1D	9.742519		
Sd 1E	8	9.144762	0.720646
Sd 2A	9.695291		
Sd 2B	6.565064		
Sd 2C	14.83146		
Sd 2D	5.098494		
Sd 2E	7.114062	8.660874	3.828242
Sd 3A	1.392434		
Sd 3B	1.813237		
Sd 3C	0.945626		
Sd 3D	2.349072		
Sd 3E	0.924214	1.484917	0.605874
Sd 4A	3.762935		
Sd 4B	3.60117		
Sd 4C	3.330162		
Sd 4D	4.105839		
Sd 4E	4.2007	3.800161	0.35908

	04-08-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	2.361833		
Sd 1B	2.349624		
Sd 1C	2.825524		
Sd 1D	2.672606		
Sd 1E	1.806277	2.403173	0.3911
Sd 2A	1.403181		
Sd 2B	2.250225		
Sd 2C	1.854427		
Sd 2D	2.285714		
Sd 2E	0.958084	1.750326	0.569108
Sd 3A	2.84495		
Sd 3B	2.810963		
Sd 3C	3.200732		
Sd 3D	3.390651		
Sd 3E	3.228782	3.095216	0.254798
Sd 4A	3.814064		
Sd 4B	3.863801		
Sd 4C	3.881611		
Sd 4D	4.249292		
Sd 4E	3.752345	3.912223	0.194996

	02-10-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	13.38976		
Sd 1B	17.4958		
Sd 1C	14.68129		
Sd 1D	16.7635		
Sd 1E	17.99333	16.06474	1.957366
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0.391324		
Sd 3B	1.180735		
Sd 3C	0.63855		
Sd 3D	1.21566		
Sd 3E	0.310093	0.747272	0.429221
Sd 4A	8.341697		
Sd 4B	8.422227		
Sd 4C	8.321569		
Sd 4D	8.81381		
Sd 4E	7.855958	8.351052	0.341059

**Table B7: Iron concentration in sediment samples over the entire sampling period
at Kuils River (2005-2006)**

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	5349.0628		
Sd 1B	5159.7636		
Sd 1C	5823.4009		
Sd 1D	5794.6065		
Sd 1E	5835.4344	5592.454	316.1099
Sd 2A	1896.8718		
Sd 2B	2161.0955		
Sd 2C	2768.3453		
Sd 2D	2058.4841		
Sd 2E	1422.2947	2061.418	486.1184
Sd 3A	692.24077		
Sd 3B	652.74103		
Sd 3C	695.94672		
Sd 3D	623.18741		
Sd 3E	655.02437	663.8281	30.37672
Sd 4A	1134.1669		
Sd 4B	1155.7723		
Sd 4C	1013.0656		
Sd 4D	1203.6893		
Sd 4E	1127.3515	1126.809	70.25211

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	4260.6548		
Sd 1B	4331.589		
Sd 1C	4248.1279		
Sd 1D	3947.5844		
Sd 1E	4276.3091	4212.853	151.6754
Sd 2A	1684.0469		
Sd 2B	1693.9254		
Sd 2C	1670.9966		
Sd 2D	1644.9122		
Sd 2E	1597.3573	1658.248	38.68627
Sd 3A	747.42949		
Sd 3B	578.87105		
Sd 3C	489.94974		
Sd 3D	673.75672		
Sd 3E	806.93835	659.3891	127.3982
Sd 4A	1997.7945		
Sd 4B	1982.5507		
Sd 4C	1897.9249		
Sd 4D	2178.5773		
Sd 4E	2060.1023	2023.39	104.2777

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	11052.649		
Sd 1B	10558.061		
Sd 1C	10545.074		
Sd 1D	11601.092		
Sd 1E	10741.861	10899.75	442.3613
Sd 2A	1862.588		
Sd 2B	1787.8137		
Sd 2C	2048.6395		
Sd 2D	1768.4833		
Sd 2E	2011.2364	1895.752	128.1201
Sd 3A	345.9039		
Sd 3B	439.11002		
Sd 3C	288.89295		
Sd 3D	282.10826		
Sd 3E	396.94901	350.5928	68.01321
Sd 4A	1030.7738		
Sd 4B	990.86555		
Sd 4C	1072.3597		
Sd 4D	988.36302		
Sd 4E	963.86929	1009.246	42.66079

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	4916.2637		
Sd 1B	5606.1704		
Sd 1C	5452.6431		
Sd 1D	5380.0758		
Sd 1E	5641.6816	5399.367	290.7247
Sd 2A	570.1315		
Sd 2B	588.86702		
Sd 2C	665.74086		
Sd 2D	605.20467		
Sd 2E	597.88565	605.5659	36.10606
Sd 3A	1228.4782		
Sd 3B	1172.2514		
Sd 3C	1233.2015		
Sd 3D	994.30766		
Sd 3E	1250.0346	1175.655	105.5138
Sd 4A	2244.2867		
Sd 4B	2422.459		
Sd 4C	2434.1734		
Sd 4D	2729.5932		
Sd 4E	2624.4882	2491	189.4336

	09-06-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	5476.402		
Sd 1B	5757.767		
Sd 1C	5240.241		
Sd 1D	5130.596		
Sd 1E	5277.176	5376.437	247.106
Sd 2A	5006.002		
Sd 2B	5057.444		
Sd 2C	5082.247		
Sd 2D	4608.575		
Sd 2E	4855.585	4921.971	196.0402
Sd 3A	2078.905		
Sd 3B	1878.06		
Sd 3C	2024.586		
Sd 3D	2124.971		
Sd 3E	1868.762	1995.057	116.6392
Sd 4A	2586.077		
Sd 4B	2805.312		
Sd 4C	2988.582		
Sd 4D	3238.139		
Sd 4E	3002.567	2924.135	243.57

	04-08-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	1411.904		
Sd 1B	1445.489		
Sd 1C	1385.919		
Sd 1D	1437.862		
Sd 1E	1221.495	1380.534	91.94042
Sd 2A	825.5379		
Sd 2B	914.9415		
Sd 2C	825.6838		
Sd 2D	878.1714		
Sd 2E	746.3473	838.1364	63.7198
Sd 3A	985.7752		
Sd 3B	995.5493		
Sd 3C	1090.992		
Sd 3D	1052.555		
Sd 3E	1102.86	1045.546	53.5527
Sd 4A	1232.896		
Sd 4B	1194.88		
Sd 4C	1209.122		
Sd 4D	1265.817		
Sd 4E	1092.402	1199.023	65.37603

	02-10-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	8698.462		
Sd 1B	9703.656		
Sd 1C	8758.509		
Sd 1D	9395.443		
Sd 1E	9560.242	9223.262	465.1321
Sd 2A	643.9667		
Sd 2B	589.863		
Sd 2C	735.7817		
Sd 2D	784.8483		
Sd 2E	664.4056	683.7731	76.97379
Sd 3A	861.4385		
Sd 3B	952.2986		
Sd 3C	918.4993		
Sd 3D	996.3978		
Sd 3E	937.5417	933.2352	49.35429
Sd 4A	3355.438		
Sd 4B	3597.189		
Sd 4C	3332.489		
Sd 4D	3602.571		
Sd 4E	3652.896	3508.117	151.6347

