A Survey of Inorganic Chemical Pollution in the Bottelary River, Cape Town

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A mini-thesis submitted in partial fulfillment of the requirements for the degree of Magister Scientiae, Integrated Water Resources Management in the Faculty of Natural Science, University of the Western Cape.

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KEY WORDS

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ABSTRACT

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A survey of the levels of eutrophication (nutrient concentrations), heavy metals and salinity in the Bottelary River was undertaken. Dissolved oxygen (DO), electrical conductivity (EC), pH, nitrate (NO_3^-), nitrite (NO_2^-), ammonium ion (NH_4^+), total nitrogen, phosphate (PO_4^{3-}), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb) and zinc (Zn) were measured in water samples collected six times at 13 different sampling sites along the Bottelary River from March to September in 2004.

The results showed that the water quality in the Bottelary River has been polluted by nutrients and heavy metals. High concentrations of nitrogen, phosphorus, cadmium, copper and zinc were observed in the water samples from the river. Eutrophication problem would be caused by the excessive nitrogen and phosphorus levels. The lead levels were within the South African Water Quality Guidelines for aquatic ecosystems recommendations. There was no salinity problem in the river as revealed by the low levels of conductivity. Concentrations of nutrients, cadmium, iron and zinc increased over the study period as a consequence of anthropogenic inputs, particularly urban and agricultural runoff during rainy season.

The main sources of pollutants in the Bottelary River were agricultural runoff, urban runoff from Scottsdene Town and treated sewage effluent from the Scottsdene Wastewater Treatment Works (WWTW). Recommendations for the control of water pollution in the Bottelary River based on a whole ecosystem approach as advocated by Integrated Water Resources Management (IWRM) principles are presented.

Date: 12 May 2005

DECLARATION

I declare that *A Survey of Inorganic Chemical Pollution in the Bottelary River, Cape Town* is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full name: Xiao Yi Feng   Date: 12 May 2005

Signed ……………………………………

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Water Pollution in Rivers

1.1 INTRODUCTION

Fresh water is a critical, finite, vulnerable, renewable resource on the earth, and plays an important role in our living environment; without it, life is impossible. Since the beginning of the "Industrial Revolution", increasing human population, economic activities as well as shortcomings in their management have resulted in more pollutants being introduced into watercourses. An increasing number of surface water bodies have come under serious threat of degradation. The global freshwater resources are under increasing pressure (GWP Technical Advisory Committee, 2000). The anthropogenic impact on aquatic ecosystems has become a crucial topic of increasing concern. These problems have led to the adoption of an integrated approach to the management of water resources, which is called Integrated Water Resources Management (IWRM).

Rivers and streams are a valuable freshwater resource, irreplaceable, priceless assets providing important habitats and corridors for nature conservation, recreation, amenity and economic growth. A river, comprising both the main course and its tributaries, is a complex ecological system carrying in one-way flow a significant load of matter in dissolved and particular phases from both natural and anthropogenic sources towards the sea (Bellos *et al.*, 2004). The rivers and their catchments play major roles in the social development and have been utilized by humankind over the centuries. So far, most rivers have been modified by human activities and very few are now in their natural condition (Wetzel, 2001).

The water quality in rivers and streams may vary depending on the geological morphology, vegetation and land use (modification by human activities such as agriculture, industrialization and urbanization) in the catchment. Industries, agriculture and urban settlements produce nutrients (sewage effluent and fertilizers) and toxic substances, such as organic and inorganic pollutants, and other chemicals including heavy metals. Water pollution in rivers occurs when these substances, which degrade the water quality of river, enter the waterway and alter their natural function (Water and Rivers Commission, 1997).

From a public health or ecological view, water pollution is defined as the direct or indirect alteration of the physical, chemical or biological properties of a water resource thereby adversely affecting living resources and ecological systems, and making a water resource unsuitable for one or more of its beneficial uses (Cunningham & Saigo, 1990). The major categories of water pollutants include organic chemicals (pesticides and herbicides), inorganic chemicals (acids, alkalis, salts and metals), nutrients (nitrogen and phosphorus), pathogens (bacteria, viruses and parasites), certain radioactive materials (uranium, thorium, cesium, iodine and radon), sediment (soil and silt) and thermal (heat) (Cunningham & Saigo, 1990; Mason, 2002). Although many authors did not mention it, solid wastes are also considered as water contaminants.

This chapter examines information relevant to the concept of IWRM. Aspects of water pollution in rivers, especially eutrophication (nutrients enrichment), heavy metals and salinity, are reviewed. It also briefly reviews pesticides, solid waste, alien organisms and pathogens.

1.2 INTEGRATED WATER RESOURCES MANAGEMENT

The deteriorating water quality caused by pollution influences water usability, threatens human health and the functioning of aquatic ecosystems thereby reducing the availability of water of adequate quality. These problems are further aggravated by sectoral approaches to water resources management, which leads to fragmented and uncoordinated development (GWP Technical Advisory Committee, 2000). In order to address these gaps, it has become necessary to adopt IWRM, whose basic aim is to satisfy the freshwater needs of all countries for their sustainable development (Radif, 1999).

The Global Water Partnership (GWP) defines the IWRM as follows:
"IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (GWP Technical Advisory Committee, 2000).

The key elements of IWRM are sustainability of water resources, adequate water policy and management of the resource (Radif, 1999). The concept of IWRM recognizes that terrestrial ecosystems in the upstream areas of a basin are important for rainwater infiltration, groundwater recharge and river flow regimes. Ecosystems depend on water flows, seasonality and watertable fluctuations and have water quality as a fundamental determinant; this realization has led governments to adopt an ecosystem protection approach to water resource management (GWP Technical Advisory Committee, 2000).

The South African government through the National Water Act, No. 36 of 1998 (NWA) requires the establishment of the "Reserve". The NWA defines "Reserve" as follows:
"the quantity and quality of water required to satisfy basic human needs by securing a basic water supply…for people who are now or who will, in the reasonably near future, be relying upon; taking water from; or being supplied from, the relevant water resource; and to protect aquatic ecosystems in order to secure ecologically sustainable development and use of relevant water resource" (RSA, 1998).

Under the NWA, Resource Directed Measures (RDM) is required for the maintenance of ecosystem functions and services (DWAF, 1999; Mackay, 2000). RDM includes the classification, the "Reserve" and Resource Quality Objectives (RQOs) (Mackay, 2001). RQOs have four critical components, which include:

- *"The quantity, pattern, timing, water level and assurance of instream flow;*
- *The water quality, including the physical, chemical and biological characteristics of the water;*
- *The characteristics and condition of the instream and riparian habitat, and*
- *The characteristics, condition and distribution of the aquatic biota"* (RSA, 1998).

RQOs should include all the four key aspects of resource quality (water quantity, water quality, habitat and biota) in order to ensure protection of ecosystem function and health. DWAF defines water quality as follows:
"... the physical, chemical, biological and aesthetic properties of water that determine its fitness for a variety of uses and for the protection of the health and integrity of aquatic ecosystems. Many of these properties are controlled or influenced by constituents that are either dissolved or suspended in water" (DWAF, 1996).

In general, according to the origins of polluting substances, water pollutants are broadly segregated into two categories, point sources and non-point sources (diffuse sources).

1.3 POINT AND NON-POINT SOURCES

Point source pollution originates from discernable and/or discrete sources that discharge into the aquatic systems through a specific outlet or at a specific location of high concentration of pollution, such as drainpipes, ditches, channels and effluent outfalls (Cunningham & Saigo, 1990; Pegram & Görgens, 2001). These sources are readily identifiable, as a result, they are relatively easy to monitor and regulate. Examples of point sources are discharges of effluents from sewers or sewage treatment plants, drains, and factory outfalls releasing organic loads, heavy metals and nutrients (Abel, 1996).

Non-point source pollution often accounts for a majority of the contaminants and occurs when there is no discrete point of discharge. The pollution enters the aquatic systems by a multitude of pathways, such as agricultural runoff, urban runoff, livestock manure, animal and human waste, atmospheric deposition, precipitation, drainage, interflow, seepage, groundwater flow and river course modification (Abel, 1996; Pegram & Görgens, 2001). The non-point sources are becoming increasingly important, as they are more difficult to measure and regulate than point sources of pollution. Non-point sources occur over wide areas and are variable in time due to effects of weather (Arms, 1994).

1.4 CHEMICAL POLLUTION

The chemical composition of surface water is affected by climatic conditions (rainfall and temperature), atmospheric inputs, aquatic biota (fauna and flora), human activities and the characteristics of the catchment area, such as geomorphology, geology and soils (Förstner & Wittman, 1979; Bricker & Jones, 1995; Davies & Day, 1998). Since the birth of the "chemical age", surface water bodies have been heavily impacted worldwide by many anthropogenic toxic chemicals. Toxic chemicals, through runoff and seepage, change the chemical composition, decrease the aesthetic value, and alter the ecosystem by affecting aquatic organisms of water bodies (Alloway & Ayres, 1993).

Chemical pollution of surface water is regarded as the most serious environmental issue facing many countries. It is caused by various pollutants, such as nitrogen, phosphorus, heavy metals, salts, pesticides, urban toxic chemicals, oil, certain radioactive isotopes, sediments and atmospheric depositions, both from point and diffuse source discharges (Cunningham & Saigo, 1990; Botkin & Keller, 2000). Nutrients, heavy metals and salts, as well as organic pollutants such as pesticides, are identified as being among the major pollutants.

1.4.1 Eutrophication

The term "eutrophication" has been used globally in the context of excess nutrients in an aquatic system. One of the widely accepted definitions of eutrophication is given by the Organization for Economic Cooperation and Development (OECD, 1982), which describes the eutrophication process as following:

"…the nutrient enrichment of waters which results in the stimulation of an array of symptomatic changes, amongst which increased production of algae and aquatic macrophytes, deterioration of water quality and other symptomatic changes are found to be undesirable and interfere with water uses."

Eutrophication has been identified as the most ubiquitous water quality impairment in rivers, lakes, estuaries and coastal oceans, caused by excessive inputs of nitrogen (N) and phosphorus (P) during the past few decades (Water and Rivers Commission, 1997; Carpenter *et al.*, 1998; Smith *et al.*, 1999). The economic and environmental consequences of nutrient enrichment and eutrophication can be very severe. The costs of damage by freshwater eutrophication in England and Wales are estimated to be $105–160 million per year (Pretty *et al.*, 2003).

The eutrophication problem has been studied all over the world. Although the focus of freshwater eutrophication research during the past several decades is on lakes and reservoirs, the nutrient enrichment is also of great concern in running water, such as rivers and streams (Smith *et al.*, 1999). For example, Jarvie *et al.* (2002) examined the behaviour of phosphorus in a stream and a river in southern England. Bellos *et al.* (2004) monitored the impact of human activities on the fluctuation of nutrients and seasonal variations in the Pinios River, Greece.

Nutrients are typical contamination indicators of water. Nitrogen and phosphorus are the most common limiting nutrients in freshwater and have been identified as key nutrients causing the eutrophication problem (Davies & Day, 1998; Botkin & Keller, 2000). The nitrogen includes both the dissolved forms of inorganic nitrogen components and those adsorbed onto suspended inorganic and organic material present in aquatic system in the form of nitrate (NO_3^-), nitrite (NO_2^-), ammonia (NH_3) and ammonium ion (NH_4^+). Phosphorus, as orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically bound phosphates, may be present in waters as dissolved and particulate forms, as well as inorganic and organic forms (DWAF, 1996).

Most nutrients are not toxic to aquatic organisms and are vital to aquatic plant growth (Davies & Day, 1998). The concentrations and ratios of nutrients present in freshwater determine the rate and extent of primary production of aquatic plants (Walmsley, 2000). In natural processes, the cycles of nutrients are constant and the process of build-up of nutrients coming in from the catchment is slow (Anon., 2000).

However, during the 20th century, the global bio-geochemical cycles of carbon, nitrogen and phosphorus have been greatly impacted by human activities (Schlesinger, 1991; Vitousek *et al.*, 1996; Vitousek *et al.*, 1997 a&c; UNEP/RIVM, 1999). Vitousek *et al.* (1997) indicated that human alteration of the nitrogen cycle has approximately doubled the rate of nitrogen input, which is still increasing, to the terrestrial nitrogen cycle and has greatly increased the transfer of nitrogen through rivers to estuaries and coastal oceans.

Anthropogenic activities make use of numerous products and resources which act as primary sources of nutrients, such as detergents, foodstuffs, fertilizers, fossil (coal and oil) and wood fuels, and other organic materials, such as hay and grass (Walmsley, 2000). When excessive amounts of nitrogen and phosphorus derived from anthropogenic activities enter the watercourse it will suffer from *artificial* or *cultural* eutrophication, which is a reversible process and occurs more rapidly than *natural* eutrophication. *Natural* eutrophication is dependent on the geology and natural features of the catchment and results from an increase in nutrients by non-human processes, such as forest fires. It is not reversible and occurs at a slow rate. *Natural* eutrophication typically occurs as lakes age (Walmsley, 2000; Mason, 2002).

Eutrophication has many adverse consequences. The first symptom of eutrophication is a massive increase in the biomass of algae, both phytoplankton (free-floating algae) and periphyton, and/or rooted macrophytes (Vollenweider, 1968; Jeffries & Mills, 1994; Rossouw, 2001). The input of excessive nitrogen and phosphorus causes a shift in phytoplankton to bloom-forming species that may be toxic or inedible and alters the macrophyte species composition (Smith, 1998).

As the aquatic plant growth explodes, it can have a major influence on the oxygen budget of the water (Nijboer & Verdonschot, 2004; Parr & Mason, 2004). When the blooms die, the remains add to the organic wastes in the water; eventually, causing the destruction of habitat and depletion of dissolved oxygen, by senescence and decomposition of nuisance plants, as oxygen is required for decomposition (Carpenter *et al.*, 1998). This in turn may lead to the disappearance of intolerant aquatic insect species and fish, reduced aquatic biological diversity, decreased bacterial activity, increased turbidity, increased taste and odour problems, decreased aesthetic value of the water body and increased water treatment costs (Rossouw, 2001; Arheimer *et al.*, 2004; Nijboer & Verdonschot, 2004). The eutrophication process can also contribute to air pollution by releasing greenhouse and acidifying gases (Pretty *et al.*, 2003).

The major sources of nitrogen that enter surface waters originate from surface runoff from the surrounding catchment area, the discharge of effluent containing human and animal excrement, agricultural fertilizers, and organic industrial wastes (DWAF, 1996). The natural sources of phosphorus in the aquatic system include the decomposition of organic matter, the weathering of rocks and the subsequent leaching of phosphate salts. Human-made sources of phosphorus include point source discharges such as domestic and industrial effluents, and non-point sources, such as sewage from animal feedlots, urban runoff, atmospheric precipitation, and drainage from agricultural land, in particular from land on which fertilizers have been applied (DWAF, 1996).

Carpenter *et al.* (1998) identified non-point pollution, of nitrogen and phosphorus due to agricultural runoff, urban runoff, industry and atmospheric deposition, as the causal factor in water quality deterioration. Excess fertilization and manure production may cause nitrogen and phosphorus surplus to accumulate in soil and leach to aquatic ecosystems. A significant amount of nitrogen and phosphorus enters surface water from urban non-point sources, such as construction sites, runoff of lawn fertilizers and pet wastes, and inputs from unsewered developments.

The eutrophication problem can be reversed by decreasing input rates of nitrogen and phosphorus to aquatic ecosystems, but rates of recovery are often very slow (Carpenter *et al.*, 1998; Smith *et al.*, 1999). The non-point sources of pollution of surface waters could be reduced by decreasing: surplus nutrient flows in agricultural systems and processes, agricultural and urban runoff, and nitrogen emissions from burning fossil fuel (Carpenter *et al.*, 1998).

1.4.2 Heavy Metals

Generally, heavy metals include aluminum (Al), arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni) and zinc (Zn) (Alloway & Ayres, 1993; Abel, 1996).

There are many different definitions for the term “heavy metals” in the environmental literature, but no authoritative definition is agreed on. One definition as given by Alloway and Ayres (1993) states that it is a collective term applying to the group of metals (Cd, Cu, Hg, Ni, Pb, etc.) and some metalloids with a density greater than 6 g/cm^3 (e.g. As). Abel (1996) noted that “heavy metals” is an imprecise term including the metallic elements with an atomic weight greater than 40, and excludes the alkaline earth metals, alkali metals, lanthanides and actinides. Davies and Day (1998) defined the “heavy metals” as all metals with atomic weights greater than that of calcium (Ca), such as Fe, Hg, Mn, Pb and Zn. Nies (1999) mentioned that heavy metals are metals with densities higher than 5 g/cm^3. Mason (2002) defined the term as metals with an atomic number greater than 20.

Duffus (2002) and Hodson (2004) described heavy metals as being a loose general term referring to a group name for metals and metalloids that have relatively high values in density, atomic weight and atomic number, and have been associated with contamination and potential toxicity at low concentrations. Duffus (2002) summarized a range of definitions for the term heavy metals and considered it to be a meaningless and misleading term because it has been given such a wide range of meanings for different uses by different authors.

Heavy metals are stable and persistent natural constituents of the earth's crust and cannot be degraded or destroyed. Although many heavy metal elements, such as Cu and Zn, are unequivocally required by most living organisms in small concentrations for normal healthy growth and metabolism, excess metal levels and their radioactive isotopes in surface water may pose a threat to aquatic ecosystems, animal life and human use of water resources (Alloway & Ayres, 1993; Pegram & Görgens, 2001). Many other heavy metal elements, such as As, Cd and Pb, have no known essential biochemical function; they are also referred to as toxic elements (Alloway & Ayres, 1993; Abel, 1996; Bruins *et al.*, 2000).

Heavy metals have been identified as dangerous inorganic pollutants that may cause major environmental and human health problems because of their bioaccumulation in organisms, biomagnification in food chains and toxic effects on biota (Alloway & Ayres, 1997; Davies & Day, 1998; Goodyear & McNeill, 1999). Aquatic organisms can take up some heavy metal elements. Heavy metals are bioaccumulated up the food chain, becoming highly concentrated in top predators; for example, any biological organism at the top of the food chain (humans, etc.) faces a serious risk of heavy metal poisoning by eating such contaminated organisms (fish, etc.).

Coetzee *et al.* (2002) investigated the bioaccumulation of Al, Cr, Cu, Fe, Mn, Ni, Pb and Zn in the skin, muscle, liver and gill tissues of *Clarias gariepinus* and *Labeo umbratus* from the Upper Olifants River and Klein Olifants River, South Africa. High concentrations of these heavy metals were observed in the gill and liver tissues, with lower values in the skin and muscle tissues. The bioaccumulation patterns were found to vary as a function of the species of the fish, mainly according to the different feeding habits and the routes of metal uptake, as well as the different places where the fish were collected.

In aquatic systems, metals are present as dissolved ions and complexes, colloids and suspended solids in sediments (Larocque & Rasmussen, 1998), depending upon the physical and chemical characteristics of the water body, such as water pH, hardness and sediment concentration (Pegram & Görgens, 2001). The pH of a water body determines the chemical species of many metals and may alter the availability and toxicity of constituents, such as trace metals and ammonium ion. Metals, such as cadmium, copper, lead and zinc, are most likely to have increased detrimental environmental effects as a result of lowered pH (DWAF, 1996).

Abel (1996) listed heavy metals in order of decreasing toxicity as follows: Hg, Cd, Cu, Zn, Ni, Pb, Cr, Al, Co. He mentioned that the most important heavy metals as water pollutants are Cd, Cr, Cu, Pb, Hg, Ni and Zn, which are widely distributed in the aquatic environment.

On the global scale, many rivers and streams have become contaminated with heavy metals such as copper, lead and zinc as a result of human activities (Akcay *et al.*, 2003; Fatoki & Awofolu, 2003; Diagomanolin *et al.*, 2004). Entry of heavy metals into rivers and streams can occur naturally from leaching of ore deposits and from anthropogenic sources, such as atmospheric deposition, domestic wastewater effluents, and wash off from urban areas, industrial sites, solid waste disposal units and agricultural materials. These sources tend to have high metal concentrations, particularly As, Cd, Cr, Cu, Mn, Ni, Pb and Zn (Nriagu & Pacyna, 1988; Alloway & Ayres, 1993; Pegram & Görgens, 2001).

Agriculture constitutes one of the very important non-point sources of heavy metal pollutants, such as impurities in fertilizers (Cd, Cr, Pb and Zn), pesticides (As, Cu, Pb and Zn), desiccants, wood preservatives (As and Cu), wastes from intensive pig and poultry production (As and Cu), composts and manures (As, Cd, Cu, Ni, Pb and Zn), sewage sludge (Cd, Cu, Ni, Pb and Zn) and corrosion of metal objects (Cd and Zn) (Alloway & Ayres, 1993).

A possible way of solving heavy metal pollution is through phytoremediation, a new and powerful technology that uses specially selected metal accumulating plants to extract, sequester, remove and/or detoxify heavy metals or pollutants from both soil and water (Memon *et al.*, 2001).

1.4.3 Salinity

Salinity is the term used when referring to the total concentration of dissolved salts in the water, in soil or rocks, and for most purposes can be considered to be equivalent to total dissolved solids (TDS) (Davies & Day, 1998). The increased salinity and the result of this process are regarded as “salinization” (sometimes termed “mineralization”), which refers to an increased concentration, in water or soil, of occurring mineral ions, particularly bicarbonate, calcium, chloride, magnesium, potassium, sodium and sulphate ions (Williams, 1987; Davies & Day, 1998).

The salinization of flowing water has been identified as one of the most insidious and difficult to treat of all environmental problems, which poses ecological disturbances and hazards on a global scale, particularly in semi-arid and arid regions (Ghassemi *et al.*, 1995; Williams, 2001; Goss, 2003). This increasing global phenomenon of salinization has been reported by different authors in many countries. Choudhari and Sharma (1984) reported the increased stream salinity in the Indian arid zone. Flügel (1995) drew attention to the river salinization due to dryland agriculture in the semi-arid Western Cape Province of South Africa.

The salts in rivers and streams originate from the atmosphere, the groundwater, and the terrestrial material (Williams, 1987). River salinization could result from natural processes, such as evaporative concentration, wind-borne sea spray, groundwater stores of "fossilized" seawater, sea salt stored in rocks, and easily weathered rocks that naturally contain high concentrations of mineral ions (Davies & Day, 1998).

Human-induced activities could also cause river salinization. A variety of anthropogenic activities have disturbed the natural ecosystems and the hydrological cycle, the movement of salts onto land and into waters has been accelerated, which causes the unnatural phenomenon of increases in the salinity of inland waters, particularly rivers and streams (Förstner & Wittman, 1979; Williams, 1987; Williams, 2001). The ecological effects of anthropogenic salinization on natural inland aquatic ecosystems include: biodiversity decreases, changes in the character of aquatic ecosystems, and reduced agricultural productivity (Williams, 2001).

The main human contribution to salinization of rivers and streams could result from dry-land farming and long term irrigation, particular spraying carried out in the arid and semi-arid regions of the world and/or in areas where the rocks or soil have high concentrations of minerals (Williams, 1987; Umali, 1993; Silva & Davies, 1997; Smedema & Shiati, 2002; Causapé *et al.*, 2004). The rising salinity in surface waters could also result from other causes, such as municipal wastes (du Plessis & van Veelen, 1991), the construction of river impoundments, the clearance of natural vegetation, the rising levels of saline groundwater, and the discharge of saline industrial, mine, and agricultural effluents (Davies & Day, 1998; Williams, 2001).

Williams (1987) drew attention to the ecological hazards of salinization in rivers and streams in many dry parts of the world. He mentioned that relatively “small” increases in the salinity of rivers and streams could cause the development of highly saline or even saturated waters, thereby reducing its value. Disturbances of the natural hydrological cycle such as those that convert fresh waters of a salinity of less than 0.3 g/l, to waters of salinity between 0.3 and 10 g/l (usually between 0.3 and 1.5 g/l), are an example of the above.

River salinization has considerable irreparable economic, social and environmental costs. Any salinity increase beyond a low minimum value (for most purposes, about 0.3 g/l in rivers and streams) may impair the water use for agricultural, domestic, urban, industrial and ecological purposes (Williams, 1987). Although plants can tolerate and even require certain levels of salinity for growth (Umali, 1993), when salinities attain 1 g/l, the river water is useless for agriculture (Williams, 2001). The excess salinity may stunt the growth of plants, reduce crop yields and limit the choice of crops that can be grown, which can cause severe crop damage and reduce land values (Umali, 1993).

The salinity level is the measure of the salt load of a water body such as a river, creek, stream, lake, dam or groundwater. The total concentration salts (salinity) can be measured in milligrams per liter (mg/l) and strictly requires comprehensive ionic analysis, but for reasons of analytical simplification, the real salinity indicator is usually described in electrical conductivity (EC) of water in units (mhos) (DWAF, 1996; Burger & Čelková, 2003). Electrical conductivity is a useful and easy indicator of the salinity or total salt content in a water sample. It is a measure of the ability of water to conduct an electrical current (DWAF, 1996).

1.4.4 Organic Contaminants

Thousands of different organic chemicals are used for different purposes in our everyday life. The discharge of excessive quantities of organic matter into the aquatic system causes the most widespread form of water pollution, which is a serious threat to human health and to the aquatic ecosystem. Organic contaminants are synthetic chemicals containing the element carbon and include chemicals like pesticides and dioxins. The major sources of toxic organic chemicals in water are sewage and domestic wastes, runoff of pesticides from agricultural lands, various forms of food processing and manufacture, and numerous industries involving the processing of natural materials, such as textile and paper manufacture (Abel, 1996).

