LONG-TERM ASSESSMENT OF THE SURFACE WATER QUALITY IN THE BLESBOKSPRUIT RAMSAR WETLAND

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for the degree MSc (Environmental Management) in the Faculty of Science
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AFFIDAVIT

To whom it may concern

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DEDICATION

This work is dedicated to my late grandfather, Jean-René Mbourou,

and

my grandmother, Germaine Mbourou née Ambani Ayine.

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"Without clear guidance and support, the road of success seems unreachable."

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ABSTRACT

Surface water quality in the Blesbokspruit Ramsar wetland has been an area of concern since the 1990s, especially following the authorised and subsidised pumping of underground waters—high in salts—from Grootvlei Mine Shaft No. 3. The pumping was necessary to maintain their underground mining operations and to avert flooding of low-lying areas from decantation of derelict gold mines in the Blesbokspruit catchment. High levels of salt, coupled with a change in the flow of the system, contributed to the loss in the ecological character of the Blesbokspruit wetland in 1996 and, its subsequent listing on the Montreux Record during the same year. In Ramsar terms, the Blesbokspruit was under threat and on the brink of losing its international Ramsar status if management action was not taken to improve the surface water quality of this wetland. The Blesbokspruit has become, since 1996, a wetland in need of restoration to optimum hydrological conditions, i.e. water quality and quantity. A return to desirable water conditions in the Blesbokspruit wetland would enhance aquatic species diversity and abundance—especially the important waterfowl species that gave the Blesbokspruit wetland its international reputation.

With the shutting down of the mine and the cessation of pumping operations at Grootvlei (Aurora) Mine in December 2010, the surface water in the Blesbokspruit wetland should have improved and enhanced the agricultural activities (irrigation and livestock watering) adjacent to this wetland, as well as contributed to healthier aquatic conditions much needed by local and migratory birds. An investigation of the surface water quality in the Blesbokspruit wetland was performed on historical water quality data for the period 2000 - 2011, obtained from Rand Water. The study revealed that there was a distinct seasonal and spatial pattern in the salts (i.e. sulphate, chloride, sodium, and magnesium), and related electrical conductivity and pH values for sites downstream of the underground water pumping point at Grootvlei Mine Shaft No. 3. Such observable seasonal and spatial patterns in the sites downstream of the underground mine-water discharge point could validate previous findings that had associated saline pollution with the pumping operations of Grootvlei Mine. Inter-annual trends showed a progressive decline in the concentrations of the salts and associated electrical conductivity values, with pH readings between neutral and slightly alkaline. Improvements in the salinity and acidity levels in the Blesbokspruit wetland could then be associated with the number of water management interventions adopted, particularly by Grootvlei Mine, from the mid-1990s until December 2010 (the year when mining and pumping operations ceased at Grootvlei Mine). Nevertheless, during the year 2011, the chemical properties of the Blesbokspruit revealed a step alteration—a substantial drop in concentrations of sulphate and magnesium salts—following cessation of underground pumping the preceding year, also confirming previous investigations linking saline water contamination to underground mine-water pumping operations at Grootvlei Mine.

Nevertheless, from the seasonal and inter-annual trends, it was established that upstream industries—specifically the pulping plant at a paper mill—was an important source of saline burden entering the Blesbokspruit wetland. As NaCl is not an effluent that is required to be reported by industries to the Department of Water Affairs and Forestry, this contribution had remained largely unnoticed. This evidence is contrary to the general assertions that the underground mine-water discharges were the primary or only source of high salinity in the Blesbokspruit wetland.

This investigation has helped establish and verify the spatial and temporal patterns and trends in the surface water, and evaluate its fitness of use for agriculture and aquatic biota, all of which depend on desirable surface water conditions in the Blesbokspruit wetland. A continuous improvement in the surface water quality would enhance the restoration of the Blesbokspruit wetland and thereby support the delisting of this wetland from the Montreux Record. Water management interventions at the Blesbokspruit wetland had been successful in controlling salinity and acidity in this water resource and therefore should remain more important, especially if mining and inherent underground mine-water pumping activities were resumed at Grootvlei Mine in future (especially at Shaft No. 3, located upstream of the Blesbokspruit wetland). Recommendations are given to assist in the preparation of an application for the delisting of Blesbokspruit wetland from the Montreux Record.

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1. INTRODUCTION

This chapter sets the scene for the study by looking at: wetlands in general; the Ramsar Convention and the Blesbokspruit Ramsar wetland—the area under investigation.

1.1 Wetlands as crucial ecosystems under threat

Wetlands cover approximately *"…9% of the Earth's land surface…"* [International Institute for Sustainable Development, 2012]. Although considered 'wastelands' in the past, wetlands have attracted a great deal of attention from different perspectives [Barbier *et al*., 1997; Environmental Protection Agency, 2001; Schuyt & Brander, 2004]. Nowadays, wetlands have been identified as sensitive areas and the *"…third most important ecosystems…"* on Earth because of the number of invaluable benefits, functions and services they offer to both humans and the natural environment [International Union for the Conservation of Nature, 1980; Barbier *et al*., 1997]. Wetlands function as water quality filters, floodwater buffers or sponges, provide habitat for wildlife and aquatic species, and promote biological productivity and diversity [Environmental Protection Agency, 2001; Woodward & Wui, 2001; Schuyt & Brander, 2004]. From a human perspective, they add many aesthetic, sociocultural, economic and educational values to local communities who use wetlands as source of water, fuelwood, medicinal plants, food, income, and as grounds for scientific and recreational activities [Woodward & Wui, 2001; Environmental Protection Agency, 2001; Woodward & Wui, 2001; Schuyt & Brander, 2004].

Despite their considerable value, wetlands have been gradually—and negatively—impacted, reduced in size and destroyed, mainly through increases in the human activities needed for socioeconomic development and growth—and despite the call for the proper management of natural resources [Barbier, 1993; Barbier *et al*., 1997; Schuyt & Brander, 2004]. The main reason is that the socioeconomic and ecological values of wetlands have long been (and are still being) under-estimated or barely understood by decision-makers and local communities [Woodward & Wui, 2001; Schuyt & Brander, 2004]. This occurs when decision-makers or local communities do not completely value the services of wetlands when comparing wetlands with the needs of agricultural, irrigation, residential, electricity generation or mining projects intended for the socioeconomic upliftment of communities [Barbier, 1993; Spash, 1998; Woodward & Wui, 2001; Schuyt & Brander, 2004]. The problem of wetland degradation or loss also arises when no clear wetland ownership rights are recognised [Schuyt & Brander, 2004]. This issue has been exacerbated with the weak or absent land-use planning regulations, leading to the destruction of numerous wetlands—since the year 1900, more than half of global wetlands have disappeared [Barbier, 1993; Schuyt & Brander, 2004; Whitten & Bennett, 2005].

As a response to the alarming rate of wetlands degradation and loss and the implications thereof—unsustainable livelihoods caused by unhealthy natural environments—the need to protect these invaluable ecosystems has been encapsulated in the terms of the *Ramsar Convention* [Barbier *et al*., 1997; Woodward & Wui, 2001; Environmental Protection Agency, 2001; Woodward & Wui, 2001; Schuyt & Brander, 2004; Ramsar, 2012]. The *Ramsar Convention* (thereafter the Convention) was established at a meeting that took place at the city of Ramsar, Iran in 1971 [Schuyt & Brander, 2004; International Institute for Sustainable Development, 2012]. This Convention, interchangeably called the '*Ramsar Convention on Wetlands of International Importance'*, is considered one of the first international environmental treaties, binding together different countries— including South Africa—that share common aims and goals towards promoting good wetland management [Barker, 1995; Schuyt & Brander, 2004; Ramsar, 2012]. The aim of this Convention was to improve the status of wetlands firstly by appraising the "*…conservation and wise use of wetlands as a habitat for water birds…"* [Barbier, 1993; Barker, 1995; Barbier *et al*., 1997; Schuyt & Brander, 2004; Wetlands International, 2007; Ramsar, 2012].

Contracting parties to the Convention agreed to designate only specific wetlands, ones worthy of special protection because of their outstanding values or functions when rated against the listed recognition criteria as promoted by the Convention [Barker, 1995; Wetlands International, 2007; Marti, 2011; Ramsar, 2012]. However, with time, the Convention has evolved and now includes both biotic and abiotic factors as recognised criteria for Ramsar site designation [Schuyt & Brander, 2004; Marti, 2011]. The Convention requires all contracting parties to apply the principles and objectives of sustainable development as an essential part of the framework guiding any development around designated Ramsar Sites [Smart, 1997; Schuyt & Brander, 2004; Ramsar, 2010; Marti, 2011; International Institute for Sustainable Development, 2012; Adair *et al*., 2012]. Nowadays, this Convention has further developed their ambit of wetlands—from waterfowl habitats to include other water resources in need of conservation and wise use. In addition, the Convention applies to protecting water resources from mis-use through other activities—tourism and recreation [Barbier, 1993; Barbier *et al*., 1997; Schuyt & Brander, 2004; Wetlands International, 2007; Ramsar, 2012; Adair *et al*., 2012; International Institute for Sustainable Development, 2012]. By July 2012, more than 2 000 sites had been granted the status of international wetlands under the Ramsar Convention [Ramsar, 2012; International Institute for Sustainable Development, 2012].

1.2 The Blesbokspruit Ramsar wetland in South Africa

Wetlands in South Africa have not been saved from degradation and loss [Walmsley, 1988; Collins, 2005; Mulungufhala, 2008]. With more than *"...800 naturally-occurring freshwater wetlands…"* [South African River Health Programme, 2001], more than 50 per cent of South African wetlands have been lost because of unsustainable practices inherent to socioeconomic development projects (for example: mining, agriculture, residential expansion and population growth) [South African River

Health Programme, 2001; Collins, 2005]. In 2001, out of the 800 South African delineated wetlands, only *"…14% had full protection within a national park, provincial nature reserve or wildlife sanctuary and 4% were partly protected…"* [South African River Health Programme, 2001]. Inconsistencies in the management of South African wetlands could then be addressed with the implementation of "*…conservation and wise use…"* approach developed under the Ramsar Convention [Barker, 1995; Ramsar, 2000; South African River Health Programme, 2001; Collins, 2005; Mulungufhala, 2008; Ramsar, 2012].

South Africa has been a contracting party to the *Ramsar Convention* since 1975, making the country one of the first signatories of that convention [Barker, 1995; Ramsar, 2000; Ramsar, 2012]. Since its accession to the Convention, South Africa has been busy compiling an inventory of national wetlands for designation as Ramsar sites to fulfil its obligations [Barker, 1995; Cowan & Van Riet, 1998; Ramsar, 2000; Kotze, 2000; Collen, 2004; Ramsar, 2012]. By December 2012, twenty South African wetlands had ascended to the status of *Wetlands of International Importance*, with one among them (St. Lucia) being further declared a *World Heritage Site* [United Nations, 2009; Ramsar, 2012]. South African Ramsar Sites are under the responsibility of the relevant national authority, i.e. the Department of Environmental Affairs, designated as the *"…administrative authority of the Ramsar Convention on Wetlands in South Africa, which involves promotion of conservation and wise use of wetlands…"* [South African National Assembly, 2009]. In turn, the Department of Environmental Affairs delegates management authority to the respective provincial governments where the Ramsar sites are located [Barker, 1995; Cowan & Van Riet, 1998; Ramsar, 1998; Ramsar, 2000; Kotze, 2000; Collins, 2005; Ramsar, 2012; South African National Assembly, 2009; Ramsar, 2012]. Provincial governments, in turn, work with local municipalities, non-governmental and private organisations as well as local communities, towards better coordination of the wise use and conservation of their respective Ramsar sites [Cowan & Van Riet, 1998; Ramsar, 1998; Ramsar, 2000; Kotze, 2000; Collins, 2005; Ramsar, 2012].

The current study deals with the Blesbokspruit[1] Ramsar wetland (hereafter 'the Blesbokspruit wetland'), which was declared a *Wetland of International Importance* in 1986, based on the rich diversity of waterfowl it supported during its early development [Van Wyk & Munnik, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999, Ramsar, 2000; Macfarlane & Muller, 2011]. The Blesbokspruit is the most important wetland of the Gauteng Province of South Africa, more precisely located within the Ekurhuleni Metropolitan Municipality (EMM) of the East Rand region [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Ekurhuleni Metropolitan Municipality, 2008]. The East Rand is an area of increasing and continuous socioeconomic

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[1] *Spruit* means 'a small stream' in Afrikaans. *Blesbok* is the Afrikaans name of a species of antelope once common in the area.

development and population growth [Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006]. These activities are taking place around the Blesbokspruit wetland, thus ultimately affecting this wetland in quality and quantity [Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006].

The Blesbokspruit wetland formed as an inland artificial wetland that developed into a permanent 'wet meadow' wetland because of discharge of large quantities of water from underground gold mines in the early 1990s [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Thorius, 2004]. Permitted additional discharges of between ~65 - 100 Ml per day of underground water were made by Grootvlei Proprietary Mines Ltd (hereafter Grootvlei Mine), one of the last existent gold mines in the Far East Rand Mining Basin [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999, Thorius, 2004]. The pumped underground mine-water contributed to the expansion in the surface area of the Blesbokspruit wetland [Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; AngloGold Ashanti, 2004; De Wet & Prinsloo, 2004]. Nowadays, the Blesbokspruit wetland is known as a Ramsar site 1 858 hectares in extent [Haskins, 1998; South African Wetlands Conservation Programme, 1999; AngloGold Ashanti, 2004).

The Blesbokspruit wetland is associated with Blesbokspruit River and its catchment area [Blesbokspruit Forum, 2003; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Phaleng, 2009]. The Blesbokspruit catchment is a tributary of the Vaal River system and falls within the Upper Vaal Catchment Management Area [Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Phaleng, 2009]. Water from the whole Vaal catchment, including the Blesbokspruit sub-catchment, is vital to the Gauteng province, since socioeconomic activities in this province depend on water resources located within the Vaal catchment [Abbott Grobicki , 2002; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006]. As such, water running through the Blesbokspruit River and associated wetland enhances socioeconomic activities and the livelihood of communities in the Blesbokspruit catchment [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Abbott Grobicki , 2002; Blesbokspruit Forum, 2003; AngloGold Ashanti, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Ekurhuleni Metropolitan Municipality, 2008].

The Blesbokspruit wetland is the only Ramsar site in Gauteng, making it of special value in the highly urbanised East Rand region and a priority conservation area because wetlands in Gauteng are under continuous threat [Haskins, 1998; South African Wetlands Conservation Programme, 1999; AngloGold Ashanti, 2004, Naledzi Environmental Consultants, 2007]. The Blesbokspruit wetland offers numerous values, services and functions for the benefit humans and the natural environment [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Abbott Grobicki , 2002; Ekurhuleni Metropolitan Municipality, 2008]. The most remarkable service is its ability to regulate the flows and to maintain the physicochemical characteristics of the Blesbokspruit River [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Ekurhuleni Metropolitan Municipality, 2008]. This wetland used to provide habitat and breeding grounds to diverse and abundant local and migratory water bird species, before the decline in its surface water quality in the mid-1990s [Rogers, 1995; Van Eeden & Schoonbee, 1996; Haskins, 1998; South African Wetlands Conservation Programme, 1999]. It supports diverse plant and other animal species; assists in the circulation of nutrients; and provides food, water, raw materials and intangible values for humans [Rogers, 1995; Van Eeden & Schoonbee, 1996; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2000; Abbott Grobicki , 2002; Naledzi Environmental Consultants, 2007].

To ensure that the Blesbokspruit wetland continues to retain its values and functions, and to counter the potential negative impacts of anthropogenic activities around and within this wetland, one of the Ramsar obligations applicable to South Africa was the development and implementation of a management plan [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Macfarlane & Muller, 2011]. The management plan would act as a guideline for: a) any development adjacent to or b) use of the wetland [Ramsar, 2000; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Ekurhuleni Metropolitan Municipality, 2008; Macfarlane & Muller, 2011]. The elaboration of the management plan is the responsibility of the Gauteng Department of Agricultural and Rural Development (GDARD). GDARD ultimately liaises with the Ekurhuleni Metropolitan Municipality (EMM), other government departments and stakeholders—where activities or decisions made by these various factions may have negative effects on the Blesbokspruit wetland [South African Wetlands Conservation Programme, 1999; Kotze, 2000; South African National Assembly, 2009; Macfarlane & Muller, 2011]. Based on the Blesbokspruit Ramsar Information Sheet (published in the late 1990s), the management plan for this site remained a draft document, initially developed in the early 1990s, and not fully implemented until the year 2012 [Barker, 1995; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Collen, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Naledzi Environmental Consultants, 2007; Ekurhuleni Metropolitan Municipality, 2008; South African National Assembly, 2009; Macfarlane & Muller, 2011]. One item still on the agenda of the Blesbokspruit Forum then, and other organisations interested in the conservation of Blesbokspruit wetland, is the desire to achieve an holistic management plan for the Blesbokspruit wetland—one to address and guide any current and future anthropogenic activities likely to affect this important water resource and ecosystem [South African National Assembly, 2009; Macfarlane & Muller, 2011; ; BirdLife South Africa, 2013; Coughlan, 2013]. The lack of a fully formulated guideline is why, since its recognition as an international wetland, the Blesbokspruit has been misused and pressured by anthropogenic threats which have lowered its ecological health [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Richards, 2001; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Ekurhuleni Metropolitan Municipality, 2008; Macfarlane & Muller, 2011].