Table B8: Manganese concentration in sediment samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	56.394096		
Sd 1B	52.584501		
Sd 1C	60.052151		
Sd 1D	57.999558		
Sd 1E	57.883183	56.9827	2.781951
Sd 2A	25.869402		
Sd 2B	25.588196		
Sd 2C	26.740048		
Sd 2D	26.25808		
Sd 2E	23.033787	25.4979	1.443851
Sd 3A	7.6557724		
Sd 3B	8.2016109		
Sd 3C	7.7716461		
Sd 3D	7.8504332		
Sd 3E	7.6101365	7.81792	0.234458
Sd 4A	6.3825006		
Sd 4B	6.4237128		
Sd 4C	5.4414869		
Sd 4D	7.2131072		
Sd 4E	6.4312925	6.37842	0.628373

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	36.743913		
Sd 1B	38.737514		
Sd 1C	39.17071		
Sd 1D	36.394089		
Sd 1E	39.693301	38.14791	1.485689
Sd 2A	9.3690257		
Sd 2B	21.522496		
Sd 2C	10.432568		
Sd 2D	9.3886878		
Sd 2E	8.3454508	11.81165	5.47846
Sd 3A	3.5970696		
Sd 3B	2.9605263		
Sd 3C	2.2173721		
Sd 3D	5.1685649		
Sd 3E	4.5057162	3.68985	1.179083
Sd 4A	13.116214		
Sd 4B	12.47391		
Sd 4C	11.797587		
Sd 4D	13.836908		
Sd 4E	12.489362	12.7428	0.769167

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	99.075562		
Sd 1B	93.978302		
Sd 1C	94.41542		
Sd 1D	104.91611		
Sd 1E	96.743291	97.82574	4.456462
Sd 2A	70.258373		
Sd 2B	61.747735		
Sd 2C	73.063564		
Sd 2D	60.141242		
Sd 2E	70.520382	67.14626	5.794368
Sd 3A	2.2111342		
Sd 3B	0.7879213		
Sd 3C	0.9655172		
Sd 3D	1.25253		
Sd 3E	1.357852	1.314991	0.549715
Sd 4A	5.5057951		
Sd 4B	5.3818182		
Sd 4C	5.671564		
Sd 4D	5.1699819		
Sd 4E	5.1304755	5.371927	0.227421

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	67.641174		
Sd 1B	77.057678		
Sd 1C	73.500354		
Sd 1D	71.354502		
Sd 1E	77.261774	73.3631	4.051028
Sd 2A	8.9265563		
Sd 2B	10.472459		
Sd 2C	10.126225		
Sd 2D	10.02152		
Sd 2E	10.168471	9.943046	0.592465
Sd 3A	4.4603473		
Sd 3B	4.369403		
Sd 3C	4.713863		
Sd 3D	4.2695967		
Sd 3E	3.9285393	4.34835	0.286805
Sd 4A	13.289233		
Sd 4B	13.806375		
Sd 4C	14.070419		
Sd 4D	15.424802		
Sd 4E	14.862061	14.29058	0.851274

	09/06/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	70.34728		
Sd 1B	74.75728		
Sd 1C	68.70399		
Sd 1D	69.12549		
Sd 1E	66.35294	69.857399	3.098229
Sd 2A	55.40166		
Sd 2B	43.61079		
Sd 2C	36.40449		
Sd 2D	35.68946		
Sd 2E	44.58146	43.137571	7.961241
Sd 3A	6.498027		
Sd 3B	5.893019		
Sd 3C	6.619385		
Sd 3D	7.047216		
Sd 3E	5.545287	6.3205869	0.598469
Sd 4A	9.407338		
Sd 4B	9.903219		
Sd 4C	10.94196		
Sd 4D	12.31752		
Sd 4E	10.26838	10.567683	1.126888

	04/08/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	17.47756		
Sd 1B	18.79699		
Sd 1C	17.89498		
Sd 1D	19.15367		
Sd 1E	16.25649	17.915941	1.146148
Sd 2A	3.274088		
Sd 2B	4.050405		
Sd 2C	2.781641		
Sd 2D	3.657143		
Sd 2E	2.874251	3.3275057	0.533269
Sd 3A	7.112376		
Sd 3B	8.432888		
Sd 3C	8.6877		
Sd 3D	8.234439		
Sd 3E	7.841328	8.0617463	0.614263
Sd 4A	16.20977		
Sd 4B	14.97223		
Sd 4C	15.04124		
Sd 4D	15.58074		
Sd 4E	13.60225	15.081247	0.96488

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	90.12788		
Sd 1B	97.48172		
Sd 1C	86.04164		
Sd 1D	93.97311		
Sd 1E	97.20392	92.965654	4.882818
Sd 2A	5.086441		
Sd 2B	8.052937		
Sd 2C	5.492137		
Sd 2D	6.136258		
Sd 2E	5.417337	6.0370221	1.189356
Sd 3A	8.297595		
Sd 3B	9.975805		
Sd 3C	10.10509		
Sd 3D	10.52716		
Sd 3E	9.613889	9.703908	0.85124
Sd 4A	23.71079		
Sd 4B	25.80341		
Sd 4C	23.00946		
Sd 4D	24.56016		
Sd 4E	24.12191	24.241146	1.04343

Table B9: Nickel concentration in sediments samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	2.4582943		
Sd 1B	2.6007005		
Sd 1C	3.8315133		
Sd 1D	1.8465959		
Sd 1E	3.239231	2.795267	0.761954
Sd 2A	3.2097948		
Sd 2B	0.8419405		
Sd 2C	0.0944844		
Sd 2D	0.3501511		
Sd 2E	0.7311122	1.045497	1.246233
Sd 3A	0.9000705		
Sd 3B	0.4222602		
Sd 3C	0.4828735		
Sd 3D	0		
Sd 3E	0	0.361041	0.37744
Sd 4A	0.0635907		
Sd 4B	0		
Sd 4C	0.1156494		
Sd 4D	0		
Sd 4E	1.155102	0.266868	0.498895

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	0		
Sd 1C	0		
Sd 1D	0		
Sd 1E	1.331579	0.266316	0.5955
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0		
Sd 4E	0	0	0

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	2.601148		
Sd 1B	2.810849		
Sd 1C	1.360544		
Sd 1D	6.300343		
Sd 1E	2.078366	3.03025	1.911791
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0		
Sd 3B	0		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0	0
Sd 4A	0		
Sd 4B	0		
Sd 4C	0		
Sd 4D	0.594033		
Sd 4E	0	0.118807	0.265659

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	2.121387		
Sd 1B	4.693113		
Sd 1C	2.871432		
Sd 1D	2.988433		
Sd 1E	4.048291	3.344531	1.019885
Sd 2A	0.548846		
Sd 2B	1.163863		
Sd 2C	1.621324		
Sd 2D	0.585623		
Sd 2E	1.002824	0.984496	0.443551
Sd 3A	0		
Sd 3B	1.646922		
Sd 3C	2.626451		
Sd 3D	0.060263		
Sd 3E	2.93573	1.453873	1.384197
Sd 4A	2.585034		
Sd 4B	1.106966		
Sd 4C	0.915449		
Sd 4D	4.57088		
Sd 4E	3.52809	2.541284	1.564894