1.4.4.1 Pesticides

Pesticides are a wide range of synthetic organic compounds used to kill, control, repel, or mitigate many different types of weeds, insects and other pests (Levings *et al.,* 1998). They mainly comprise insecticides, herbicides, fungicides, rodenticides, germicides and nematocides (Cunningham & Saigo, 1990).

Pesticides have been used in a wide variety of agricultural and urban settings all over the world for many years. In modern farming practices, most agricultural production relies on the use of pesticides to protect the crop against pests and insects. In urban areas, pesticides are applied on lawns, streets, road embankments, and to building materials to prevent biological deterioration. Pesticides are also used in many industrial processes, for example in the manufacture of textiles (Abel, 1996).

Despite their benefits, the widespread use of pesticides over the past half-century has produced a wide range of toxic side effects that cause serious environmental pollution and a risk of permanent soil and water contamination. On the global scale, the total pesticides use amounts to millions of tons per year. Much of these materials may enter the nearest waterway by various pathways, such as land runoff (Cunningham & Saigo, 1990).

The contamination of surface waters with pesticides due to agricultural activities has been widely documented by numerous authors around the world (Baun *et al.*, 1998; Kreuger, 1998; Dabrowski *et al.*, 2002; Golfinopoulos *et al.*, 2003; Palma *et al.*, 2004). However, a few studies have demonstrated pesticide pollution of surface waters due to urban uses (Kimbrough & Litke, 1996; Blanchoud *et al.*, 2004). Gerecke *et al.* (2002) emphasized urban pesticide sources and studied pesticide contamination in the effluent from the wastewater treatment plants. They mentioned that the degradation period of pesticides used as material protection agents in buildings is much longer than that of agricultural pesticides and is a potential long-term risk.

The amount of pesticides reaching rivers depends upon application rates, chemical characteristics of pesticides and natural conditions during application (Huber *et al.*, 2000). Pesticide residues are introduced into aquatic systems from the application sites by a number of different mechanisms including (Menzies & Peterson, 1993):

1) in solution with surface runoff and in association with sediment in surface runoff;
2) volatilization into the atmosphere followed by deposition into surface water;
3) deposition through drift from aerial and ground spraying;
4) in association with inaccurate application rates;
5) leaching; and
6) improper handling, storage and disposal of pesticides.

The most important classes of pesticides are organochlorine and organophosphorous compounds (Golfinopoulos *et al.*, 2003). Organochlorine pesticides like DDT and dieldrin are persistent, insoluble, photostable and highly toxic to many target and non-target organisms (Davies & Day, 1998). They are known to resist biodegradation and tend to accumulate in living organisms and become “biomagnified” through food chains (Davies & Day, 1998; Sankararamakrishnan *et al.*, 2005).

The environmental contamination of natural waters by pesticide residues is of greater concern in developing countries. So far, many highly toxic, persistent and bio-accumulating pesticides such as DDT have been banned in the developed countries, in favor of more modern pesticide formulations. In the developing countries, however, these kinds of highly toxic pesticides have not been banned because of reasons such as cost and efficacy (Sankararamakrishnan *et al.*, 2005).

1.5 SOLID WASTES

Solid wastes are the useless, unwanted or discarded waste arising from industrial, domestic and agricultural activities, which cannot be disposed of as a liquid by way of a sewage system, and it must be disposed of elsewhere (Kupchella & Hyland, 1989; Arms, 1994). Human activities have released enormous amounts of solid wastes into the environment for many years. The rivers and streams may be contaminated by solid wastes through land runoff, leaching, and direct dumping or via the storm water system (Kupchella & Hyland, 1989).

The types of solid waste are often classified by their sources. Urban wastes include municipal waste, industrial waste from manufacturing and industrial processes, commercial waste from stores, offices and other business activities, and domestic waste. Agricultural wastes include that from the rearing and slaughtering of animals, the processing of animal products, and orchards and field crops (Kupchella & Hyland, 1989). The main sources of solid wastes from industry include wood factories, paper mills, steel and aluminum factories, all kinds of packing companies, glass factories, and industries that deal with metallurgy, food and chemicals (Soliman *et al.*, 1998).

According to Cunningham & Saigo (1990) and Armitage & Rooseboom (2000), solid wastes can be classified as follows: paper (wrappers, newspapers, etc.); metals (foil, cans, etc.); plastics (shopping bags, wrapping, etc.); animals (dead animals and sundry skeletons); vegetation (branches, leaves, rotten fruit and vegetables); construction material (shutters, timber props, etc.) and miscellaneous (old clothing, tyres, etc.). There are many ways to dispose of solid wastes, such as landfills, open dumps, incineration and resources recovery. Some of the solid wastes, such as paper, glass and some metals, are suitable for recycling.

Plastics are synthetic organic polymers (Gorman, 1993). The toxic chemicals in plastic packaging include benzene, cadmium compounds, carbon tetrachloride, lead compounds, styrene, and vinyl chloride (Kupchella & Hyland, 1989). Plastics are less biodegradable, tremendously popular, lightweight, unbreakable, and make up an ever-increasing portion of the solid waste stream. The waste stream is the steady flow of varied waste that is produced from industrial, commercial, domestic activities and construction refuses (Cunningham & Saigo, 1990). Since the plastic debris can disperse over long distances and persist for centuries, plastics waste may pose a serious hazard to the aquatic system.

Davies and Day (1998) drew attention to the effect of solid wastes in rivers and streams. Silt as a solid waste threatens animal health and the aquatic ecosystem. Excessive silt entering into the rivers may break the cycle of aquatic communities by killing the animals and their eggs, and can impoverish the fauna. Furthermore, solid wastes, such as plastic bags and tin cans, can physically choke small streams.

1.6 ORGANISMS

1.6.1 Alien Organisms

Alien organisms are plants, animals and microorganisms, which are deliberately or accidentally introduced by various human activities to ecosystems outside of their natural range (DEAT, 1997). They occur in all major taxonomic groups, including algae, amphibians, birds, ferns, fish, fungi, higher plants, invertebrates, mammals, mosses, reptiles and viruses (McNeely *et al.*, 2001). Alien species can be considered as biological pollutants when they cause harm to ecosystems (Mason, 2002).

Invasion by alien organisms into habitats and ecosystems has been recognized as an economic and an environmental problem, threatening ecosystem functioning, global biodiversity, the integrity of species, water availability, the attractiveness of natural areas and human health (Vitousek *et al.*, 1996; Richard & Dean, 1998). The major economic damages are due to alien aquatic plants clogging navigation routes, water intakes and fishing equipment, reducing the recreational value of rivers and lakes, and the cost of controlling measures (Larson, 2003). Pimentel *et al.* (2000) reported that the approximately 50,000 alien species in the United States cause about $137 billion per year in damages.

The environmental damage of invasive alien organisms, such as reducing the earth's biological diversity (through the extinction of genetically distinct populations or species), can be caused by competition with rare native species or habitat modification (Vitousek *et al.*, 1996; Larson, 2003). Invaders may completely alter ecosystem processes such as primary productivity, decomposition, hydrology, geomorphology, nutrient cycling and/or disturbance regimes (Vitousek *et al.*, 1997 b).

Le Maitre *et al.* (2000) reported that invasion by alien plants, mainly trees and woody shrubs, has had a significant impact on the water resources of South Africa, replacing indigenous vegetation and altering riparian ecosystem functioning. Invasive alien plants utilized more water when compared to South African indigenous vegetation, which results in the reduction of runoff and stream flow. Alien plants have invaded an area of estimated 10.1 million ha of South Africa and Lesotho. The total incremental water use of invading alien plants is estimated to be 3300 million m^3 per year.

Bruton and Merron (1985) reported that at least 93 species of alien and translocated indigenous aquatic animals have established populations in southern Africa and all major river systems are inhabited by alien animal species, especially fishes, which constitute the majority (68.8%) of the invasive species. The harmful effects of invasive fishes include habitat alterations, removal of vegetation, reduction of water quality, introduction of parasites and diseases, trophic alterations, hybridization, extinction of endemic species through predation, grazing, competition, and overcrowding.

1.6.2 Pathogens

Pathogens are microscopic disease-causing organisms, which include bacteria, viruses, fungi, protozoa and parasitic worms. These have a tremendous effect evidenced by their ability to pose an immediate and serious health threat (Mason, 2002). The water-borne pathogens may cause many serious human diseases, such as cholera, typhoid, bacterial and amoebic dysentery, enteritis, polio and infectious hepatitis. Pathogenic organisms from human and animal wastes have been regarded as the most serious water pollutants with the prime concern being the direct risk to human health (Cunningham & Saigo, 1990; Jeffries & Mills, 1994).

Worldwide, there have been countless numbers of large-scale waterborne disease outbreaks and poisonings throughout history resulting from pathogenic contamination of drinking water (Ritter *et al.*, 2002), usually because of faecal contamination of water resources (Mason, 2002). The sources of the pathogenic organisms in rivers and streams include untreated or improperly treated human waste, animal waste from feedlots or fields near waterways, and food processing plants with inadequate waste treatment facilities (Cunningham & Saigo, 1990).

1.7 CONCLUSION

It has now been recognized that the sectoral and fragmented approach to water resources management can best be addressed by adopting Integrated Water Resources Management. The concept of Integrated Water Resources Management has become accepted very much in conjunction with the concerns about sustainability (Voinov & Costanza, 1998) and the recognition that existing water management boundaries are not able to account for both the socioeconomic and ecological features of existing systems (Jewitt, 2001). The South African government has introduced the whole systems approach to the management of water resources through the "Resource Directed Measures". This aims at determining the quantity and quality of water required to maintain ecosystem integrity, i.e. the "Reserve", which must then be implemented (MacKay, 2000).

Rivers and streams are highly complex systems and serve a number of functions: irrigation, drinking water supply, hydroelectric power generation, fish farming, waste disposal, community development, draining storm runoff and conveying effluents (Smith, 2000). There is an increasing demand for good quality freshwater from rivers due to rapid population growth, economic activities, agricultural irrigation and industrial development.

The water quality in rivers is closely linked to water use and economic development. In many parts of the world, rivers and their catchment have been degraded by many factors, such as urban development, pollution, riverbank erosion, solid wastes, channel engineering, and poor agricultural practices. Nutrients, heavy metals, salts, pesticides, solid wastes, alien organisms and pathogens are identified as the water pollutants, which may affect the water quality in rivers and the aquatic ecosystem. It is therefore necessary to monitor the water quality in the rivers closely.

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CHAPTER 2

Inorganic Chemical Pollution in the Bottelary River

2.1 INTRODUCTION

Of all the natural resources needed for sustainable development, fresh water is one of the most essential. Fresh water resources, such as rivers and streams, have undergone human-derived changes through the last century and have been under increasing threat of pollution in recent years due to increasing anthropogenic activities.

South Africa is a semi-arid country and is currently facing a water supply crisis. This is caused by a combination of high evaporation rates, increasing population and low rainfall (DWAF, 1996 d) as well as scarcity of rivers. An average annual rainfall of only 464 mm is well below the world average of 857 mm (Anon., 2004 b). The scarcity of rivers in South Africa makes them all the more precious.

The Bottelary River is a major tributary of the Kuils River and is situated on the eastern side of the Cape Town Metropolitan Area, Western Cape, South Africa. The main use of water from the Bottelary River is for agricultural irrigation and livestock watering. The mode of discharge and water quality in the Bottelary River is influenced by climatic conditions, bedrock geology, soil type and human activities in the catchment area. The major land use activity in the Bottelary catchment is agriculture including livestock farming. As the human population grows and urbanization increases, there will continue to be an increase in pollution and catchment destruction. The Bottelary catchment area illustrates a system that has been altered due to human impacts, which have resulted in biophysical changes that, in turn have impaired the natural processes and reduced the ecological, aesthetic and recreational potential of the catchment area.

A survey of the concentrations of nutrients (nitrogen and phosphorous), heavy metals (cadmium, copper, iron, lead and zinc) and salinity in the Bottelary River was undertaken. The results of this inorganic chemical pollutant monitoring study are presented.

2.2 AIM

This study aims to assess the degree of chemical contamination, specifically nutrients, heavy metals and salinity, in the Bottelary River over a period of more than a year. This report represents the initial results, but the study is still continuing.

2.3 RESEARCH OBJECTIVES

The main objectives of the study are:

- To analyze and evaluate the water quality in the Bottelary River with respect to nitrogen, phosphorus, selected heavy metals and salinity;
- To examine the affect of the seasonality on water quality in the river.

The specific objectives of the study are:

- To assess the influence of the farming activities in the river catchment on water quality;
- To provide information on the river water quality for the farmers who use the water from the river for agricultural irrigation and livestock watering;
- To provide information essential to policy formulation, on the management of water quality in the Bottelary catchment;
- To suggest possible solutions toward a more appropriate management scheme for prevention of pollution in the river system.

2.4 RESEARCH QUESTIONS

The research questions are:

- Does eutrophication take place in the Bottelary River?
- Are the levels of selected heavy metals (cadmium, copper, iron, lead and zinc) in the Bottelary River a problem?
- Is there a salinity problem in the Bottelary River?

Hypotheses:
The concentrations of nutrients, heavy metals and salinity in the Bottelary River are within acceptable limits. There is no distinct seasonal pattern in nutrients, heavy metals and salinity concentrations in the Bottelary River.

2.5 CHARACTERISTICS OF THE STUDY AREA

The Bottelary River is a small tributary of the Kuils River and arises in the Bottelary Hills between Kraaifontein and Stellenbosch, Western Cape, South Africa. The river flows down across the flat lowland towards its confluence with the Kuils River in the suburb of Kuilsriver. The latter river in turn flows south-east through the Cape Flats and joins the Eerste River towards the False Bay coast. The location of the river is shown in Figure 1. The length of the Bottelary River is approximately 14–15 km (Ninham Shand, 2001; van Driel, 2003). The gradient of the riverbank is relatively steep as shown in Figure 2.

The Bottelary catchment is a sub-catchment of the Kuils River (Figure 3). Some of the upper sections of the catchment are urbanized (Kraaifontein), after which follows an intensive agricultural area that takes up most of the catchment, downstream of the catchment follows another urbanized area (Kuilsriver). The catchment is relatively short, wide and situated largely in a more rural area, with a catchment area of approximately 80 km^2. It generates an estimated virgin Mean Annual Runoff (MAR) of 6.2 cubic meters per annum (SD 4.469, CV 0.719) with high fluctuations between wet winter and dry summer months, according to the Department of Water Affairs and Forestry (DWAF), as estimated by a preliminary reserve numerical model, using WR90 data (van Driel, 2003).

The Bottelary catchment is within the winter rainfall area of the Western Cape (Ninham Shand, 1979). The total monthly rainfall ranged from 0.2 to 169.7 mm in

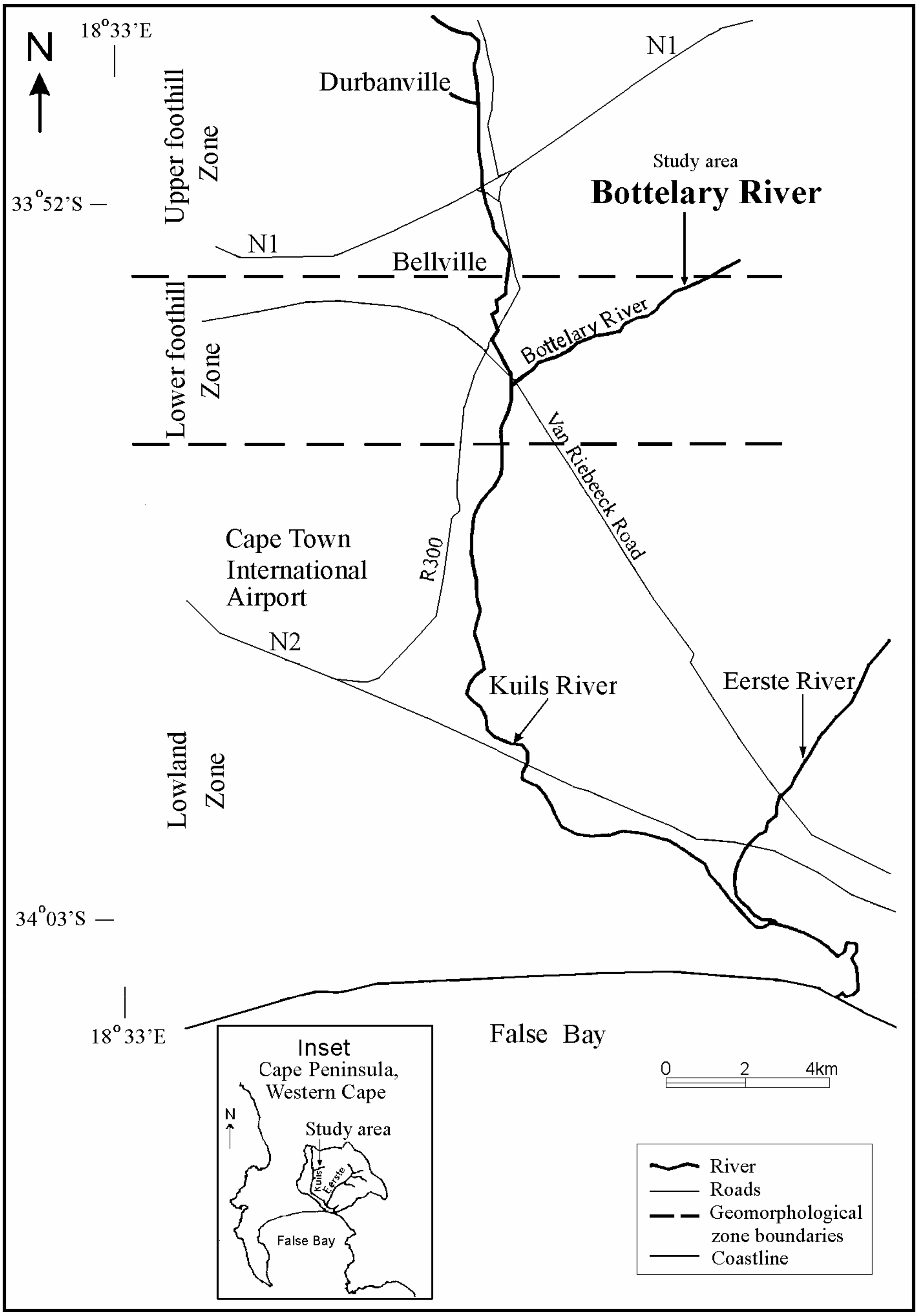


Figure 1. The Locality of the Bottelary River (Adapted from Ninham Shand & Chittenden Nicks, 1999)

Figure 2. The Bottelary River downstream of the Amandel Road Bridge showing the steepness of the riverbanks (site 2)

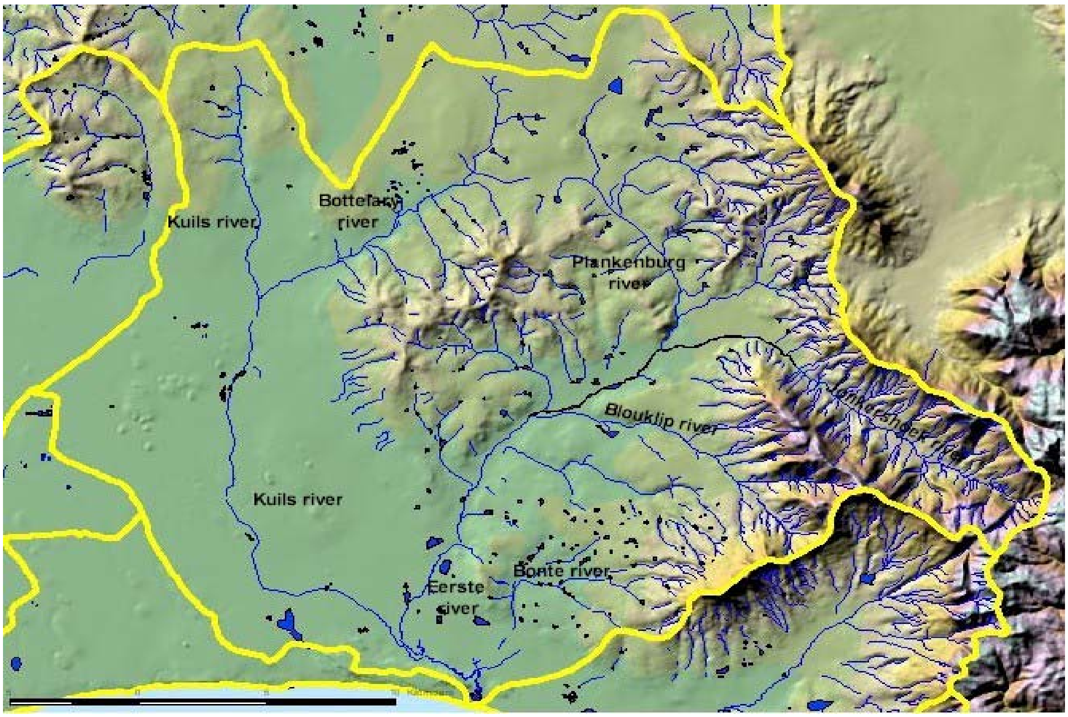


Figure 3. The catchment of the Bottelary River, the Kuils River and the Eerste River (Meyer, 2003)

2004 (Figure 4). The highest monthly rainfall occurred in August. The rainfall pattern displayed very big temporal variations during the year (Figure 4). The rainfall data was supplied by the South African Weather Service, for their station at the Cape Town International Airport. The location of the Cape Town International Airport is shown in Figure 1. Details are supplied in Appendix 1.

The water flow is strongly seasonal in the Bottelary River. The winter rainfall often occurs as storms of short duration; the resulting runoff washes pollutants accumulated in the catchment, into the river. Riverbank erosion occurs due to moderately high flow velocities at peak discharges (Ninham Shand, 2001). There are approximately 80 farm dams scattered across the catchment (van Driel, 2003). During the wet season, some of the farm dams overflow their banks and discharge into the Bottelary River, which influences the water quality in the river.

During the summer dry months, the river water is regulated and abstracted for various water uses such as livestock watering, crop irrigation purposes, the Kuils River Golf course, sports grounds and watering of domestic gardens, which results in a decrease in the water flow, thereby stressing the aquatic ecosystems (Ninham Shand, 2001). Furthermore, due to the low rainfall in the dry season, the water volume in the Bottelary River is much lower in certain areas in comparison to other parts of the river. Some streams may dry up completely.

The Swart River and the De Novo tributary are some of the tributaries of the Bottelary River. The Swart River is the upper tributary of the Bottelary River. The De Novo tributary seasonally originates from the streets in Brackenfell and Wallacedene. It flows towards the south and joins with the Bottelary River. The Swart River and the De Novo tributary are strongly seasonal, almost dry during the summer and flowing during the wet winter. Figure 5 (A) shows low water flow in the De Novo tributary during the dry summer season, while Figure 5 (B) shows an increased in water flow during the wet winter season.

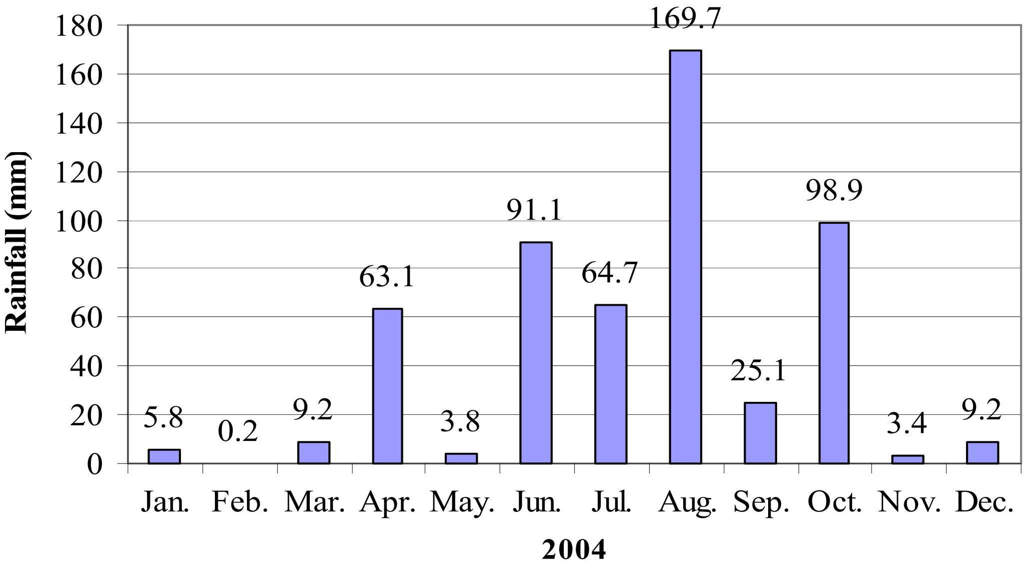


Figure 4. Total monthly rainfalls for the year 2004 (Data from South African Weather Service)

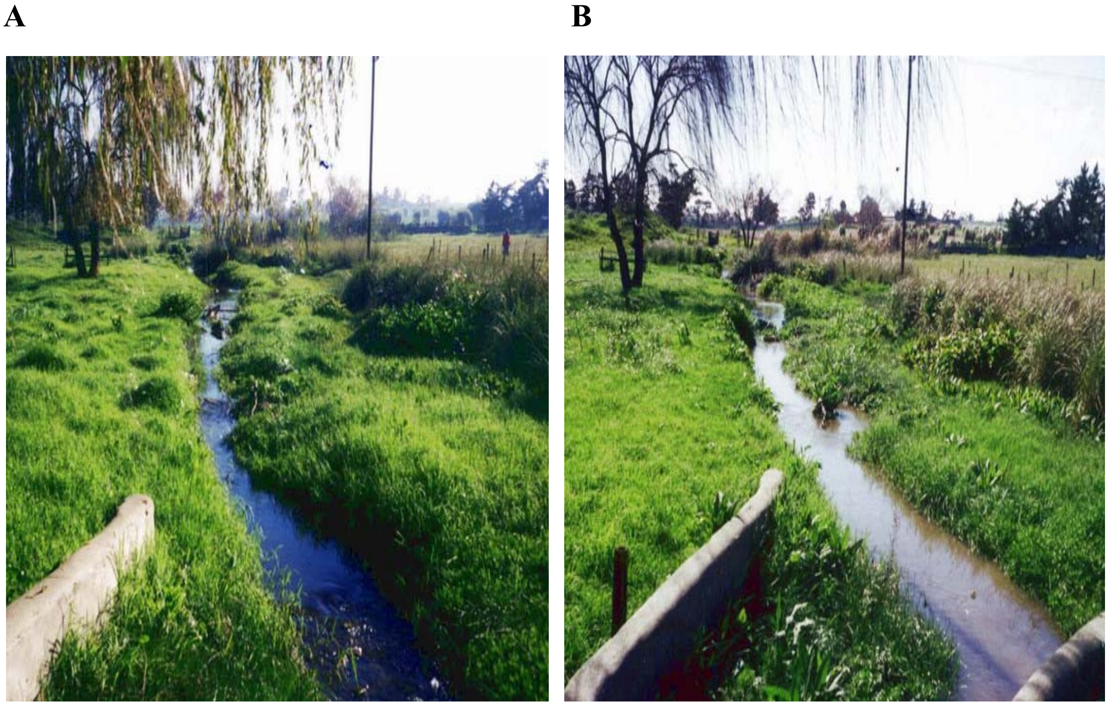


Figure 5. Showing the water flow of the river downstream in the De Novo tributary (site 6) during the dry summer season (A) and the wet winter season (B)

Some parts of the Bottelary River and its tributaries are channelized and straightened. The upper section where the De Novo tributary passes the Scottsdene Wastewater Treatment Works (WWTW) (Figure 6) and the last section of the Bottelary River (Figure 7) are concrete canals. The channelization of the river has accelerated the water flow. Other river sections are covered with riparian vegetation as shown in Figure 8.