1.3 Problem statement

1.3.1 *Surface water quality deterioration and the degradation of the Blesbokspruit wetland*

The proximity of the Blesbokspruit wetland to anthropogenic activities has contributed to a decrease in its ecological integrity [Rogers, 1995; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Richards, 2001; Thorius, 2004; South African National Assembly, 2009; Macfarlane & Muller, 2011]. The loss of the ecological character of the Blesbokspruit was caused by a progressive deterioration of the quality of water running through its system, in just a few years following its designation (in 1986) as a *Wetland of International Importance* [Van Wyk & Munnik, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Richards, 2001]. During the early 1990s, the surface water in the Blesbokspruit wetland was already showing sufficiently high salinity levels to negatively affect aquatic biota and decrease the aesthetic value of this wetland [Haskins, 1998; Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Macfarlane & Muller, 2011].

Surface water deterioration in the Blesbokspruit wetland is a complex and long-standing issue [Van Wyk & Munnik, 1998; Haskins, 1998; Wood & Reddy; 1998; South African Wetlands Conservation Programme, 1999; Ekurhuleni Municipality, 2003, 2004; 2008; Eastern Basin Blesbokspruit Catchment Task Team, 2006; South African National Assembly, 2009; Macfarlane & Muller, 2011]. Historical underground mine-water pumping operations by past and current mines (i.e. Grootvlei Mine) were necessary for the mines within the whole Witwatersrand Basin—including the Far East Rand Mining Basin—to allow access to deeper gold-bearing ores [Van Wyk & Munnik, 1998; Wood & Reddy, 1998]. However, considering the financial constraints inherent in pumping and treating underground mine-waters, gold mining in the Far East Rand Mining Basin subsided, leaving only few gold mines which had inherited the pumping responsibilities—in the 1960s Sallies (S.A. Lands and Exploration Gold Mining Company) and from the 1990s onwards—Grootvlei Mine [Van Wyk & Munnik, 1998; Wood & Reddy, 1998]. In addition to mine-water discharges, effluents from other adjacent and upstream water/land users (i.e. defunct mines, tailings dams, sewerage plants, industries, residential areas, agricultural smallholdings and animal husbandry) were also a major source of water pollutants [Van Wyk & Munnik, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Thorius, 2004; Tonkin, 2005].

From 1995, Grootvlei Mine was permitted to pump approximately 100 Ml daily of polluted or partially treated mine-water from its underground mine works [VanWyk & Munnik, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Thorius, 2004]. However, with the permitted discharges of underground mine-water by Grootvlei Mine from Shaft No. 3, acid mine drainage, in the form of elevated salt and iron waters, was allowed to run through the Blesbokspruit wetland. This caused an outcry from the local, regional and international communities [Van Wyk & Munnik, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999]. The addition of considerable volumes of acidic and saline mine-waters in the Blesbokspruit wetland contributed to the loss of its ecological integrity and to the permanent flooding conditions [Van Wyk & Munnik, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Richards, 2001; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Macfarlane & Muller, 2011; Ramsar, 2012]. The decline in the quality of the Blesbokspruit wetland was first indicated by the death of aquatic species (fish, crabs) and the decline in the diversity and abundance of bird species (especially waterfowl) [BirdLife South Africa, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2000; Richards, 2001; Thorius, 2004]. Since then, surface water deterioration in the Blesbokspruit wetland has become associated with Grootvlei Mine [Wyk & Munnik, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Richards, 2001; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Macfarlane & Muller, 2011; Ramsar, 2012].

In 1996, in response to this environmental crisis, the Department of Environmental Affairs requested from the Ramsar Committee the inclusion of Blesbokspruit wetland in the Montreux Record [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2000; Eastern Basin Blesbokspruit Catchment Task Team, 2006]. The Montreux Record is a Ramsar register used to monitor *Wetlands of International Importance* being threatened or likely to be negatively affected by either natural or anthropogenic factors [Richards, 2001; Ramsar, 2012; Adair *et al*., 2012]. The main reason for listing the Blesbokspruit wetland on the Montreux Record was the negative effects caused by acidic and saline mine-waters, whereby the quality of the surface water quality had deteriorated far beyond the designated Ramsar limits [Van Wyk & Munnik, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Eastern Basin Blesbokspruit Catchment Task Team, 2006]. Acid mine drainage into the Blesbokspruit wetland was considered a threat to maintening integrity of the wetland aquatic and avian biota [BirdLife South Africa, 1998; South African Wetlands Conservation Programme, 1998].

Having the Blesbokspruit wetland listed onto the Montreux Record had (and still has) many negative implications for South Africa [Van der Merwe, member of Blesbokspruit Forum. personal communication, 2009; Muller, GDARD official overseeing Blesbokspruit, personal communication, 2009; Adair *et al*., 2012]. Firstly, the Blesbokspruit wetland lost its privileges under the Ramsar Convention [Van der Merwe, 2009; Muller, 2009; Adair *et al*., 2012]. Secondly, South Africa, as a Contracting Party, failed to respect its obligations in terms of the wise use and conservation of Ramsar sites [Barker, 1995; South African Wetlands Conservation Programme, 1999; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Macfarlane & Muller, 2011; Adair *et al*., 2012]. Thirdly, South Africa had compromised its international reputation and image regarding effective management of its natural resources [South African National Assembly, 2009; Marti, 2011; Adair *et al*., 2012].

Fourthly, the inclusion of the Blesbokspruit wetland on the Montreux Record ultimately implied that South Africa was in breach of an international agreement or international environmental law (even if the Ramsar Convention has not always been regarded as legally binding by some parties) [Barker, 1995; Ramsar, 2012; Adair *et al*., 2012]. Lastly, having Blesbokspruit still listed on the Montreux Record in 2012, regardless of the development of national environmental legislation, implies that the water quality and quantity management of the Blesbokspruit wetland is a very complex issue [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Muller, 2009; Van der Merwe, 2009].

The issue is complex because surface water pollution in the Blesbokspruit wetland had begun several years before the Blesbokspruit wetland became a Ramsar site and continued after its listing [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ekurhuleni Municipality, 2003, 2004; 2008; Eastern Basin Blesbokspruit Catchment Task Team, 2006]. The continuous and long-standing presence of water pollutants in the Blesbokspruit wetlands, from both diffuse and point sources, renders it difficult for decision-makers to address the problem effectively [Ekurhuleni Municipality, 2003, 2004; 2008; Eastern Basin Blesbokspruit Catchment Task Team, 2006; South African National Assembly, 2009; Macfarlane & Muller, 2011]. This once again emphasises the need for a comprehensive management plan for the Blesbokspruit wetland and for an effective national wetland policy to guide development or land use around all South African Ramsar sites [Collins, 2005; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Muller, 2009; Macfarlane & Muller, 2011]. Prior to the mid-1990s, there was a weakness in (or even total non-existence of) adequate legislative and regulatory measures—legislation which could have identified the wetland as a crucial ecosystem and water resource in need of careful use and strengthened the management of the Blesbokspruit.[Haskins, 1998; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Macfarlane & Muller, 2011]. After 1997, with the passing of new water-, biodiversity- and environmental-related legislation, policies and guidelines, the conservation and wise use of wetlands has become compulsory, and developers/decision-makers have become more aware of the rationale behind natural resource management [Collins, 2005; Macfarlane & Muller, 2011].

Despite being considered a wetland that lost its Ramsar status in 1996, this wetland is still of interest to various organisations—including government, private companies, local and international communities and non-governmental organisations [Van der Merwe, 2009; Muller, 2009; De Fontaine, 2012: member of Blesbokspruit Forum and Rand Water Quality Manager. personal communication]. In 1996, several members of these organisations came together and formed the Blesbokspruit Forum [Blesbokspruit Forum, 2003a; Eastern Basin Blesbokspruit Catchment Task Team, 2006]. The Blesbokspruit Forum was established to discuss various water-related issues (i.e. to present reports on water users, routine water discharge and any incidents/deviations in the Blesbokspruit catchment area, including the Blesbokspruit wetland) [Blesbokspruit Forum, 2003a; De Fontaine, 2012]. One major point discussed during the Blesbokspruit Forum meetings is the monitoring results (received from the Department of Water Affairs, Rand Water and/or any other water users in the Blesbokspruit catchment performing water monitoring as part of their water use licence requirements [Van der Merwe, 2009; Muller, 2009; De Fontaine, 2012]. For the forum, any possible source of water pollution needs to be controlled through appropriate actions/outcomes arising from the continuous monitoring, treatment and reporting of the results to the monthly meetings [Blesbokspruit Forum, 2003a; De Fontaine, 2012]. Management interventions include, *inter alia*, the construction and upgrading of water treatment plants to reduce the level of pollutants discharged into the Blesbokspruit stream, the management of ingress water, or the promotion of following in-stream water quality guidelines for the Blesbokspruit catchment water users [Bowell, 2000; Lea *et al*., 2003; Blesbokspruit Forum, 2003a; Blesbokspruit Forum, 2003b; Thorius, 2004; Phaleng, 2009; De Fontaine, 2012]. In addition, by looking at the water quality in the Blesbokspruit catchment, the forum wishes to see the re-instatement of the Blesbokspruit wetland as a Ramsar site, especially if continuous water quality monitoring results show long-term positive trends [Van der Merwe, 2009; Blesbokspruit Forum, 2003a; Muller, 2009; De Fontaine, 2012]. In other words, the Blesbokspruit wetland could be delisted from the Montreux Record based on consistent improvement in the quality of its surface water, particularly the lowering of salts previously introduced by Grootvlei Mine [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; Bowell, 2000; Lea *et al*., 2003; Van der Merwe, 2009; Muller, 2009; Macfarlane & Muller, 2011; Adair *et al*., 2012].

The procedure for having a listed site de-listed and removed from the Montreux record is provided in documents referred as "*Guidelines for Operation of the Montreux Record*" and *"Montreux Record – Questionnaire"* respectively [Ramsar, 1996a, 1996b]. For the delisting of site from Montreux Record, the questionnaire includes a checklist of criteria that have to be met and can serve as evidence that the potential or current threats to a Ramsar site have been isolated [Ramsar, 1996b; Adair *et al*., 2012]. Isolation of threats to the Blesbokspruit wetland will then translate to improved surface water quality with evidence supplied through continuous and effective monitoring of the water quality conditions over the long-term [Macfarlane & Muller, 2011; De Fontaine, 2012]. Regular monitoring is expected to help ensure that the quality of the water will no longer pose a threat to the ecological health of the Blesbokspruit wetland or for other water uses (irrigation of crops and livestock watering) which depend on desirable water quality standards [Department of Water Affairs and Forestry, 1996a, 1996b, 1996c; Van der Merwe, 2009; Macfarlane & Muller, 2011].

For this study, the Rand Water network of water monitoring sites was selected, on the basis of their continuous long-term record (11 years) of monitoring data (with few missing measurements). Rand Water is the agency responsible for monitoring surface water quality in the Vaal Catchment [De Fontaine, 2012]. The agency operates a wide network and maintains appropriately certified testing laboratory [De Fontaine, 2012]. Rand Water performs routine and *ad hoc* monitoring, depending on the task at hand [De Fontaine, 2012]. Six Rand Water monitoring sites lie within the study area, of which five are in the Blesbokspruit wetland and one on a side stream. From the monitoring routine, water quality data spanning the period from January 2000 to December 2011 were made available to the researcher of this study. Until this study, comprehensive evaluation and summary of these data had not been carried out to establish past and present trends and the influences and evaluate the results against the Ramsar/Montreux criteria for a wetland of international reputation.

1.3.2 *Aim*

The aim of this study is to determine whether there has been a restoration in the quality of the surface water in the Blesbokspruit wetland since the Grootvlei Mine contamination incident in 1996 (described above), the subsequent water management interventions from 1996 onwards, and the cessation of underground mine-water pumping in December 2010. An investigation into the changes over recent years will assist in the verification of the suitability of the surface water quality of the Blesbokspruit wetland for agriculture (i.e. irrigation and livestock watering activities on surrounding farms) and for maintaining the aquatic biota in this wetland. The information for this task has become available through the many years of sampling and water quality analysis (data which has become more consistent from the year 2000 on). This database provides the starting point for systematic, quantitative analyses of the water quality records to determine whether the Blesbokspruit wetland qualifies to be removed from the Montreux Record. The results of this study will then serve as evidence to determine whether, after more than fifteen years of underground mine-water discharges by Grootvlei Mine into this wetland, saline pollution remains a concern in the Blesbokspruit wetland.

1.3.3 *Objectives*

To achieve the purpose of this study, the following objectives were set:

- to investigate the criteria of the Ramsar Convention and requirements of the Montreux Record that determine the integrity of the water quality in a wetland (such as the Blesbokspruit);
- to undertake a review of published and unpublished work dealing with the Blesbokspruit wetland, with particular focus on its water quality so that identification of different water quality events can be summarised in a chronological order;
- to acquire the comprehensive set of water quality data of the Blesbokspruit wetland from the Rand Water Board and perform a quality and validity check;
- to analyse seasonal, spatial and time trends in water quality data, covering the period 2000[2] to 2011;
- to evaluate selected water quality variables against the Target Water Quality Standards as established by the Department of Water Affairs both for agricultural use (i.e. irrigation and livestock watering) and the aquatic environment, and also against the water quality guidelines for the management of the Blesbokspruit catchment;

[2] Water quality data in original numeric format is no longer available from Rand Water for years prior to 2000. Time trends from 1996 to 2000 were extracted from printed summaries in Rand Water technical reports and other sources.

- to ascertain whether management interventions, in terms of the different approaches of water quality management in the whole Blesbokspruit catchment, have been sufficiently successful to enable the Blesbokspruit wetland to be removed from the Montreux Record and reinstated as a *Ramsar Wetland of International Importance*.

1.4 Justification of the study

This study is important because it will provide a basis for the motivation to the Department of Environmental Affairs (former Department of Environmental Affairs and Tourism) to apply for the delisting of the Blesbokspruit wetland from the Montreux Record. This will only be possible if it can be shown that surface water in the Blesbokspruit wetland has improved over a long-term period and that the Montreux Record requirements for delisting a Ramsar site have been met [Ramsar, 1996a; Ramsar, 1996b; Van der Merwe, 2009; Macfarlane & Muller, 2011]. For that purpose, continuous monitoring and suitable water quality conditions— i.e. consistent reduction in salt levels in the Blesbokspruit wetland case—should be regarded as the criteria for the *Ramsar Committee* to return its international status [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 1996a; Ramsar, 1996b; Ramsar, 2012]. A comprehensive study is therefore needed if Gauteng is to recover from the negative public image associated with the de-listing of its only Ramsar site—in 1996 because of considerable water quality degradation [Haskins, 1998; South African Wetlands Conservation Programme, 1998; Ekurhuleni Metropolitan Municipality, 2008; Macfarlane & Muller, 2011]. The criticisms have been of a political and environmental nature, trying to prove that South Africa, as a Ramsar Contracting Party, inadequately faced the challenges in implementing the *"wise use"* and "*conservation"* of its natural resources and, more specifically, of its Ramsar sites [Barker, 1995; South African National Assembly, 2009; Macfarlane & Muller, 2011].

South Africa is a water scarce country requiring a proper management of its existing water resources [Department of Water Affairs and Forestry, 2004; Uys, 2004]. As a freshwater resource, the Blesbokspruit wetland could still play a vital role in sustaining agricultural, sociocultural, recreational, domestic and industrial activities as well as upholding the well-being of the aquatic ecosystems in the East Rand (Ekurhuleni) region [South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Thorius, 2004; Naledzi Environmental Consultants, 2007; Muller, 2009; Macfarlane & Muller, 2011]. According to the Gauteng Department of Agricultural and Rural Development (GDARD), the East Rand region plays an important role in the food security of the whole Gauteng—many of the cultivable lands and farms of the province are found in this area and depend on water within the Blesbokspruit catchment, including the Blesbokspruit wetland area [Ekurhuleni Municipality, 2008; Mail & Guardian, 2012]. On these grounds, the *National Water Act* (Act No. 36 of 1998) states that water resources, like the Blesbokspruit wetland, should be protected from any pollution and degradation because they contribute to the sociocultural and economic upliftment of the country [Collins, 2005; Mulungufhala, 2008]. This study is intended to provide an updated assessment of progress towards re-establishing the suitability of the surface water in the Blesbokspruit wetland for a possible removal from the Montreux Record. The study will also provide an informed analysis of the current water quality to be available to selected water users (namely irrigation, livestock watering) and the aquatic ecosystem. An improvement in surface water quality in the Blesbokspruit wetland would also contradict the previously accepted postulate that, even if underground water pumping activities have ceased at Grootvlei Mine, the Blesbokspruit wetland would still be affected negatively by acid mine waters decanting from historical underground mine-waters [Wood & Reddy, 1998].

1.5 Study design and chapter overview

This study will follow the empirical route, making use of a descriptive and evaluative approach to the question regarding the state of the surface water quality in the Blesbokspruit wetland from 2000 to 2011 [Mouton, 2001]. Such an approach will rely on existing literature and primary or secondary data, based on the research question [Mouton, 2001]. Previous studies related to the Blesbokspruit wetland were consulted to identify the research problem and limits, as well as identify the data needed for the completion of the study. This information was derived from technical reports, flyers, published and unpublished sources consulted at libraries, Grootvaly Environmental Centre, Marievale Bird Sanctuary, the internet and personal communication with members of the Blesbokspruit Forum. In addition, site visits were undertaken to visualise the study area and identify the land use, potential sources of water pollutants and any water-related events. All gathered information has been recorded—in either photographic or written formats. This assembled information gave an overview of the study area and its status.