	09/06/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	0		
Sd 1B	2.4271845		
Sd 1C	1.3383895		
Sd 1D	1.3917884		
Sd 1E	0	1.031472	1.036811
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0		
Sd 3B	0.4533092		
Sd 3C	0		
Sd 3D	1.4094433		
Sd 3E	0.4621072	0.464972	0.575449
Sd 4A	1.4111007		
Sd 4B	0.4501463		
Sd 4C	0		
Sd 4D	0.4562044		
Sd 4E	1.4002334	0.743537	0.632135

	04/08/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	3.3065659		
Sd 1B	1.174812		
Sd 1C	4.2382858		
Sd 1D	1.1135857		
Sd 1E	0	1.96665	1.74486
Sd 2A	0		
Sd 2B	3.150315		
Sd 2C	3.245248		
Sd 2D	1.1428571		
Sd 2E	1.1976048	1.747205	1.408268
Sd 3A	3.793267		
Sd 3B	4.2164441		
Sd 3C	3.657979		
Sd 3D	4.3594091		
Sd 3E	3.6900369	3.943427	0.322418
Sd 4A	4.2908224		
Sd 4B	5.7957015		
Sd 4C	4.3668122		
Sd 4D	3.7771483		
Sd 4E	3.2833021	4.302757	0.941897

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	1.2019231		
Sd 1B	3.7851281		
Sd 1C	1.08061		
Sd 1D	5.4741399		
Sd 1E	4.9014216	3.288645	2.052666
Sd 2A	0		
Sd 2B	0		
Sd 2C	0		
Sd 2D	0		
Sd 2E	0	0	0
Sd 3A	0		
Sd 3B	2.2958229		
Sd 3C	0		
Sd 3D	0		
Sd 3E	0	0.459165	1.026723
Sd 4A	0		
Sd 4B	0		
Sd 4C	2.3312572		
Sd 4D	0		
Sd 4E	0	0.466251	1.04257

**Table B10: Zinc concentration in sediment samples over the entire sampling period
at Kuils River (2005-2006)**

	07-10-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control			
Sd 1A	62.679475		
Sd 1B	58.409807		
Sd 1C	66.819701		
Sd 1D	62.906278		
Sd 1E	97.295206	69.62209	15.75335
Sd 2A	16.377234		
Sd 2B	16.755645		
Sd 2C	23.664269		
Sd 2D	13.521507		
Sd 2E	13.098545	16.68344	4.233209
Sd 3A	11.455913		
Sd 3B	13.271662		
Sd 3C	9.2683159		
Sd 3D	17.060192		
Sd 3E	11.458577	12.50293	2.915872
Sd 4A	15.371265		
Sd 4B	15.010864		
Sd 4C	12.824231		
Sd 4D	16.017874		
Sd 4E	21.386848	16.12222	3.178167

	01-12-2005		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	59.542174		
Sd 1B	35.510231		
Sd 1C	34.7618		
Sd 1D	32.900582		
Sd 1E	34.300478	39.40305	11.29821
Sd 2A	12.767463		
Sd 2B	11.219986		
Sd 2C	12.492609		
Sd 2D	10.169231		
Sd 2E	40.769621	17.48378	13.05875
Sd 3A	9.0769231		
Sd 3B	8.0578947		
Sd 3C	6.4021164		
Sd 3D	8.7685649		
Sd 3E	8.7182246	8.204745	1.073928
Sd 4A	36.463929		
Sd 4B	33.141631		
Sd 4C	35.596068		
Sd 4D	37.387846		
Sd 4E	40.189226	36.55574	2.572944

	10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	122.62554		
Sd 1B	117.36651		
Sd 1C	116.12472		
Sd 1D	128.40137		
Sd 1E	118.62693	120.629	4.983388
Sd 2A	27.57512		
Sd 2B	25.894077		
Sd 2C	38.741185		
Sd 2D	29.354258		
Sd 2E	51.554158	34.62376	10.6917
Sd 3A	8.7193347		
Sd 3B	10.524813		
Sd 3C	7.2643678		
Sd 3D	6.5737821		
Sd 3E	6.2459386	7.865647	1.764501
Sd 4A	31.592953		
Sd 4B	30.635885		
Sd 4C	31.081991		
Sd 4D	29.840868		
Sd 4E	28.732256	30.37679	1.121962

	03-04-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	50.55047		
Sd 1B	56.29302		
Sd 1C	53.0309		
Sd 1D	51.96689		
Sd 1E	54.68802	53.30586	2.25245
Sd 2A	10.63605		
Sd 2B	9.239917		
Sd 2C	9.812097		
Sd 2D	9.265568		
Sd 2E	9.646118	9.719949	0.567906
Sd 3A	27.84327		
Sd 3B	30.65019		
Sd 3C	30.16617		
Sd 3D	26.12188		
Sd 3E	24.67191	27.89068	2.563402
Sd 4A	45.66925		
Sd 4B	46.26635		
Sd 4C	51.29581		
Sd 4D	49.93332		
Sd 4E	49.3531	48.50356	2.429043

	09/06/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	40.07124		
Sd 1B	41.26214		
Sd 1C	38.36716		
Sd 1D	38.04222		
Sd 1E	40.94118	39.736787	1.469399
Sd 2A	102.9548		
Sd 2B	87.6905		
Sd 2C	64.7191		
Sd 2D	79.7219		
Sd 2E	64.02656	79.822564	16.39086
Sd 3A	34.34672		
Sd 3B	30.37171		
Sd 3C	33.56974		
Sd 3D	33.35682		
Sd 3E	27.26433	31.781864	2.943304
Sd 4A	19.75541		
Sd 4B	21.60702		
Sd 4C	25.68982		
Sd 4D	25.54745		
Sd 4E	23.80397	23.280733	2.571219

	04/08/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	8.502598		
Sd 1B	7.048872		
Sd 1C	4.709206		
Sd 1D	5.790646		
Sd 1E	4.064123	6.0230891	1.790116
Sd 2A	4.209542		
Sd 2B	2.70027		
Sd 2C	3.245248		
Sd 2D	5.028571		
Sd 2E	3.832335	3.8031933	0.893765
Sd 3A	32.24277		
Sd 3B	35.60553		
Sd 3C	37.49428		
Sd 3D	35.84403		
Sd 3E	36.43911	35.525145	1.974525
Sd 4A	31.94279		
Sd 4B	31.87636		
Sd 4C	31.53809		
Sd 4D	30.21719		
Sd 4E	27.2045	30.555785	1.998647

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Sd 1A	120.5231		
Sd 1B	131.2365		
Sd 1C	133.206		
Sd 1D	126.7318		
Sd 1E	136.0466	129.54881	6.079556
Sd 2A	3.132075		
Sd 2B	2.788484		
Sd 2C	3.289547		
Sd 2D	3.236118		
Sd 2E	3.726834	3.2346115	0.337212
Sd 3A	22.54439		
Sd 3B	25.65624		
Sd 3C	25.10326		
Sd 3D	29.21655		
Sd 3E	25.53657	25.611404	2.380624
Sd 4A	74.15452		
Sd 4B	77.29255		
Sd 4C	70.87797		
Sd 4D	75.7639		
Sd 4E	73.05087	74.227963	2.468006