The geology of the Bottelary catchment is constituted by rocks of the Malmsbury Group, which consist of quartzites, phyllite, greywacke and shales of Pre-Cambrian age and are covered by recent thin deposits of turf and loam. Ninham Shand (1979) and Ninham Shand (1994) indicated that the surface runoff in the Bottelary catchment is relatively high in the upper reaches and the subsurface flow is low because of the geological features. The Malmsbury Shales of the Western Cape are easily weathered rocks that naturally contain high concentrations of mineral ions, which may cause salinity (Davies & Day, 1998).

Everything that happens in the catchment area is reflected in the discharge and the quality of the river water. Apart from the effects of climate change, and geological features, the water quality in the Bottelary River is largely influenced by human activities in the catchment area, such as intensive agriculture, treated or untreated wastewater from Kraaifontein and Brackenfell, a golf course, chicken farms, and wineries and brick and tile works. These land uses may affect the quality and quantity of runoff during and following rainfall (Ngoye & Machiwa, 2004). The major pollutants from these sources are microbes, inorganic ions such as heavy metals, nutrients and salts, which are identified as priority pollutants to be monitored in the river catchment (Fatoki *et al.*, 2001).

The major point source discharging into the Bottelary River is a small sewage treatment facility, the Scottsdene WWTW with a present capacity of 7.5 Ml/day. It is located in the upper reaches of the Bottelary River and is registered with the DWAF

Figure 6. The channelized De Novo tributary (site 6.1)

Figure 7. The channelized lower end of the Bottelary River

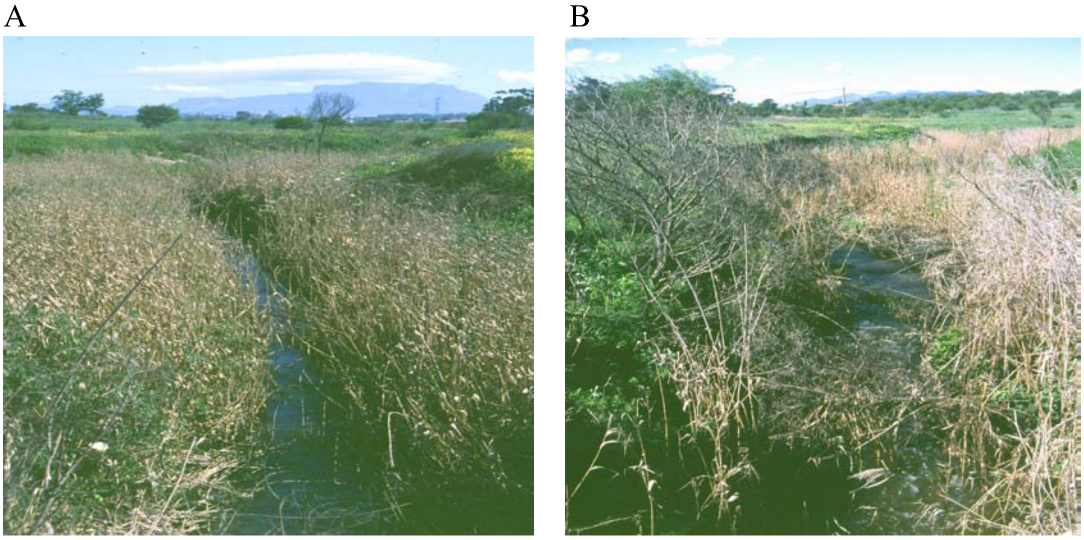


Figure 8. The Bottelary River downstream (A) and upstream (B) from the Rainbow Chicken Farm Bridge with a lush riparian vegetation (site 3): note the Table Mountain in the background in A.

under permit No. 896 B (Cape Wastewater Consultants, 1999; Ninham Shand, 2001). The Scottsdene WWTW receives wastewater from the urban areas of Scottsdene, Wallacedene and part of Kraaifontein as well as a small light industrial area, and the service area covers approximately 350 ha (Cape Wastewater Consultants, 1999).

The final treated effluent from the Scottsdene WWTW is usually well within DWAF permit guidelines and is discharged into the De Novo tributary and a dam downstream, from which water is withdrawn for crop irrigation purposes, resulting in very little flow of effluent down the river during the dry summer season (Ninham Shand, 2001). During the wet season, the runoff of storm water dilutes the treated sewage effluent downstream of Scottsdene as it flows down the Bottelary River (van Driel, 2003).

Non-point source pollution of the Bottelary River is mainly caused by urban runoff and agricultural runoff. Cultivation is the main land-use activity in the catchment area beyond the urban boundary. The major sources of pollution in agriculture are fertilizers containing nutrients such as nitrogen and phosphorus, and heavy metals such as cadmium, copper, lead and zinc. As farming intensifies, nutrients and heavy metals may be applied in excess of plant needs. The excess nitrogen, phosphorus and heavy metals in the form of land run-off and drainage from agricultural land have a potential to pollute river water quality and may pose a potential health hazard (Alloway & Ayres, 1997; Withers & Lord, 2002).

On the other hand, the farming practices tend to speed surface runoff and remove the protective cover on the land (Haslam, 1995). The return flows from irrigated agriculture may increase the salt and nutrient concentrations of the receiving water bodies, limiting agricultural, industrial, urban and ecological uses (Causapé *et al.*, 2004). Furthermore, the water quality in the Bottelary River may also be altered by livestock manure, animal and human waste, and atmospheric deposition.

2.6 MATERIALS AND METHODS

The research methodology involved field tests as well as laboratory analysis. The analyzed parameters include dissolved oxygen (DO), electrical conductivity (EC), pH, water temperature, nitrate (NO_3^-), nitrite (NO_2^-), ammonium ion (NH_4^+), phosphate (PO_4^{3-}), cadmium (Cd), copper (Cu), iron (Fe), lead (Pb) and zinc (Zn). The sampling was conducted six times (Table 1) at 13 different sites along the Bottelary River over a period of seven months from March 2004 to September 2004, starting from the dry through to the wet season and will be continued beyond a year.

Table 1. Sampling dates

Field Trips	**Dates**
1	29.03.2004
2	04.05.2004
3	29.06.2004
4	27.07.2004
5	24.08.2004
6	21.09.2004

2.6.1 Description of Sampling Sites

According to the characteristics of the Bottelary River and the possible sources of pollution, the representative sampling sites along the Bottelary River were chosen to evaluate the water quality situation in the river and reflect different activities in the catchment. The sampling sites along the Bottelary River were selected for accessibility, and to cover the length of the river and its main branches. The list of sampling sites on the Bottelary River is shown in Table 2. The location of the selected sites along the river is shown in Figure 9 and 10.

Table 2. List of the sampling sites on the Bottelary River

Sites	**Description**	**Sites**	**Description**
1.1	Kuils River upstream of Bottelary junction	6	Below Scottsdene WWTW
1.2	Kuils River downstream of Bottelary junction	6.1	Concreted Canal from Scottsdene Town
1.3	Lower Bottelary River	7	Varswater Farm
2	Amandel Road Bridge	7.1	Varswater Tributary
3	Rainbow Chicken Farm Bridge	8	Swart River
4	Bottelary Road Bridge	9	Mesco Farm
5	Groenland Farm Bridge	10	Bottelary Culvert

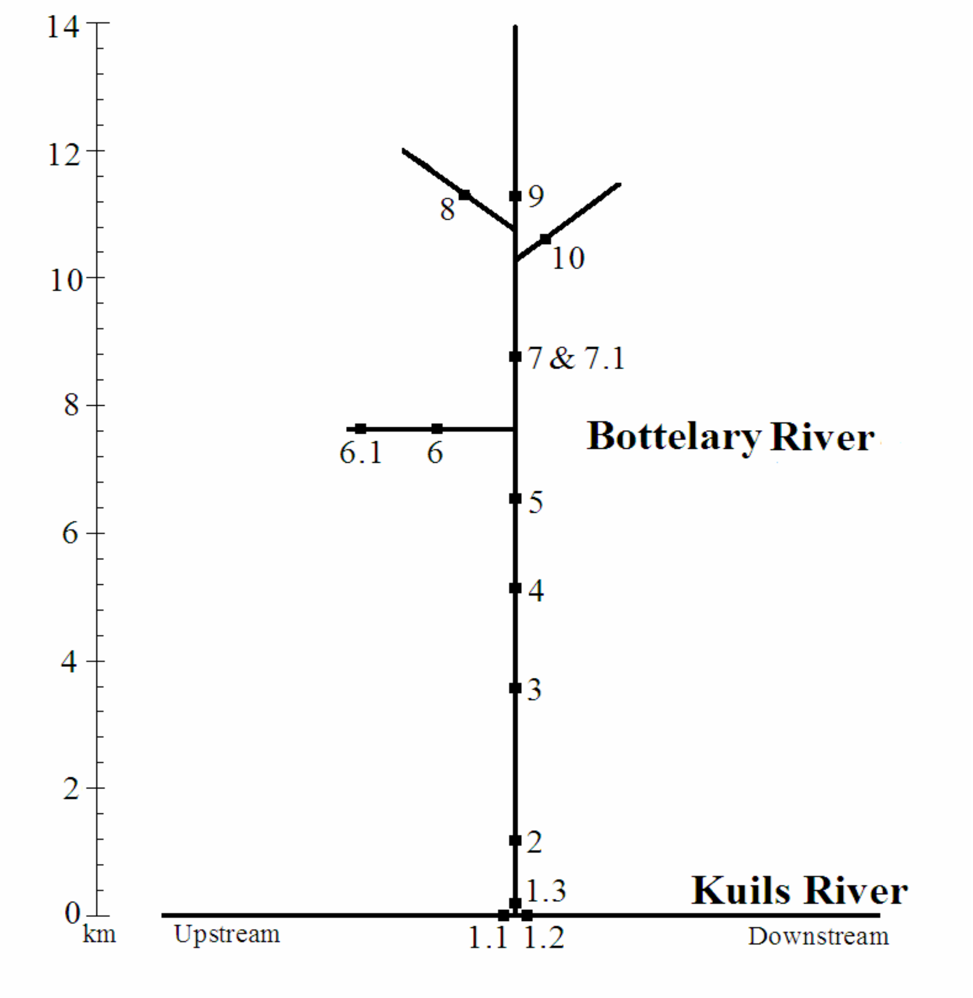


Figure 9. Diagrammatic representation of the relative positions of the sampling sites

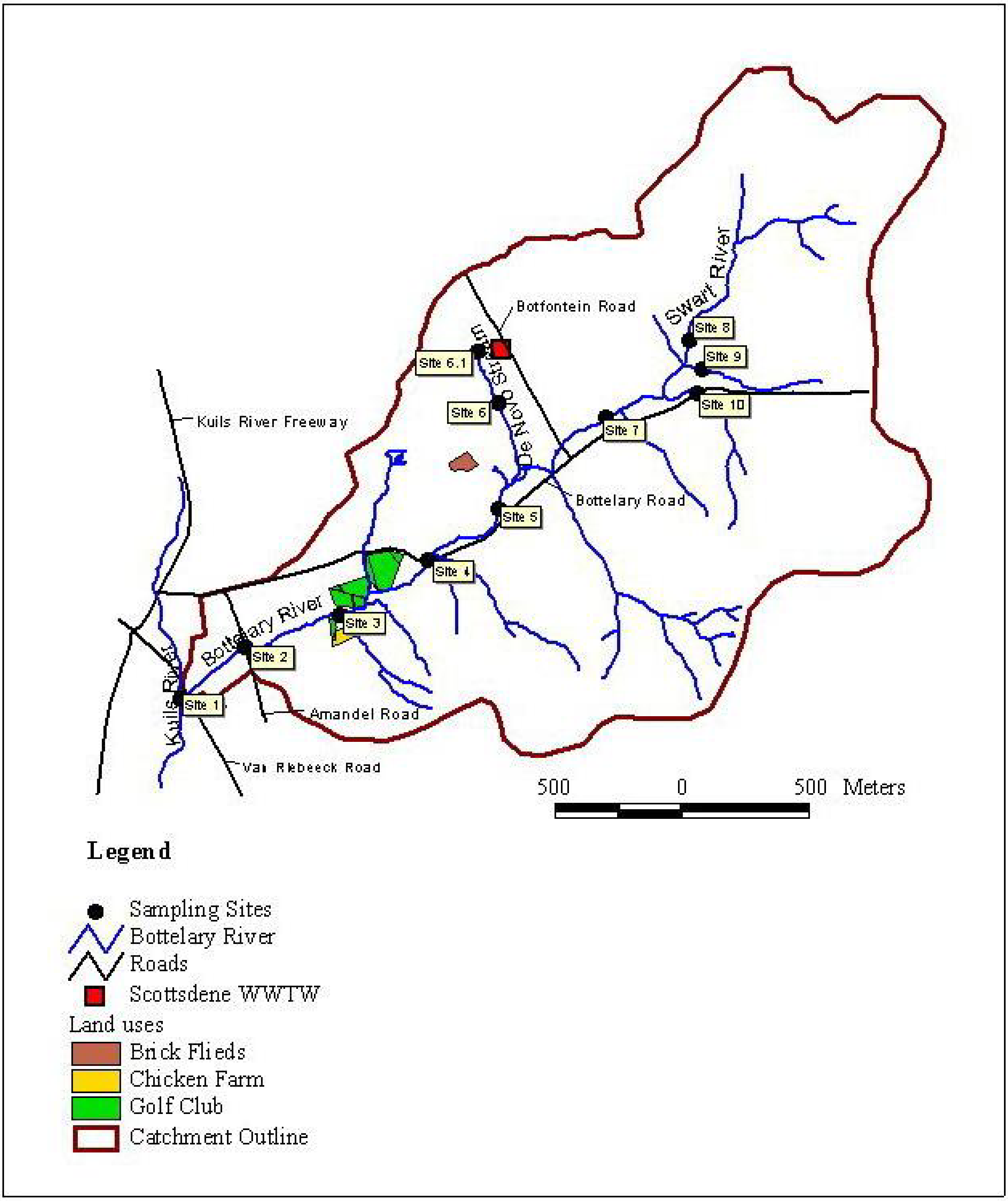


Figure 10. Location of the sampling sites on the Bottelary River

Three sampling sites were located around the junction of the Kuils River and the Bottelary River to reflect the water quality in different systems as shown in Figure 11. Site 1.1 was located just above the junction of the Kuils River and the Bottelary River in the Kuils River. Site 1.2 was located in the Kuils River downstream of the Bottelary River junction. Site 1.3 was located at the lower end of the Bottelary River.

Site 2 was located downstream of the Amandel Road Bridge (Figure 2). Site 3 (Figure 8) was a point located at a small bridge providing access to the Rainbow Chicken Farm. Site 4 was located at the Bottelary Road Bridge that crosses the middle of the river. Site 5 was located at a bridge on the Groenland Farm as shown in Figure 12.

Site 6 (Figure 5) was located below the Scottsdene WWTW in the De Novo tributary so that the impact of effluent discharge from Scottsdene WWTW on the water quality in the river could be assessed. Measurement point 6.1 was located upstream in the concreted De Novo tributary, running from Scottsdene in Kraaifontein as shown in Figure 6, which was chosen in order to investigate urban runoff from Scottsdene.

Site 7 was located at a small bridge on the Varswater Farm (Figure 13); site 7.1 was a small additional tributary which ran during August and September. Site 8 was situated in the upper tributary, the Swart River (Figure 14). Site 9 was located on the Mesco Farm as shown in Figure 15. Site 10 was at the Bottelary culvert where the Bottelary Road crosses the upper river. Site 11 was situated in a dam that collects the winery effluent upstream of site 9.

Figure 11. Location of three sites at the junction of the Kuils River and the Bottelary River

Figure 12. Showing site 5 on the Groenland Farm

Figure 13. Showing site 7 on the Varswater Farm

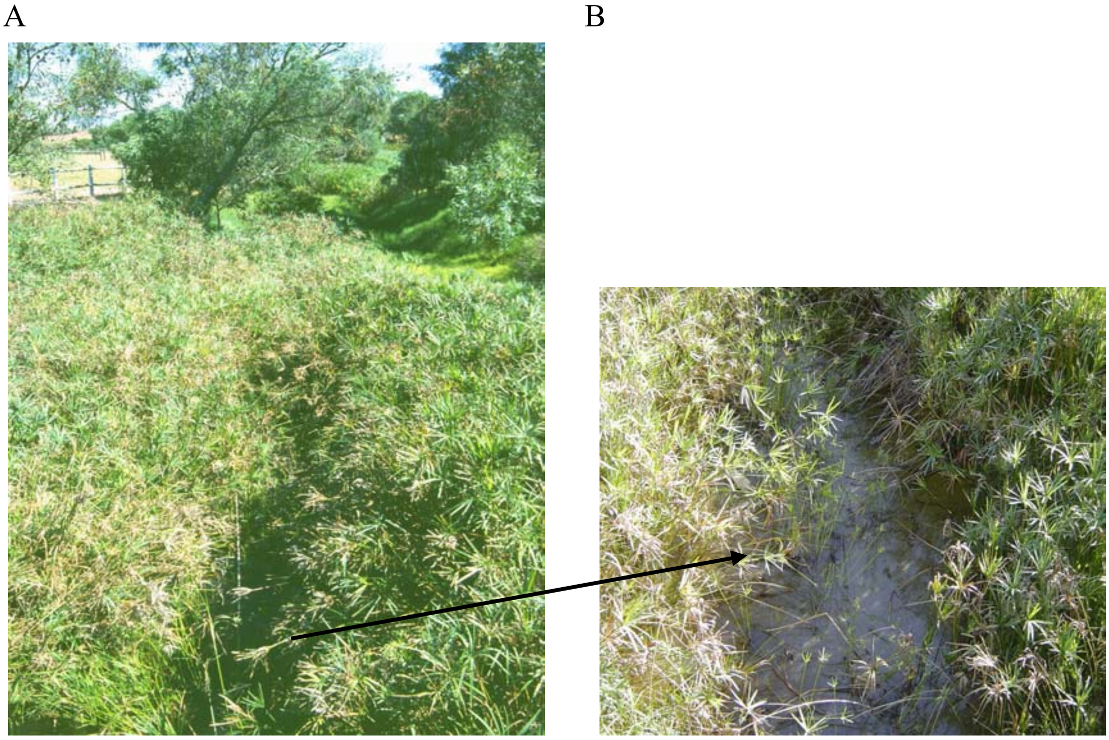


Figure 14. (A) and (B) showing site 8 in Swart River

Figure 15. Showing site 9 on the Mesco Farm

2.6.2 Field Procedures

Water samples were collected six times, using clean 500 ml plastic sampling bottles, at different sampling sites. Dissolved oxygen and water temperature were determined in the field for each site using a handheld dissolved oxygen meter (YSI Model 55 Handheld Dissolved Oxygen System, Japan). Dissolved oxygen was reported as milligrams per liter (mg/l), while water temperature was reported as degree centigrade (ºC).

2.6.3 Laboratory Procedures

Water samples were analyzed as soon as possible in the laboratory for pH, electrical conductivity, nitrate, nitrite and ammonia. They were then filtered, acidified, and stored at 4 ºC until all the sample collections had been made. Finally, the phosphate and the heavy metals concentrations were determined.

The water samples were measured for hydrogen ion activity using a pH meter (PHM 64 Research pH meter, Radiometer Copenhagen) and for electrical conductivity using a conductivity meter (Metrohm 644 conductometer, Switzerland) as a measure of salinity. A 0.5 cm^{-3} aliquot of hydrochloric acid (HCL) was added per 100 cm^{-3} of water before storage in a cold room.

2.6.4 Nitrogen Analysis

For nitrogen, three components were measured: nitrate, nitrite and ammonium ion. The concentration of inorganic nitrogen species in water is obtained by adding together the individual concentrations of nitrate, nitrite and ammonia (DWAF, 1996 d). Aquamerck Reagent Kits were used to estimate levels of nitrate, nitrite and ammonium ion in the laboratory. The detection limits for nitrogen by Aquamerck Reagent Kits were 2.5 mg/l for nitrate, 0.013 mg/l for nitrite and 0.25 mg/l for ammonium ion.

Nitrate was measured by using a Merck Nitrate Kit (Aquamerck^R 8032 Nitrate MERCK), which uses the reduction of nitrate to nitrite through the formation of an azo dye with sulphanilic/gentisic acid. The reagent kit included a colour scale. Comparison with the colour scale permits a rapid and semiquantitative assessment of the nitrate content present.

Nitrite was estimated using a Merck Nitrite Kit (Aquamerck^R 8025 Nitrite MERCK) which uses colorimetric determination with sulfanilic acid and N-(1-naphty1) ethylenediammonium dichloride reagent, with a colour scale. In acidic solution, nitrite ions react with sulfanilic acid to form a coloured diazonium salt and then reacts with N-(1-naphty1) ethylenediammonium dichloride to form a red-violet azo dye. The colour formation was used to estimate the nitrite concentration by visual comparison of the colours of the solution with the colour standards.

Ammonium was determined in the laboratory using a Merck Ammonium Kit (Aquamerck^R 11 117 Ammonium Test MERCK), which uses colorimetric determination with Nessler's reagent with a colour scale. Ammonium ions react with Nessler's reagent to form a characteristic yellow to brown dye. Again, a colour scale enabled estimations of ammonium levels.

2.6.5 Phosphorus Analysis

Phosphorus in natural waters is usually found in the form of phosphates and its concentrations are usually determined as orthophosphates, total inorganic phosphate or total dissolved phosphorus (which includes organically bound phosphorus and all phosphates). The operational categories of phosphates are soluble reactive phosphate, soluble unreactive phosphate, particulate reactive phosphate, and particulate unreactive phosphate. The most commonly measured is Soluble Reactive Phosphate (SRP), which is referred to as orthophosphate (DWAF, 1996 b).

The phosphate in the water samples was determined by using the ascorbic acid-molybdate blue method of Murphy and Riley (1962), which is based on the finding that antimony (as potassium antimonyl tartrate solution) reacts with phosphate solution containing the original single solution reagent (Murphy and Riley solution) to form an intense bluish-purple colour. The Murphy and Riley solution was made from a mixture of four reagents: sulphuric acid, ammonium molybdate, ascorbic acid, and potassium antimonyl tartrate (Murphy & Riley, 1962).

During the Murphy and Riley procedure, a standard phosphate solution was made in order to produce a standard curve before running the digested samples. The colour was allowed to develop for one hour and the absorbance was measured at 882 nm. One ml of unknown sample was pipetted into a fifty ml volumetric flask, and twenty-five ml of distilled water were added. Eight ml of the Murphy and Riley solution were then added and made up to volume with distilled water and thoroughly mixed. The resultant solutions were measured for their absorbance by using a Shimadzu 160-A UV visible recording spectrophotometer. The detection limit of phosphate by Murphy and Riley (1962) method was in the order of 0.1µg/l.

The phosphate was calculated using the following formula:
P (mg/l) (water) = Concentration (mg) ×1000/aliquot (ml) (Allen *et al.*, 1986)

2.6.6 Heavy Metals Analysis

The water samples were analyzed to determine the concentrations of cadmium, copper, and lead by using a Unicam Solaar M Series Atomic Absorption Spectrometer (AAS) with GF95 Graphite Furnace System. The detection limits were 0.56 pg/l for cadmium, 1.8 pg/l for copper and 1.5 pg/l for lead. The concentrations of iron and zinc were determined by using the same instrument with an air/acetylene flame system. The detection limits were 0.06 pg/l for iron and 0.013 pg/l for zinc.