Secondary data, in numeric format, were obtained from Rand Water. These data represented monthly average monitoring results for physicohemical constituents as recorded from January 2000 until December 2011 for the sites located along and aside of the wetland. On an *ad hoc* basis, this researcher joined a routine monitoring trip to observe first-hand water sampling procedures. Visits were made to the Rand Water chemical, hydrological and microbiological laboratories for the researcher to become acquainted with the methods and materials used to analyse water samples. The water quality data obtained were provided in MS Excel® format. This database required further quality checking and formatting to adapt the data for statistical analyses, using Excel® 2010 Spreadsheet descriptive statistics functions. These analyses were used to develop seasonal and inter-annual variations of water parameters at the different monitoring sites. This was a preparatory stage towards evaluating the water quality against both the national standards prescribed by Department of Water Affairs *Target Water Quality Ranges* for irrigation, livestock and the aquatic environment and the guidelines developed for the Blesbokspruit catchment. Secondly, the seasonal and annual trends were intended to confirm whether the surface water quality in the Blesbokspruit wetland had been improving in response to those management interventions made since the listing of the Blesbokspruit wetland on the Montreux Record. The trends were expected to identify other circumstantial changes. Finally, the question of whether the Blesbokspruit wetland was eligible for reinstatement as a Ramsar *Wetland of International Importance* would be addressed. The answer would be based on whether or not recent data showed the Ramsar water quality requirements for the Blesbokspruit wetland—i.e. desirable surface water enhanced by a consistent drop in the salt loads—had been met. A report was then to be compiled as part of a communication strategy, to disseminate the results to a wider audience—including the Blesbokspruit Forum, Rand Water, relevant authorities and members of the Gauteng public.

The thesis structure is illustrated in Figure 1, which provides an overview of the main sections of this minor dissertation.

Chapter 1 introduces the importance and issues around wetlands in general, with a particular emphasis on South African wetlands under threat and the Blesbokspruit wetland as a Ramsar site of International Importance. A problem statement is formulated; the scope of the study specified; aims and objectives set out. A justification of the study is presented and the general approach to the study is outlined.

In Chapter 2, a review of the existing literature pertaining to the topic and its implications is presented. Particular attention is given to relevant sections of the Ramsar Convention and the stipulations of the Montreux Record (Objective i); and to the published literature and unpublished reports on the Blesbokspruit (Objective ii).

Chapter 3 describes the site locality, sampling points and methods used to present and evaluate the water quality data for objectives iii through vi.

In Chapter 4 the results of the water quality analyses are presented and discussed to provide answers to the questions of this research.

Finally, this research reaches completion in Chapter 5 with concluding notes dealing with:

- the current Ramsar status of the Blesbokspruit wetland;
- progress related to the recovery of the Blesbokspruit wetland;
- recommendations for additional management steps to further improve the quality of the water in the Blesbokspruit wetland;
- the possible removal of the Blesbokspruit wetland from the Montreux Record.

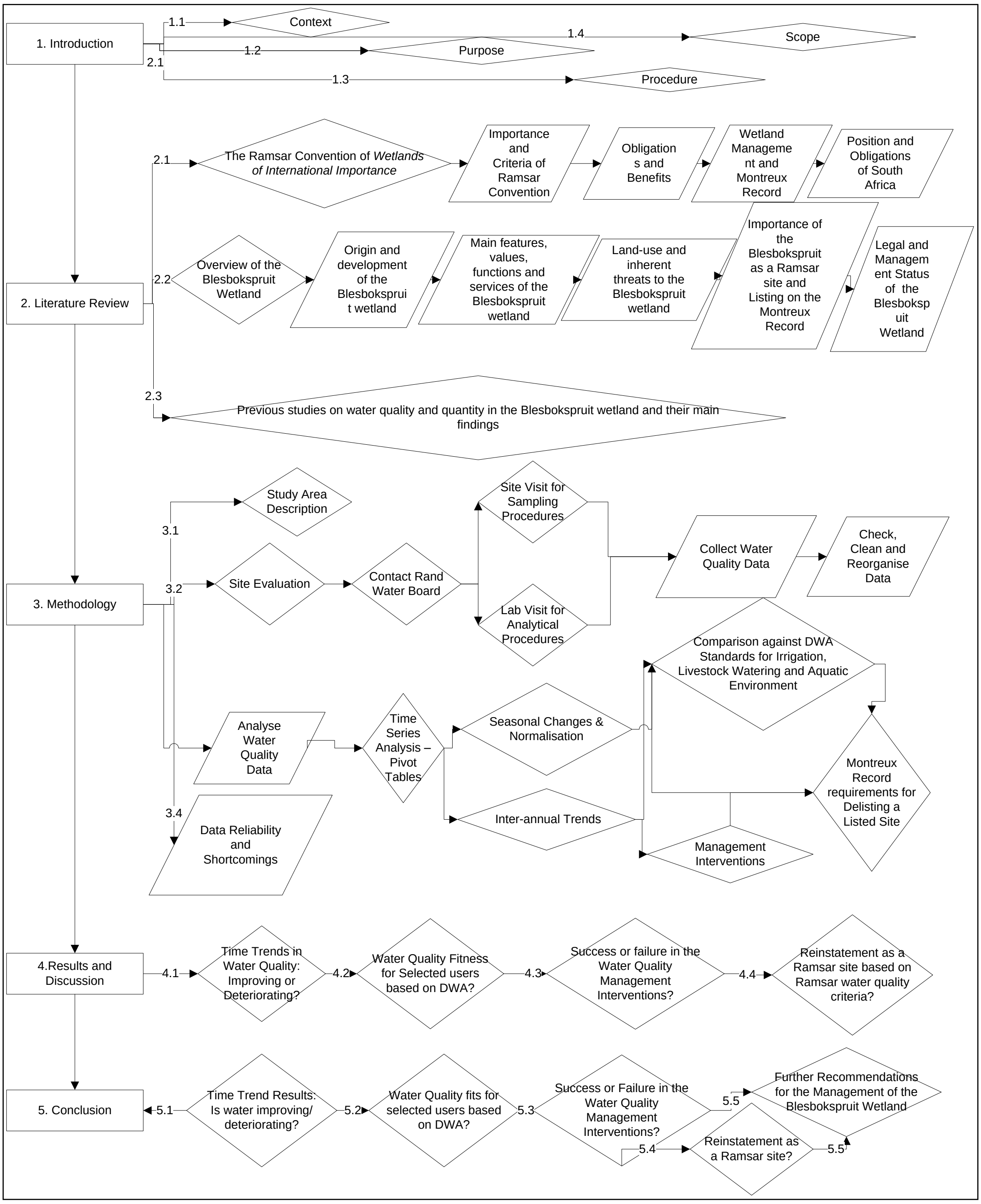

Figure 1: Research outline for studying the water quality of the Blesbokspruit wetland

2. LITERATURE REVIEW

This chapter provides specific information on Ramsar Convention, the Blesbokspruit wetland and concludes with information gathered from the previous investigations on water quality in the Blesbokspruit wetland.

2.1 The Ramsar Convention on *Wetlands of International Importance*

The Ramsar Convention was established at a meeting that took place at the city of Ramsar, Iran on 2 February 1971 [Ramsar, 2012], but only came into force in 1975 [Willoughby *et al*., 2001]. This convention is officially identified as the *Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat* [Marti, 2011], and represents an international treaty binding together Contracting Parties who have agreed on a certain number of biotic and abiotic factors to designate specific wetlands as worthy of special protection [Cowan & Van Riet, 1998; Wetlands International, 2007; Ramsar, 2012].

2.1.1 *Importance, role and mission of the Ramsar Convention*

The Ramsar Convention is considered one of the oldest "…*global multilateral environment agreements…"*, having been in existence for more than 40 years [Ramsar, 2011a]. It is the *"…only ratified global environmental treaty dealing with a particular ecosystem to date…"* [Marti, 2011]. Its importance was first recognised by the Convention on Biological Diversity because, prior to the Ramsar Convention, wetlands were being degraded and destroyed at an alarming rate, mainly through factors emanating from anthropogenic needs for socioeconomic development [Barbier *et al*., 1997; Schuyt & Brander, 2004; Ramsar, 2011a; Ramsar, 2012]. The general claims and observations were that anthropogenic activities were contributing to the decline in the waterfowl populations, especially the duck communities around the world, as their natural habitats (i.e. wetlands) were being destroyed by man [Barbier *et al*., 1997]. The implications of such mismanagement of wetlands motivated a search for their protection and wise use with the establishment of the Ramsar Convention [Barbier *et al*., 1997; Schuyt & Brander, 2004; AngloGold Ashanti, 2004; Marti, 2011; Ramsar 2012].

The Ramsar Convention was the first international treaty to deal openly with wetland management issues and to propose actions towards sustainable development on a global scale rather than being limited to localised issues [Smart, 1997; Barbier *et al*., 1997; Willoughby *et al*., 2001 Ramsar, 2012, Marti, 2011]. Thus, by environmentally sound development, the ecological integrity of all Ramsar sites should be preserved for the benefit of all [Willoughby *et al*., 2001]. The Ramsar Convention is considered as *"…the only international convention that concentrates on a particular type of ecosystem—wetlands—rather than on species or other issues. Such an approach is natural, given the widely held view that wetlands and forests are two of the most threatened ecosystems in world terms."* [Smart, 1997]. Although the Convention originally related only to wetlands as

"…habitat for waterfowl…", its focus has further expanded to *"…an international instrument dealing with wetlands from a broader point of view…"* [Smart, 1997]. This change of ambit occurred with the realisation of the restrictive nature of the first intention of the Ramsar agreement [Marti, 2011]. That is why this convention has further developed to include nowadays the various aspects pertaining to wetland conservation; i.e. the identification of wetlands as crucial ecosystems in need of conservation and valuable to people [Marti, 2011]. The broader purpose of the convention also recognises other water resources as Ramsar sites in need of conservation [Barbier, 1993; Barbier *et al*., 1997; Schuyt & Brander, 2004; Wetlands International, 2007; Ramsar, 2012].

The aim of the Ramsar Convention was to improve the status of wetlands by firstly appraising the *"…conservation and wise use of wetlands as a habitat for water birds…"* [Barbier, 1993; Barbier *et al*., 1997; Schuyt & Brander, 2004; Wetlands International, 2007; Ramsar, 2012] and then providing wetlands with an international status and role [Marti, 2011]. The Ramsar Convention promotes the establishment of a global wetland network and the monitoring of potential threats to Ramsar wetlands, thereby identifying any threat to a wetland that could be detrimental for migratory birds or other wildlife species [Cowan & Van Riet, 1998]. Ramsar campaigns also educate communities about the values and importance of Ramsar sites through better management policy advice and offering technical guidance where needed [Ramsar, 2011a]. From the Ramsar principle of *"wise use"* of wetlands, there is an aim to promote the sustainability of these ecosystems [Ramsar, 2010]. The sustainable development agenda is thus promoted within the international community, reconciling socioeconomic goals with environmental conservation by advocating for the *"wise use and conservation"* of Ramsar sites located in areas where development projects are being initiated [Quental *et al.*, 2009]. By the *"wise use and conservation"* of Ramsar sites, the values and functions of these wetlands are emphasised [Quental *et al.*, 2009]. The principle of *"wise use and conservation"* also highlights the importance of biological diversity conservation—attainable through Ramsar sites and other wetlands [Ramsar, 2010]. Ramsar sites or wetlands since the Ramsar Convention could become one of the *"…six main policy pillars proposed to substitute the traditional three pillar approach, which seems to be of limited capacity to encompass the variety of sustainability issues…"* [Quental *et al*., 2009]. Hence, wetlands are regarded as life supporting systems (Figure 2) [Quental *et al*., 2009].

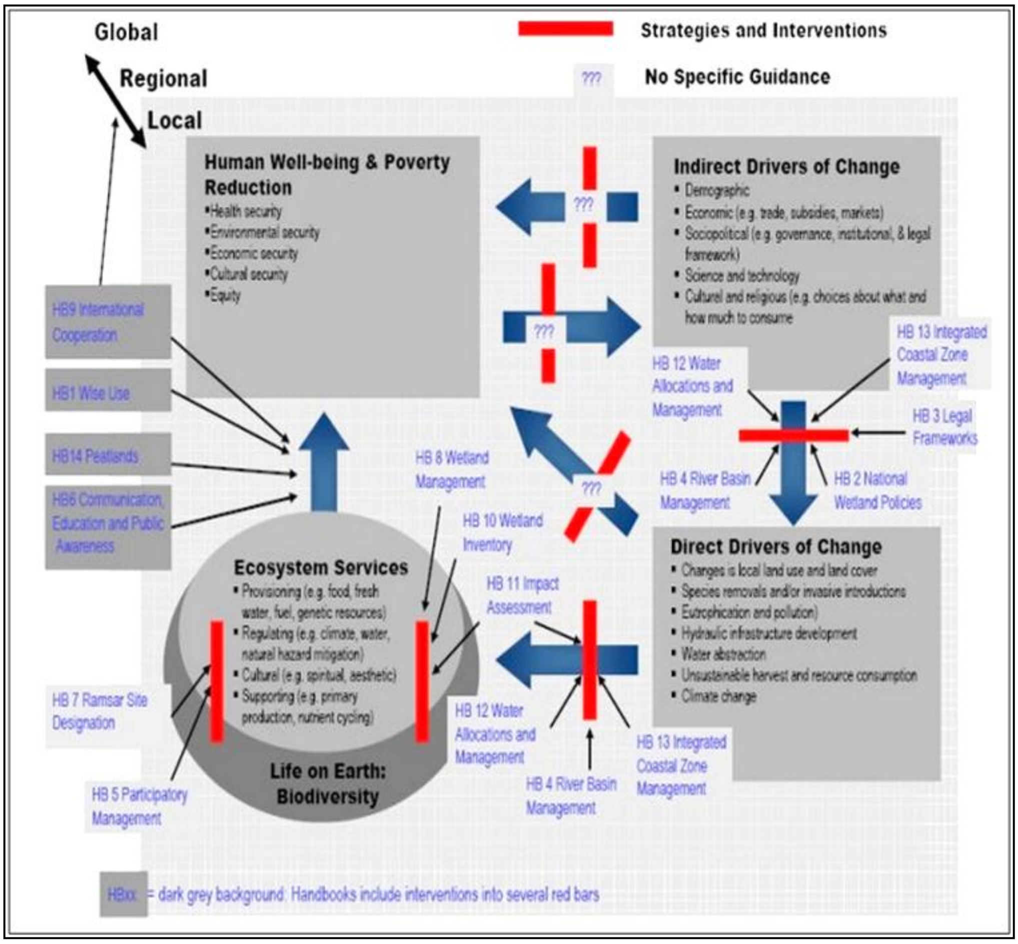

Figure 2: **A conceptual framework for the wise use of wetlands and the maintenance of their ecological character [Ramsar, 2005]**

The convention has also achieved success stories and developed a more global network so that by July 2012, "…a total of 2 040 wetland sites covering over 193.4 million hectares are included in the Ramsar List of Wetlands of International Importance…" [International Institute for Sustainable Development, 2012]. These 2 040 Ramsar wetlands, designated by the 162 Contracting Parties (including South Africa) are protected under international law [Bowman, 2002; Adair et al., 2012; International Institute for Sustainable Development, 2012]. The contracting parties to the Ramsar Convention select representative members who meet every three years at the 'Conference of the Contracting Parties' (COP) [Ramsar, 2000; Ramsar, 2012]. COP is considered the policy-making organ of this Convention: every National Report is reviewed and decisions are adopted proposing possible ways to improve the Convention as a whole [Ramsar, 2000; Institute for Sustainable Development, 2012]. Furthermore, within such triennium meetings, a series of technical sessions on problems related to wetland conservation and wise use and key concepts are reviewed [Ramsar, 2000; Ramsar, 2012]. The Ramsar Convention:

> *"Embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the 'wise use', or sustainable use, of all of the wetlands in their territories…and furthermore, the conservation and wise use of all wetlands through local, regional and national actions*

and international cooperation, as a contribution towards achieving sustainable development throughout the world." [Marti, 2011]

Other international organisations or agreements (e.g. Convention on Biological Diversity, International Union for Conservation of Nature, BirdLife International, Wetlands International and the World Wide Fund for Nature) are strongly and continuously involved in the administration, governance and strengthening of the Ramsar Convention [Ramsar, 2000; Ramsar, 2012; Ramsar, 2011a]. These organisations generally provide technical support for wetland conservation and management by assisting those countries whose Ramsar sites initially may be at risk of losing—or may even lose—their Ramsar status [Barbier *et al*., 1997]. International organisations, sharing the same interests, have established long-standing relationships and partnerships between government agencies and The Ramsar Convention [Barbier *et al*., 1997; Ramsar, 2000].