Appendix C

Table C1: Aluminium concentration in snails samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005		StDev (ppm)
	Conc mg/kg	Mean (ppm)	
Control			
Snail 1A	1335.872611		
Snail 1B	1854.854167		
Snail 1C	1568.135922		
Snail 1D	1557.857143		
Snail 1E	1651.037736		
Snail 1F	1661.589744	1604.891	169.5641
Snail 2A	1307.818182		
Snail 2B	1883.142857		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	1595.481	406.816
Snail 3A	2252.721649		
Snail 3B	1511.238095		
Snail 3C	1322.835681		
Snail 3D	1371.58209		
Snail 3E	1249.324324		
Snail 3F	1239.45614	1491.193	385.9665
Snail 4A	1235.192488		
Snail 4B	1075.096386		
Snail 4C	1376.259542		
Snail 4D	983.7829912		
Snail 4E	1325.307692		
Snail 4F	1463.117647	1243.126	183.5377

	01-12-2005		StDev (ppm)
	Conc mg/kg	Mean (ppm)	
Snail 1A	1340.585		
Snail 1B	1853.358		
Snail 1C	946.6471		
Snail 1D	1216.396		
Snail 1E	1089.958		
Snail 1F	3683.41	1688.392	1025.609
Snail 2A	680.8571		
Snail 2B	1037.459		
Snail 2C	853.9608		
Snail 2D	1205.081		
Snail 2E	771.3285		
Snail 2F	1185.638	955.7208	219.8315
Snail 3A	669.037		
Snail 3B	637.0081		
Snail 3C	752.2105		
Snail 3D	1016.45		
Snail 3E	944.4526		
Snail 3F	775.0857	799.0407	151.2176
Snail 4A	1617.821		
Snail 4B	2165.031		
Snail 4C	1399.228		
Snail 4D	859.4961		
Snail 4E	836.2718		
Snail 4F	1278.434	1359.38	499.5062

	10-02-2006		StDev (ppm)
	Conc mg/kg	Mean (ppm)	
Snail 1A	958.3407		
Snail 1B	1756.79		
Snail 1C	929.9408		
Snail 1D	2301.333		
Snail 1E	1581.356		
Snail 1F	184.8727	1285.439	746.5117
Snail 2A			
Snail 2B			
Snail 2C			
Snail 2D			
Snail 2E			
Snail 2F			
Snail 3A	192.381		
Snail 3B	476.6275		
Snail 3C	504.7727		
Snail 3D	221.542		
Snail 3E	0		
Snail 3F	264.2326	276.5926	189.1341
Snail 4A	707.1807		
Snail 4B	886.1915		
Snail 4C	1299.831		
Snail 4D	2053		
Snail 4E	880.5811		
Snail 4F	1418.552	1207.556	495.6556

		03/04/2006					
		Conc mg/kg	Mean (ppm)	StDev (ppm)			
Snail 1A		915.39535					
Snail 1B		1931.1406					
Snail 1C		1995.2295					
Snail 1D		2051.4455					
Snail 1E		1800.7451					
Snail 1F		1956.375	1775.055	429.3676			
Snail 2A							
Snail 2B							
Snail 2C							
Snail 2D							
Snail 2E							
Snail 2F							
Snail 3A		1304.6063					
Snail 3B		1182.7204					
Snail 3C		963.11258					
Snail 3D		835.76768					
Snail 3E		1422.9126					
Snail 3F		1149.687	1143.134	215.7967			
Snail 4A		1406.7246					
Snail 4B		1248.8923					
Snail 4C		1388.3412					
Snail 4D		1554.6271					
Snail 4E		1276.4058					
Snail 4F		1418.7213	1382.285	110.1521			

		09/06/2006					
		Conc mg/kg	Mean (ppm)	StDev (ppm)			
Snail 1A		1450.7772					
Snail 1B		1809.9548					
Snail 1C		1551.7241					
Snail 1D		1257.1429					
Snail 1E		2264.1509					
Snail 1F		1766.7845	1683.422	350.2536			
Snail 2A		863.30935					
Snail 2B		2000					
Snail 2C		1666.6667					
Snail 2D		0					
Snail 2E		0					
Snail 2F		0	754.996	905.8661			
Snail 3A		1363.6364					
Snail 3B		1879.1946					
Snail 3C		2222.2222					
Snail 3D		1655.1724					
Snail 3E		1562.5					
Snail 3F		1739.1304	1736.976	294.0105			
Snail 4A		1944.4444					
Snail 4B		2162.1622					
Snail 4C		1896.5517					
Snail 4D		1792.4528					
Snail 4E		1584.1584					
Snail 4F		2040.8163	1903.431	200.8965			

		04/08/2006					
		Conc mg/kg	Mean (ppm)	StDev (ppm)			
Snail 1A		1454.5455					
Snail 1B		1212.1212					
Snail 1C		1171.1712					
Snail 1D		1265.8228					
Snail 1E		1781.3765					
Snail 1F		1443.299	1388.056	225.879			
Snail 2A		0					
Snail 2B		0					
Snail 2C		0					
Snail 2D		0					
Snail 2E		0					
Snail 2F		0	0	0			
Snail 3A		1124.2604					
Snail 3B		2352.9412					
Snail 3C		961.53846					
Snail 3D		1538.4615					
Snail 3E		2083.3333					
Snail 3F		1538.4615	1599.833	537.0413			
Snail 4A		1829.2683					
Snail 4B		1350.211					
Snail 4C		2385.3211					
Snail 4D		1621.6216					
Snail 4E		1914.8936					
Snail 4F		1833.3333	1822.441	343.184			

	02/10/2006		
	Conc mg/kg	Mean (ppm)	StDev (ppm)
Snail 1A	0		
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0	0
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	1035.3697		
Snail 4B	0		
Snail 4C	335.04862		
Snail 4D	3.5010101		
Snail 4E	829.38933		
Snail 4F	0	367.2181	461.097

Table C2: Cadmium concentration in snails samples over the entire sampling period at Kuils River (2005-2006).