2.6.7 Statistical Analysis

The statistical analysis was based on the raw data in the Appendix 2. This analysis was professionally carried out by the Agricultural Research Council using SAS Version 8.2 (SAS, 1999).

2.6.8 Comparison of Results with the South African Water Quality Guidelines

The South African Water Quality Guideline series was published by the Department of Water Affairs and Forestry for water resource protection and water quality management. In order to compare the results to the South African Water Quality Guidelines the background concentrations of the particular water sources need to be known. To estimate the background concentration of a water quality constituent there has to be a data set covering at least one hydrological cycle for an unimpacted point at which:

- there are no identifiable point or diffuse sources upstream; and
- there are enough data available to be certain that there is no temporal trend at the 85% confidence interval.

The background concentration is then taken to be the 90-percentile concentration of the water quality constituent in this data set (DWAF, 1996 d). For the portion of the Bottelary River that was studied, it was not possible to determine the background concentration of the water quality parameters as there was neither enough data covering a single hydrological cycle nor was there any portion that could be considered as not being impacted by various sources.

The water hardness is defined as the sum of the calcium ions (Ca^{2+}) and magnesium ion (Mg^{2+}) concentrations, both expressed as carbonate, in milligrams per liter (DWAF, 1996 d; Baird & Cann, 2005). The South African Water Quality Guidelines define the water as being medium if its hardness index lies between 60–119 mg/l and as being soft if its hardness index is below 60 mg/l (DWAF, 1996 d). According to the historical results obtained by van Driel (2003), the sum of the Ca^{2+} and Mg^{2+} concentrations in the Bottelary River was 95.6 mg/l in July 2003 (winter) and was 48.5–50.7 mg/l in January and February 2001 (summer), which was within the medium and soft ranges.

2.7 RESULTS AND DISCUSSION

The raw data are available in Appendix 2.

2.7.1 Nitrogen Concentrations

The (inorganic) nitrogen in water usually occurs in the form of nitrate, nitrite and ammonium ion (Davies & Day, 1998). Nitrate is the end product of the oxidation of nitrite or ammonia and does not cause direct toxic effects (DWAF, 1996 c&d). Nitrite is the inorganic intermediate of the inter-conversion of nitrate and ammonia (Davies & Day, 1998). It causes direct toxic effects to aquatic organisms and is 10–15 times more toxic than nitrate (DWAF, 1996 c). In the aquatic environment, the inter-conversion between nitrates and nitrites readily occurs. Under oxidizing conditions nitrite is converted to nitrate, which is usually far more abundant in the aquatic environment than nitrite (DWAF, 1996 c&d).

Ammonia is reduced form of inorganic nitrogen and can occur either in a free un-ionized form (NH_3) or in an ionized form as ammonium ion (NH_4^+) (DWAF, 1996 d). In solution, un-ionized ammonia occurs in equilibrium with the ammonium ion (DWAF, 1996 a). The relative proportion and toxicity of un-ionized ammonia are significantly affected by pH and water temperature (DWAF, 1996 d). The ammonia toxicity is also influenced by the concentrations of dissolved oxygen, carbon dioxide and total dissolved solids, and the presence of other toxicants, such as metal ions. The ammonium ion generally has little or no toxicity to aquatic biota, but contributes to eutrophication (DWAF, 1996 d).

2.7.1.1 Nitrate Concentrations

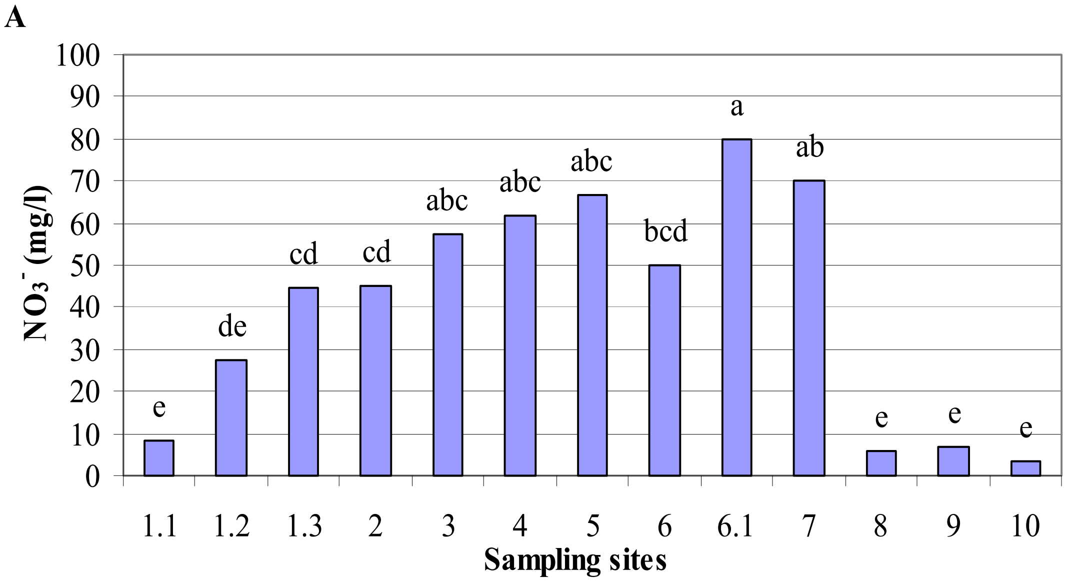
Nitrate concentrations ranged from 0 to 100 mg/l in the water samples from the Bottelary River. The mean values of nitrate were in the range of 3.58–80.00 mg/l, with the highest concentrations at sites 6.1 and 7 (Figure 16A). Since site 6.1 was located upstream in the De Novo tributary, running from Scottsdene, and site 7 was situated on the Varswater Farm, the high nitrate values could be attributed to urban and agricultural runoff.

The relatively low concentration of nitrate at site 6 (Figure 16A), which was located downstream in the De Novo tributary, seems to suggest that the discharge from the Scottsdene WWTW diluted the high nitrate value from upstream in the De Novo tributary (site 6.1). As the De Novo tributary enters the Bottelary River downstream of site 7, its nitrate concentration increased due to mixing with the high aggregate nitrate concentration coming downstream from the farmlands.

The nitrate concentrations from site 5 downstream to site 1.3 displayed a gradual decrease. The Kuils River upstream (site 1.1) and upstream in the Bottelary River (sites 8, 9 and 10) showed significantly lower levels of nitrate. These can be attributed to natural cleaning of urban drainage in the Kuils River and to the absence of effluents from urban and agricultural runoff in the Bottelary River.

The sampling was conducted between March and September in 2004. The results showed that the average nitrate concentrations were in the range of 22.27–53.39 mg/l and increased over the sampling period (Figure 16B). This may be due to increased runoff because of increased rainfall during the wet season (Figure 4).

According to the South African (SA) Water Quality Guidelines for livestock watering, the Target Water Quality Range (TWQR) for nitrate in water is 0–100 mg/l (DWAF, 1996 c&e). This limit was not exceeded in the water samples from the Bottelary



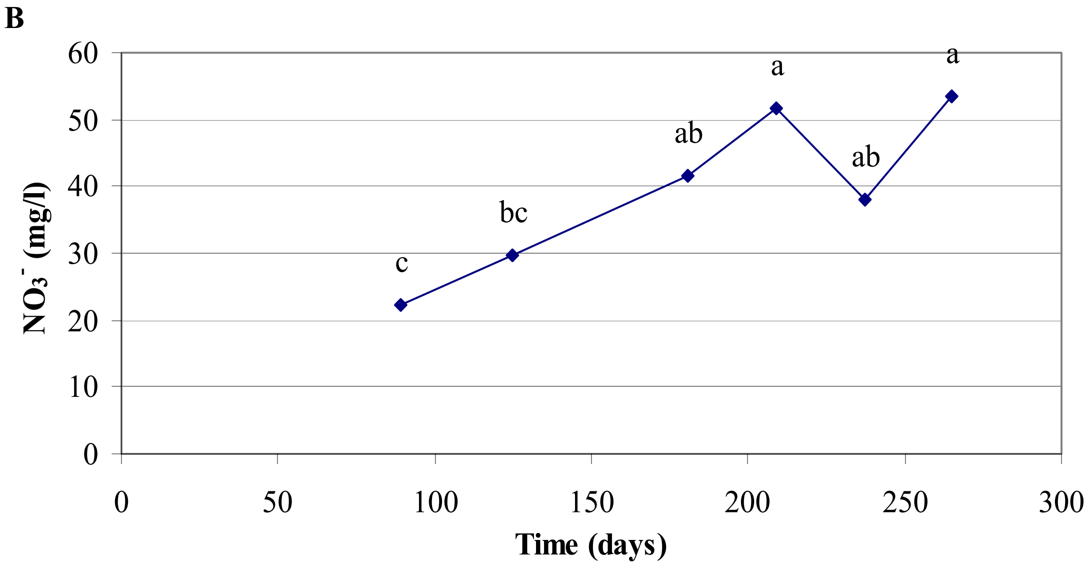


Figure 16. Means with the same letter are not significantly different at $p=0.05$. (A) Nitrate levels (mg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of nitrate in the Bottelary River and its main tributaries.

River; thus nitrate levels in the river are not considered to pose a problem for livestock watering.

The SA Water Quality Guideline for nitrate in domestic water states a limit of 26 mg NO_3^-/l as being a safe limit for babies (DWAF, 1996 a). From the results, about 54% of the nitrate concentrations in the water samples from the Bottelary River exceeded this limit. The values of nitrate at sites 1.1, 8, 9 and 10 were within this level (Figure 16). The nitrate concentrations are thus not considered safe for domestic use.

2.7.1.2 Nitrite Concentrations

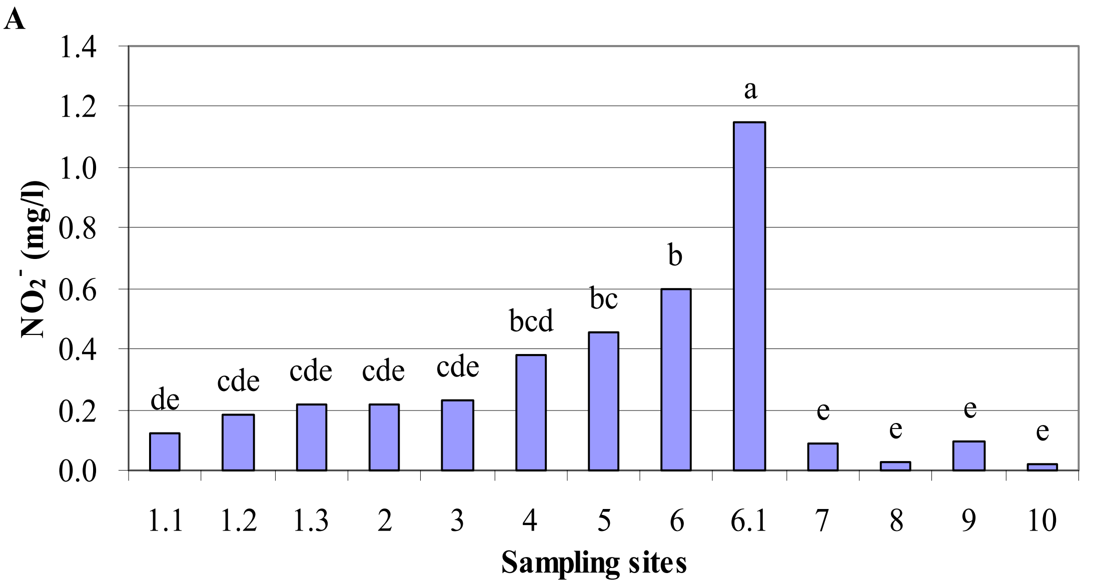
Nitrite concentrations ranged between 0 and 2 mg/l. The mean values of nitrite were in the range of 0.019–1.150 mg/l. The highest mean value of nitrite was noted at site 6.1 (concreted canal from Scottsdene) upstream in the De Novo tributary (Figure 17 A). This high nitrite value could be attributed to urban runoff from Scottsdene. The nitrite concentrations gradually decreased away from this polluted source (site 6.1), towards the junction of the Kuils River and the Bottelary River.

The concentrations of nitrite were significantly lower at sites 7, 8, 9 and 10 in the upper section of the Bottelary River and at site 1.1 in the Kuils River (Figure 17A), which showed that the impact of nitrite in these river sections was lower.

During the study period, the mean concentrations of nitrite were in the range of 0.07–0.54 mg/l and increased (Figure 17B), probably due to increased runoff because of increased rainfall during the wet season (Figure 4).

The SA Water Quality Guideline for nitrite in water to be used for livestock watering is 0–10 mg/l (DWAF, 1996 e). This level was not exceeded in the water samples from the Bottelary River. Thus, the water use from the river for livestock should not cause nitrite poisoning.

The SA Water Quality Guideline for nitrite in domestic water is 20 mg NO_2^-/l as a safe limit for babies (DWAF, 1996 a). This limit was not exceeded in the water samples. However, the World Health Organization (WHO) safe limit guideline for short-term exposure is 3 mg/l and for long-term exposure is 0.2 mg/l (WHO, 2004). The nitrite values in the water samples did not exceed the limit for short-term exposure, but exceeded the limit for long-term exposure. The nitrite concentrations are thus considered to pose a problem for domestic use.



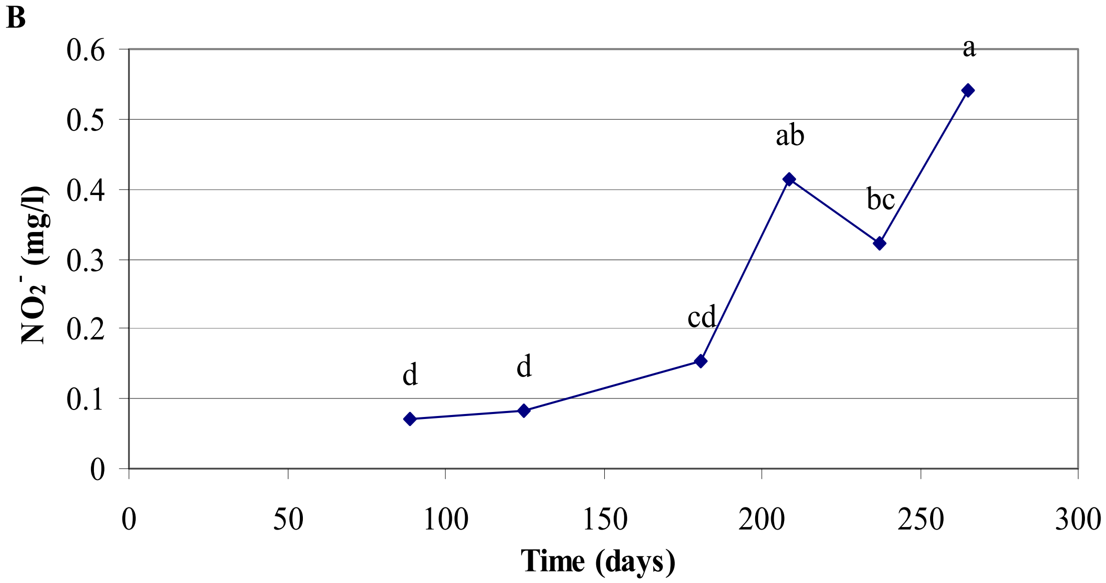


Figure 17. Means with the same letter are not significantly different at $p=0.05$. (A) Nitrite levels (mg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of nitrite in the Bottelary River and its main tributaries.

2.7.1.3 Ammonia Concentrations

The ammonium ion concentrations ranged from 0 to 10 mg/l. The mean values of ammonium ion varied between 0.33 and 6.17 mg/l. Figure 18 (A) shows that the mean concentrations of ammonium ion were significantly higher at site 6 (below the Scottsdene WWTW) and site 6.1(concreted canal from Scottsdene) in the De Novo tributary. The distinct peak in the concentrations of ammonium ion could have resulted from the discharge of treated sewage effluent from the Scottsdene WWTW and urban runoff from Scottsdene. The values of ammonium ion were significantly lower in the Kuils River and the main course of the Bottelary River, which were less impacted.

Figure 18 (B) shows that average ammonium ion concentrations were in the range of 0.69–2.40 mg/l and increased over the study period probably due to increased runoff because of increased rainfall during wet season (Figure 4).

The SA Target Water Quality Range for ammonia in aquatic ecosystems is based on the un-ionised ammonia fraction, which is 0–0.007 mg NH_3/l (DWAF, 1996d). The Chronic Effect Value (CEV) is 0.015 mg NH_3/l and the Acute Effect Value (AEV) is 0.1 mg NH_3/l. The guideline states that ammonium ions are converted to the highly toxic un-ionized ammonia when the pH value is above eight. Ammonia is found predominantly as ammonium ion in water at low and near-neutral pH, while at high pH (approximately 11), un-ionized ammonia predominates as a gas in solution, the latter being considerably more toxic to aquatic organisms, but it can be released to the atmosphere from the water. The percentage ammonia also increased with increased water temperature (DWAF, 1996 d).

The average ammonia concentrations for the sites in the De Novo tributary, estimated from the table provided by DWAF (1996 d) for 20˚C and pH 7.5, are approximately ten times the Target Water Quality Range maximum. This is well above the Chronic Effect

Value for aquatic ecosystems. The highest values obtained are well above the Acute Effect Value. Ammonia concentrations in the river would be a problem for aquatic ecosystems.

The SA Water Quality Guideline for ammonia in water for agricultural use for irrigation and livestock watering is not available (DWAF, 1996 b, c&e).

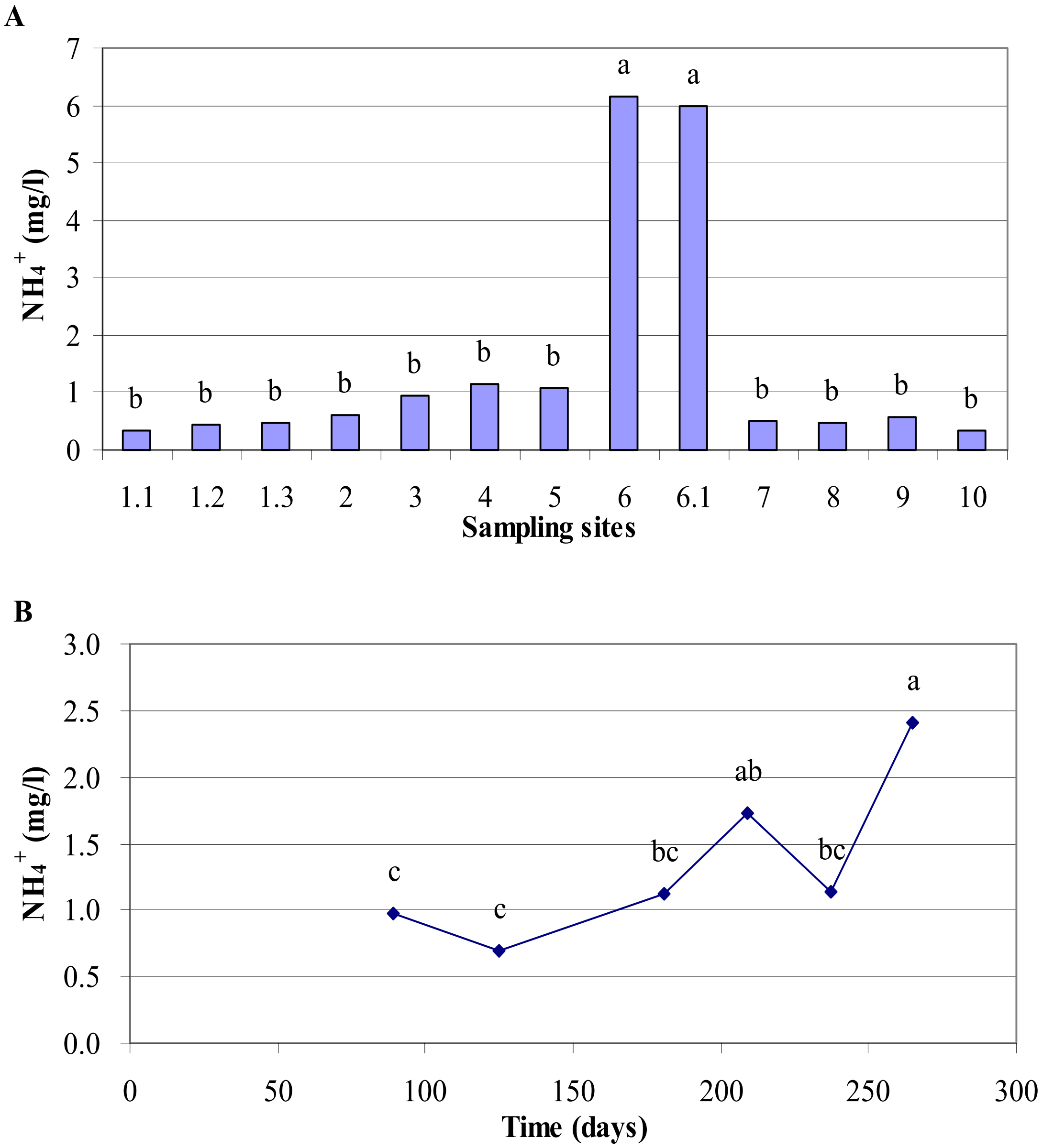


Figure 18. Means with the same letter are not significantly different at $p=0.05$. (A) Ammonium levels (mg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of ammonium in the Bottelary River and its main tributaries.

2.7.1.4 Total Nitrogen Concentrations

Total nitrogen concentrations in the water samples from the Bottelary River were in the range of 0.21–102.60 mg/l. The mean values of total nitrogen ranged from 3.94 to 87.15 mg/l. Figure 19 (A) shows that the maximum mean concentrations of total nitrogen were observed at site 6.1 (concreted canal from Scottsdene) and site 7 (Varswater Farm). The minimum mean concentrations were found in the Kuils River upstream of the Bottelary River junction (site 1.1) and upstream in the Bottelary River (sites 8, 9 and 10).

Figure 19 (B) shows that the mean concentrations of total nitrogen varied between 23.32 and 56.33 mg/l, and increased over the study period probably due to increased runoff because of increased rainfall during wet season (Figure 4).

The spatial and temporal distributions pattern of total nitrogen is similar to that of nitrate (see discussion on nitrate under section 2.7.1.1) because nitrate is the major component of total nitrogen. The results indicated that the total nitrogen in the Bottelary River mainly came from urban runoff from Scottsdene and agricultural runoff from the Varswater Farm. There was relatively less impact of nitrogen in the Kuils River above the Bottelary junction and upstream in the Bottelary River.

According to the SA Water Quality Guidelines for aquatic ecosystems (DWAF, 1996 d), the nitrogen criterion (Table 3) is based on summer values due to the enhanced effects on plant growth at higher temperature. The dry season values, though the lowest we obtained (Figure 19B), were in the hypertrophic range (Table 3). The high values of nitrogen would be a problem in the Bottelary River because of eutrophication.

The SA Target Water Quality Range for nitrogen in water to be used in agricultural irrigation equipment is 0–0.5 mg/l, while that for crop yield, quality, and prevention

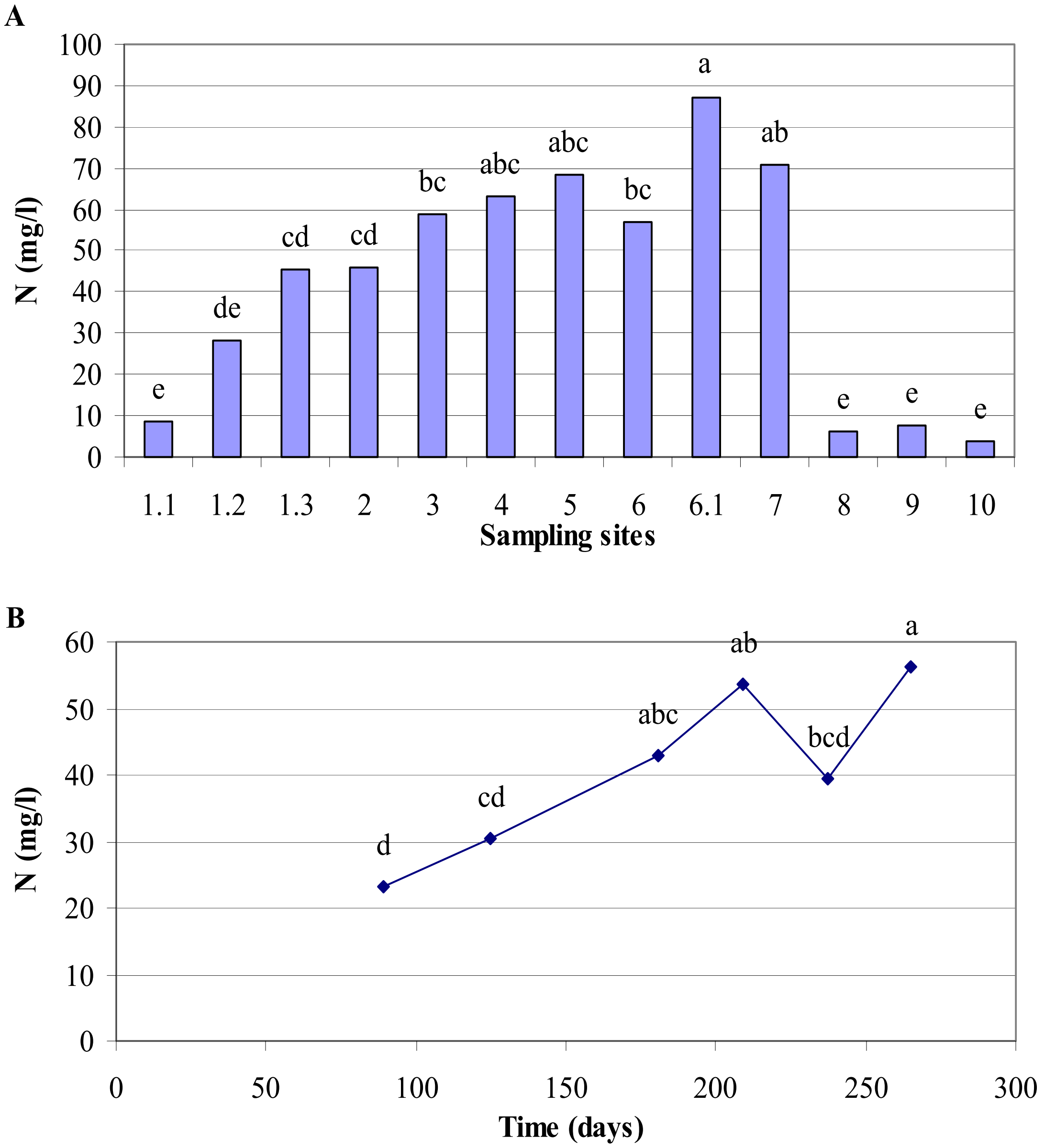


Figure 19. Means with the same letter are not significantly different at p=0.05. (A) Total nitrogen levels (mg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of total nitrogen in the Bottelary River and its main tributaries.