2.1.2 *Criteria for identifying a Ramsar site*

Ramsar criteria serve as guidelines for a contracting party willing to designate its national wetlands as Ramsar sites [Cowan & Van Riet, 1998; Ramsar, 1998]. In the 1990s, the criteria, originally defined under Article 2.2 of the Convention, were adopted in Montreux [Cowan & Van Riet, 1998]. These criteria represent the degree of significance of a wetland/site in terms of its zoology, limnology, hydrology, ecology, botany or as an important waterfowl habitat [Cowan & Van Riet, 1998; Bowman, 2002]. However, to facilitate the identification of *Wetlands of International Importance*, three groupings have been elaborated under Ramsar Convention [Cowan & Van Riet, 1998]. They involve:

- *"Criteria for representative of unique wetlands;*
- *General criteria based on plants or animals*;
- *Specific criteria for using waterfowl*" [Cowan & Van Riet, 1998].

These criteria are believed to make Ramsar sites more valuable than other common and/or familiar wetlands and these criteria have become the benchmark against which any potential change in the ecological character of a Ramsar site can be assessed [Ramsar, 2000; Bowman, 2002].

2.1.3 *Obligations of parties under the Ramsar Convention*

The objectives of the Ramsar Convention represent the obligations that each contracting party, including South Africa, must fulfil as part of the attainment of the purpose of this treaty, i.e. wise use and conservation of the Ramsar sites [Cowan & Van Riet, 1998]. Each member of the Ramsar Convention is required to:

- designate at least one of its national wetlands to be included in the List of Wetlands of International Importance (commonly called the Ramsar List);
- stem the loss of its wetlands;
- promote the wise use of all its national wetlands;

- promote the special protection of its listed wetlands;
- promote the training of personnel;
- promote the implementation of the parties' obligations in terms of the Convention [Smart, 1997; Ramsar, 2000; Bowman, 2002; Collen, 2004; Ramsar, 2012].

In addition to these obligations, members wishing for a site to be deleted from the Ramsar list can only be granted such approval by the Ramsar Committee if there is sufficient evidence (as stipulated in Article 4.2 of the Convention) that such request is:

> *"In the urgent national interest, and if a site is deleted, then the Contracting Party concerned should as far as possible compensate for any loss of wetland resources and in particular it should create additional nature reserves for waterfowl and for the protection, either in the same area or elsewhere, of an adequate portion of the original habitat" [Ramsar, 1992; Smart, 1997].*

2.1.4 *Benefits linked to Ramsar sites*

By ascending to the Ramsar status, a wetland automatically gains the following benefits:

- *"Recognition at a national level and by the international community as being of significant value not only for the country, or the countries, where they are located, but for humanity:*
- *better protection by government, through high level political commitment to maintain the sites ecological character;*
- *increased opportunities for tourism;*
- *greater access to expertise and training opportunities;*
- *implementation of management plans which include wise use of resources, and development of monitoring programmes;*
- *and lastly the profile of the wetland raised through its promotion as a focal point or flagship for demonstrating conservation, good management and wise use of wetlands in the region*" [Ramsar, 2000].

These benefits inform members/stakeholders of the management of Ramsar sites at international and local levels [Ramsar, 2000].

2.1.5 *Management of Ramsar sites*

The Ramsar Convention is a *"... traditional protected areas approach to conservation, elevated to an international level ..."* [Smart, 1997]. Nevertheless, Ramsar sites should not be regarded the same as simple national parks or reserves, but as ecosystems to which *"...governments accept an undertaking before the world community to maintain the ecological character of Ramsar sites thus making a direct contribution to the conservation of wetland biodiversity..."* [Smart, 1997]. The Ramsar Convention in itself is also considered a management framework under which wetlands are protected [Ramsar, 2010;

Marti, 2011]. It provides management at a global level and guidance for both international cooperation and national action over the "*wise use*" and "*conservation*" of wetlands as valuable resources and crucial habitats [Barbier *et al*., 1997; Ramsar, 2000; AngloGold Ashanti, 2004; Ramsar, 2012].

In 2002, during the eighth COP meeting, several resolutions pertaining to wetland management were agreed upon by the contracting parties [Naledzi Environmental Consultants, 2007]. These resolutions recognised the need for comprehensive national wetland inventories to serve as suitable databases for each respective wetland [Naledzi Environmental Consultants, 2007]. These database (or wetland inventories) would provide information regarding the "… *wise use of wetlands, including policy development, identification and designation of Ramsar Sites, documentation of wetland loss, and identification of wetlands with potential for restoration …*" [Naledzi Environmental Consultants, 2007]. In addition, a number of measures, serving as management tools for contracting parties and the Ramsar Committee itself, have been promulgated to apply the basic concept of *"wise use"* of Ramsar sites [Smart, 1997]. Among the agreed measures are:

- "*The Criteria for Identifying Wetlands of International Importance;*
- *A simple, worldwide Classification System for Wetland Types;*
- *The Montreux Record; and*
- *The Management Guidance Procedure (formerly known as the Monitoring Procedure)"* [Smart, 1997].

To substantiate its mission, the framework, under which Ramsar sites and other wetlands should be managed, was developed during the COP meeting in 2010 [Ramsar, 2010]. This framework requires the Contracting Parties, *inter alia*, to put into place management plans for their respective sites, and to reinforce these plans through the application of specific laws and appointment of competent administrative bodies (Figure 3) [Ramsar, 2010].

In addition to the wetland planning and management framework, a management plan should be developed and implemented by the contracting parties [Ramsar, 2010]. The plan should consist of five main sections and be applied to the different features/functions of the Ramsar sites—such as the ecological character, socioeconomic values, and cultural interests [Ramsar, 2010]. Such planning serves as a tool to be used and consistently followed for successful implementation of the management plan (Figure 4) [Ramsar, 2010].

Relevant implementation commitments made by Contracting Parties in COP Resolutions

Resolution 5.7: Management planning for Ramsar Sites and other wetlands

THE CONFERENCE OF THE CONTRACTING PARTIES

CALLS ON Contracting Parties to develop management plans for each wetland designated for the Ramsar List;

REQUESTS Contracting Parties to establish the appropriate legal and administrative structures for the application of such management plans, and to provide funds for the implementation of the plans and for training of the necessary staff.

Resolution VIII.14: New Guidelines for management planning for Ramsar Sites and other wetlands

THE CONFERENCE OF THE CONTRACTING PARTIES

10. STRONGLY URGES Contracting Parties to apply the New Guidelines to establish and implement management planning processes, particularly for those Ramsar Sites within their territory that do not yet have such processes and plans in place;

17. RECOMMENDS that Contracting Parties, when planning the management of Ramsar Sites and other wetlands, should take into account the wider management implications of activities within river basins and other catchments, [...];

20. STRONGLY URGES Contracting Parties to utilize the management planning process and the New Guidelines for management planning for Ramsar Sites and other wetlands to establish for each site on the Ramsar List a monitoring programme, including indicators of ecological character features, and to put into place national mechanisms so as to be informed when the ecological character of a site has changed, is changing, or is likely to change, and FURTHER URGES Contracting Parties to report such matters, without delay, to the Ramsar Bureau in accordance with Article 3.2 of the Convention.

Resolution X.15: Describing the ecological character of wetlands, and data needs and formats for core inventory: harmonized scientific and technical guidance

THE CONFERENCE OF THE CONTRACTING PARTIES

7. INVITES Contracting Parties and those responsible for the management of Ramsar Sites to apply these guidelines in the preparation of ecological character descriptions of Ramsar Sites, and as part of their management planning processes, so that these descriptions constitute a complementary basis to the Information Sheets on Ramsar Wetlands (RIS) for detecting and notifying changes in ecological character, as established through Article 3.2 of the Convention text, and RECOMMENDS that Contracting Parties provide any completed descriptions of the ecological character of Ramsar Sites to the Secretariat as a supplement to the information provided in the RIS.

Figure 3: Framework for managing *Wetlands of International Importance* and other wetland sites [Ramsar, 2010]

Coupled with management plans for wetlands, contracting parties are expected to develop strategies that will lead to respecting the Ramsar mission [Ramsar, 2010]. These strategies should take into consideration that wetland planning and management are inevitably intertwined with water resource management (Figure 5) [Ramsar, 2010].

Planning and management of wetlands (from a Ramsar perspective) requires contracting parties to: help stakeholders, or communities deal with any potential threat to Ramsar sites; to understand the linkages between wetland, water and river basin management [Ramsar, 2010]. Nevertheless and regardless of the considerable progress made under the Ramsar Convention for the *"wise use and conservation"* of wetlands, many wetlands are still negatively impacted by anthropogenic activities for socioeconomic development [Naledzi Environmental Consultants, 2007].

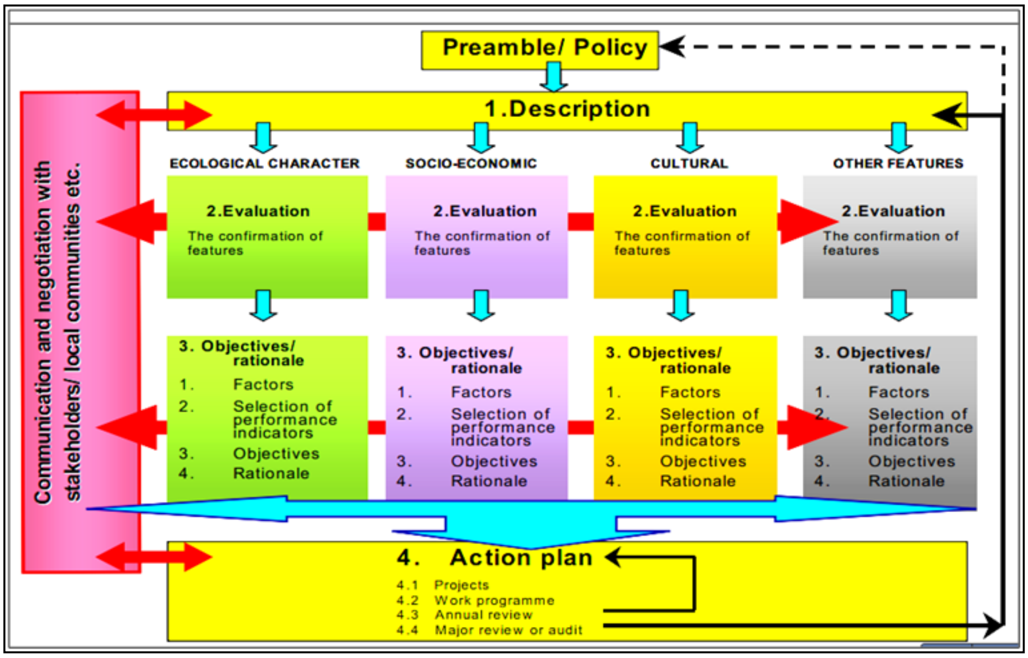

Figure 4: **Recommended structure and content of a management plan for a Ramsar site or other wetland [Ramsar, 2010]**

2.1.6 *Inclusion and/or removal from the Montreux Record*

The Montreux Record represents a Ramsar management tool which is continuously updated and maintained as part of the bigger Ramsar database [Ramsar, 1996a, 1996b; Ramsar, 2000; Richards, 2001; Ramsar, 2010]. The record is used to identify Ramsar sites in need of particular management and conservation measures or to list priority sites likely to be negatively impacted by human interference [Ramsar, 1996a, 1996b; Ramsar, 2000; Richards, 2001; Ramsar, 2010; Adair *et al*., 2012]. It also ensures that identified impacts are mitigated or, in the case of already impacted wetlands, outlines the restorative or rehabilitative measures to be taken [Ramsar, 1996a, 1996b; Ramsar, 2000; Richards, 2001; Ramsar, 2010; Adair *et al*., 2012]. The Montreux Record is considered a register where Ramsar sites, already being threatened or likely to be threatened by anthropogenic activities in particular, are listed [Ramsar, 1996a, 1996b; Ramsar, 2000; Richards, 2001; Ramsar, 2012; Ramsar, 2010; Adair *et al*., 2012]. Threats that impact negatively consequently lead to a change in the 'ecological character' of such wetlands [Ramsar, 2000; Ramsar, 2010]. The 'ecological character' (or 'health') of Ramsar wetlands is believed to encompass all the ecosystem ecological, biological and hydrological functions of those wetlands as described on the approved Ramsar Information Sheet at the time of designation [Ramsar, 2010]. Functions, values and attributes of wetlands depend on the maintenance of the ecological processes [Naledzi Environmental Consultants, 2007]. If such processes are disrupted, wetlands will lose their intrinsic functions, values and attributes [Naledzi Environmental Consultants, 2007]. Loss of function is why the maintenance of the ecological character or health of wetland is seen as vital [Naledzi Environmental Consultants, 2007; Ramsar, 2010; Adair *et al*., 2012].

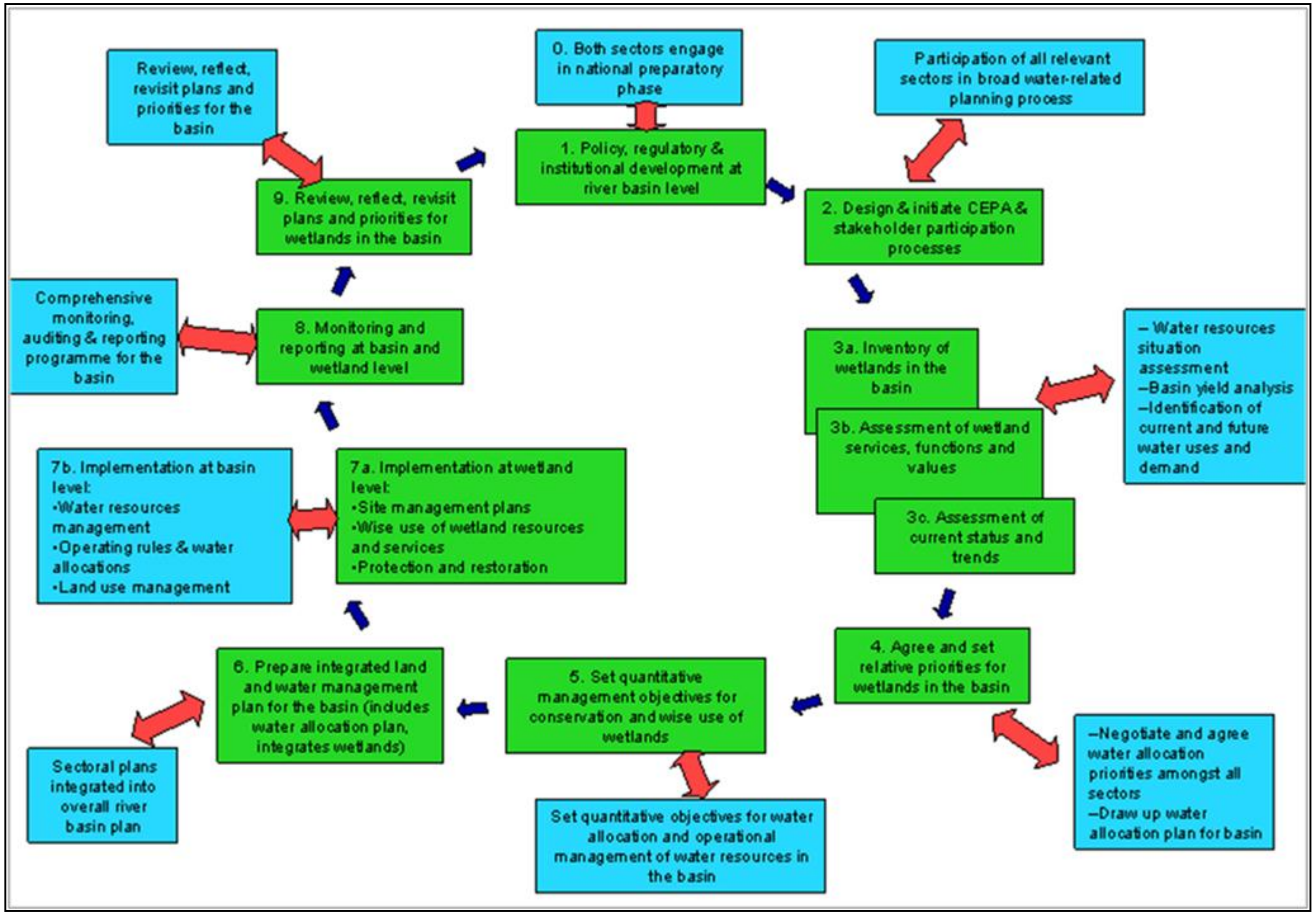

Figure 5: **Planning and management of wetlands as key factors to water resource management [Ramsar, 2010]**

Once a site has been listed on the Montreux Record, there are procedures that a Contracting Party must follow for the site to be delisted and reinstated as a *Wetland of International Importance* compliant with Ramsar standards [Ramsar, 1996a, 1996b; Ramsar, 2000; Richards, 2001; Ramsar, 2012; Ramsar, 2010; Adair *et al*., 2012]. Requirements include the institution of activities (such as: continuous monitoring of the water quality in water polluted wetlands; restoration of the water quality to desirable conditions) for the maintenance of the ecological character or health of a threatened Ramsar site [Ramsar, 1996a, 1996b; Ramsar, 2000; Ramsar, 2012; Ramsar, 2010; Adair *et al*., 2012]. This applies to the Blesbokspruit wetland, which has been listed on the Montreux Record since 1996 because of reasons that will be explained in *Section 2.3* [Haskin, 1998; South African Wetlands Conservation Programme, 1999; Richards, 2001; Ramsar, 2012]. In addition, to substantiate the delisting of negatively impacted sites (like Blesbokspruit wetland) the Ramsar Scientific and Technical Review Panel requires that scientific evidence be provided together with the completed application for removal (Appendix 4: Guidelines for operation of the Montreux Record) [Ramsar, 1996a, 1996b; Adair *et al*., 2012]. All relevant documentation is then to be submitted to the Scientific and Review Panel and Ramsar Bureau for comment. A site visit is arranged before any decision is made [Ramsar, 1996a, 1996b; Ramsar, 2010; Adair *et al*., 2012]. The findings of the panel are made available to the contracting party (for instance—South Africa) It is ultimately the contracting party who will decide about the delisting of the site from the Montreux Record based on the outcomes of the work covered by the Scientific and Technical Review Panel and Ramsar Bureau [Ramsar, 1996a, 1996b; Adair *et al*., 2012]. *Objective (vi)* of this study is to provide scientific evidence that the Blesbokspruit wetland could be reinserted into the Ramsar list of *Wetlands of International Importance*. This is possible if there is sufficient recorded data detailing a continuous (or long-term improvement) in the surface water quality of this wetland—especially proving the drop in the levels of salt in the wetland [Van Wyk & Munnik, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Richards, 2001; Thorius, 2004; Phaleng, 2009; South African National Assembly, 2009; Macfarlane & Muller, 2011].