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	0			0			0		
Snail 1B	0			0			0		
Snail 1C	0			0.7352941			0		
Snail 1D	2.3809524			0			0		
Snail 1E	0			0.7042254			0		
Snail 1F	0	0.396825	0.97202	0.952381	0.39865	0.444992	0	0	0
Snail 2A	0			0					
Snail 2B	0	0	0	0					
Snail 2C				0					
Snail 2D				0					
Snail 2E				0					
Snail 2F				0	0	0		0	0
Snail 3A	0			0			0		
Snail 3B	0			0			0		
Snail 3C	0			1.0526316			0		
Snail 3D	0			0			0		
Snail 3E	2.7027027			0			0		
Snail 3F	0	0.45045	1.103374	0.952381	0.334169	0.518662	2.3255814	0	0
Snail 4A	0			0			0		
Snail 4B	1.2048193			0			0.5319149		
Snail 4C	0			0			1.6949153		
Snail 4D	0			0			0.4385965		
Snail 4E	0			0			0.6756757		
Snail 4F	0	0.200803	0.491865	0	0	0	0.2531646	0	0

	03-04-2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	0.7751938		
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0.9803922		
Snail 1F	0	0.292598	0
Snail 2A			
Snail 2B			
Snail 2C			
Snail 2D			
Snail 2E			
Snail 2F			
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	0	0

	09/06/2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A			
Snail 1B			
Snail 1C			
Snail 1D			
Snail 1E			
Snail 1F	0	0	0
Snail 2A			
Snail 2B			
Snail 2C			
Snail 2D			
Snail 2E			
Snail 2F	0	0	0
Snail 3A			
Snail 3B			
Snail 3C			
Snail 3D			
Snail 3E			
Snail 3F	0	0	0
Snail 4A			
Snail 4B			
Snail 4C			
Snail 4D			
Snail 4E			
Snail 4F	0	0	0

	04/08/2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	0		
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0	0
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	0	0

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StdDev (ppm)
Snail 1A	0		
Snail 1B	0		
Snail 1C	4.901961		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0.8169935	2.001217
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	5.050505		
Snail 4E	0		
Snail 4F	0	0.8417508	2.06186

Table C3: Lead concentration in snails samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	0			0			0		
Snail 1B	0			0			24.39024		
Snail 1C	0			0			29.5858		
Snail 1D	0			0			0		
Snail 1E	0			0			84.74576		
Snail 1F	64.102564	10.68376	26.16976	0	0	0	0	23.1203	32.99927
Snail 2A	0			0			0		
Snail 2B	0	0	0	0			0		
Snail 2C				0			0		
Snail 2D				0			0		
Snail 2E				0			0		
Snail 2F				0	0	0	0	0	0
Snail 3A	0			0			0		
Snail 3B	0			0			0		
Snail 3C	0			0			0		
Snail 3D	0			0			0		
Snail 3E	0			0			0		
Snail 3F	0	0	0	0	0	0	0	0	0
Snail 4A	0			0			60.24096		
Snail 4B	0			0			26.59574		
Snail 4C	0			0			84.74576		
Snail 4D	0			0			84.07895		
Snail 4E	0			0			33.78378		
Snail 4F	0	0	0	0	0	0	12.65823	50.35057	30.5873

	03-04-2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	0			
Snail 1B	0			
Snail 1C	0			
Snail 1D	0			
Snail 1E	0			
Snail 1F	0	0	0	
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0			
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	0			
Snail 3E	0			
Snail 3F	0	0	0	
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	0			
Snail 4E	0			
Snail 4F	0	0	0	

	09/06/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	31.08808			
Snail 1B	27.14932			
Snail 1C	0			
Snail 1D	68.57143			
Snail 1E	0			
Snail 1F	0	21.134805	27.29658	
Snail 2A	129.4964			
Snail 2B	150			
Snail 2C	100			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	63.2494	71.08642	
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	110.3448			
Snail 3E	0			
Snail 3F	0	18.390805	45.04809	
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	28.30189			
Snail 4E	0			
Snail 4F	0	4.7169811	11.5542	

	04/08/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A				
Snail 1B				
Snail 1C				
Snail 1D				
Snail 1E				
Snail 1F	0	0	0	
Snail 2A				
Snail 2B				
Snail 2C				
Snail 2D				
Snail 2E				
Snail 2F	0	0	0	
Snail 3A				
Snail 3B				
Snail 3C				
Snail 3D				
Snail 3E				
Snail 3F	0	0	0	
Snail 4A				
Snail 4B				
Snail 4C				
Snail 4D				
Snail 4E				
Snail 4F	0	0	0	

	02/10/2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	0		
Snail 1B	0		
Snail 1C	49.01961		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	8.1699346	20.01217
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	21.0084		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	3.5014006	8.576645

Table C4: Cobalt concentration in snails samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	0			0			0		
Snail 1B	0			0			0		
Snail 1C	0			0			0		
Snail 1D	0			0			0		
Snail 1E	0			0			0		
Snail 1F	0	0	0	0	0	0	0	0	0
Snail 2A	0			0					
Snail 2B	0	0	0	0					
Snail 2C				0					
Snail 2D				0					
Snail 2E				0					
Snail 2F				0	0	0			
Snail 3A	0			0			0		
Snail 3B	0			0			0		
Snail 3C	0			0			0		
Snail 3D	0			0			0		
Snail 3E	0			0			0		
Snail 3F	0	0	0	0	0	0	0	0	0
Snail 4A	0			0			0		
Snail 4B	0			0			0		
Snail 4C	0			0			0		
Snail 4D	0			0			0		
Snail 4E	0			0			0		
Snail 4F	0	0	0	0	0	0	0	0	0

	03-04-2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	0	0	
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0	0
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0		
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	0	0

	09/06/2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	0		
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0	0
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	0	0

	04/08/2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	0		
Snail 1B	0		
Snail 1C	0		
Snail 1D	8.438819		
Snail 1E	0		
Snail 1F	0	1.4064698	3.445133
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	6.410256	1.0683761	2.616976
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	0	0

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Snail 1A	0		
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0	0
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	0	0

Table C5: Copper concentration in snails samples over the entire sampling period
at Kuils River (2005-2006)

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	235.40127			12.693878			25.25926		
Snail 1B	178.04167			36.113208			72.46829		
Snail 1C	142.1165			3.6911765			78.43787		
Snail 1D	121.11905			243.94595			96.73016		
Snail 1E	170.73585			32.28169			74.94915		
Snail 1F	158.69231	167.6844	39.00017	26.32381	59.17495	91.33844	38	64.30746	27.00959
Snail 2A	321.87879			42.428571					
Snail 2B	93.642857	207.7608	161.3872	9.3834586					
Snail 2C				0					
Snail 2D				21.303704					
Snail 2E				425.85401					
Snail 2F				97.657143	99.43782	163.648			
Snail 3A	28.041237			1220.0296			71.5873		
Snail 3B	115.54762			113.56098			43.94771		
Snail 3C	36.807512			192.94737			29.25		
Snail 3D	59.701493			0			19.80153		
Snail 3E	37.594595			0			326.1667		
Snail 3F	6.5263158	47.3698	37.5478	6.6095238	255.5246	478.933	124.186	102.4899	115.8323
Snail 4A	15.107981			4485.8571			77.37349		
Snail 4B	0.4698795			8.421875			144.766		
Snail 4C	10.656489			0			229.8644		
Snail 4D	0			0			56.76316		
Snail 4E	0			28.291262			107.473		
Snail 4F	0	4.372392	6.742786	94.240964	769.4685	1820.998	15.10886	105.2248	75.29767

	03-04-2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	2785.519		
Snail 1B	295.7831		
Snail 1C	0		
Snail 1D	93.68317		
Snail 1E	53.78431		
Snail 1F	0	538.1283	1106.416
Snail 2A			
Snail 2B			
Snail 2C			
Snail 2D			
Snail 2E			
Snail 2F			
Snail 3A	0		
Snail 3B	0		
Snail 3C	51.53642		
Snail 3D	108.798		
Snail 3E	4.708738		
Snail 3F	345.0783	85.02023	134.3306
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	270.7627		
Snail 4E	0		
Snail 4F	0	45.12712	110.5384