Table 3. Classification for aquatic ecosystems based on the concentrations of inorganic nitrogen and inorganic phosphorus (DWAF, 1996 d)

Average Summer Inorganic Nitrogen Concentration (mg/l)	**Average Summer Effects Inorganic Phosphorus Concentration (mg/l)**	**Effects**
< 0.5	< 0.005	Oligotrophic conditions; usually moderate levels of species diversity; usually low productivity systems with rapid nutrient cycling; no nuisance growth of aquatic plants or the presence of blue-green algal blooms.
0.5 – 2.5	0.005 – 0.025	Mesotrophic conditions; usually high levels of species diversity; usually productive systems; nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms seldom toxic.
2.5 – 10	0.025 – 0.25	Eutrophic conditions; usually low levels of species diversity; usually highly productive systems, nuisance growth of aquatic plants and blooms of blue-green algae; algal blooms may include species which are toxic to man, livestock and wildlife.
> 10	> 0.25	Hypertrophic conditions; usually very low levels of species diversity; usually very highly productive systems; nuisance growth of aquatic plants and blooms of blue-green algae, often including species which are toxic to man, livestock and wildlife.

of groundwater contamination is 0–5 mg/l (DWAF, 1996 b&e). The values of total nitrogen in the water samples from the Bottelary River significantly exceeded these limits, which indicated that the high concentrations of nitrogen would be a problem if the water to be used directly for agricultural irrigation.

The high values of nitrogen in the irrigation water could cause adverse effects on crops (by its stimulatory effect on the growth of weeds leading to delayed crop maturity and poor crop quality), increased likelihood of leaching and contaminating groundwater, and continuous growth of nuisance plants and blue-green algal blooms in irrigation structures in the absence of other growth-limiting factors (DWAF, 1996 b).

The SA Water Quality Guideline for nitrogen in water to be used for livestock watering is not available (DWAF, 1996 c&e).

2.7.2 Phosphorous Concentrations

Phosphorus is an essential macronutrient in life processes and is considered to be the principle nutrient controlling the degree of eutrophication in aquatic ecosystems (DWAF, 1996 d). The addition of large quantities of phosphorus accelerates algal and macrophyte growth in natural waters, enhancing eutrophication.

The phosphate concentrations in the water samples from the Bottelary River were in the range of 0–25.809 mg/l. The mean values of phosphate ranged from 0.527 to 18.202 mg/l. The highest mean concentration of phosphate was noted at site 6, below the effluent discharge point from the Scottsdene WWTW in the De Novo tributary (Figure 20A). Thus the high levels of phosphate in the Bottelary River could be attributed to the effluent discharge from the Scottsdene WWTW.

The phosphate concentrations displayed a gradual decrease from site 6 to the lower Bottelary River (site 1.3). There were significantly lower phosphate values in the Kuils River above the Bottelary junction (site 1.1) and upstream in the Bottelary River (sites 8, 9 and 10) (Figure 20A), which may be due to the absence of effects of the effluent discharge from the Scottsdene WWTW on these river sections. The mean phosphate value at site 1.2 differed from most other sites due to the dilution from the Kuils River.

During the period of investigation, the mean concentrations of phosphate were generally in the range of 4.52–9.79 mg/l and increased (Figure 20B). It may be due to increased runoff because of increased rainfall during wet season (Figure 4). Data from the Scottsdene WWTW also suggests an increase in phosphate concentrations in the effluent over the study period as shown in Figure 21 (Scientific Services, City of Cape Town, 2004).

According to the SA Water Quality Guidelines for aquatic ecosystems, the phosphorus criterion (Table 3) is based on summer values due to the enhanced effects on plant growth (DWAF, 1996 d). The dry season values, though the lowest we obtained (Figure 20B), were in the hypertrophic range (Table 3). The high concentrations of phosphorus would cause eutrophication in the Bottelary River. The Target Water Quality Range and criteria for phosphorus in water to be used for livestock watering and agricultural irrigation are not available (DWAF, 1996 e).

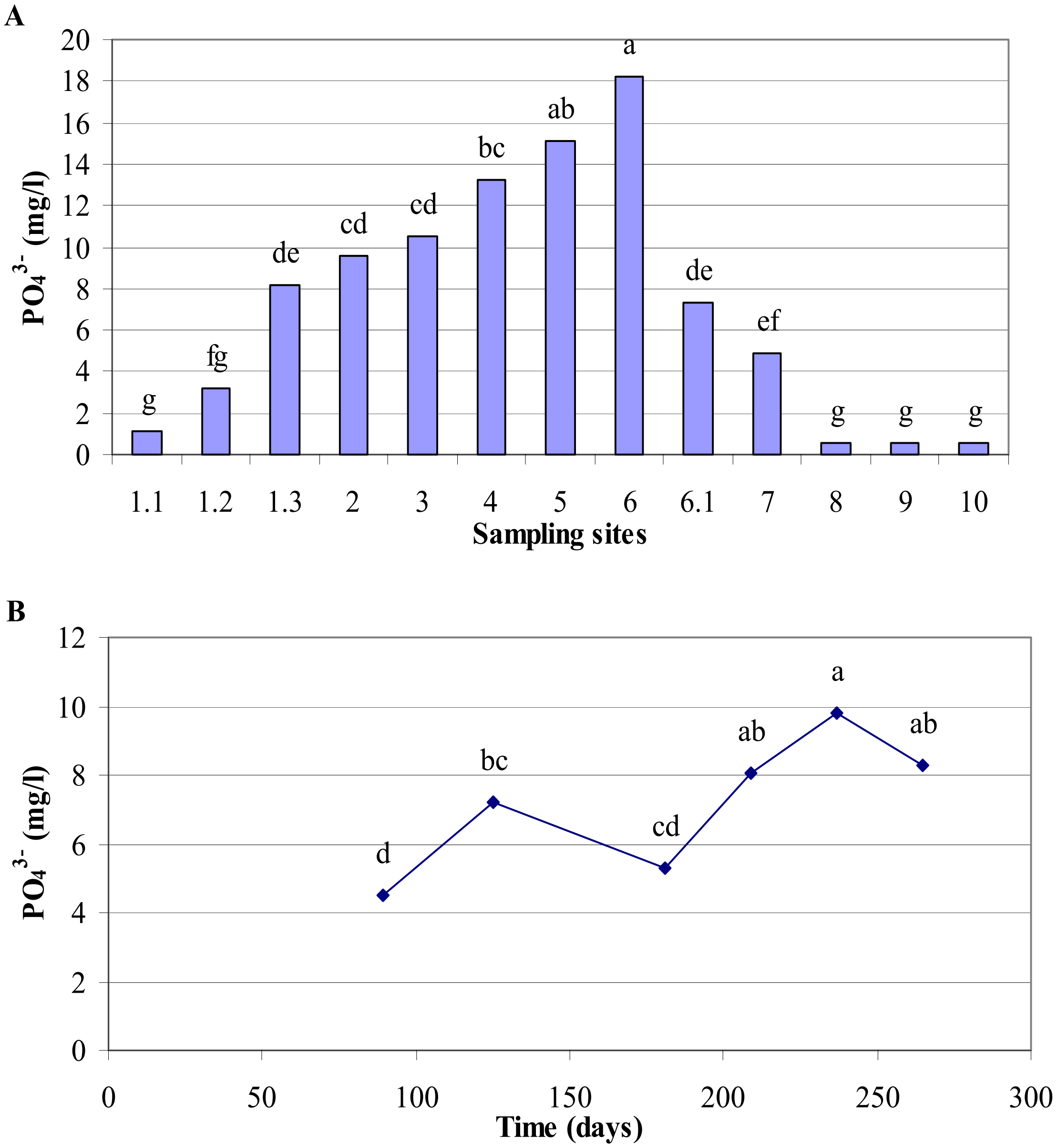


Figure 20. Means with the same letter are not significantly different at $p=0.05$. (A) Phosphate levels (mg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of phosphate in the Bottelary River and its main tributaries.

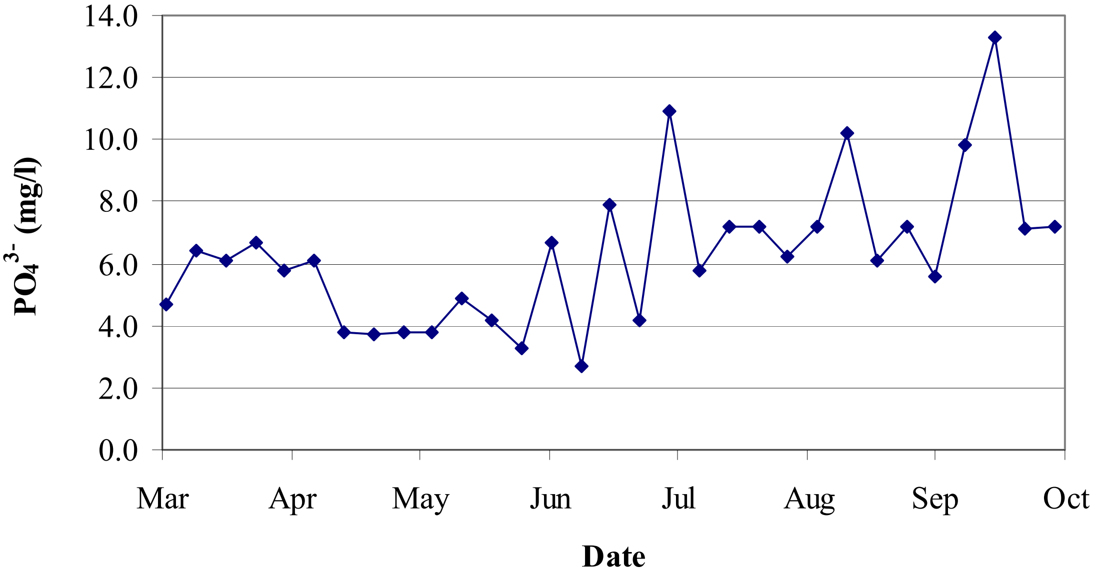


Figure 21. Phosphate levels in effluent from the Scottsdene Wastewater Treatment Works from March to September, 2004 (Data from Scientific Services, City of Cape Town, 2004)

2.7.3 N:P Ratios

The SA Water Quality Guidelines for aquatic ecosystems state that it is important to evaluate the ratio of inorganic nitrogen to inorganic phosphorus for any assessment of the influence of inorganic nitrogen and inorganic phosphorus. The unimpacted streams typically have N:P ratios greater than 25–40:1, while most impacted (i.e., eutrophic or hypertrophic) systems have ratios of less than 10:1 (DWAF, 1996 d).

Intermediate N:P ratios ranging from 10–15:1 were recorded upstream in the De Novo tributary (site 6.1) and upstream in the Bottelary River (sites 7, 8 and 9), except site 10 (Figure 22). The relatively high ratios at sites 6.1 and 7 were due to the high nitrogen levels. Sites 8 and 9 were less impacted by nitrogen and phosphorus than other sites in the river, which were subjected to severe pollution levels. The lowest N:P ratio was observed at site 6 (below Scottsdene WWTW), indicating the high level phosphorus impact from the Scottsdene WWTW.

A low N:P ratio was also noted at site 2 (Amandel Road Bridge) (Figure 22). In comparison to the historical water quality monitoring results for the same site obtained by Van Driel *et al.* (2001) reported in Ninham Shand (2001), the N:P ratio has dropped to 4.76 from 11.69. It indicated that the water quality in the Bottelary River has deteriorated.

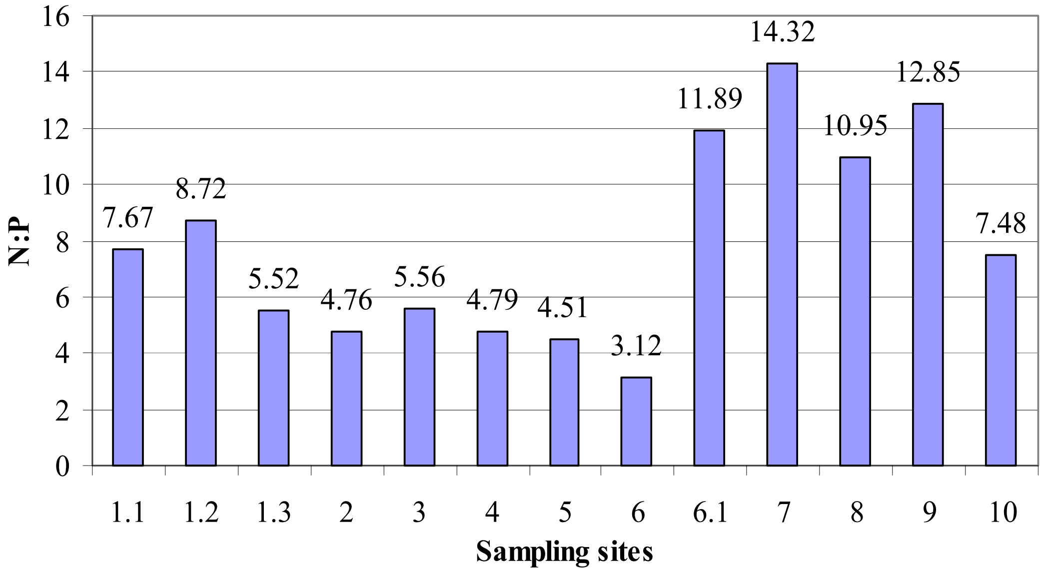


Figure 22. Ratios of inorganic nitrogen to inorganic phosphorus (based on means) for the water sample sites on the Bottelary River

2.7.4 Cadmium Concentrations

Cadmium is a heavy metal element and extremely toxic to aquatic organisms. The sources of cadmium in the aquatic environment are from natural weathering processes, mining, metal smelters, industries, agricultural use of sludges, fertilizers and pesticides, burning of fossil fuels, and the deterioration of galvanized materials and cadmium-plated containers (DWAF, 1996 d).

The cadmium toxicity in water is influenced by water hardness, salinity, chemical speciation, pH, water temperature, ligands and coexisting metal cations. Cadmium has a low solubility at neutral or alkaline pH values and is more soluble under acidic conditions. The toxicity effects of cadmium generally increase as salinity decreases. The presence of cadmium and other metals may result in either synergistic or antagonistic interactions; for instance, the interaction of cadmium and copper may result in a fivefold increase in the toxicity of both metals (DWAF, 1996 d).

The cadmium concentrations in the water samples from the Bottelary River varied between 0.0521 and 4.4776 µg/l. The mean values of cadmium ranged from 0.2216 to 1.3386 µg/l, with the highest concentrations at site 5 (Groenland Farm) and site 6.1 (concreted canal from Scottsdene). The lowest cadmium value was observed at site 10 (Bottelary Culvert) (Figure 23 A). The results suggest that the main source of cadmium in the Bottelary River could be urban runoff from Scottsdene.

During the study period, the average cadmium concentrations were in the range of 0.2198–1.4350 µg/l over time and increased (Figure 23B) probably due to increased runoff because of increased rainfall during wet season (Figure 4).

The SA Target Water Quality Range for cadmium in aquatic ecosystems is below 0.15 µg/l in soft water and less than 0.25 µg/l in moderately soft water. The Chronic Effect Value for cadmium is 0.3 µg/l in soft water and 0.5 µg/l in moderately soft

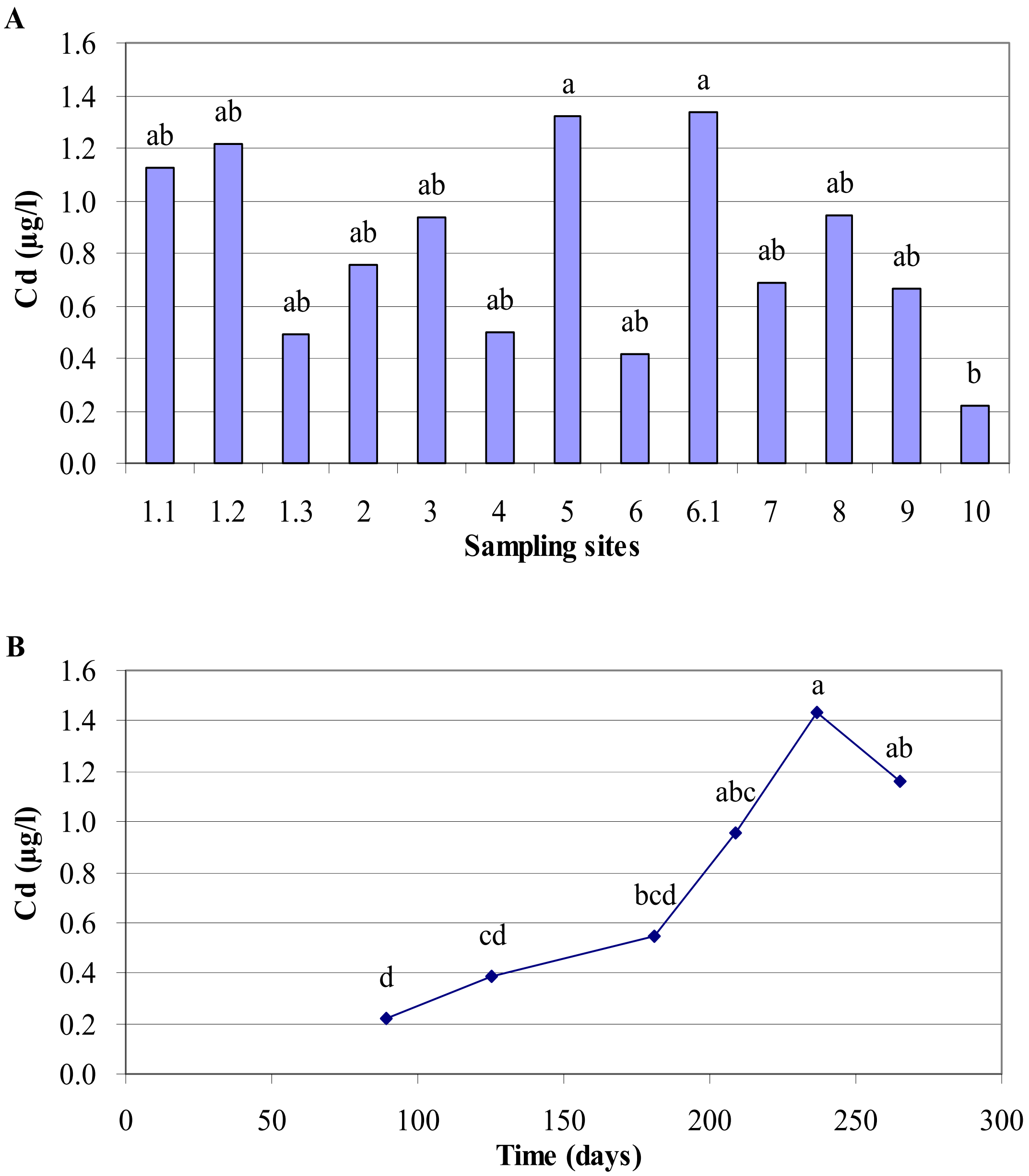


Figure 23. Means with the same letter are not significantly different at p=0.05. (A) Cadmium levels (µg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of cadmium in the Bottelary River and its main tributaries.

water, while the Acute Effect Value is 3 µg/l in soft water and 6 µg/l in moderately soft water. The guideline states that ninety percent (90%) of all cadmium measurements should be within the Target Water Quality Range and "all measurements should be below the Chronic Effect Value to ensure protection of aquatic ecosystems" (DWAF, 1996 d).

From the results, only about ten percent (10%) of the cadmium concentrations in the water samples from the Bottelary River were found within the 0.15 µg/l Target Water Quality Range for soft water. About twenty-eight percent (28%) of the cadmium values were observed within the 0.25 µg/l Target Water Quality Range for moderately soft water. The concentrations of cadmium exceeded the Chronic Effect Value and the Acute Effect Value in soft water, and the Chronic Effect Value in moderately soft water. Thus, the cadmium concentrations are unsuitable for sustaining aquatic ecosystems and the river water could cause adverse chronic and acute effects to aquatic organisms due to cadmium poisoning.

The cadmium levels detected in the water samples from the Bottelary River were lower than the SA Water Quality Guideline of 10 µg/l (DWAF, 1996 b&e) in water for agricultural irrigation. The concentration of cadmium in the river water is suitable for agricultural irrigation and is not toxic to plants.

The SA Water Quality Guideline for cadmium in water to be used for livestock watering is 0–10 µg/l (DWAF, 1996 c&e). This level was not exceeded in the water samples from the Bottelary River. The river water should not lead to adverse chronic or acute effects of cadmium poisoning in livestock.

2.7.5 Copper Concentrations

Copper has been used widely all over the world. It is a micronutrient, which can be rapidly accumulated by plants and animals. The main sources of copper in the aquatic environment include geological weathering, corrosion of brass and copper pipes by acidic waters, sewage treatment plant effluents, copper compounds used as aquatic algaecides, runoff and groundwater contamination from the use of copper as fungicides and pesticides, and liquid effluents and atmospheric depositions from industrial sources (DWAF, 1996 d).

In aquatic ecosystems, copper may be present in the forms of a solution of cupric ions, complexed with inorganic or organic ligands, associated with suspended or bed sediments, and as precipitates of hydroxides, phosphates and sulphides. Copper has a high solubility in acidic waters, and precipitates as copper hydroxides at pH values greater than 6.5. The toxicity of copper increases in aquatic systems with a decrease in water hardness, a decrease in dissolved oxygen, and when present in combination with other metals. Copper toxicity decreases in the presence of chelating agents (humic acids, amino acids and suspended solids), with an increase in alkalinity, and in the presence of zinc, molybdenum, sulphate, calcium and magnesium (DWAF, 1996 d).

Copper concentrations in the water samples from the Bottelary River ranged from 0 to 15.6532 µg/l. It was noted that the highest level of copper was 15.6532 µg/l at site 7.1. Since site 7.1 was an additional small tributary on the Varswater Farm and only ran in August and September during the sampling period, its mean concentration was not displayed in Figure 24.

The mean copper values ranged between 2.0364 and 5.3661 µg/l. Low concentrations of copper were displayed in the Kuils River above the Bottelary River junction (site 1.1), the Swart River (site 8) and on the Mesco Farm (site 9). The highest mean value of copper was observed at site 10 (Bottelary Culvert). The concentrations of copper also displayed high levels at site 4 (Bottelary Road Bridge) and site 7 (Varswater Farm) (Figure 24A). The high levels of copper could be attributed to runoff from the use of copper based pesticides on the farms, and the brick fields upstream of site 10. Figure 24 (B) shows that average copper concentrations were in the range of 2.5913–3.8333 µg/l and did not differ significantly over the sampling period.

According to the SA Water Quality Guidelines, the Target Water Quality Range for copper in aquatic ecosystems is less than 0.3 µg/l in soft water and below 0.8 µg/l in medium soft water. The Chronic Effect Value for copper in water for aquatic ecosystems is 0.53 µg/l in soft water and 1.5 µg/l in medium soft water, while the Acute Effect Value for copper is 1.6 µg/l in soft water and 4.6 µg/l in medium soft water (DWAF, 1996 d). The guideline also states that "ninety percent (90%) of all dissolved copper measurements for the site in question should be within the Target Water Quality Range", while "all measurements should be below the Chronic Effect Value to ensure protection of aquatic ecosystems" (DWAF, 1996 d).

From the results, only about one percent (1%) of the copper values in the water samples from the Bottelary River were within the 0.3µg/l Target Water Quality Range for soft water, while about four percent (4%) were found to be within the 0.8µg/l Target Water Quality Range for medium soft water. The concentrations of copper in the water samples from the Bottelary River exceeded the Chronic Effect Value and the Acute Effect Value for soft and medium soft water. Thus the river water is unsuitable for aquatic ecosystems and could cause adverse chronic and acute effects to aquatic organisms due to copper poisoning.