2.1.7 *Position and obligations of South Africa as a contracting party to the Ramsar Convention*

In South Africa, as in any other country, wetlands degradation and loss is not new [Barbier *et al*., 1997; Walmsley, 1988; South African River Health Programme, 2001; Environmental Protection Agency, 2001; Abbott Grobicki, 2002; Schuyt & Brander, 2004; Collins, 2005; Mulungufhala, 2008]. In fact, in South Africa, more than half of the country's wetlands have already been destroyed, mainly because of the growth in urbanisation [Walmsley, 1988; Abbott Grobicki, 2002; Collins, 2005; Mulungufhala, 2008]. Wetland degradation, conversion and loss have a number of negative returns—ranging from socioeconomic losses to environmental crises [Cowan & Van Riet, 1998; Davies & Day, 1998; Barbier *et al*., 1997; Walmsley, 1988; Whyte & Shepherd, 1999; South African River Health Programme, 2001; Environmental Protection Agency, 2001; Abbott Grobicki, 2002; Schuyt & Brander, 2004; Collins, 2005; Naledzi Environmental Consultants, 2007 Mulungufhala, 2008]. South

Africa, to conserve and use the remaining national wetlands in a more sustainable manner, became the fifth country contracted to The Ramsar Convention on 12 March 1975—making the country one of the first supporters of this convention [Barker, 1995; Cowan & Van Riet, 1998; Ramsar, 1998; Ramsar, 2000; Collen, 2004; Ramsar, 2012].

Under the Ramsar Convention, South Africa is obliged *"…to preserve and use these wetlands with 'wisdom' by establishing nature reserves on them and providing for wardens to look after them …"* [Barker, 1995]. This means that South Africa must respect and show commitment to the Ramsar obligations and collaborate with other members contracted to the Convention for the protection of wetlands [Barker, 1995; Cowan & Van Riet, 1998; Ramsar, 1998; Ramsar, 2000; Collen, 2004; Ramsar, 2012]. Following 1975, the year of its acceptance as a Ramsar contracting party, South Africa drafted a number of pieces of legislation, policies or guidelines, in parallel with programmes and initiatives specifically aimed at improving wetland use and management at the national level (Table 1) [Barker, 1995; Kotze, 2000]. Nevertheless, it is important to note that, in addition to the national legislation, more localised programmes and initiatives prevail in the different provinces and municipalities [Collins, 2005]

Table 1: Examples of treaties, regulations, programmes and initiatives applicable to wetland conservation and management in South Africa since the 1970s [Adapted from Barker, 1995; Kotze, 2000; Collins, 2005; Department of Environmental Affairs and Tourism, 2005]

International and regional agreements/treaties/standards	National legislation, policies and guidelines
Ramsar Convention on Wetlands	Wetlands Conservation Act
Convention on Biological Diversity	National Water
Agenda 21	National Environmental Management
ISO 14 000	Integrated Environmental Management
Agreement on the Conservation of African-Eurasian Migratory Waterbirds	Environmental Conservation Act
Convention on Migratory Species	Conservation of Agricultural Resources Act
	National Wetland Policy
	Mountain Catchment Areas Act
	National Forest Act
	Different wetland policy at provincial level
	Environmental Impact Regulations
	Minerals Act
	South African National Roads Agency Limited and National Roads Act
	Development Facilitation Act
	Town Planning or Land Use Planning Ordinances
	National Biodiversity Strategy and Action Plan

However, with the socioeconomic and political change in South Africa, pieces of the legislation have been amended or completely repealed by new ones believed to be more comprehensive [Kotze, 2000]. What is important to note is that the legislation pertaining to wetlands remains too fragmented [Kotze, 2000]. Therefore, it becomes clear that a comprehensive or holistic piece of legislation—one that could effectively promote the 'wise use and conservation' of South African wetlands—is needed. At present the interpretation of the various wetland regulations is too complex for interested parties to apply efficiently [Kotze, 2000; Macfarlane & Muller, 2011]. This was recognised by the Department of Environmental Affairs and Tourism (DEAT) in 2005 when, in putting together its national Environmental Outlook Report, DEAT pointed out:

> *"The protection of wetlands needs to combine water resource management with land use management strategies. To date, implementation has been weak due to fragmented institutional arrangements, confusion about overlapping jurisdiction and areas of responsibility, and lack of appropriate management strategies that mainstream wetlands in the water and natural resource sectors"* [Department of Environmental Affairs and Tourism, 2005].

At the time South Africa acceded to the Ramsar Convention, two of its national wetlands were included in the Ramsar List; namely the Barberspan and De Hoop Vlei wetlands [Ramsar, 2000; Ramsar, 2012]. By the end of 2012, there were twenty South African national wetlands (Table 2) listed as Ramsar sites of International Importance (with their criteria, values and features recorded under their respective Ramsar Information Sheets) [Ramsar, 2012]. These South African Ramsar sites covered a total area of 553 178 ha [Ramsar, 2012]. The twenty sites are sparsely located throughout the country, with the majority of them located in the KwaZulu Natal Province; Gauteng has only one designated site—the Blesbokspruit wetland [Ramsar, 2012]. This gives the Blesbokspruit wetland a high conservation status in the highly industrialised and urbanised Gauteng Province [Naledzi Environmental Consultants, 2007; Mulungufhala, 2008; Macfarlane & Muller, 2011].

Table 2: South African Designated Ramsar sites by 2012, including the Blesbokspruit wetland (highlighted in light grey and in italics) (Ramsar Sites with subscript MR means added to the Montreux Record) [Adapted from Ramsar, 2012]

Ramsar Sites	Designation Date	Area (ha)	Province
Barberspan	12/03/75	3 118	Northwest;
De Hoop Vlei	12/03/75	750	Western Cape
Blesbokspruit[MR]	**02/10/86**	**1 858**	**Gauteng;**
De Mond (Heuningnes Estuary)	02/10/86	918	Western Cape
St. Lucia System	02/10/86	155 500	KwaZulu Natal
Turtle Beaches/Coral Reefs of Tongaland	02/10/86	39 500	KwaZulu Natal
Langebaan	25/04/88	6 000	Western Cape
Kosi Bay	28/06/91	10 982	KwaZulu/Natal
Lake Sibaya	28/06/91	7 750	KwaZulu/Natal
Orange River Mouth[MR]	28/06/91	2 000	Northern Cape

Ramsar Sites	Designation Date	Area (ha)	Province
Verlorenvlei	28/06/91	1 500	Western Cape
Wilderness Lakes	28/06/91	1 300	Western Cape
Natal Drakensberg	21/01/97	242 813	KwaZulu/Natal
Ndumo Game Reserve	21/01/97	10 117	KwaZulu/Natal
Seekoeivlei Nature Reserve	21/01/97	4 754	Free State
Nylsvley Nature Reserve	07/07/98	3 970	Northern Province
Verloren Valei Nature Reserve	16/10/01	5 891	Mpumalanga
Makuleke Wetlands	22/05/07	7 757	Limpopo
Prince Edward Islands	22/05/07	37 500	Western Cape
Ntsikeni Nature Reserve	02/02/10	9 200	KwaZulu Natal

Of these twenty South African Ramsar sites, two sites are listed on the Montreux Record—namely the Orange River Mouth (in 1991) and the Blesbokspruit (in 1996) (Table 2—sites with the subscript MR) [Ramsar, 2012]. The St Lucia system, which was previously included in the Montreux Record (in 1990—because of the surrounding mining activities that were posing a threat to the ecology of the entire system) was successfully restored and delisted from the Montreux database in 1996 [Ramsar, 2000; Ramsar, 2011b]. Scientific evidence of the isolation of the threats to St Lucia were provided by DEAT to the Ramsar Scientific Panel [Ramsar, 1992; Ramsar, 2011b]. The successful removal of the St Lucia System from the Montreux Record and reinstatement of its Ramsar status has proved that other threatened Ramsar sites in South Africa—such as the Blesbokspruit wetland—could also be successfully restored to desirable conditions [Ramsar, 1992].

2.2 Overview of the Blesbokspruit wetland

Wetlands, including the Blesbokspruit wetland, have been classified and recognised according to specific criteria (including their origin, development, geology, landscape, biota, hydrology, and socioeconomic and cultural values) [Semeniuk & Semeniuk, 1995; Barbier *et al*., 1997; South African Wetlands Conservation Programme, 1999; Castañeda & Herrero, 2008; Ramsar, 2010]. The following paragraphs describe the origin, development, features, importance, land ownership, land-use and their potential influences on the Blesbokspruit wetland, and the legal status and management of this wetland.

2.2.1 *Origin and Development of the Blesbokspruit Wetland*

Before mining activities began (in the early 1900s) in the Far East Rand Mining Basin, the area surrounding the Blesbokspruit wetland was a *"… typical flat Highveld terrain of grassland and crop farming …"* [Haskins, 1998; Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Dini, 1999]. At the time the Blesbokspruit River was free flowing through the area, with very little disturbance in the proliferation of reedbeds along its channel [Scott, 1995; Ramsar, 1998; South African Wetlands Conservation Programme, 1999]. However, with the development of mining, major constructions (for instance: embankments for roads and pipelines) took place along the spruit and diverted the flow of the system, causing the flooding of vast areas of land [Haskins, 1998; Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Dini, 1999]. These waterlogged conditions created shallow water and a few permanent wetlands—one of which is the Blesbokspruit wetland [Scott, 1995; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999]. The Blesbokspruit River then turned into a perennial spruit, fed by a number of springs, after anthropogenic land disturbances to accommodate socioeconomic development had taken place in the region [Scott, 1995; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999]. The diversion of the river system also contributed to the increase of the catchment size and drainage areas of the Blesbokspruit River [Scott, 1995; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999].

The Blesbokspruit wetland was historically a narrow, meandering and non-perennial stream, which developed into a permanent wetland through the addition of water—both from the diversion of its connected spruit and the continuous pumping of underground mine-waters [Scott, 1995; Haskins, 1998; Van Wyk & Munnik, 1998; Wood & Reddy, 1998; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999; Dely *et al.*, 1999]. The wetland consequently expanded in size to cover an official surface area of 1 858 ha, and the enlarged area was recognised as a Ramsar site by the Ramsar Convention during in 1986 [Scott, 1995; Haskins, 1998; Van Wyk & Munnik, 1998; Wood & Reddy, 1998; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2012].

Nowadays, the Blesbokspruit wetland is surrounded by a number of socioeconomic developments dealing with *land uses and ownership* (discussed in Section 2.2.7*)* (Figure 6) [Ekurhuleni Metropolitan Municipality, 2003, 2004, 2008].

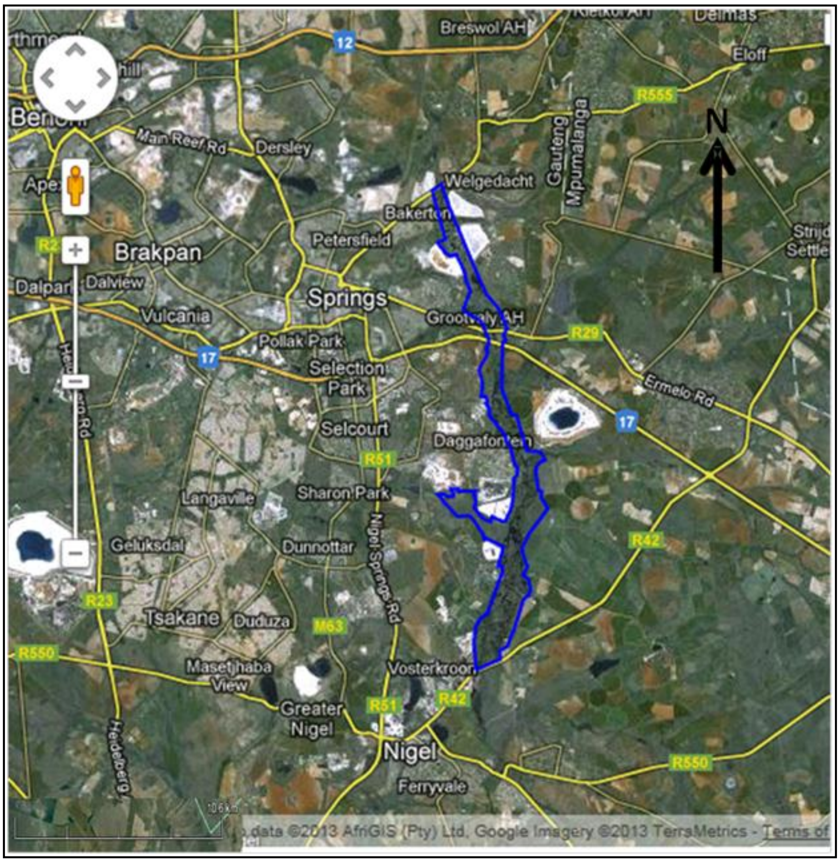

Figure 6: **The Blesbokspruit wetland (delineated in blue) and surrounding land use [Google Earth, 2013, 2013]**

2.2.2 *Definition and classification of the Blesbokspruit wetland*

No clear, easy and straightforward definition exists to designate and describe any wetland, including the Blesbokspruit wetland [Barbier *et al.*, 1997]. For a number of reasons many controversies, substitutes, ambiguities, and difficulties have arisen when attempting to define the concept of wetlands[Barbier *et al.*, 1997]. Reasons for the ambiguities include the imprecise wetland boundaries and their individual intrinsic differences [Barbier *et al.*, 1997]. Various often recurring definitions of wetlands include:

> *"Areas of submerged or water saturated land, whether natural or artificial, permanent or temporary, whether water is static or flowing, fresh, brackish or salt. Water dominated areas to be considered would include marshes, sloughs, bogs, swamps, fens, peat lands, estuaries, bays, sounds, ponds, lagoons, lakes, rivers and reservoir."* [Gopal *et al*., 1990; Marti, 2011].

> *"Land which is transitional between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is periodically covered with shallow water, and which land in normal circumstances supports or would support vegetation typically adapted to life in saturated soil"* [South African National Water Act, 1998].

With the Blesbokspruit being a Ramsar site, the Ramsar definition of wetlands would be retained as the most relevant:

"Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six meters" [Barbier *et al*., 1997; Ramsar, 2000; Ramsar, 2012].

Based on the origin and historical development of the Blesbokspruit wetland, the Ramsar Information Sheet describes this wetland as a *"...permanently inundated reed-dominated (Typha and Phragmites) wetland ..."* whose reedbeds *"...are probably supported by eutrophic status of water ..."* [Haskins, 1998; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999]. In addition, the Blesbokspruit wetland is considered a *"non-forested peatland",* with *"...permanent freshwater marshes/pools; marshes and swamps on inorganic soils; with emergent vegetation waterlogged for at least most of the growing season ..."* [Haskins, 1998; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999]. Considering the origin and development of the Blesbokspruit wetland, it can be concluded that this inland wetland is permanently inundated and portrays both natural and human-made features (as described in Table 3) [Semeniuk & Semeniuk, 1995; Haskins, 1998; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999]

Table 3: A classification of wetland habitats [Dugan, 1990] (Areas highlighted in light grey and in bold and italics could be used as a reference to the Blesbokspruit wetland)

NATURAL WETLANDS	
Wetland Type	**Description**
Endoreic	Permanent and seasonal. Brackish, saline or alkaline lakes, flats, pans and marshes
Riverine perennial	***Rivers and streams; Inland deltas***
Riverine seasonal	Seasonal rivers and streams. Riverine floodplains
Lacustrine permanent	Permanent freshwater lakes (> 8 ha). Permanent freshwater ponds pans (> 8 ha)
Lacustrine seasonal	Seasonal freshwater lakes (> 8 ha) Seasonal freshwater ponds, pans (> 8 ha)
Palustrine emergent	***Permanent freshwater marshes and swamps*** ***Permanent peat-forming freshwater swamps. Seasonal freshwater marshes, peatlands and fens. Alpine and polar wetlands. Springs and oases, volcanic fumaroles, thermal springs***
Palustrine forested	Shrub swamps. Freshwater swamp forest. Forested peatlands
MAN-MADE WETLANDS	
Wetland Type	**Description**
Aquaculture/mariculture	Aquaculture ponds
Agriculture	***Irrigated land including seasonal flooded agriculture land***
Salt exploitation	Salt pans and evaporation pans
Urban/industrial	**Excavations. Wastewater treatment areas**
Water storage areas	***Reservoirs. Hydro-dams***

2.2.3 *Main physical features of the Blesbokspruit wetland*

Many natural and anthropogenic features characterise the Blesbokspruit catchment, including the wetland [Ekurhuleni Metropolitan Municipality, 2003; Hoare *et al.*, 2008]. These features are described in the following sections:

Climate and rainfall

The Ekurhuleni region is considered semi-arid [Ekurhuleni Metropolitan Municipality, 2003; Naledzi Environmental Consultants, 2007]. Since the 1920s, the climatic conditions in the area have been categorised as being 'mild uniform', 'temperate', and 'Highveld with short winter period with temperature below the freezing point' [Ekurhuleni Metropolitan Municipality, 2003; Van der Merwe, 2003; Naledzi Environmental Consultants, 2007; Hoare *et al.*, 2008]. Ekurhuleni falls within the summer rainfall region, with mild temperatures and intense thunderstorms (which mainly occur in the afternoon) and with an annual average rainfall between 670 mm and 735 mm [Haskins, 1998; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Thorius, 2004; Naledzi Environmental Consultants, 2007; Hoare *et al.*, 2008]. The area is also subject to frequent hail and frost, both of which can cause severe damage to crops, deciduous fruits and the built environment [Hoare *et al.*, 2008]. Winds in the region are usually moderate [Hoare *et al.*, 2008]. These seasonal changes and primarily the occurrence or absence of rainfall are believed to play major roles in the episodic fluctuations of the water level, depth and quality in the study area [Haskins, 1998; Ramsar, 1998; Haskins & Compaan, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Thorius, 2004; Naledzi Environmental Consultants, 2007; Hoare *et al.*, 2008].