	09/06/2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	0		
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0	0
Snail 2A	0		
Snail 2B	0		
Snail 2C	33.33333		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	5.5555556	13.60828
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	13.7931		
Snail 3E	0		
Snail 3F	0	2.2988506	5.631011
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	18.86792		
Snail 4E	0		
Snail 4F	0	3.1446541	7.702798

	04/08/2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	127.2727		
Snail 1B	95.2381		
Snail 1C	108.1081		
Snail 1D	168.7764		
Snail 1E	113.3603		
Snail 1F	113.4021	121.02628	25.56519
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	11.53846		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	1.9230769	4.710557
Snail 4A	12.19512		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	2.0325203	4.978638

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Snail 1A	79.91705		
Snail 1B	90.68613		
Snail 1C	31.86275		
Snail 1D	18.07246		
Snail 1E	4.112903		
Snail 1F	0	37.441882	38.87957
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	33.33023		
Snail 3B	57.36735		
Snail 3C	0		
Snail 3D	52.36111		
Snail 3E	91.71429		
Snail 3F	27.63889	43.735311	31.12027
Snail 4A	10.94958		
Snail 4B	41.75926		
Snail 4C	0		
Snail 4D	13.33333		
Snail 4E	47.84		
Snail 4F	41.95349	25.97261	20.21291

Table C6: Chromium concentration in snails samples over the entire sampling period
at Kuils River (2005-2006)

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	0			0			0		
Snail 1B	0			0			0		
Snail 1C	14.524272			0			0		
Snail 1D	0			0			0		
Snail 1E	0			0			0		
Snail 1F	0	2.420712	5.929509	0	0	0	0	0	0
Snail 2A	22.727273			0					
Snail 2B	0	11.36364	16.07061	0					
Snail 2C	0			0					
Snail 2D	0			0					
Snail 2E	0			0					
Snail 2F	0			0	0	0			
Snail 3A	0			0			0		
Snail 3B	0			0			0		
Snail 3C	0			0			0		
Snail 3D	0			0			0		
Snail 3E	0			0			0		
Snail 3F	0	0	0	0	0	0	0	0	0
Snail 4A	0			0			0		
Snail 4B	0			0			0		
Snail 4C	0			0			0		
Snail 4D	0			0			0		
Snail 4E	0			0			0		
Snail 4F	0	0	0	0	0	0	0	0	0

	03-04-2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	0			
Snail 1B	0			
Snail 1C	0			
Snail 1D	0			
Snail 1E	0			
Snail 1F	0	0		0
Snail 2A				
Snail 2B				
Snail 2C				
Snail 2D				
Snail 2E				
Snail 2F				
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	0			
Snail 3E	0			
Snail 3F	0	0		0
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	0			
Snail 4E	0			
Snail 4F	0	0		0

	09/06/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	0			
Snail 1B	0			
Snail 1C	0			
Snail 1D	0			
Snail 1E	0			
Snail 1F	0	0		0
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0		0
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	0			
Snail 3E	0			
Snail 3F	0	0		0
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	0			
Snail 4E	0			
Snail 4F	0	0		0

	04/08/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	0			
Snail 1B	0			
Snail 1C	0			
Snail 1D	0			
Snail 1E	0			
Snail 1F	0	0		0
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0		0
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	0			
Snail 3E	0			
Snail 3F	0	0		0
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	0			
Snail 4E	0			
Snail 4F	0	0		0

	02/10/2006		StDev (ppm)
	Conc. mg/kg	Mean (ppm)	
Snail 1A	0		
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0	0
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	0		
Snail 4B	0		
Snail 4C	0		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	0	0

Table C7: Iron concentration in snails samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	2545.7962			24236.136			7463.748		
Snail 1B	3416.6458			34288.981			7972.478		
Snail 1C	5586.9709			18073.471			1212.97		
Snail 1D	2485.8571			25764.072			0		
Snail 1E	3666.0755			18503.465			0		
Snail 1F	3036.7692	3456.352	1142.989	23273.067	24023.2	5914.249	0	2774.866	3861.087
Snail 2A	3515.2121			12225.629			0		
Snail 2B	8116.5714	5815.892	3253.652	23286.556			0		
Snail 2C				24265.216			0		
Snail 2D				18957.422			0		
Snail 2E				11981.854			0		
Snail 2F				13889.562	17434.37	5525.483	0	0	0
Snail 3A	2813.3196			9857.0519			0		
Snail 3B	2594.1429			13385.301			0		
Snail 3C	2048.3474			19230.863			0		
Snail 3D	1585.5821			19575.75			0		
Snail 3E	594.7027			13055.124			0		
Snail 3F	2249.3333	1980.905	802.9214	15580.629	15114.12	3793.057	0	0	0
Snail 4A	940.43192			7327.7857			0		
Snail 4B	698.3012			12699.453			0		
Snail 4C	664.61069			10863.49			0		
Snail 4D	439.97654			11033.228			1705.623		
Snail 4E	407.25641			8566.3301			0		
Snail 4F	1295	740.9295	333.5708	11365.446	10309.29	1979.234	259.6253	327.5414	683.0599

	03/04/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	4496.124			
Snail 1B	1293.173			
Snail 1C	2704.918			
Snail 1D	3009.901			
Snail 1E	7352.941			
Snail 1F	3900	3792.8428	2060.355	
Snail 2A	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2E	0			
Snail 2F	0	0	0	
Snail 3A	2669.683			
Snail 3B	935.4839			
Snail 3C	2052.98			
Snail 3D	1585.859			
Snail 3E	475.7282			
Snail 3F	1060.87	1463.4339	804.2316	
Snail 4A	1623.188			
Snail 4B	1215.385			
Snail 4C	1289.1			
Snail 4D	1254.237			
Snail 4E	1420.29			
Snail 4F	3540.984	1723.8639	902.4785	

	09/06/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	11575.13			
Snail 1B	5773.756			
Snail 1C	4293.103			
Snail 1D	2880			
Snail 1E	7490.566			
Snail 1F	3604.24	5936.1325	3216.151	
Snail 2A	8906.475			
Snail 2C	17850			
Snail 2D	13900			
Snail 2E	0			
Snail 2E	0			
Snail 2F	0	6776.0791	7945.644	
Snail 3A	6386.364			
Snail 3B	5208.054			
Snail 3C	5317.46			
Snail 3D	3227.586			
Snail 3E	3281.25			
Snail 3F	3304.348	4454.1769	1360.097	
Snail 4A	8222.222			
Snail 4B	14378.38			
Snail 4C	11086.21			
Snail 4D	2471.698			
Snail 4E	2138.614			
Snail 4F	6367.347	7444.0777	4816.368	