The copper concentrations in the water samples did not exceed the SA Water Quality Guideline of 200 µg/l (DWAF, 1996 b) in water to be used for agricultural irrigation. Thus, copper in the river water is suitable for irrigation and is considered safe for plants.

The SA Water Quality Guideline for copper in water to be used for livestock watering is 500 µg/l for sheep and pre-weaned calves, 1000 µg/l for cattle, and 5000 µg/l for horses, pigs and poultry (DWAF, 1996 c&e). The maximal values of copper in the water samples from the river did not exceed these limits. The use of water for livestock should not lead to adverse chronic or acute effects due to copper poisoning.

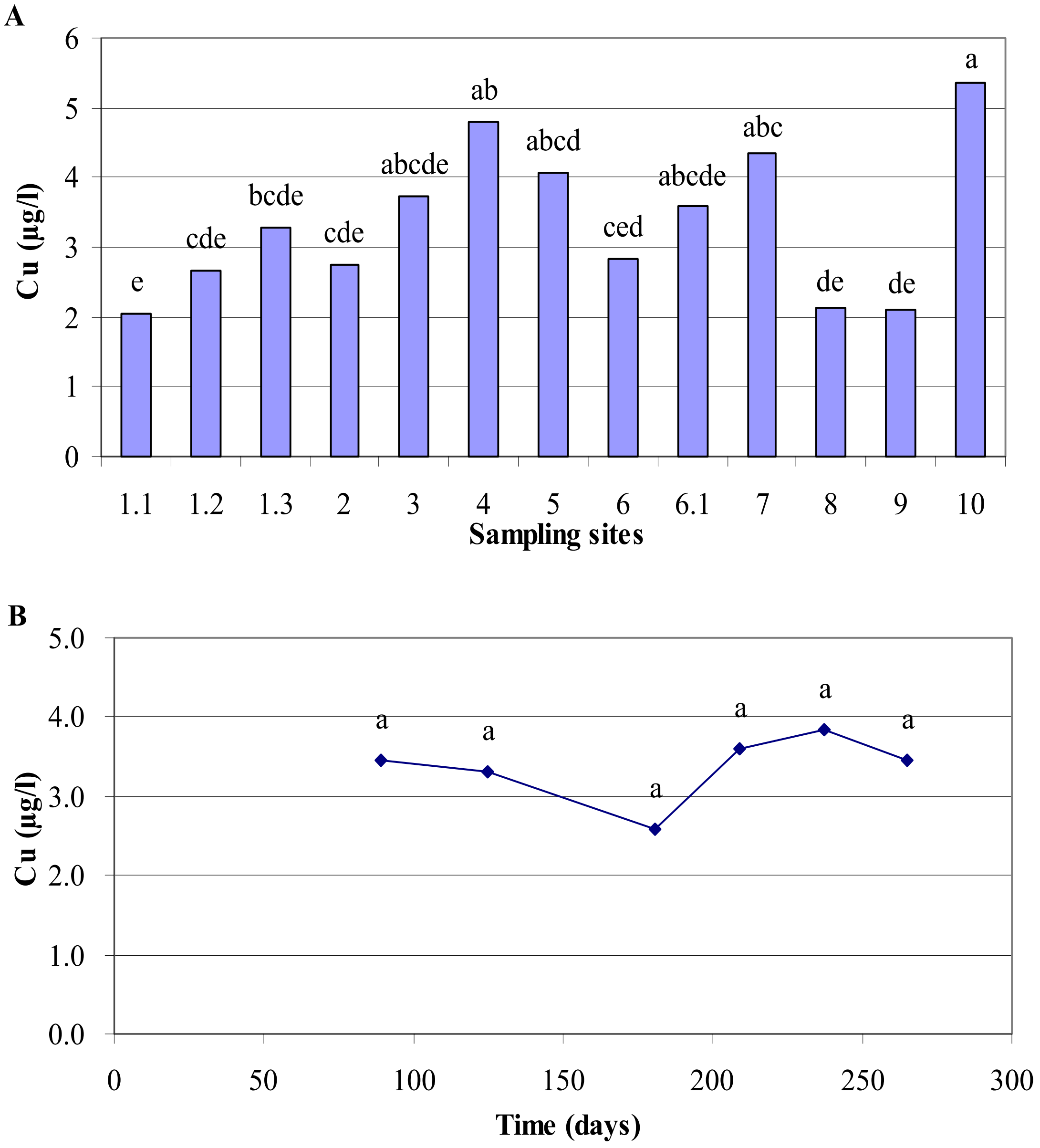


Figure 24. Means with the same letter are not significantly different at p=0.05. (A) Copper levels (µg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of copper in the Bottelary River and its main tributaries.

2.7.6 Iron Concentrations

Iron is the fourth most abundant element in the earth's crust and may be present in natural waters. It is an essential micronutrient for all organisms. Iron is released into the environment by natural processes, mainly from weathering of sulphide ores and igneous, sedimentary and metamorphic rocks, and by human activities, mainly from the burning of coke and coal, acid mine drainage, mineral processing, sewage, landfill leachates and the corrosion of iron and steel (DWAF, 1996 d).

In the aquatic environment, oxidation-reduction reactions, pH and the presence of co-existing inorganic and organic complexing agents determine the chemical behaviour of iron. The iron concentrations may be affected by the biological interactions in surface waters. The demand for iron during algal blooms can significantly reduce iron concentrations in the water (DWAF, 1996 d).

The iron values in the water samples varied between 0.0327 and 2.9013 mg/l. The mean concentrations of iron were in the ranged of 0.1881–0.7491 mg/l. High values of iron were found upstream in the Bottelary River, including sites 7 (Varswater Farm), 8 (Swart River), 9 (Mesco Farm) and 10 (Bottelary Culvert) (Figure 25A), probably due to agricultural runoff and runoff from the brick fields upstream of site 10. Since site 9 was located downstream of site 11 (dam containing winery effluents), the high iron value at this site could be attributed to the overflow of the dam due to the high rainfall during the wet season.

Low values of iron were found at sites 1.1 (the Kuils River upstream of the Bottelary River junction), 2 (Amandel Road Bridge), 5(Groenland Farm) and 6.1(concreted canal from Scottsdene) (Figure 25A), which indicated these river sections were less impacted.

During the period of investigation, the mean concentrations of iron were in the range of 0.2208–0.6764 mg/l and increased (Figure 25B). The highest value of iron was noted in August, which coincided with the occurrence of the highest rainfall. This may be due to increased runoff because of increased rainfall during the wet season (Figure 4).

The SA Target Water Quality Range for iron in water to be used for agricultural irrigation is 0–5 mg/l, while that for livestock watering is 0–10 mg/l (DWAF, 1996 b, c&e). These limits were not exceeded in the water samples from the Bottelary River. Thus, the iron values in the river would not be a problem if the water to be used for agricultural irrigation and livestock watering.

Since the data on the acute and chronic toxicity of iron to both invertebrates and vertebrates are rather limited, the SA Water Quality Guideline for iron in aquatic ecosystems is tentative, indicating that "the iron concentration should not be allowed to vary by more than 10% of the background dissolved iron concentration for a particular site or case, at a specific time" (DWAF, 1996 d). Determining the background dissolved iron concentration for the water sampling sites in the Bottelary River was not possible, as there were no uncontaminated sites upstream (see discussion under section 2.6.8). Therefore, the above criterion could not be used for the interpretation of the iron results.

On the other hand, the SA Water Quality Guideline for domestic use states that the concentration of dissolved iron in unpolluted surface water is in the range of 0.001–0.500 mg/l (DWAF, 1996 a). About eighty-two percent (82%) of the iron concentrations in the water samples were within this level. This indicated that most of the river sections were unpolluted.

The SA Water Quality Guideline for iron in water for domestic use is 0–0.1 mg/l (DWAF, 1996 a&e). From the results, only fourteen percent (14%) of the iron concentrations in the water samples were found to be within this level. Based on this parameter, the river water is unsuitable for direct domestic use.

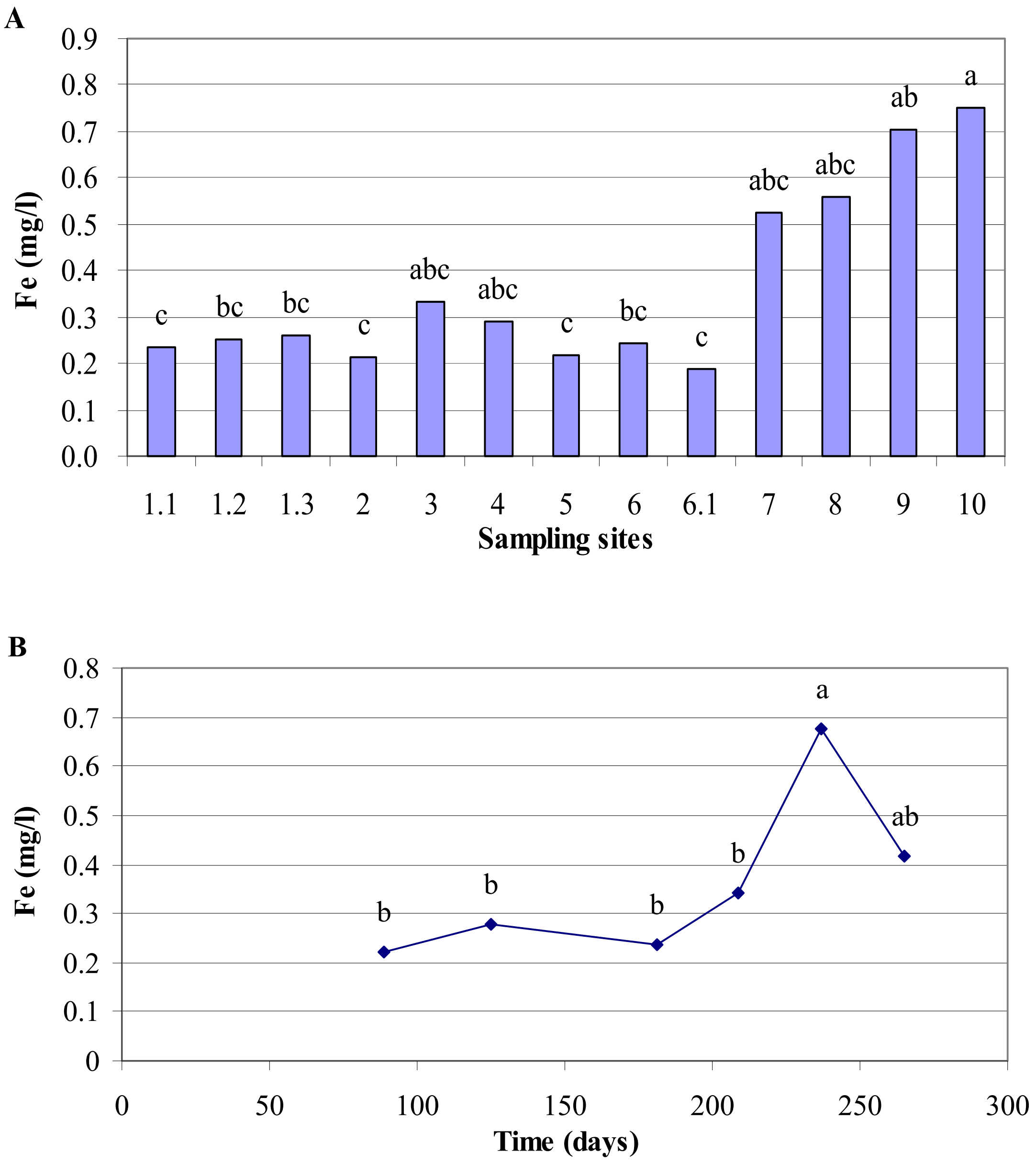


Figure 25. Means with the same letter are not significantly different at $p=0.05$. (A) Iron levels (mg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of iron in the Bottelary River and its main tributaries.

2.7.7 Lead Concentrations

Lead occurs as metallic lead, and inorganic and organometallic compounds, which readily accumulates in living tissue. It is considered potentially hazardous and toxic to most forms of life, and relatively accessible to aquatic organisms. The major sources of lead in the aquatic environment include the weathering of sulphide ores, especially galena, precipitation, fallout of lead dust, street runoff, industrial and municipal wastewater discharge, mining, milling and smelting of lead and combustion of fossil fuels (DWAF, 1996 d).

Lead levels were in the range of 0–0.2686 µg/l in the water samples from the Bottelary River. The mean values of lead ranged from 0.0232 to 0.1027 µg/l. Figure 26 (A) shows that the highest mean concentration of lead was recorded at site 3, which was located near the Rainbow Chicken Farm, while the lowest concentrations of lead were found at site 5 (Groenland Farm) and site 6 (below the Scottsdene WWTW).

Figure 26 (B) shows that the average concentrations of lead varied erratically between 0.0187 and 0.0968 µg/l, and did not show the increase through to the wet season reported for many other elements.

According to the SA Water Quality Guidelines for aquatic ecosystems, the Target Water Quality Range for lead is 0–0.2 µg/l in soft water and 0–0.5 µg/l in medium soft water. The guideline states that "ninety percent (90%) of all dissolved lead measurements should be within the Target Water Quality Range" and "all measurements should be below the Chronic Effect Value to ensure protection of aquatic ecosystems" (DWAF, 1996 d).

From the results, ninety-five percent (95%) of the lead values in the water samples were found to be below the 0.2 µg/l Target Water Quality Range for the soft water.

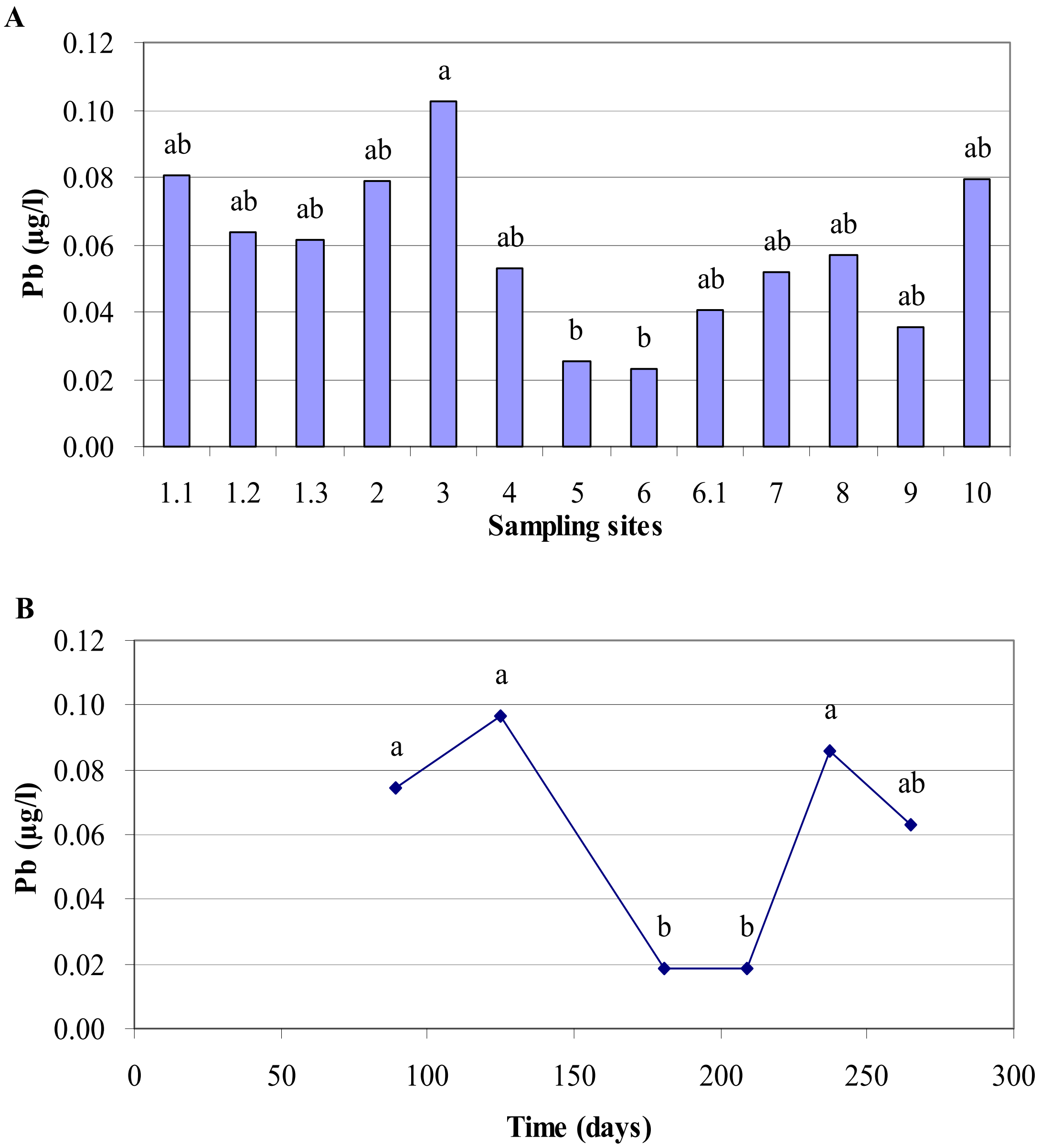


Figure 26. Means with the same letter are not significantly different at p=0.05. (A) Lead levels (µg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of lead in the Bottelary River and its main tributaries.

None of the lead concentrations exceeded 0.3 µg/l. Since the Chronic Effect Value for lead in the aquatic ecosystems is 0.5 µg/l in soft water and 1.0 µg/l in medium soft water (DWAF, 1996 d), these levels were not exceeded in the water samples from the Bottelary River. The river water is suitable for aquatic ecosystems and no adverse chronic and acute effects to aquatic organisms would be expected to occur due to lead poisoning.

The concentrations of lead in the water samples did not exceed the SA Water Quality Guideline of 200 µg/l (DWAF, 1996 b&e) in water for the use of agricultural irrigation. Lead is not expected to be a problem in the river water for agricultural irrigation.

The SA Water Quality Guideline for lead in the water to be used for livestock watering is 0–500 µg/l for pigs, and 0–100 µg/l for all other livestock (DWAF, 1996 c&e). These levels were not exceeded in the water samples from the Bottelary River. The use of the river water for livestock watering should not cause adverse chronic and/or acute effects due to lead poisoning.

2.7.8 Zinc Concentrations

Zinc is an essential micronutrient for all organisms as it forms the active site in various metalloenzymes, and occurs in two oxidation states in aquatic ecosystems, namely as the metal, and as zinc (II). The zinc (II) ion is toxic to fish and aquatic organisms even at low concentrations. Zinc can enter aquatic ecosystems through natural processes, such as weathering and erosion, and human activities, such as industries (e.g. metal galvanizing, dye manufacture and processing, pigments, pharmaceuticals, fertilizer and insecticide) (DWAF, 1996 d).

The mean values of zinc in the water samples ranged from 13.95 to 38.25 µg/l. The highest mean concentrations of zinc were observed in the concreted canal from Scottsdene upstream in the De Novo tributary (site 6.1) and in the Kuils River downstream of the Bottelary River junction (site 1.2) (Figure 27A). The high values of zinc in the Bottelary River could be attributed to urban runoff from Scottsdene. The mean zinc value at site 1.2 was relatively high, which could be due to mixing with the high aggregate zinc concentration coming from upstream in the Kuils River (site 1.1).

Figure 27 (B) shows that average zinc values ranged from 11.855 to 38.485 µg/l over time and increased over the sampling period. The highest value of zinc was noted in August, which coincided with the occurrence of the highest rainfall. This may be due to increased runoff because of increased rainfall (Figure 4).

The zinc concentrations in the water samples generally ranged between 5.8 and 93.7 µg/l. High zinc concentrations may pose a risk to the aquatic ecosystem integrity. If zinc values exceed the Acute Effect Value, chronic and acute toxicity effects may occur. According to the SA Water Quality Guideline for zinc in water for aquatic ecosystems, the Target Water Quality Range is 0–2 µg/l, the Chronic Effect Value is 3.6 µg/l, and the Acute Effect Value is 36 µg/l (DWAF, 1996 d). These limits were exceeded in the water samples from the Bottelary River. Based on this, the river water

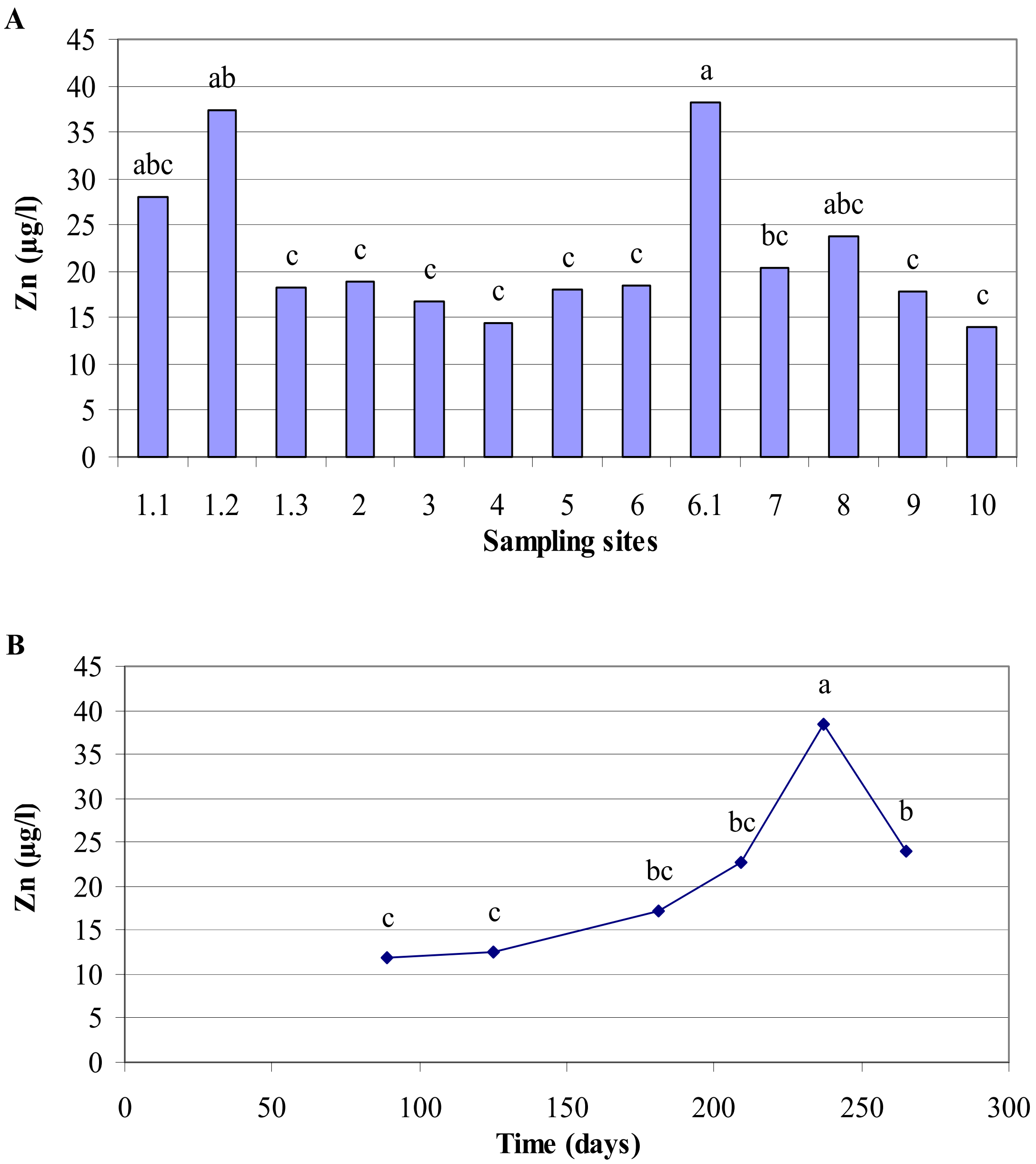


Figure 27. Means with the same letter are not significantly different at p=0.05. (A) Zinc levels (µg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of zinc in the Bottelary River and its main tributaries.

is unsuitable for aquatic ecosystems and could cause adverse chronic and acute effects to aquatic organisms due to zinc poisoning.

The SA Water Quality Guideline for zinc in water to be used for agricultural irrigation is 1000 µg/l and for livestock watering is 20000 µg/l (DWAF, 1996 b, c&e). The zinc concentrations in the water samples were much lower than these limits. Thus zinc would not be a problem in the river water to be used for agricultural irrigation and livestock watering.

2.7.9 Electrical Conductivity

The levels of electrical conductivity varied between 0.14 and 5.75 mS/cm in the water samples from the Bottelary River. The mean values of electrical conductivity ranged from 0.72 to 3.20 mS/cm and displayed a distinct peak at site 8 (Swart River), while the lowest electrical conductivity value was observed at site 10 (Bottelary Culvert) (Figure 28A).

During the period of investigation, the average values of electrical conductivity were in the range of 1.01–1.41 mS/cm and did not differ significantly (Figure 28B).

The SA Water Quality Guideline for electrical conductivity in water to be used for the domestic water supply is 70 mS/m (DWAF, 1996 a&e), which is equivalent to 0.7 mS/cm. This limit was exceeded in some of the water samples. Based on this parameter, the river water is not suitable for direct domestic use.