Catchment, drainage and hydrology

The Blesbokspruit (or Blesbok Spruit) River forms part of the Eastern Basin [Eastern Basin Blesbokspruit Catchment Task Team, 2006] and is found in the Ekurhuleni Metropolitan Municipality (former East Rand). The Blesbokspruit River (Figure 7, dashed line) flows eastward between Benoni and Boksburg, then turns southward past Springs and Nigel [Ramsar, 1998; Haskins, 1998; Van der Merwe, 2003; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Hoare *et al.*, 2008]. Its course crosses the Grootvlei Mine and Marievale Bird Sanctuary areas before joining the Suikerbosrand and, ultimately, the Vaal River. The Blesbokspruit is one of the largest tributaries of the Vaal River [BirdLife South Africa, 1998; Van der Merwe, 2003; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Hoare *et al.*, 2008].

The Vaal River System is considered to be a crucial source of water for the whole of Gauteng Province [Haskins, 1998; Van der Merwe, 2003; Eastern Basin Blesbokspruit Catchment Task Team, 2006; De Fontaine, 2012], fulfilling water needs for diverse socioeconomic activities and ecological reserve [Van der Merwe, 2003; Eastern Basin Blesbokspruit Catchment Task Team, 2006]. The

Blesbokspruit Catchment is located within the Upper-Vaal Catchment Management Area section C21E (Figure 7) [Eastern Basin Blesbokspruit Catchment Task Team, 2006; De Fontaine, 2012].

The Blesbokspruit River system is about 60 km long and drains a surface area of approximately 1 000 km^2 [Ramsar, 1998; Haskins, 1998; Blesbokspruit Forum, 2003a; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Hoare *et al.*, 2008; De Fontaine, 2012]. This catchment is one of the largest drainage areas in Gauteng [Ramsar, 1998; Haskins, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Blesbokspruit Forum, 2003a; Thorius, 2004; Bodenstein *et al.*, 2005; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Hoare *et al.*, 2008]. The Blesbokspruit catchment then subdivides into two main branches flowing eastwards and includes several minor dams [Haskins, 1998; Ramsar, 1998; South African Wetlands Conservation Programme, 1999]. The section of the Blesbokspruit River that has been designated as a Ramsar site is illustrated in Figure 8 [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Hoare *et al.*, 2008; Ekurhuleni Metropolitan Municipality, 2008]. Other important biodiversity features within the spruit are the Marievale Bird Sanctuary Reserve, and numerous natural wetlands towards the east. The western parts of the wetland have been modified mainly by human activities (for instance: agriculture lands, housing, sewage works, industries, landfills and mines, including mine dumps and slimes dams) [Hoare *et al.*, 2008].

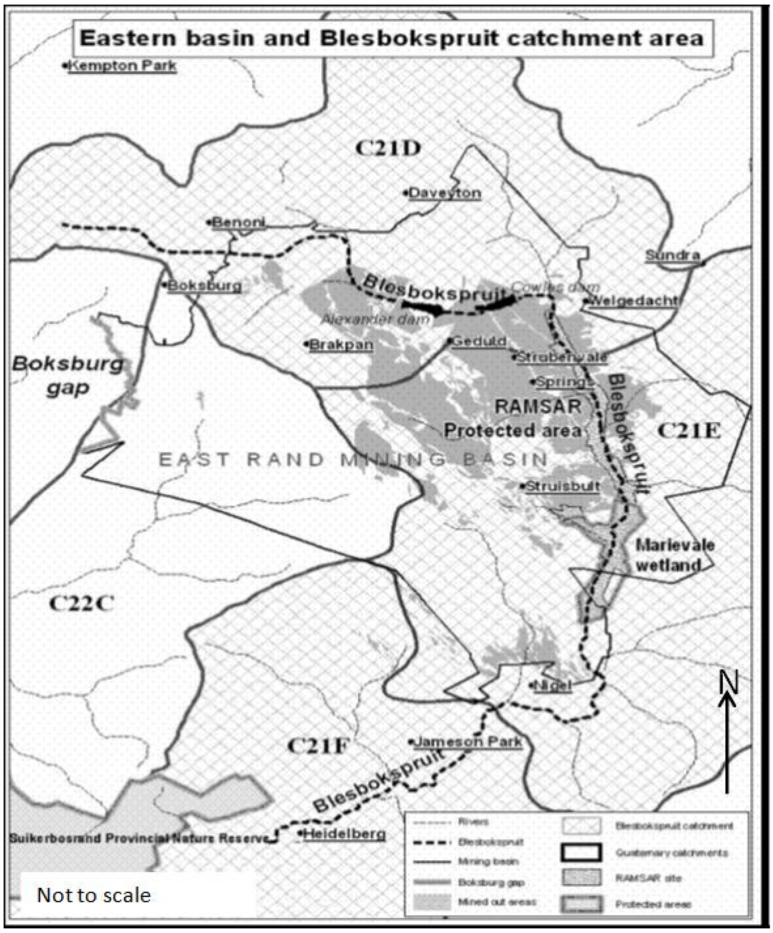

Figure 7: **The Blesbokspruit River system, a sub-catchment of the Vaal River Catchment [Eastern Basin] [Ekurhuleni Metropolitan Municipality, 2008]**

The Ekurhuleni region is dominated by *"… Karst, intergranular and fractured aquifers…";* the Karst aquifer is considered the most important type in South Africa [Hoare *et al.*, 2008]. High groundwater yield from aquifers in the region is found in dolomitic areas, characterised by low surface drainage but considerable underground water flow [Hoare *et al.*, 2008]. However, as previously mentioned, the natural hydrology of the region, including the Blesbokspruit wetland, has been modified with the continuous input of eutrophic waters from the various anthropogenic activities, especially the underground water pumping activities and sewage run-off [Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Hoare *et al.*, 2008]. The input of eutrophic waters has also altered the seasonal fluctuations in the water regimes of both the Blesbokspruit River and the wetland [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Hoare *et al.*, 2008]. During the dry season, because of the seasonal fluctuation in the natural flow, the water in the river and wetland has been primarily the result of *"… point source discharges…"*, principally associated with the previous pumping of underground mine-water by Grootvlei Mine [Haskins, 1998; Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Eastern Basin Blesbokspruit Catchment Task Team, 2006].

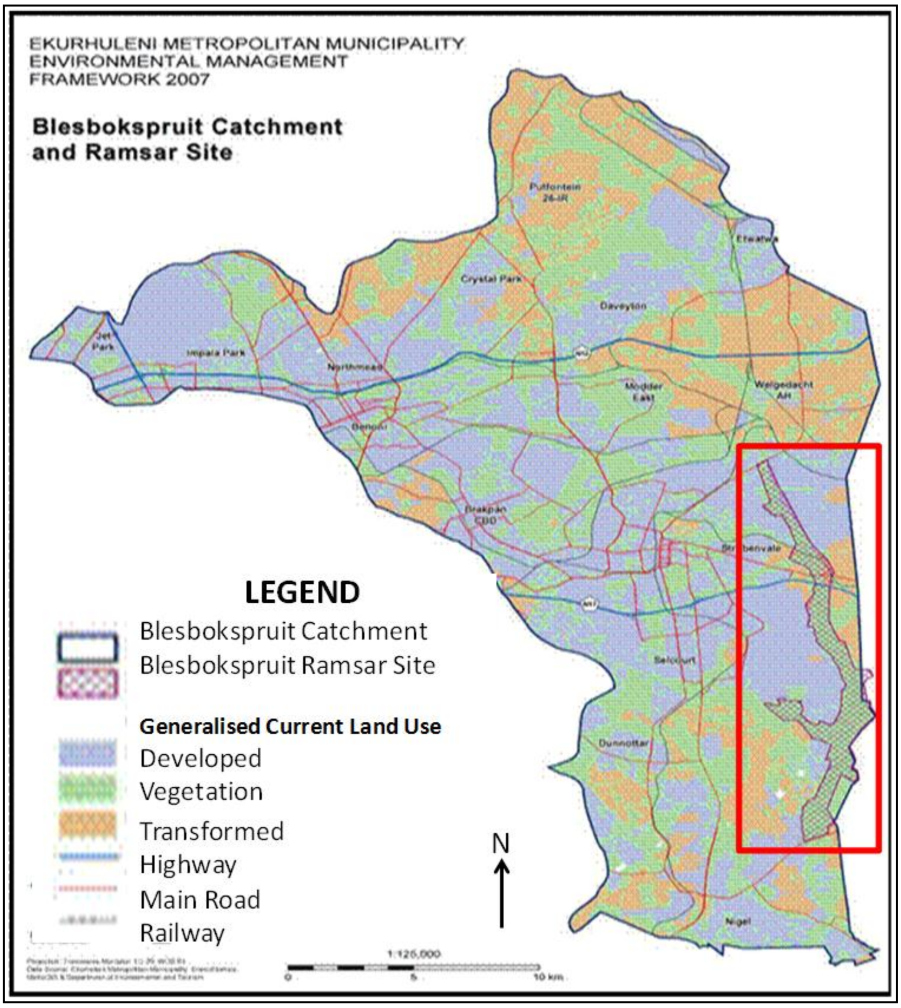

Figure 8: **The Blesbokspruit wetland (inside the red rectangle) as part of the Blesbokspruit catchment Geology, landscape and soils**

The dominant geological formation in the region is *"... dolomite of the Chuniespoort Group (part of the Transvaal System) and tillites of the Dwyka Group (part of the Karoo System), both of which carry water ..."* [Hoare *et al.*, 2008]. Other geological features prevailing in the study area are *"... faults, fissures and fractures zones, as well as contact zones of intrusions such as dykes and sills, dictate the occurrence of groundwater…"* [Hoare *et al.*, 2008]. *"The main aquifer present is a dolomitic aquifer that forms part of the Transvaal Supergroup. In the northern part of the mining area, the dolomite overlies Witwatersrand sediments, where it is up to 200 m thick. A prominent set of sills occurs in the dolomite below 60 m, referred to as the Green sill. These sills have resulted in the development of perched aquifers. Due to the depth of mining, the perched aquifers are not significantly affected by mining activities ..."* [Lea *et al*., 2003]. *"Three main mechanisms of recharge to the underground workings exist, namely recharge from the dolomitic aquifer, direct recharge along reef outcrops and seepage from the Blesbokspruit ..."* [Lea *et al.*, 2003].

Within the Blesbokspruit wetland lies a *"fairly simple"* geology with "… *flat lying sedimentary rocks of Karoo and Transvaal age (250 Ma and 2 200 Ma respectively) overlying older formations of gold bearing Witwatersrand (2 500 Ma) ..."* [South African Wetlands Conservation Programme, 1999]. Despite the Witwatersrand reefs in the East Rand having been exploited from the 1930s, "… *these reefs do not crop out on the surface. The Black Reef Quartzite Formation overlies the Witwatersrand strata (Figure 9) unconformably and is in turn overlain by Malmani dolomites, which form an important natural water reservoir, these two formations form a part of the Transvaal sequence. Extensive erosion took place prior to the deposition of the Karoo sequence. The basal formation of this sequence, the Dwyka Diamictite Formation is a clay-rich rock containing rounded rock fragments (up to boulder size) and is the product of Carboniferous continental glaciations. Overlying the Diamictite, and the most common rock types to be found in the area, are sandstones and shales of the Vryheid Formation. Associated with these strata are coal seams which have been mined adjacent to the Blesbokspruit in the Groot valley area. During the entire geological history of the area, the whole sequence of rock has been intruded by igneous rock (mainly dolerite). The pattern of the outcropping rock strata today reflects an inlier, where younger rock (Karoo) has been eroded along the course of the Blesbokspruit and the older rocks (Transvaal) can thus be seen adjacent to the spruit ...*" [Ramsar, 1998; South African Wetlands Conservation Programme, 1999].

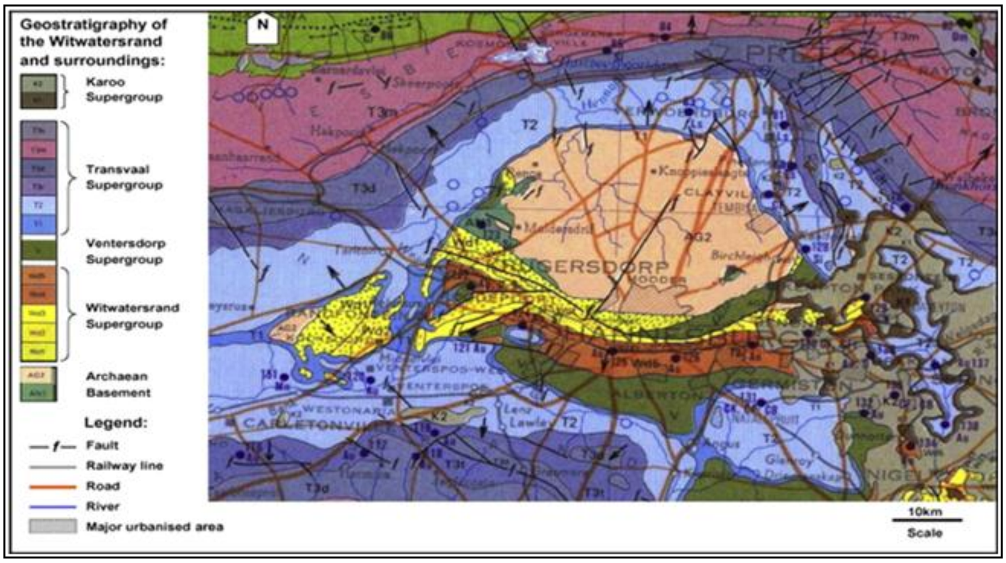

Figure 9: **Geostratigraphy of the Witwatersrand and surroundings [Durand, 2012]**

The landscape surrounding the Blesbokspruit wetland is approximately 1 600 m above sea level [South African Wetlands Conservation Programme, 1999]. This landscape varies between natural or man-made [Haskins, 1998]. Man-made landscaping surrounding the Blesbokspruit wetland has been the result of long years of developmental activities (mining, rock dumps, construction of slimes dams, roads, pipelines, bridges) [South African Wetlands Conservation Programme, 1999]. These anthropogenic disturbances changed the landscape of the area and turned it into a typical flat land (Figure 10) with a gradual topography [South African Wetlands Conservation Programme, 1999]. This type of topography increases the water flow and contributes to expansion in breadth rather than depth of the Blesbokspruit wetland [Haskins, 1998; South African Wetlands Conservation Programme, 1999]. The Blesbokspruit wetland is thus located in a *"…superimposed river valley on plains with pans…"* [Naledzi Environmental Consultants, 2007; Hoare *et al.*, 2008].