	04/08/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	1757.576			
Snail 1B	1393.939			
Snail 1C	1486.486			
Snail 1D	1282.7			
Snail 1E	3036.437			
Snail 1F	1608.247	1760.8978	646.3663	
Snail 2A	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2E	0			
Snail 2F	0	0	0	
Snail 3A	1745.562			
Snail 3B	1462.185			
Snail 3C	596.1538			
Snail 3D	4025.641			
Snail 3E	2041.667			
Snail 3F	1564.103	1905.8852	1146.001	
Snail 4A	2048.78			
Snail 4B	666.6667			
Snail 4C	2495.413			
Snail 4D	2000			
Snail 4E	1042.553			
Snail 4F	1800	1675.5689	685.6766	

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Snail 1A	3176.406		
Snail 1B	2482.496		
Snail 1C	934.549		
Snail 1D	2301.261		
Snail 1E	3696.419		
Snail 1F	2071.935	2443.8443	953.2789
Snail 2A	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2E	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	346.5674		
Snail 3B	0		
Snail 3C	305.3807		
Snail 3D	0		
Snail 3E	2218.81		
Snail 3F	0	478.45961	867.5184
Snail 4A	2277.58		
Snail 4B	1058.722		
Snail 4C	975.9569		
Snail 4D	584.0808		
Snail 4E	1876.8		
Snail 4F	0	1128.8566	834.0719

Table C8: Manganese concentration in snails samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	1403.0318			120.19048			152.37037		
Snail 1B	1457.5208			434.58491			168.91707		
Snail 1C	918.75728			84.352941			52.224852		
Snail 1D	546.14286			117.45946			42.603175		
Snail 1E	348.67925			88.098592			36.813559		
Snail 1F	1869.9231	1090.676	585.8326	121.02857	160.9525	135.0533	108.98182	93.65181	58.13859
Snail 2A	356.18182			505.98571			0		
Snail 2B	878.35714			730.76692			0		
Snail 2C	0			606.72549			0		
Snail 2D	0			758.23704			0		
Snail 2E	0			573.0073			0		
Snail 2F	0	617.2695	369.2337	697.90476	645.4379	98.94363	0	0	0
Snail 3A	38.639175			197.3037			0		
Snail 3B	141.52381			64.617886			0		
Snail 3C	381.96244			127.13684			0		
Snail 3D	56.402985			230.675			0		
Snail 3E	54.081081			152.59854			0		
Snail 3F	41.736842	119.0577	134.3256	95.580952	144.6522	62.21819	0	0	0
Snail 4A	23.183099			0			0		
Snail 4B	20.891566			30.71875			0		
Snail 4C	25.938931			42.924138			0		
Snail 4D	43.876833			90.519685			12.236842		
Snail 4E	16.923077			36.563107			0		
Snail 4F	58.617647	31.57186	16.20891	8.3614458	34.84785	31.93892	16.172152	4.734832	7.439986

	03-04-2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	199.28682			
Snail 1B	60.827309			
Snail 1C	87.606557			
Snail 1D	69.762376			
Snail 1E	42.333333			
Snail 1F	33.8	82.2694	60.46805	
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	0
Snail 3A	1.9547511			
Snail 3B	1.2150538			
Snail 3C	0			
Snail 3D	1.1616162			
Snail 3E	6.8543689			
Snail 3F	0	1.864298	2.560292	
Snail 4A	14.724638			
Snail 4B	0			
Snail 4C	11.791469			
Snail 4D	10.610169			
Snail 4E	0			
Snail 4F	0	6.187713	6.909452	

	09/06/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	41.45078			
Snail 1B	72.39819			
Snail 1C	0			
Snail 1D	160			
Snail 1E	0			
Snail 1F	49.46996	53.886489	59.30332	
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	0
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	0			
Snail 3E	0			
Snail 3F	0	0	0	0
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	0			
Snail 4E	0			
Snail 4F	0	0	0	0

	04/08/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	212.1212			
Snail 1B	86.58009			
Snail 1C	621.6216			
Snail 1D	143.4599			
Snail 1E	364.3725			
Snail 1F	134.0206	260.36265	201.7336	
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	0
Snail 3A	17.75148			
Snail 3B	50.42017			
Snail 3C	15.38462			
Snail 3D	25.64103			
Snail 3E	0			
Snail 3F	25.64103	22.473052	16.60536	
Snail 4A	48.78049			
Snail 4B	8.438819			
Snail 4C	36.69725			
Snail 4D	27.02703			
Snail 4E	42.55319			
Snail 4F	33.333333	32.805018	14.0909	

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Snail 1A	102.0184		
Snail 1B	75.40146		
Snail 1C	48.01961		
Snail 1D	63.05797		
Snail 1E	103.2419		
Snail 1F	220.6667	102.06768	62.00184
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	28.79832		
Snail 4B	3.796296		
Snail 4C	29.98769		
Snail 4D	5.333333		
Snail 4E	10.34667		
Snail 4F	0	13.043718	13.0972

Table C9: Nickel concentration in snails samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	0			0			0		
Snail 1B	0			0			0		
Snail 1C	0			0			0		
Snail 1D	0			0			0		
Snail 1E	0			0			0		
Snail 1F	0	0		0	0	0	0	0	0
Snail 2A	0			0			0		
Snail 2B	35	17.5	24.74874	0			0		
Snail 2C	0			0			0		
Snail 2D	0			0			0		
Snail 2E	0			0			0		
Snail 2F	0			0	0	0	0		
Snail 3A	0			0			0		
Snail 3B	0			0			0		
Snail 3C	0			0			0		
Snail 3D	0			0			0		
Snail 3E	5.567568			0			0		
Snail 3F	0	0.927928	2.27295	0	0	0	0	0	0
Snail 4A	0			0			0		
Snail 4B	0			0			0		
Snail 4C	14.25954			0			0		
Snail 4D	0			0			0		
Snail 4E	0			0			0		
Snail 4F	0	2.37659	5.821434	0	0	0	0	0	0

	03-04-2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	0			
Snail 1B	0			
Snail 1C	0			
Snail 1D	0			
Snail 1E	0			
Snail 1F	0	0	0	0
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	0
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	0			
Snail 3E	0			
Snail 3F	0	0	0	0
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	0			
Snail 4E	0			
Snail 4F	0	0	0	0

	09/06/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	0			
Snail 1B	0			
Snail 1C	0			
Snail 1D	0			
Snail 1E	0			
Snail 1F	0	0	0	0
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	0
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	0			
Snail 3E	0			
Snail 3F	0	0	0	0
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	0			
Snail 4E	0			
Snail 4F	0	0	0	0

	04/08/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	0			
Snail 1B	0			
Snail 1C	0			
Snail 1D	0			
Snail 1E	0			
Snail 1F	0	0	0	0
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	0
Snail 3A	0			
Snail 3B	0			
Snail 3C	0			
Snail 3D	0			
Snail 3E	0			
Snail 3F	0	0	0	0
Snail 4A	0			
Snail 4B	0			
Snail 4C	0			
Snail 4D	0			
Snail 4E	53.19149			
Snail 4F	41.66667	15.809693	24.76194	