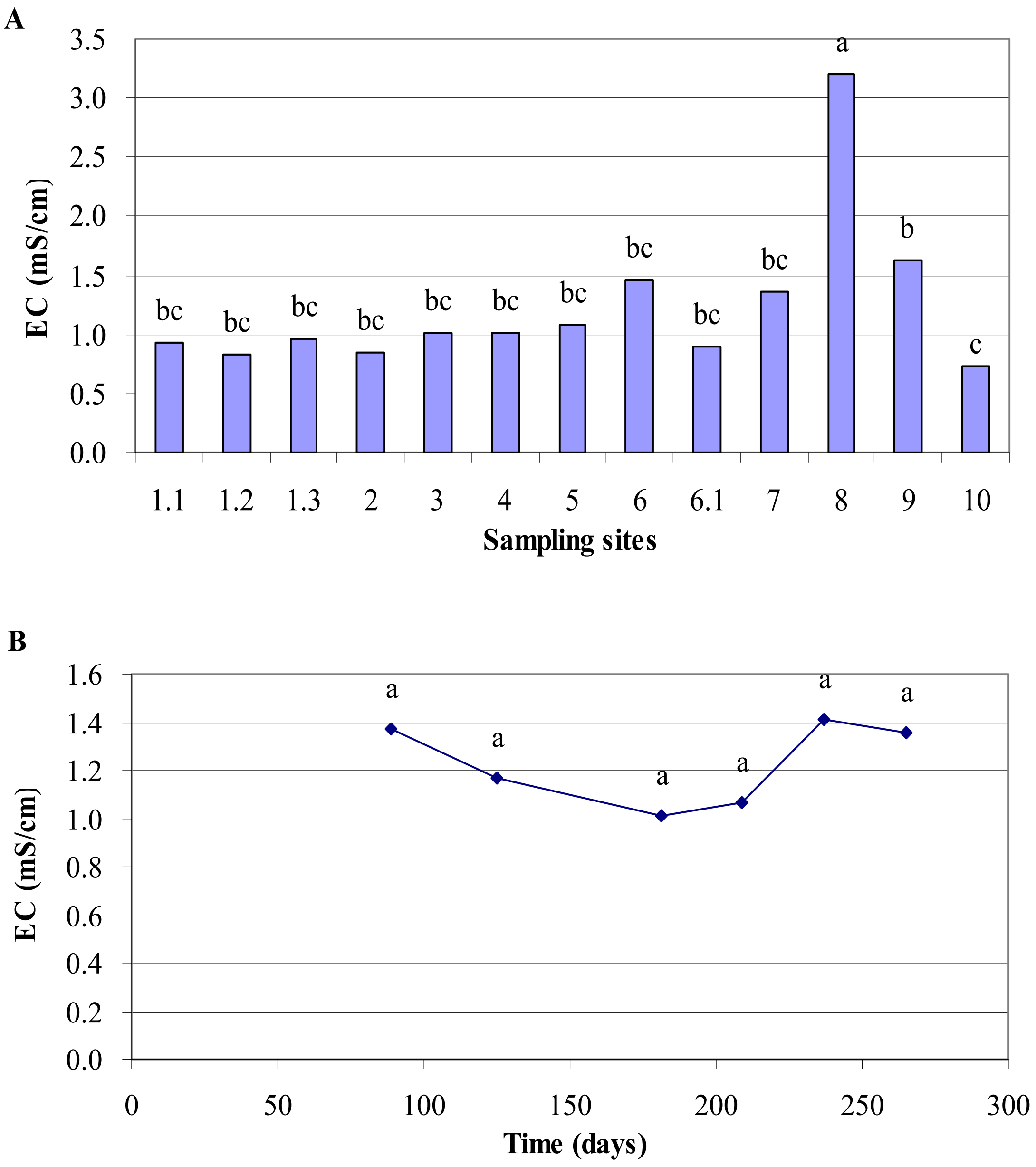


Figure 28. Means with the same letter are not significantly different at p=0.05. (A) Electrical conductivity (mS/cm) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of electrical conductivity in the Bottelary River and its main tributaries.

2.7.10 pH Measurements

The pH is a measure of the hydrogen ion activity in solution. In surface water, pH ranges from 4 (acidic) to 11 (alkaline), with 7 being neutral. The pH may be affected by water temperature, the concentrations of inorganic and organic ions, and biological activities (DWAF, 1996 d).

The range of pH in the water samples from the Bottelary River generally varied between 6.15 and 8.43. The mean pH ranged from 6.73 to 8.02 (Figure 29A). The results indicated that the pH values in the water samples were slightly alkaline at the junction of the Kuils River and the Bottelary River (sites 1.1, 1.2 and 1.3) where the water was in a concrete channel. The lowest pH value was found in the Swart River (site 8). During the study period, the mean values of pH were in the range of 7.02–7.76 and no extreme pH values were recorded (Figure 29B).

Based on the SA Water Quality Guidelines, the Target Water Quality Range for pH in water to be used for agricultural irrigation is 6.5–8.4, for domestic use is 6.0–9.0 and for recreation is 6.5–8.5 (DWAF, 1996 a, b&e). All of the pH values obtained from the Bottelary River fell within these ranges. Thus the pH in the river water would not adversely affect its use for irrigation, domestic and recreational purposes.

The SA Target Water Quality Range and criteria for pH in water for aquatic ecosystems require the use of background values, which are not available for the Bottelary River (see discussion under section 2.6.8). Thus, the above Target Water Quality Range and criteria could not be used for the interpretation of the pH results.

The SA Water Quality Guideline for pH in water to be used for livestock watering is not available (DWAF, c&e).

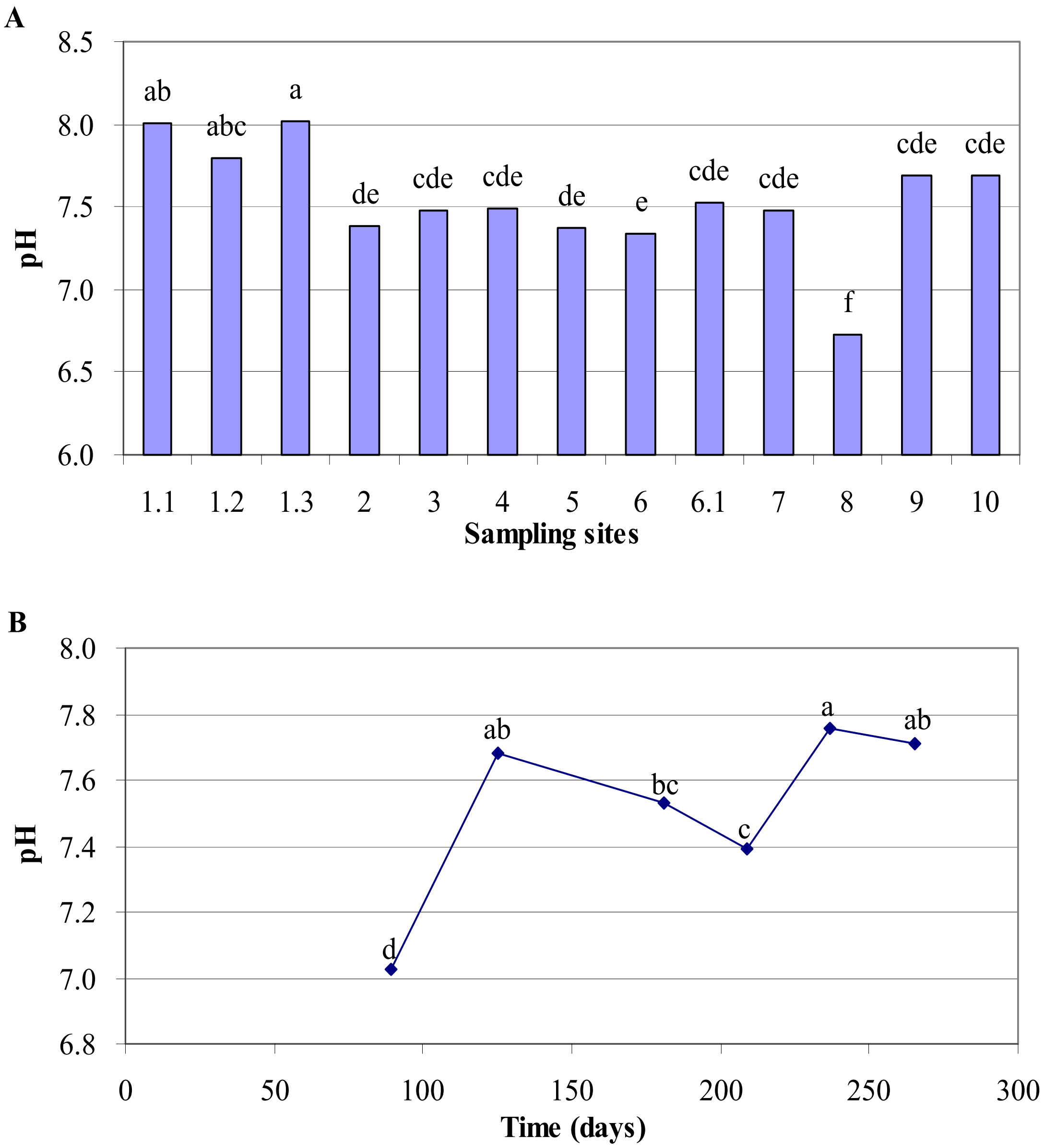


Figure 29. Means with the same letter are not significantly different at p=0.05. (A) The pH at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of pH in the Bottelary River and its main tributaries.

2.7.11 Dissolved Oxygen Concentrations

Dissolved oxygen is the concentration of free molecular oxygen (a gas) dissolved in water and is an important element for water quality control. The concentrations of dissolved oxygen are considered to be the most commonly employed measurement of the health of aquatic ecosystems and an indicator of a water body's ability to support desirable aquatic organisms (Anon., 2004 a).

The dissolved oxygen concentrations are usually close to saturation in unpolluted surface water, but the excess of saturation (super-saturation of oxygen) indicates eutrophication in a water body. The solubility of dissolved oxygen in water can be changed by water temperatures. Higher water temperatures can decrease the dissolved oxygen concentrations in water and thus its availability to aquatic organisms (DWAF, 1996 d).

The dissolved oxygen concentrations in the water samples from the Bottelary River ranged between 0.97 and 17.90 mg/l, indicating an oxygen saturation range of 10.6–145.0%. The mean values of dissolved oxygen ranged from 4.07 to 10.87 mg/l, i.e. oxygen saturation range of 41.80–111.96%.

Figure 30 (A) shows that the mean values of dissolved oxygen in the water samples were significantly higher at the junction of the Kuils River and the Bottelary River (sites 1.1, 1.2 and 1.3), while low concentrations of dissolved oxygen were observed at sites 5 (Groenland Farm), 6 (below the Scottsdene WWTW), and 9 (Mesco Farm).

Figure 30 (B) shows that the mean concentrations of dissolved oxygen were in the range of 6.01–10.19 mg/l over the sampling period. The highest mean concentration of dissolved oxygen was noted in July, probably due to the low water temperature (Figure 31B).

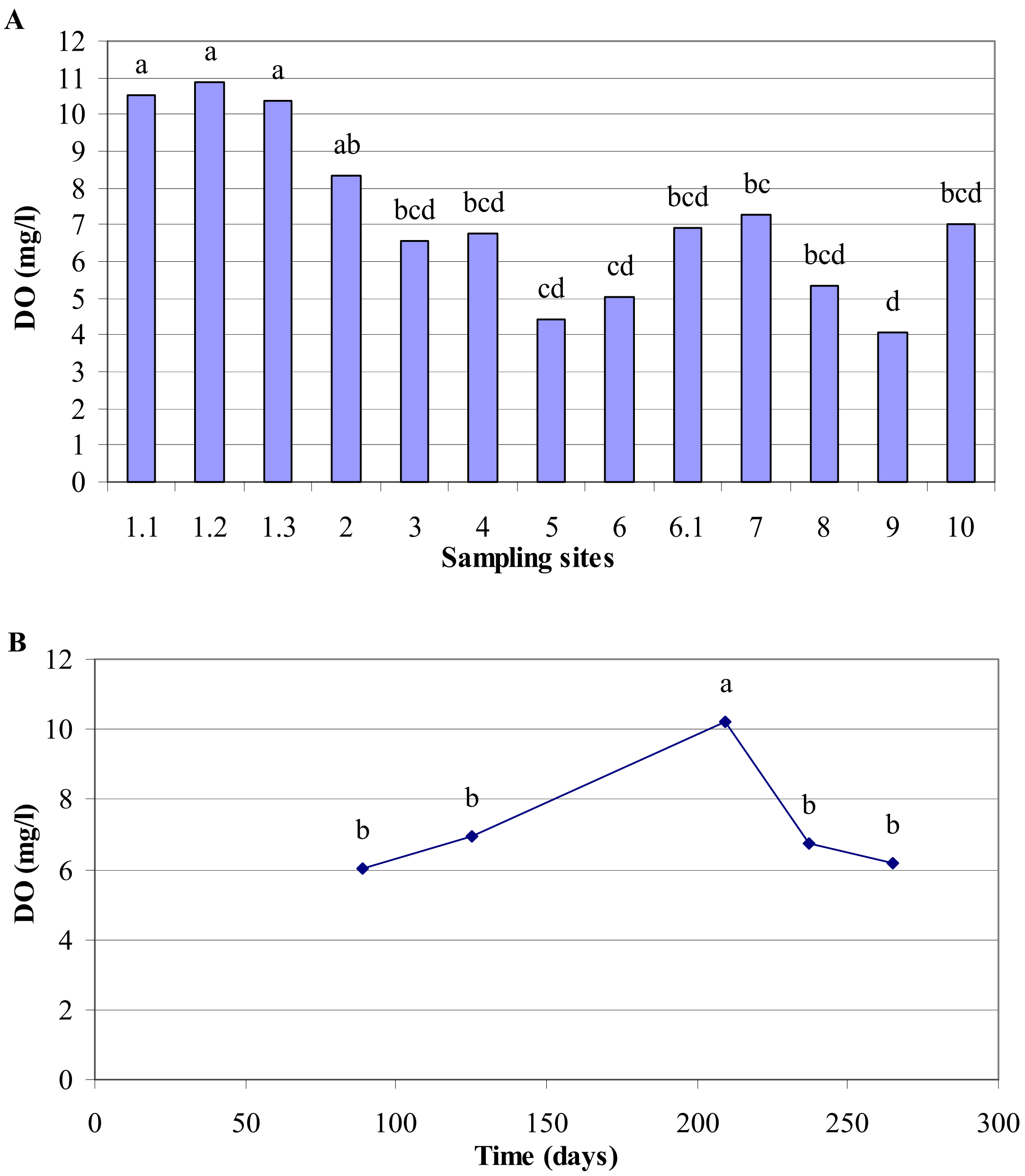


Figure 30. Means with the same letter are not significantly different at p=0.05. (A) Dissolved oxygen levels (mg/l) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of dissolved oxygen levels in the Bottelary River and its main tributaries.

WHO (1993) as cited by Ngoye and Machiwa (2004) recommended a concentration of dissolved oxygen of 5 mg/l or above. From the results, about twenty-five percent (25%) of the dissolved oxygen concentrations in the water samples from the Bottelary River were less than 5 mg/l. Dissolved oxygen levels below 5 mg/l could cause adverse affects to aquatic life (Fatoki *et al.*, 2003).

According to the SA Water Quality Guidelines for aquatic ecosystems, the Target Water Quality Range for dissolved oxygen is 80–120 %. The guideline states that “the dissolved oxygen concentration must be measured as the lowest instantaneous concentration recorded in a 24-hour period, or as the instantaneous concentration at 06h00. If dissolved oxygen is measured at some other time of day or night, then interpretation of the result will require knowledge and understanding of the chemical and biological conditions at the sampling site over the 24-hour cycle ”(DWAF, 1996 d). Due to the limitations of this study, continual measurement throughout the day was not possible, thus the SA Water Quality Guidelines for aquatic ecosystems could not be used for the interpretation of the dissolved oxygen results.

The SA Target Water Quality Range for dissolved oxygen in water to be used for agricultural irrigation and livestock watering is not available (DWAF, 1996 e).

2.7.12 Water Temperature

Temperature plays an important role in water by affecting the rates of chemical reactions and the metabolic rates of organisms, and controlling the distribution of aquatic organisms. The changes of water temperature can result from natural processes, such as climatic and hydrological factors, and anthropogenic sources, such as discharge of heated effluents, heated return-flows of irrigation water, removal of riparian vegetation cover (an increase in the amount of solar radiation reaching the water), inter-basin water transfers, and discharge of water from impoundments (DWAF, 1996 d).

The water temperature generally ranged from 9.2 to 23.1 ºC. The mean water temperature varied between 14.4 and 18.6 ºC, while high water temperatures were found at site 6 (below the Scottsdene WWTW) and at the junction of the Kuils River and the Bottelary River (sites 1.1, 1.2 and 1.3) (Figure 31A). These river sections were located at open spaces with less riparian vegetation cover. The lowest mean water temperature was observed at site 8 (Swart River), which had more riparian vegetation cover (Figure 14).

Figure 31 (B) shows that the mean water temperatures were in the range of 11.5–19.7 ºC over the sampling period.

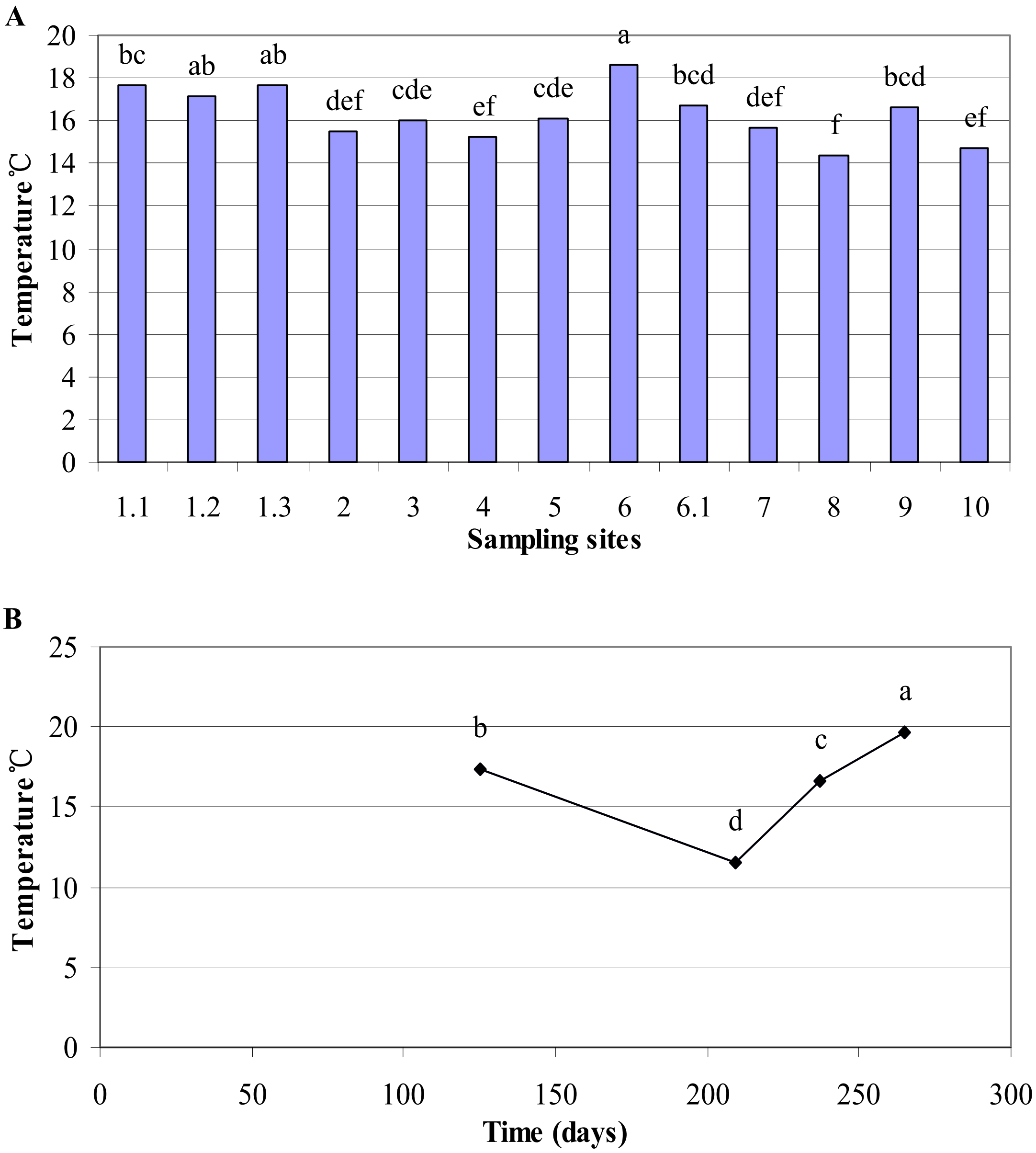


Figure 31. Means with the same letter are not significantly different at p=0.05. (A) Water temperature (ºC) at the sampling sites on the Bottelary River over the sampling period (2004). (B) Seasonal variation of water temperature in the Bottelary River and its main tributaries.

2.7.13 Water Quality in a Dam

Site 11 was in a dam containing the winery effluent, which was only measured once in September during the study period. The dam is located upstream of site 9 and downstream of the winery. During the wet season, heavy rainfall could cause the water overflow from the dam into the river, which would affect the water quality in the river.

The N:P ratio at site 11 was only 0.52:1, which is below the SA Water Quality Guideline of 10:1 (DWAF, 1996 d). This indicated that the water in the dam had been impacted by nitrogen (6.0 mg/l) and phosphate (11.6 mg/l), which can cause eutrophication. The lowest concentration overall of dissolved oxygen recorded was 0.62 mg/l.

High concentrations of cadmium, copper and zinc in the dam were above the SA Water Quality Guideline values for aquatic ecosystems. The iron concentration was also high. The electrical conductivity was 1.7 mS/cm, which is above the SA Water Quality Guideline value for domestic use. The results showed that water in the dam could cause adverse chronic and acute effects to aquatic organisms.

The concentrations of cadmium, copper, lead, iron and zinc in the water sample from the dam were within the SA Water Quality Guideline values for agricultural irrigation and livestock watering, which indicated that the water in the dam is safe for plants and livestock.

2.8 CONCLUSION

The results showed that the Bottelary River and its tributaries have been chemically polluted, especially by nitrogen, phosphorus and some heavy metals (cadmium, copper and zinc). The probable sources of the chemical pollutants in the Bottelary River include both point sources from the wastewater treatment works, and diffuse sources from urban runoff and agricultural runoff in the catchment area. However, the main urban pollution enters the De Novo tributary as a point source (site 6.1).

The concentrations of nitrogen, phosphorus, cadmium, copper and zinc were above the South African Water Quality Guideline values for aquatic ecosystems in the Bottelary River and the dam below the winery, which may adversely affect the health of aquatic ecosystems. The pH and lead levels were within the South African guidelines for aquatic ecosystems. The values of electrical conductivity, nitrate and iron in the water samples were above guideline values for domestic use. There was no salinity problem in the Bottelary River system as shown by the low levels of electrical conductivity obtained, except in the Swart River.

During the period of investigation, the increasing concentrations of nitrate, nitrite, ammonium ion, total nitrogen, phosphate, cadmium, iron and zinc are thought to be due to the increased load in the runoff because of the rainfall during the wet winter season.

The high values of nitrogen and phosphorus would be very harmful to the aquatic ecosystems, as it would encourage eutrophication in the Bottelary River and the dam, especially in the De Novo tributary. The N:P ratios showed that the water in the middle and lower part of the Bottelary River was in the hypertrophic condition.

The levels of cadmium, copper, lead, iron, and zinc were within the South African Water Quality Guidelines for water uses for agricultural irrigation and livestock watering. At these levels of concentrations, the use of the water for plants and livestock may not lead to toxicity.

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CHAPTER 3

Summary and Recommendations

3.1 SUMMARY

Chemical pollution of freshwater is a worldwide environmental problem; eutrophication, heavy metals and salinity are amongst the most widely used indicators of pollution. The aim of the study was to assess the status of nutrients, heavy metals and salinity, and their seasonal variation in the Bottelary River. The results showed that the water quality in the Bottelary River has deteriorated due to inorganic chemical pollutants, especially nitrogen, phosphorus, cadmium, copper and zinc. The main sources of inorganic chemical pollution in the Bottelary River include both diffuse sources from urban and agricultural runoff, and point source discharge from the Scottsdene WWTW, Scottsdene, and Kraaifontein.

The high concentrations of nitrate, nitrite, ammonium ion, phosphate, cadmium, copper, and zinc in the water samples from the Bottelary River were observed to be above the Target Water Quality Range when compared to the South African Water Quality Guidelines for aquatic ecosystems (DWAF, 1996 b), which may adversely affect the health of the aquatic ecosystems. The excessive nitrogen and phosphorus would cause eutrophication in the Bottelary River. The pH and lead levels were within the guideline recommendations. The values of electrical conductivity, nitrate and iron in the water samples were above guideline values for domestic use. There was no salinity problem in the river as revealed by the low levels of electrical conductivity.

The major sources, that caused the high values, of nitrogen, phosphorus, cadmium and zinc in the Bottelary River were from the De Novo tributary. The urban runoff in the concreted canal from Scottsdene contained high levels of nitrate, nitrite, ammonium ion, total nitrogen, cadmium and zinc. The high values of phosphorus that were found downstream in the De Novo tributary, were attributed to the effluent discharge from the Scottsdene WWTW. Agricultural runoff also significantly contributed to high concentrations of nitrogen and heavy metals in the Bottelary River.