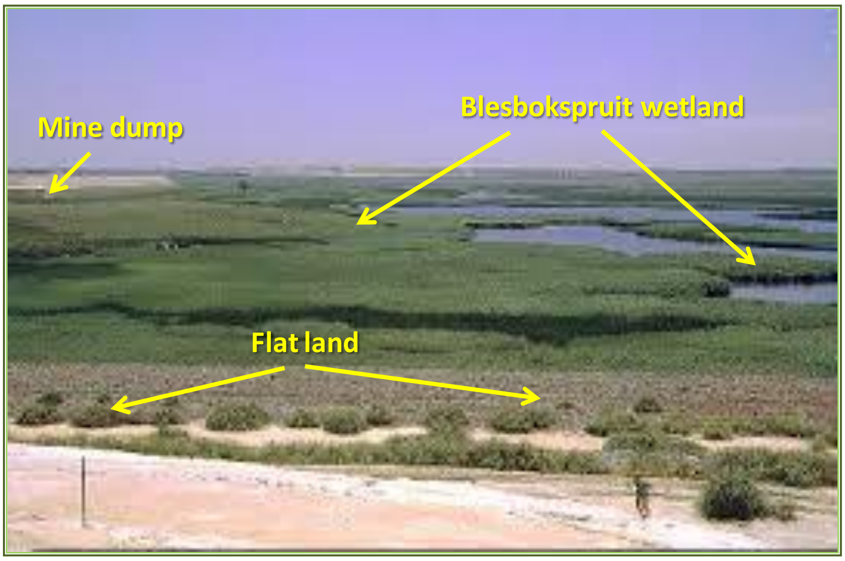

Figure 10: **Flat land and mine dump surrounding the Blesbokspruit wetland [Saving Water SA, 2010]**

The soils found in areas adjacent to the Blesbokspruit wetland are of Ba (30%) and Bb (65%) land types found in the shales and sandstones of the Madzaringwe Formation (Karoo Supergroup) [Naledzi Environmental Consultants, 2007]. These soils usually consist of deep, well-drained red loamy to deep, imperfectly drained yellow-brownish loamy material (Table 4) [Thorius, 2004; Naledzi Environmental Consultants, 2007] and are most suitable for irrigated crops requiring water of high to moderate quality [Thorius, 2004].

Table 4: Soils within the Blesbokspruit area [Thorius, 2004]

Soil Description	Dominant Soil Form	Subdominant Soil Form
Mainly deep, well drained red loamy soils	Hutton	Shortlands; Swartland; Oakleaf
Predominantly deep to moderately deep imperfectly drained yellow brown loamy soils	Avalon	Clovelly; Glencoe; Tukulu
Shallow imperfectly drained yellow brown loamy soils	Avalon; Glencoe	Westleigh
Other soils	Rensburg; Mispah; Glenrosa; Estcourt; Groondal	Katspruit; Willowbrook

2.2.4 *Importance of the Blesbokspruit wetland*

The Blesbokspruit wetland is one of the largest wetlands in Southern Africa and is the only Ramsar site in the Gauteng Province [AngloGold Ashanti, 2004; Ekurhuleni Metropolitan Municipality, 2008]. This situation confers a higher conservation value on the Blesbokspruit wetland since it is located in a highly industrialised and urbanised area (i.e. Ekurhuleni Metropolitan Municipality (EMM)) [Ramsar, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Thorius, 2004; AngloGold Ashanti, 2004; Tonkin, 2005; Naledzi Environmental Consultants, 2007; Hoare *et al.*, 2008]. Wetlands, including the Blesbokspruit, represent crucial habitats in the Ekurhuleni region because of the values, functions and services inherent in such ecosystems [Hoare *et al.*, 2008].

Previously, wetlands were not judged according to their full potential; this led to their fragmentation and destruction [Barbier *et al.*, 1997]. The fate of individual wetlands has not been isolated in South Africa—approximately 50 per cent of the national wetlands have been either converted or destroyed by human activities [Department of Environmental Affairs and Tourism, 2005]. However, as scientific knowledge has increased, wetlands (around the globe) have gradually been recognised as valuable ecosystems and identified as the *"… third most important ecosystem in the world …"* or as *"… the kidneys of the landscape …"* or *"biological supermarkets"* [International Union for the Conservation of Nature, 1980; Mitsch & Gosselink, 1993; Barbier *et al.*, 1997].

The following features of the Blesbokspruit wetland have thus contributed to its identification as an important ecosystem.

2.2.5 *Blesbokspruit as a Ramsar site*

The Blesbokspruit wetland became a Ramsar site on 2 October 1986 [Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2012]. This wetland was *"... one of the few permanent wetlands in the region ..."* at that time [Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2012]. The Blesbokspruit was then providing refuge and was *"... reliable source of food ..."* to at least 20 000 waterfowl of various species—one of the criteria for recognition as a Ramsar sites [Ramsar, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2000; Bowman, 2002; Ramsar, 2012]. The criteria supporting the acceptance of the Blesbokspruit onto a Ramsar Wetland of International Importance were:

> *"1c: Wetland is a particularly good representative example of a wetland which plays a substantial hydrological, biological or ecological role in the natural functioning of a major river basin;*
>
> *2a: It supports an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plant or animal, or an appreciable number of individuals of any one or more of these species;*
>
> *3b: It regularly supports substantial numbers of individuals from particular groups of waterfowl, indicative of wetland values, productivity or diversity" [Ramsar, 1998; South African Wetlands Conservation Programme, 1999].*

This site is numbered 343 on the Ramsar List and is the third of the South African designated Ramsar sites [Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2000]. As a listed site, the Blesbokspruit automatically benefits from the Ramsar protection and other benefits as previously mentioned (*Section 2.1.4 Benefits linked to Ramsar Sites*) in addition to the following privileges:

> *"An endorsement of the principles that the Convention represents, facilitating the development at national level of policies and actions, including legislation, that helps nations to make the best possible use of their wetland resources in their quest for sustainable development;*
>
> *Presents an opportunity for a country to make its voice heard in the principal intergovernmental forum on the conservation and wise use of wetlands;*
>
> *Brings increased publicity and prestige for the wetlands designated for the List of Wetlands of International Importance, and hence increased possibility of support for conservation and wise-use measures;*
>
> *Brings access to the latest information and advice on application of the Convention's internationally-accepted standards, such as criteria for identifying wetlands of international importance, guidelines on application of the wise-use concept, and guidelines on management planning in wetlands;*
>
> *Brings access to expert advice on national and site-related problems of wetland conservation and management through contacts with Bureau personnel and consultants and through application of the Management Guidance Procedure when appropriate; and,*

Encourages international co-operation on wetland issues and brings the possibility of support for wetland projects, either through the Convention's own Small Grants Fund or through the Convention's contacts with multilateral and bilateral external support agencies." [Ramsar, 2000; Ramsar, 2012].

Wetlands in Ekurhuleni have been fragmented or destroyed by the increasing industrialisation and urbanisation that have been taking place since the first mining operations in the 1930s [Ramsar, 1998; BirdLife South Africa, 1998; South African Wetlands Conservation Programme, 1999]. Thus, having a wetland like the Blesbokspruit is of paramount importance for its ecological, hydrological and socioeconomic values—as described in the following sections.

2.2.6 *Ecological status of the Blesbokspruit*

Aquatic and terrestrial species found within the Blesbokspruit define the ecological importance of this wetland [Ramsar, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Thorius, 2004; Tonkin, 2005; Naledzi Environmental Consultants, 2007]. The diversity of species consists of the avifauna (bird species), vegetation, and fauna recorded within the perimeter delimiting the Blesbokspruit wetland [BirdLife South Africa, 1998; Madden, 2002].

Avifauna

The Blesbokspruit is one of the *'Important Bird Areas of Gauteng.'* [BirdLife South Africa, 1998; Madden, 2002]. Listed as South African Bird Area number SA021 it is considered partially protected [BirdLife South Africa, 1998; Madden, 2002]. The 'Important Bird Area' SA021 covers the entire Blesbokspruit wetland system, starting from *"... Springs Bird Sanctuary in the north to Marievale Bird Sanctuary in the south ..."* [BirdLife South Africa, 1998]. More than 286 bird species have been counted within the Blesbokspruit wetland area—including 78 water bird species [BirdLife South Africa, 1998]. However, in the 1980s, the Blesbokspruit wetland used to be refuge for at least 20 000 waterbirds, which contributed to the declaration of this site as a Ramsar Wetland of International Importance in 1986 [BirdLife South Africa, 1998; Madden, 2002; Van der Merwe, 2003]. Back then, the Blesbokspruit wetland acted as an important habitat and refuge for many local and migrant water birds species [BirdLife South Africa, 1998; Madden, 2002; Van der Merwe, 2003].

The main water bird species supported by the Blesbokspruit around the 1980s were quantities of "Great Crested Grebe *Podiceps cristatus*, Yellowbilled Duck *Anas undulata* and Spurwinged Goose *Plectropterus gambensi"* (Figure 11) [BirdLife South Africa, 1998]. These species were more prominent in the dry season because of the permanently wet conditions of the Blesbokspruit (in contrast with other wetlands in the region, which often dry out during the winter months) [BirdLife South Africa, 1998]. However, the number of these species has dropped considerably over the years and nowadays, no species population has exceeded the *"... 1% of the biogeographical population estimate for over a decade ..."* [BirdLife South Africa, 1998]. In addition, the Blesbokspruit wetland used to be a feeding ground for many other bird species—for instance: the Lesser Flamingo *Phoeniconaias minor* and Greater Flamingo *Phoenicopterus ruber* [BirdLife South Africa, 1998].

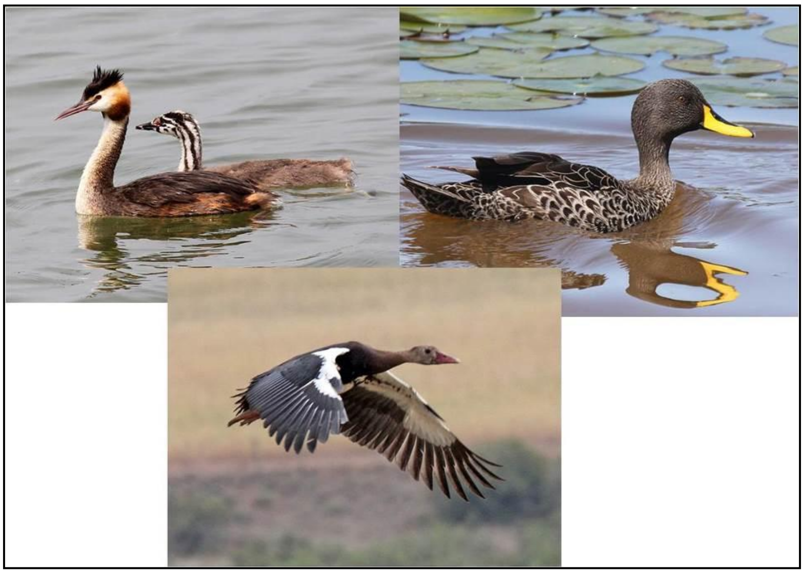

Figure 11: Waterbird species (Great Crested Grebe *Podiceps cristatus,* Yellowbilled Duck *Anas undulata* and Spurwinged Goose *Plectropterus gambensi*) found at the Blesbokspruit wetland [Adapted from Wikipedia, 2013a, 2013b, 2013c]

Currently, the Blesbokspruit wetland supports the native water birds more common to the region: the Goliath Heron *Ardea goliath*, Purple Heron *A. purpurea*, African Spoonbill *Platalea alba,* Glossy Ibis *Plegadis falcinellus,* Avocet *Recurvirostra avosetta,* Redknobbed Coot *Fulica cristata* and Whitewinged Tern *Chlidonias leucopterus* [BirdLife South Africa, 1998]. However, with the increasing level of industrialisation and urbanisation in areas adjacent to the Blesbokspruit wetland, many water bird species have either been displaced completely or become rare visitors. This depletion of birdlife is because of the different pressures placed on their habitat or sources of food [BirdLife South Africa, 1998; Madden, 2002]. The most important species ever recorded at the Blesbokspruit was the *"... African-breeding subspecies of Bittern Botaurus stellaris capensis, which is rare in South Africa …"* and it is very unlikely to be seen at this wetland again, unless this site is restored and becomes less disturbed [BirdLife South Africa, 1998]. Another South African threatened and endemic species, the Hedgehog *Atelerix frontalis,* can also be found within the Blesbokspruit wetland area [BirdLife South Africa, 1998]. Based on BirdLife South Africa's records, *"... there are at least three heron roosts with a total of over 3 500 birds ..."* [BirdLife South Africa, 1998]. The surrounding grassland and reedbeds attract birds (such as the Grass Owl *Tyto capensis)* and about 50 000 European Swallows *Hirundo rustica* have occasionally been recorded [BirdLife South Africa, 1998].

Bird counts are performed either by interested organisations or by visitors and bird watchers [BirdLife South Africa, 1998]. Prominent organisations committed to this task are the Avian Demography Unit and BirdLife South Africa; both share information about the number of avifauna recorded in different regions: in the Blesbokspruit wetland area for example [BirdLife South Africa, 1998]. The Avian Demography Unit works on data received, on a biannual basis, from the Coordinated Waterfowl Counts reports and Avifauna counts by reserve visitors, to keep track of the bird populations in both the Blesbokspruit wetland and the different local reserves [BirdLife South Africa, 1998].

Terrestrial and aquatic fauna

The Blesbokspruit wetland is a refuge for a group of terrestrial and aquatic species [Ramsar, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003]. This wetland is home to *"… a variety of fish, amphibians, reptiles, crustaceans and rodents …"* [Ramsar, 1998; Haskins, 1998; BirdLife South Africa, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003]. Smaller land and aquatic species are food for larger mammals and birds (such as the spotted-necked otters *Lutra maculicollis* and water mongoose *Atilax palidinosus)* (Figure 12) that depend on these species and others as part of their daily diet [Ramsar, 1998; Haskins, 1998; BirdLife South Africa, 1998]. Rare and uncommon species (for instance: reedbuck *Redunca arundinum)* have been spotted in the area [BirdLife South Africa, 1998].

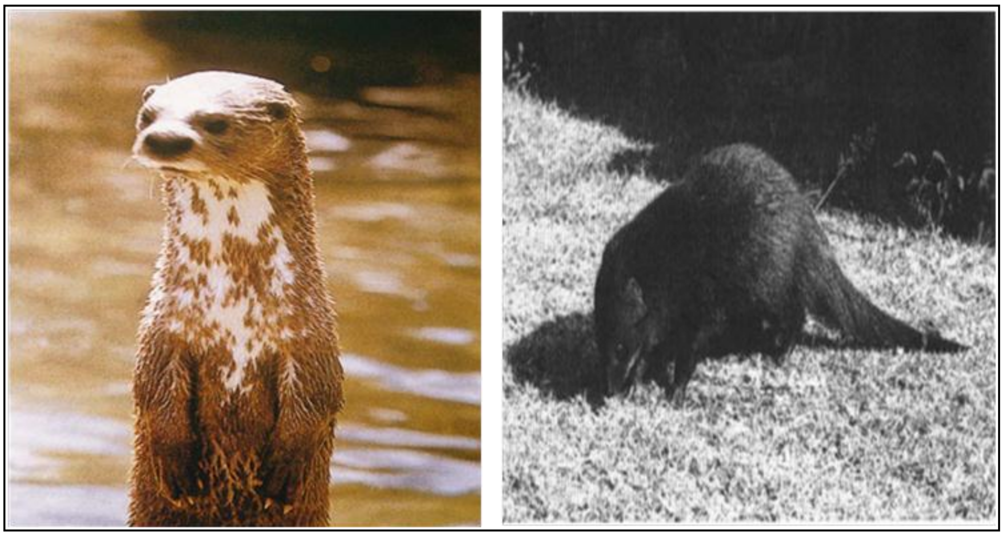

Figure 12: A spotted-necked otter *Lutra maculicollis* and water mongoose *Atilax palidinosus* that can be spotted in the Blesbokspruit wetland area [Larivière, 2002; Baker, 1992]

Terrestrial and aquatic flora

The Blesbokspruit wetland is situated in the *Cymbopogon-themeda* veld as classified by the Acocks veld type no. 48 [Thorius, 2004] or the Highveld Grassland [Ramsar, 1998; BirdLife South Africa, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999]. This type of veld is commonly a sparse, tufted sourveld and coexists with the Bankveld [Thorius, 2004]. Examples of flora species common to this type of veld are *Cunodon dactylon*, *Enyda* fluctuant, *Jancus effuses, Eragrostis* spp. and *Themeda triandra* [Acocks, 1988]. Undisturbed, this area would ideally consist of sparse, tufted veld with a variety of grass species [Thorius, 2004].

The most prolific vegetation within the wetland is the dense *Typha* and *Phragmites australis* or (Common Reed) habitats, *Typha* and the *Latifolia* (Bulrush). The less commonly occurring ones are *Spirogyra spp*. (Green Alga), *Azolla filliculoides* (Red Fern), *Ceratophyllum demersum* (Hornwort), *Potamogeton pectinatus* (Fennel-leved Pondweed) and *Potamogeton crispus* (Curly Pondweed) [Ramsar, 1998; BirdLife South Africa, 1998; South African Wetlands Conservation Programme, 1999; Thorius, 2004]. These reedbeds are unevenly distributed along the wetland, and they are found *"... as large or small single species colonies, with some mixed species clumps."* (Figure 13) [Ramsar, 1998].

Terrestrial vegetative cover consists of 'Moist Cool Highveld Grassland' dominated by *Themeda triandra* [BirdLife South Africa, 1998]. Other grasses in the area are *Triraphis andropogonoides*, *Eragrostis superba*, *Heteropogon contortus* and *Cymbopogon plurinodis* [BirdLife South Africa, 1998]. Large stands of *Crinum bulbispermum* and *Erythrina zeyheri*, *Tephrosia semiglabra, Aloe ecklonis*, *Ipomoea obscura*, *Sutera atropurpurea*, *Helichrysum rugulosum* and *Hermannia depressa* are common to the region as well [BirdLife South Africa, 1998; South African Wetlands Conservation Programme, 1999].