	02/10/2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Snail 1A	0		
Snail 1B	0		
Snail 1C	0		
Snail 1D	0		
Snail 1E	0		
Snail 1F	0	0	0
Snail 2A	0		
Snail 2B	0		
Snail 2C	0		
Snail 2D	0		
Snail 2E	0		
Snail 2F	0	0	0
Snail 3A	0		
Snail 3B	0		
Snail 3C	0		
Snail 3D	0		
Snail 3E	0		
Snail 3F	0	0	0
Snail 4A	0		
Snail 4B	0		
Snail 4C	368.2831		
Snail 4D	0		
Snail 4E	0		
Snail 4F	0	61.380513	150.3509

Table C10: Zinc concentration in snails samples over the entire sampling period at Kuils River (2005-2006)

	07-10-2005			01-12-2005			10-02-2006		
	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)	Conc. mg/kg	Mean (ppm)	StDev (ppm)
Control									
Snail 1A	76.54777			197.04762			8.5333333		
Snail 1B	56.27083			353.11321			34.321951		
Snail 1C	29.04854			197.19118			7.7869822		
Snail 1D	48.09524			297.2973			56.936508		
Snail 1E	45.98113			154.92958			0		
Snail 1F	76.28205	55.37093	18.55002	239.04762	239.7711	73.47469	0	17.9298	22.91005
Snail 2A	109.3333			826.64286			0		
Snail 2B	756.1429	432.7381	457.3634	309.80451			0		
Snail 2C				229.5098			0		
Snail 2D				189.00741			0		
Snail 2E				116.74453			0		
Snail 2F		0	0	164.11429	305.9706	263.2758	0	0	0
Snail 3A	93.17526			80.444444			0		
Snail 3B	66.44048			121.02439			0		
Snail 3C	42.33803			187.74737			0		
Snail 3D	56.29851			131.825			0		
Snail 3E	86.45946			117.54745			10.541667		
Snail 3F	82.49123	71.20049	19.6009	173.90476	135.4156	39.44902	1342.2326	225.4624	547.1197
Snail 4A	64.10016			263.44643			420.12048		
Snail 4B	181.7108			246.20313			192.73404		
Snail 4C	68.53435			127.14483			116.50847		
Snail 4D	55.39003			430.50394			330.23684		
Snail 4E	4.153846			121.80583			160.62162		
Snail 4F	154.1471	88.00605	66.63461	125.68675	219.1318	121.6887	158.51139	229.7888	118.6474

	03-04-2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	156.86822			
Snail 1B	65.638554			
Snail 1C	46.57377			
Snail 1D	65.643564			
Snail 1E	302.33333			
Snail 1F	124.8	126.9762	95.53737	
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	0
Snail 3A	176.28054			
Snail 3B	42.602151			
Snail 3C	69.483444			
Snail 3D	48.545455			
Snail 3E	88.184466			
Snail 3F	78.243478	83.88992	48.47228	
Snail 4A	51.004831			
Snail 4B	72.569231			
Snail 4C	185.64929			
Snail 4D	120.54237			
Snail 4E	124.72464			
Snail 4F	222.52459	129.5025	65.287	

	09/06/2005			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	165.8031			
Snail 1B	90.49774			
Snail 1C	51.72414			
Snail 1D	194.2857			
Snail 1E	75.4717			
Snail 1F	35.33569	102.18635	63.86725	
Snail 2A	100.7194			
Snail 2B	300			
Snail 2C	200			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	100.1199	126.4914	
Snail 3A	181.8182			
Snail 3B	120.8054			
Snail 3C	126.9841			
Snail 3D	96.55172			
Snail 3E	156.25			
Snail 3F	130.4348	135.47403	29.68841	
Snail 4A	194.4444			
Snail 4B	432.4324			
Snail 4C	362.069			
Snail 4D	245.283			
Snail 4E	297.0297			
Snail 4F	367.3469	316.43425	87.69351	

	04/08/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	145.4545			
Snail 1B	77.92208			
Snail 1C	180.1802			
Snail 1D	143.4599			
Snail 1E	113.3603			
Snail 1F	185.567	140.99068	40.71848	
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	0
Snail 3A	100.5917			
Snail 3B	151.2605			
Snail 3C	61.53846			
Snail 3D	307.6923			
Snail 3E	416.6667			
Snail 3F	128.2051	194.3258	137.7915	
Snail 4A	304.878			
Snail 4B	168.7764			
Snail 4C	513.7615			
Snail 4D	540.5405			
Snail 4E	148.9362			
Snail 4F	200	312.81543	174.7181	

	02/10/2006			StDev (ppm)
	Conc. mg/kg	Mean (ppm)		
Snail 1A	28.03687			
Snail 1B	41.73723			
Snail 1C	34.35294			
Snail 1D	30.01449			
Snail 1E	22.64516			
Snail 1F	15.20325	28.66499	9.196832	
Snail 2A	0			
Snail 2B	0			
Snail 2C	0			
Snail 2D	0			
Snail 2E	0			
Snail 2F	0	0	0	
Snail 3A	20.03721			
Snail 3B	33.34694			
Snail 3C	26.71066			
Snail 3D	16.69444			
Snail 3E	295.8571			
Snail 3F	140.0556	88.783658	111.6758	
Snail 4A	160.4202			
Snail 4B	150.2222			
Snail 4C	130.4492			
Snail 4D	152.202			
Snail 4E	622.36			
Snail 4F	8.992248	204.10765	212.5733	

Appendix D

Table A: Sediment calculations at Kuils River, sampling sites 1 to 4.

Sample Number	Mass >63 μm	Mass >2mm (G), (g)	Mass 63 μm – 2mm (S), (s)	Mass Z+C (g)	Total Mass (g)	Mass Z (Silt) (g)(4-63 μm)	Mass C (Clay) (g) (<4 μm)	Gravel (%)	Sand (%)	Mud (Silt+Clay) (%)	Silt (%)	Clay (%)
Site 1	4.746	0.000	4.746	9.581	14.327	7.283	2.298	0.00	33.13	66.87	50.83	16.04
Site 2	26.955	0.016	26.939	0.260	27.215	0.217	0.043	0.06	98.99	0.96	0.80	0.16
Site 3	27.336	0.000	27.336	0.260	27.596	0.173	0.087	0.00	99.06	0.94	0.63	0.32
Site 4	14.665	0.053	14.612	2.168	16.833	1.648	0.520	0.31	86.81	12.88	9.79	3.09

Pipetting Factor (PF) = 43.353 ; Temperature (T) = 25 °C ; *PT= Pipetting Time

Sample Number	(Z+C) Beak Mass (g)	(Z+C) beaker + Subsample (g)	Subsample X P.F (Z+K) (g)	C Beaker Mass (g)	C Beaker + Subsample (g)	Subsample X P.F (C) (g)	(Z+C)-(C) = (Z) (g)	*P.T (Z+C)	*P.T (C)	Surface Reading	Depth to be lowered (cm)	Lowered Depth (cm)
Site 1	39.804	40.025	9.581	31.687	31.740	2.298	7.283	1542	1642	9325	5.9	15.15
Site 2	32.611	32.617	0.260	40.302	40.303	0.043	0.217	1542	1645	9.3	5.9	15.2
Site 3	40.414	40.420	0.260	33.001	33.003	0.087	0.173	1548	1648	8.95	5.9	14.85
Site 4	43.155	43.205	2.168	40.290	40.302	0.520	1.648	1551	1651	9.65	5.9	15.55