The increased concentrations of nutrients, cadmium, iron, and zinc over the study period are thought to be primarily derived from the additional input of these constituents from agricultural and urban runoff because of increased rainfall during the wet winter season. During the heavy rainfall, runoff increased very rapidly. The large amounts of water containing nutrients and metal compounds were transported via surface and subsurface runoff from the farmlands into the river. The increased concentrations of heavy metals in the river water could also have been due to increased suspension of sediments that entered the river through agricultural and urban runoff.

The levels of cadmium, copper, iron, lead, and zinc in the water samples from the Bottelary River were within the South African Water Quality Guidelines values for water uses for agricultural irrigation and livestock watering. The water use may not lead to metals toxicity to plants and livestock.

3.2 RECOMMENDATIONS

The chemical composition of the water in the Bottelary River and its tributaries were greatly effected by agricultural management practices, urban pollution, the Scottsdene WWTW and climatic conditions in the catchment area. The main source of water pollution for the Bottelary River is the De Novo tributary, which receives urban runoff, agricultural runoff, and effluents from the Scottsdene WWTW. It is thus important that more attention be given to the De Novo tributary in terms of management interventions due to its high concentrations of nutrients (nitrogen compounds and phosphorus) and heavy metals (cadmium and zinc).

It is recommended that the impact of urban runoff should be reduced by a number of options for which the following could be considered:

- Planting of a riparian buffer zone
- Creating runoff containment zones
- An expanded wetland in the lower reaches of the De Novo tributary would probably solve the problem. This would also be good for wildlife.

The impacts of agricultural runoff could be ameliorated through the encouragement of farmers to practice Best Management Practices (BMP) on their farms. Some suggested solutions may include the creation of water collection ponds on the edges of the fields to trap the runoff, which would then be allowed to enter the river once the levels of nutrients and heavy metals have been reduced. Furthermore, farmers within the catchment area should be encouraged to rationalize the fertilizer applications to reduce the input of nutrients and heavy metals from the farmlands into the river through runoff.

It is further recommended that the development of “constructed wetlands” to treat urban storm runoff and agricultural runoff should be considered. The practice which many farmers have of collecting drainage water and reusing it (Jordens, pers. comm.,

2005) should be encouraged.

The treated sewage effluent from the Scottsdene WWTW generally causes the adverse impacts on water quality in the De Novo tributary and the Bottelary River. This point source pollution could be reduced by upgrading the sewage treatment works to improve its treatment performance and by reducing the input of treated sewage effluent to the river through encouraging its direct use for agricultural irrigation.

It was noted by van Driel (2003) that the Department of Water Affairs and Forestry, in their license conditions for effluent quality, have set no maximum permissible level for nitrogen and phosphorus probably due to current financial reality. This does not allow for upgrading of the works to give a decisively improved aquatic environment. However, limits still need to be set for the nutrient content of Scottsdene effluent by local and central authorities.

It is further recommended that the Cape Metropolitan Council (CMC) should develop Total Maximum Daily Loads (TMDL) for all receiving waters especially for urban rivers taking into consideration the fact that each water resource has different use category and therefore may require differential treatment.

A major use of water from the Bottelary River is for agricultural irrigation by local farmers; the high levels of nitrogen and heavy metals in the river water are of great concern. On-farm management practices available to mitigate elevated nitrogen levels in irrigation water (DWAF, 1996 a), are to:

- reduce nitrogen fertilizer application by the amount added with irrigation water;
- dilute the nitrogen-rich source if alternative water source is available;
- use the nitrogen-rich source only during vegetative plant growth stages;
- change to crops with a high nitrogen requirement;
- use a water source that is low in nitrogen during periods when crop nitrogen

needs are low;

- limit leaching as far as possible to reduce the likelihood of ground water contamination;
- control algae growth in irrigation structures chemically with copper sulphate;
- remove nuisance algae and water plants from irrigation water with screens and filters.

The use of contaminated river water for agricultural irrigation and livestock watering would be one of the possible pathways for causing human hazards partly due to the bioaccumulation of heavy meals. The heavy metal content of vegetables within the catchment has been investigated (Sogayise, 2003) and found to be a problem. It is therefore recommended that efforts should be made to reduce the heavy metal pollution in the river. One possible way would be to plant hyper-accumulating plants on the riverbank for environmental clean up.

It is recommended that the practice of building concrete canals in the river should be discouraged as it disturbs the natural behavior of the river, preventing natural cleaning of the water and turning the river into a drain.

The area could be developed into a recreational amenity, which would add value to the Kuils River municipal area.

In the context of Integrated Water Resources Management, it is recommended that the River should be managed with a view to ensuring that the resource quality necessary for the protection of the aquatic system function and integrity are maintained. Within the National Water Act (Act NO. 36 of 1998) (NWA) the "Resource quality" is defined as-

- *" the quantity, pattern, timing, water level and assurance of instream flow;*
- *the water quality, including the physical, chemical and biological characteristics of the water;*

- *the characteristics and condition of the instream and riparian habitat; and*
- *the characteristics, condition and distribution of the aquatic biota"*(RSA, 1998).

The NWA requires that all rivers be assessed with a view to classifying them into classes representing different levels of protection required for their management. The system of classification of water resources as provided for by the NWA assigns a class based on the degree of impact of the river-from extremely impacted (Class E or F) to those that are largely natural (Class A) (DWAF, 1999; Malan *et al*., 2003). It is therefore recommended that the Bottelary River should be classified so that appropriate management intervention could be made.

The Cape Metropolitan Council should be encouraged to develop plans for the rehabilitation of the Bottelary River to guarantee improved and protected water quality. After the rehabilitation, management guidelines should be developed for the river. These management guidelines, based on Integrated Water Resources Management principles, should inform the management practices to be adopted.

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Appendix 1

Rainfall recorded in 2004 at the Cape Town International Airport.

Daily rain (mm) Data for station [0021178A3]
Measured at 08:00 Lat:-33.9700 Lon:18.6000 Height:42 m

Day	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
01			6.8		0.4				2.5			1.0
02							7.2					
03		0.2		1.0			1.0					
04			1.0	9.1		19.2		15.4	6.2			
05	4.4			0.4		8.4		56.0	0.4			
06						0.9		3.3		49.0		
07						3.2		52.9		0.2		
08			0.4	3.7		0.2		6.8		5.0		
09				2.8				15.7		0.2		
10				3.2								
11												
12					1.8	2.4						
13						13.7		2.0				
14				0.2		14.0		6.3				
15				18.6		1.8		7.6				
16				11.0				3.4		1.3		
17								0.3	10.7		0.2	0.2
18				0.5		9.5			3.3			
19										0.2		
20				8.2						39.0		
21				3.0						1.0	0.2	
22						6.0	4.2					
23							20.6		2.0			
24				1.4			9.0				3.0	
25						1.4	0.6					
26						10.4						
27	1.4											
28					1.6							
29							18.4			3.0		1.0
30		***					2.3					7.0
31		***	1.0	***		***	1.4		***		***	
Total	**5.8**	**0.2**	**9.2**	**63.1**	**3.8**	**91.1**	**64.7**	**169.7**	**25.1**	**98.9**	**3.4**	**9.2**

Daily rainfall (in mm) - only rainfall >= 0.1 mm is reflected on this report

(blank) indicates that no rain fell on that day

*** indicates that data is missing or not yet available in the current month

Appendix 2

The Bottelary River water analyses: raw data

Site	Distance (km)	Date	Day of Year	DO (mg/l)	DO (%)	pH	Temp (°C)	EC (mS/cm)	NO_3^- (mg/l)	NO_2^- (mg/l)	NH_4^+ (mg/l)	TN (mg/l)	PO_4^{3-} (mg/l)	Cd (µg/l)	Cu (µg/l)	Pb (µg/l)	Zn (µg/l)	Fe (mg/l)
1.1	0.00	29.03.04	89	6.10	66.50	7.24	.	0.90	0.0	0.025	0.250	0.275	0.0211	0.0731	2.3928	0.0748	7.1	0.1225
1.2	0.00	29.03.04	89	7.35	80.50	7.26	.	1.56	0.0	0.025	0.250	0.275	1.4229	0.2354	0.6647	0.0934	5.8	0.1262
1.3	0.00	29.03.04	89	13.00	145.00	8.27	.	0.98	2.5	0.000	0.250	2.750	0.1974	0.1992	1.8694	0.1495	12.4	0.2376
2	1.15	29.03.04	89	3.48	35.80	6.46	.	0.52	10.0	0.000	0.250	10.250	0.0000	0.0905	1.8112	0.1308	11.0	0.0327
3	3.55	29.03.04	89	3.58	37.10	6.25	.	1.39	0.0	0.000	0.250	0.250	0.0000	0.3375	1.6118	0.2243	11.1	0.5428
4	5.10	29.03.04	89	6.89	67.20	7.17	.	1.53	40.0	0.050	0.500	40.550	7.7708	0.0521	5.0681	0.0000	10.2	0.1379
5	6.50	29.03.04	89	3.41	34.70	7.06	.	1.72	80.0	0.050	0.500	80.550	13.8370	0.2719	4.9435	0.0000	9.0	0.0337
6	8.65	29.03.04	89	5.13	58.30	7.20	.	0.58	10.0	1.000	7.500	18.500	21.3130	0.2307	3.2237	0.0000	11.3	0.3862
6.1	9.50	29.03.04	89	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
7	8.75	29.03.04	89	6.74	71.70	7.18	.	1.39	100.0	0.025	0.500	100.525	5.0994	0.3315	3.6806	0.0000	10.5	0.0348
7.1	8.75	29.03.04	89	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	11.50	29.03.04	89	2.46	25.60	6.15	.	4.35	0.0	0.000	0.250	0.250	0.0000	0.3355	0.5567	0.0000	10.1	0.1110
9	11.20	29.03.04	89	.	.	.	.		.	.	.	.	.	.	.	.	.	.
10	10.75	29.03.04	89	8.04	83.20	7.19	.	0.14	2.5	0.000	0.250	2.750	0.0000	0.2604	12.0649	0.1429	31.9	0.6638
11	.	29.03.04	89	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Site	Distance (km)	Date	Day of Year	DO (mg/l)	DO (%)	pH	Temp (^{o}C)	EC (mS/cm)	NO$_3^-$ (mg/l)	NO$_2^-$ (mg/l)	NH$_4^+$ (mg/l)	TN (mg/l)	PO$_4^{3-}$ (mg/l)	Cd (µg/l)	Cu (µg/l)	Pb (µg/l)	Zn (µg/l)	Fe (mg/l)
1.1	0.00	04.05.04	125	9.15	95.50	7.98	17.50	0.82	0.0	0.025	0.250	0.275	0.0000	1.0367	2.1228	0.0000	25.8	0.1238
1.2	0.00	04.05.04	125	12.50	132.10	8.43	18.00	1.03	20.0	0.050	0.500	20.550	2.6220	0.3073	2.5080	0.0130	11.5	0.0881
1.3	0.00	04.05.04	125	10.87	116.10	8.34	18.40	0.98	40.0	0.050	0.500	40.550	6.8010	0.7608	3.4834	0.0384	22.9	0.0691
2	1.15	04.05.04	125	6.78	71.80	7.66	16.90	0.96	20.0	0.025	0.250	20.275	8.9081	0.1922	2.7212	0.1279	9.2	0.0852
3	3.55	04.05.04	125	7.60	77.30	7.89	16.50	0.97	100.0	0.075	0.250	100.325	10.5660	1.1277	2.9097	0.2430	12.4	0.2249
4	5.10	04.05.04	125	7.68	78.70	7.78	16.70	0.82	60.0	0.025	0.500	60.525	15.3180	0.3062	3.3195	0.2686	9.5	0.1628
5	6.50	04.05.04	125	3.26	33.70	7.50	17.10	0.84	20.0	0.025	0.250	20.275	16.6670	0.1493	4.3112	0.0384	11.2	0.0519
6	8.65	04.05.04	125	3.40	37.40	7.48	20.10	0.47	20.0	0.400	5.000	25.400	18.7390	0.1135	2.5567	0.0762	7.9	0.1388
6.1	9.50	04.05.04	125	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
7	8.75	04.05.04	125	6.66	68.90	7.56	16.80	1.44	60.0	0.250	0.250	60.500	6.7569	0.1851	4.46	0.0381	7.0	0.4435
7.1	8.75	04.05.04	125	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	11.50	04.05.04	125	4.39	38.00	6.63	16.30	3.61	10.0	0.025	0.000	10.025	0.0000	0.2058	1.1844	0.1905	10.9	0.0869
9	11.20	04.05.04	125	4.70	49.60	7.47	17.30	1.57	5.0	0.025	0.250	5.275	0.0000	0.1303	2.8835	0.0635	8.4	0.0677
10	10.75	04.05.04	125	6.49	67.20	7.27	16.80	0.49	2.5	0.025	0.250	2.775	0.0000	0.1535	7.1147	0.0635	12.9	1.8034
11	.	04.05.04	125	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Site	**Distance (km)**	**Date**	**Day of Year**	**DO (mg/l)**	**DO (%)**	**pH**	**Temp (^{o}C)**	**EC (mS/cm)**	**NO_3^- (mg/l)**	**NO_2^- (mg/l)**	**NH_4^+ (mg/l)**	**TN (mg/l)**	**PO_4^{3-} (mg/l)**	**Cd (µg/l)**	**Cu (µg/l)**	**Pb (µg/l)**	**Zn (µg/l)**	**Fe (mg/l)**
1.1	0.00	29.06.04	181	.	.	7.92	.	0.60	5.0	0.025	0.500	5.525	0.0000	1.2610	3.1122	0.0644	45.7	0.2383
1.2	0.00	29.06.04	181	.	.	7.78	.	0.76	40.0	0.025	0.025	40.050	1.5905	0.4921	2.7364	0.0773	24.1	0.2120
1.3	0.00	29.06.04	181	.	.	7.86	.	1.15	60.0	0.025	0.500	60.525	7.2154	0.5348	3.0223	0.0000	16.4	0.1893
2	1.15	29.06.04	181	.	.	7.56	.	0.91	60.0	0.025	0.500	60.525	8.0353	0.5890	0.0000	0.0000	15.3	0.1636
3	3.55	29.06.04	181	.	.	7.77	.	0.98	60.0	0.025	1.000	61.025	8.7318	0.8945	2.7528	0.0000	15.9	0.2462
4	5.10	29.06.04	181	.	.	7.64	.	0.94	60.0	0.025	1.000	61.025	10.4590	0.3085	3.3233	0.0000	10.6	0.1996
5	6.50	29.06.04	181	.	.	7.36	.	0.94	40.0	0.075	0.500	40.575	11.5710	0.9790	3.3968	0.0000	13.6	0.0836
6	8.65	29.06.04	181	.	.	7.44	.	0.52	50.0	0.500	3.000	53.500	9.1550	0.7024	2.0658	0.0000	21.6	0.2749
6.1	9.50	29.06.04	181	.	.	7.58	.	0.90	80.0	0.600	5.000	85.600	7.3035	0.3352	2.3924	0.0000	14.8	0.2444
7	8.75	29.06.04	181	.	.	7.46	.	1.31	80.0	0.050	1.000	81.050	4.3588	0.2546	3.7152	0.0000	7.7	0.3242
7.1	8.75	29.06.04	181	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	11.50	29.06.04	181	.	.	6.67	.	2.21	5.0	0.025	0.500	5.525	0.4884	0.1193	0.8002	0.0000	16.8	0.2742
9	11.20	29.06.04	181	.	.	7.41	.	1.39	0.0	0.075	0.500	0.575	0.0000	0.3119	1.0860	0.0000	13.5	0.0669
10	10.75	29.06.04	181	.	.	6.86	.	0.56	0.0	0.025	0.500	0.525	0.0000	0.2759	5.2830	0.1009	8.5	0.5771
11	.	29.06.04	181	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Site	**Distance (km)**	**Date**	**Day of Year**	**DO (mg/l)**	**DO (%)**	**pH**	**Temp (^oC)**	**EC (mS/cm)**	**NO_3^- (mg/l)**	**NO_2^- (mg/l)**	**NH_4^+ (mg/l)**	**TN (mg/l)**	**PO_4^{3-} (mg/l)**	**Cd (µg/l)**	**Cu (µg/l)**	**Pb (µg/l)**	**Zn (µg/l)**	**Fe (mg/l)**
1.1	0.00	27.07.04	209	9.80	93.00	7.78	12.20	0.73	10.0	0.500	0.500	11.000	0.0035	2.2451	2.3271	0.0126	40.3	0.3109
1.2	0.00	27.07.04	209	17.90	100.00	7.79	11.90	0.71	15.0	0.500	1.000	16.500	0.0000	1.8563	1.6739	0.0505	56.0	0.3305
1.3	0.00	27.07.04	209	9.82	92.70	7.79	11.50	0.90	70.0	0.600	0.500	71.100	11.8090	0.7279	4.7026	0.0000	17.8	0.2396
2	1.15	27.07.04	209	17.00	130.00	7.38	10.70	0.94	70.0	0.600	0.500	71.100	13.2810	2.2578	4.4687	0.0000	33.3	0.2577
3	3.55	27.07.04	209	8.40	80.10	7.54	11.00	0.99	80.0	0.600	1.000	81.600	14.5770	1.1004	6.2944	0.0000	14.3	0.3239
4	5.10	27.07.04	209	12.00	98.20	7.43	10.60	1.03	60.0	0.600	1.500	62.100	14.8680	0.1575	5.9206	0.0000	12.2	0.3180
5	6.50	27.07.04	209	8.11	76.00	7.39	11.40	1.05	100.0	0.600	2.000	102.600	15.3180	0.5834	3.4846	0.0000	14.3	0.4729
6	8.65	27.07.04	209	10.11	118.00	7.30	14.30	0.61	80.0	0.600	5.000	85.600	18.7030	0.5064	3.1861	0.0000	19.0	0.2502
6.1	9.50	27.07.04	209	11.90	105.50	7.44	14.20	0.86	90.0	0.600	9.000	99.600	8.8464	0.2165	2.8232	0.0121	13.6	0.1386
7	8.75	27.07.04	209	9.54	88.10	7.19	11.80	1.19	70.0	0.100	0.500	70.600	7.0479	0.4837	6.3965	0.1086	16.2	0.3426
7.1	8.75	27.07.04	209	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
8	11.50	27.07.04	209	5.44	47.50	6.58	9.20	2.79	10.0	0.025	0.500	10.525	0.1534	0.7918	1.0728	0.0000	22.4	0.6658
9	11.20	27.07.04	209	6.11	57.00	7.24	12.10	1.18	10.0	0.025	0.250	10.275	0.0000	1.398	1.7746	0.0000	28.9	0.2007
10	10.75	27.07.04	209	6.34	55.50	6.54	9.60	0.85	5.0	0.025	0.200	5.225	0.0000	0.0912	2.6686	0.0595	7.2	0.5734
11	.	27.07.04	209	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Site	Distance (km)	Date	Day of Year	DO (mg/l)	DO (%)	pH	Temp (°C)	EC (mS/cm)	NO_3^- (mg/l)	NO_2^- (mg/l)	NH_4^+ (mg/l)	TN (mg/l)	PO_4^{3-} (mg/l)	Cd (µg/l)	Cu (µg/l)	Pb (µg/l)	Zn (µg/l)	Fe (mg/l)
1.1	0.00	24.08.04	237	13.06	140.40	8.37	18.60	0.86	5.0	0.075	0.100	5.175	2.8424	2.1923	1.9953	0.2143	47.2	0.2939
1.2	0.00	24.08.04	237	11.70	123.30	7.98	17.90	0.82	40.0	0.020	0.100	40.120	7.8678	1.295	3.2039	0.0834	22.8	0.3581
1.3	0.00	24.08.04	237	9.99	104.90	7.97	17.50	0.82	30.0	0.050	0.150	30.200	12.3380	0.4825	3.3905	0.1191	28.9	0.4577
2	1.15	24.08.04	237	8.21	82.70	7.80	15.70	0.80	30.0	0.050	0.200	30.250	13.7480	1.0782	3.2769	0.1548	24.1	0.3791
3	3.55	24.08.04	237	6.94	69.90	7.79	15.80	0.83	30.0	0.100	0.200	30.300	15.0180	1.9167	4.5260	0.1004	36.1	0.3807
4	5.10	24.08.04	237	3.62	36.20	7.45	15.70	0.82	60.0	0.700	0.300	61.000	16.1730	0.6984	7.0892	0.0502	23.5	0.4483
5	6.50	24.08.04	237	3.47	35.70	7.46	16.90	0.80	70.0	0.700	0.300	71.000	18.1830	1.4405	3.5527	0.1129	41.4	0.3518
6	8.65	24.08.04	237	4.37	46.60	7.32	18.40	5.75	60.0	0.600	6.500	67.100	25.8090	0.6992	2.6280	0.0627	39.0	0.1208
6.1	9.50	24.08.04	237	4.31	43.90	7.80	16.80	0.83	80.0	0.700	5.000	85.700	6.6687	4.4759	4.0150	0.0878	93.7	0.1610
7	8.75	24.08.04	237	6.92	69.30	7.86	16.80	1.07	80.0	0.070	0.300	80.370	4.9848	2.4561	5.3823	0.0000	66.2	0.8793
7.1	8.75	24.08.04	237	6.37	62.70	7.39	14.80	0.81	0.0	0.010	0.200	0.210	0.0000	0.2916	15.6532	0.0485	20.2	1.0962
8	11.50	24.08.04	237	6.67	65.80	7.26	15.10	2.31	0.0	0.100	0.500	0.600	0.8851	0.3989	6.4412	0.0242	38.8	1.5689
9	11.20	24.08.04	237	0.97	10.60	7.90	16.60	1.72	5.0	0.100	0.800	5.900	2.8071	1.3225	1.9109	0.0000	27.3	2.9013
10	10.75	24.08.04	237	7.68	75.50	7.50	14.11	0.90	2.5	0.040	0.300	2.840	0.0000	0.1989	2.4204	0.1090	11.3	0.4928
11	.	24.08.04	237	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.

Site	Distance (km)	Date	Day of Year	DO (mg/l)	DO (%)	pH	Temp (°C)	EC (mS/cm)	NO$_3^-$ (mg/l)	NO$_2^-$ (mg/l)	NH$_4^+$ (mg/l)	TN (mg/l)	PO$_4^{3-}$ (mg/l)	Cd (µg/l)	Cu (µg/l)	Pb (µg/l)	Zn (µg/l)	Fe (mg/l)
1.1	0.00	21.09.04	265	10.03	113.80	8.26	21.80	0.77	10.0	0.075	0.250	10.325	0.0000	0.4924	1.6003	0.0848	17.4	0.3602
1.2	0.00	21.09.04	265	9.50	107.20	7.97	21.10	0.98	70.0	0.500	1.000	71.500	9.8603	2.5374	3.8138	0.0969	88.8	0.3514
1.3	0.00	21.09.04	265	8.30	94.80	7.91	23.10	0.90	65.0	0.600	1.000	66.600	10.8300	0.2261	3.1450	0.0606	11.6	0.3719
2	1.15	21.09.04	265	6.30	66.30	7.45	18.70	0.90	80.0	0.600	2.000	82.600	13.7660	0.3160	4.2756	0.0606	20.1	0.3688
3	3.55	21.09.04	265	6.22	69.50	7.65	20.60	0.90	75.0	0.600	3.000	78.600	14.4290	0.2602	4.2994	0.0485	11.0	0.2838
4	5.10	21.09.04	265	3.60	37.70	7.48	17.80	0.98	90.0	0.600	3.000	93.600	14.6210	1.4655	4.1214	0.0000	20.4	0.4640
5	6.50	21.09.04	265	3.95	42.40	7.44	18.90	1.07	90.0	1.000	3.000	94.000	15.2650	4.4776	4.6470	0.0000	18.9	0.3030
6	8.65	21.09.04	265	2.20	25.80	7.28	21.60	0.81	80.0	0.800	10.000	90.800	15.4940	0.2418	3.3789	0.0000	12.2	0.2905
6.1	9.50	21.09.04	265	4.60	50.70	7.27	19.10	0.98	70.0	2.000	5.000	77.000	6.5012	0.3269	5.1309	0.0631	30.9	0.2082
7	8.75	21.09.04	265	6.57	68.90	7.61	17.20	1.72	30.0	0.025	0.500	30.525	1.3260	0.4148	2.3610	0.1640	15.1	1.1174
7.1	8.75	21.09.04	265	6.46	65.10	7.33	15.90	0.90	20.0	0.000	0.500	20.500	1.8902	0.3029	4.1631	0.0000	13.0	0.8420
8	11.50	21.09.04	265	7.75	75.30	7.08	16.80	3.94	10.0	0.000	1.000	11.000	1.9343	3.7946	2.7031	0.1265	43.4	0.6520
9	11.20	21.09.04	265	4.50	50.00	8.42	20.50	2.30	15.0	0.250	1.000	16.250	0.1710	0.1612	2.8950	0.1138	11.3	0.2808
10	10.75	21.09.04	265	6.50	63.50	7.29	18.50	1.39	9.0	0.000	0.500	9.500	3.1598	0.3495	2.6447	0.0000	11.9	0.3838
11	.	21.09.04	265	0.62	6.60	8.08	20.10	1.07	5.0	0.000	1.000	6.000	11.5970	0.2168	6.1404	0.0759	18.9	2.3512

. indicates that data is missing or not yet available

Cd: Cadmium

Cu: Copper

DO: Dissolved oxygen

EC: Electrical conductivity

Fe: Iron

NH_4^+ : Ammonium ion

NO_2^- : Nitrite

NO_3^- : Nitrate

Pb: Lead

PO_4^{3-} : Phosphate

Temp: Temperature

TN: Total nitrogen

Zn: Zinc