Figure 13: Reedbeds and other plant species surrounding the Blesbokspruit wetland [Ambani, 2009]

With the continuing development (mining, agriculture, residential expansion, sewerage works; and industrial expansion) taking place in the areas surrounding the wetland, the original vegetation of the Blesbokspruit wetland has been considerably modified and replaced with alien species [BirdLife South Africa, 1998]. Alien species that have been recorded in the area include the reedbuck *Redunca arundinum* [Ramsar, 1998; BirdLife South Africa, 1998; Thorius, 2004]. Trees are not a common occurrence in the Blesbokspruit area [Ramsar, 1998]. Exotic trees, like the South American water fern (*Azolla filiculoides*), have been introduced into the area by humans. These exotica now cover vast areas that were previously open water [Ramsar, 1998; BirdLife South Africa, 1998].

Aquatic plant communities also act as filters and thus play a major role in maintaining the quality of water flowing throughout the Blesbokspruit wetland [Van der Merwe, 2003; Collen, 2004]. But the exotic plant species have been found to alter both the quality and quantity of the water running through the Blesbokspruit wetland [Van der Merwe, 2003; Collen, 2004]. The most prolific species are the reed bed species [Ramsar, 1998; BirdLife South Africa, 1998; Thorius, 2004]. These species, and particularly the *Typha*, reduce the large surface areas of open water needed by water birds or aquatic fauna dependent on the Blesbokspruit wetland [Madden, 2002; Adair *et al*., 2012]. In response to their proliferation, bird watching communities using the Blesbokspruit wetland (i.e. the Marievale Bird Sanctuary and the Grootvaly Wetland Reserve) spray herbicides in an attempt to manage the spread of reeds or *Typha* all over the wetland [Madden, 2002].

With the different anthropogenic activities taking place within and adjacent to the Blesbokspruit wetland, there is a trend towards the fragmentation of habitats for avifauna, fauna and flora species [BirdLife South Africa, 1998]. These problems will be investigated under *Section 2.2.7 Land uses and ownership*.

Hydrological values and functions of the Blesbokspruit wetland

The Blesbokspruit wetland is a crucial water resource in a country as water stressed and water scarce as South Africa, where water resources are under continuous pressure to accommodate socioeconomic development [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Naledzi Environmental Consultants, 2007]. Both the South African Constitution of 1996 and the National Water Act 36 of 1998 consider all national wetlands as important and require that these ecosystems be used in the most sustainable manner, preventing their contamination or loss [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Naledzi Environmental Consultants, 2007; Phaleng, 2009]. Because of the permanent wet nature of the Blesbokspruit wetland (in contrast to other wetlands in the region) this wetland could provide water for the downstream or surrounding users throughout the year — particularly during the dry winter season [Eastern Basin Blesbokspruit Catchment Task Team, 2006]. Water users dependent on the Blesbokspruit catchment, and its wetland, include: mines; industries; agriculture; sewerage systems; residential areas; recreational activities located along the Spruit and its associated wetland; and the aquatic life found in the wetland system [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Naledzi Environmental Consultants, 2007]. Blesbokspruit can become a reliable and sustainable source of water supporting different activities in times of drought or crisis in the other wetlands [Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Naledzi Environmental Consultants, 2007].

The Blesbokspruit wetland regulates the flow of the Spruit and controls erosion and flooding in the surrounding areas by absorbing the excess of running and discharged waters from the various sources [Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Collins, 2001; Van der Merwe, 2003; Thorius, 2004]. This situation occurs because of the reedbeds with *"… a well-developed root structure that traps sediments …"* [Ramsar, 1998; South African Wetlands Conservation Programme, 1999]. However, with the continuous pumping of underground mine-water and running waters from other sources, the capacity of the Blesbokspruit wetland to control flooding of adjacent lands and residential areas is becoming a concern because of the longer *"… residence time of the water in the system."* [South African Wetlands Conservation Programme, 1999]. By receiving water from different sources, the natural hydrology and flow of the Blesbokspruit wetland has been modified to become a permanent wetland [Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Thorius, 2004].

This wetland also assists in the purification of the discharged effluents or wastewaters from surrounding mines, industries, sewerage works, residential areas and agricultural activities [Wood & Reddy, 1998; Ramsar, 1998]. The Blesbokspruit wetland assists in the reduction of pollutant loads—nutrients, pathogens, heavy metals and toxins—before the water enters the Vaal River [Ramsar, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Potgieter, 2002]. This purification function occurs when the reeds along its banks uptake the different pollutants through their roots [De Wet *et al*., 1990; Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Potgieter, 2002]. However, the purification and filter functions of the Blesbokspruit wetland cannot be fully performed because of the continuous load and accumulation of pollutants in the wetland system [Wood & Reddy, 1998]. Potential polluters are thus required, by law, to treat their wastewaters before discharge into the Blesbokspruit catchment and its associated wetland [Wood & Reddy, 1998; Ramsar, 1998; South African Wetlands Conservation Programme, 1999].

The hydrological value of the Blesbokspruit wetland is a key factor when determining the establishment of this specific wetland and the maintenance of the different ecological processes [Mitsch & Gosselink, 1993; Mitsch *et al*., 1998]. Wetlands hydrology—including water quality, quantity, and flow as found in the Blesbokspruit—can provide direction on how restoration can take place [Mitsch & Gosselink, 1993; Mitsch *et al*., 1998]. Water quality and quantity are criteria which define and determine the integrity of any wetlands, especially the ones on the Ramsar List of *Wetlands of International Importance* [Ramsar, 2010]. These criteria serve as requirements, agreed to by the Contracting Party after consultation with the Ramsar Committee, to declare a wetland a Ramsar site [Ramsar, 2010]. However, for this study, only the requirements related to water quality and quantity have been considered; they are most representative of the criteria for the removal of the Blesbokspruit wetland from the Montreux Record and the reinstatement of its international status [Adair *et al*., 2012].

Aspects related to water quality and quantity in a wetland according to the Ramsar must be verified (based on the published Blesbokspruit Ramsar Information Sheet) [Ramsar, 2012] and can be summarised as follows:

- The Blesbokspruit catchment depends on the hydrological functions of the wetland;
- The Blesbokspruit wetland needs “sufficient water of adequate quality” for the maintenance of ecological character and in order to maintain these hydrological functions;
- The water quality and quantity of the Blesbokspruit wetland must be continuously monitored and information kept on a database to be available for future planning.

Permanent (or flooded) status can be considered as a criterion for the delimitation of the Blesbokspruit wetland [Ramsar, 1998]. The waterlogged conditions have contributed to this wetland’s function as a habitat and *"reliable source of food"* for diverse avifauna, other faunal species and flora [Ramsar, 1998; South African Wetlands Conservation Programme, 1999] when compared with other wetlands in the region [Richard, 2001; Naledzi Environmental Consultants, 2007; Ramsar, 2012]. In addition, desirable quality and quantity of water plays a considerable role in preserving the dependent aquatic life [Bodenstein *et al*., 2005].

Water from this wetland is used for diverse socioeconomic activities in the surroundings areas (discussed in *section 2.2.7,* covering the different land uses) [Ramsar, 1998]. Therefore, good water quality of an adequate volume can be considered as the most important criteria for the Blesbokspruit wetland to maintain not only its ecological functions/values/services, but also to remain of value to humans [Ramsar, 1998]. This wetland needs careful management, especially in a country where water is scarce and stressed—scientific claims that South African is running short of water to accommodate socioeconomic growth and ecological reserve need to be considered [Cowan & Van Riet, 1998; Abbott, 2002; Bodenstein *et al*., 2005]. This situation arises because of the different pressures placed on the few water resources available in South Africa, especially when anthropogenic activities reduce the quality and quantity of water resource—as is the case in the Blesbokspruit River and associated wetland [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2000].

Other values, services and functions attached to the Blesbokspruit as a wetland

The Blesbokspruit wetland offers a number of services and fulfils a range of functions that are beneficial to both the human and the natural environments [Ramsar, 1998; South African Wetland Conservation Programme, 1999; Van der Merwe, 2003; Thorius, 2004]. Services and functions include, *inter alia*, the following:

- important tourist and cultural destination for bird watchers and religious groups [Ramsar, 1998; Haskins, 1998; South African Wetland Conservation Programme, 1999];
- importance of the site for scientific research because of its international status as a Waterfowl Habitat; a wetland with a large number of plant communities, and the potential impacts of adjacent land use to the ecological character of the wetland [Haskins, 1998; South African Wetland Conservation Programme, 1999; Ramsar, 2000; Eastern Basin Blesbokspruit Catchment Task Team, 2006];
- source of water for socioeconomic activities (mining, agriculture, industries, residential areas, sewerage, recreational activities) [Haskins, 1998; South African Wetland Conservation Programme, 1999; Ramsar, 2000; Van der Merwe, 2003; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006];
- provision of free food and materials for the subsistence of local communities (for instance: fishing and thatching material) [Haskins, 1998; South African Wetland Conservation Programme, 1999; Woodward & Wui, 2001; Schuyt & Brander, 2004].

An illustration of the general benefits inherent in a wetland like Blesbokspruit is provided in Table 5, which presents the direct and indirect values of wetlands.

Table 5: Total values of wetlands, including the Blesbokspruit wetland [adapted from Barbier *et al.*, 1997]

USE VALUES			NON-USE VALUES
Direct Use Value	**Indirect Use Value**	**Option and Quasi-Option Value**	**Existence Value**
Fish Agriculture Fuel-wood Recreation Transport Wildlife Harvesting Peat/energy	Nutrient retention Flood control Storm protection Groundwater recharge External ecosystem support Micro-climatic stabilisation Shoreline stabilisation, etc.	Potential future uses (as per direct and indirect uses) Future value of information	Biodiversity Culture, heritage Bequest values

Special services attached to the Blesbokspruit wetland are provided in Figure 14, illustrating the Blesbokspruit wetland's northern portion, namely at the Grootvaly/Blesbokspruit Conservation Trust.

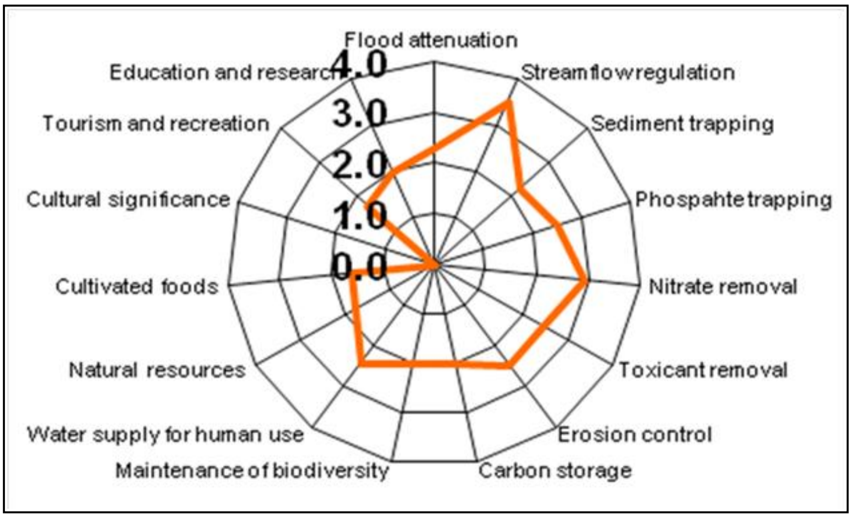

Figure 14: WET-EcoServices diagram as scored for the northern section of Blesbokspruit wetland under the management of the Grootvaly Blesbokspruit Trust [Adapted from Kotze *et al.*, 2007]

From Figure 14, the conclusion can be drawn that the Blesbokspruit wetland performs a number of services and functions with different scores. The highest scored services/functions performed by the Blesbokspruit wetland were found to be stream regulation, nitrate removal, erosion control and water supply for human use, respectively. The lowest score showed that cultural significance at the northern section of this wetland was still a concen, because this wetland is still not fully known or valued by the local communities in terms of the benefits it can offer [Barbier *et al.*, 1997; Cowan & van Riet, 1998; Whyte & Shepherd, 1999; Ramsar, 2000; Van der Merwe, 2009]. This lack of understanding may be one of the reasons for the ecological degradation of the Blesbokspruit wetland [Ramsar, 2000; Collins, 2001; Kotze *et al.*, 2007; Van der Merwe, 2009].

2.2.7 *Land uses and ownership surrounding the Blesbokspruit wetland and their inherent impacts to the ecological character of this wetland*

By the end of the 1990s, the Blesbokspruit catchment was considered 45 per cent urbanised with the remaining 55 per cent used for mining, agricultural and industrial activities [Ramsar, 1998; Haskins, 1998; South African Wetland Conservation Programme, 1999]. It is an area undergoing continuous urbanisation and industrialisation (Figure 15), thus requiring careful land planning by the Ekurhuleni Metropolitan Municipality, particularly if new developments take place in areas surrounding important natural resources like the Blesbokspruit wetland [Ekurhuleni Metropolitan Municipality, 2003; 2004; Naledzi Environmental Consultants, 2007; Ekurhuleni Metropolitan Municipality, 2008].

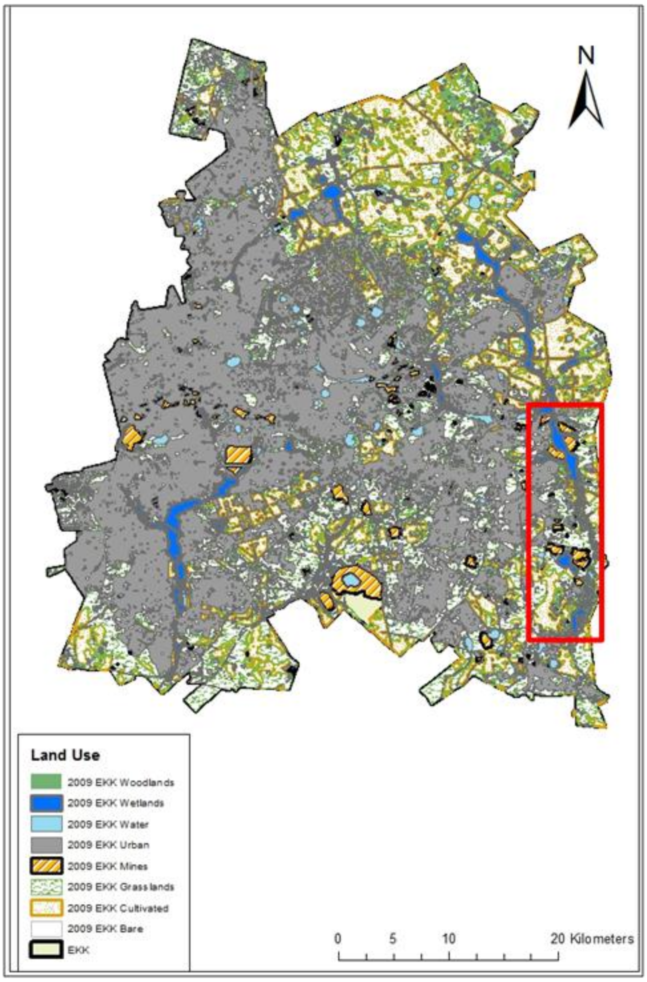

Figure 15: Land-use in Ekurhuleni Metropolitan Municipality in 2009 and, activities surrounding the Blesbokspruit wetland (inside the rectangle in red) (ArcGIS data obtained for the year 2009) [Ambani, 2012]

Different land developments in the Blesbokspruit catchment do not take place without negatively influencing on the water resources in this catchment, including the Blesbokspruit wetland [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Kotze *et al.*, 2007]. The following sections provide insights on the different land-use or developments taking place around the Blesbokspruit wetland and their inherent threats when applicable.

Environmental centres and ecological reserves

The Blesbokspruit wetland is partially protected thanks to the establishment of nature reserves, as early as the 1960s, by the mining companies that were operating at that time [Ramsar, 1998; South African Wetland Conservation Programme, 1999; Maione *et al*., 2000]. There are two main nature reserves along the Blesbokspruit wetland—the Grootvaly/Blesbokspruit Wetland Reserve at the northern section (upstream) and the Marievale Bird Sanctuary at the southern tip (downstream) of the wetland [Ramsar, 1998; South African Wetland Conservation Programme, 1999]. These reserves were or are still owned by local mining companies, e.g. Marievale Consolidated Mines and Daggafontein, which prohibited wildlife hunting for conservation purposes. Hunting has been banned because it had become too popular and uncontrolled on their premises [Ramsar, 1998; South African Wetland Conservation Programme, 1999].

In 1971, Marievale Bird Sanctuary covered 500 ha (donated to the former Gauteng Nature Conservation by the Marievale Consolidated Mines) [Ramsar, 1998; Wood & Reddy, 1998; South African Wetland Conservation Programme, 1999]. However, as time went by, the mine offered more land to the Provincial Government for the benefit of the reserve [Ramsar, 1998; South African Wetland Conservation Programme, 1999]. With the additional purchase of land by the Provincial Government, the Marievale Bird Sanctuary expanded in surface area to cover an approximate area of 1000 ha over a length of 7.4 km—currently extending over half of the area of the total Blesbokspruit wetland (Figure 16) [Ramsar, 1998; South African Wetland Conservation Programme, 1999; Madden, 2002]. The reserve is currently protected by the provincial government, i.e. the Gauteng Department of Agriculture and Rural Development [South African Wetland Conservation Programme, 1999; Muller, 2009]. The reserve is valued because it *"... supports up to 65 different water bird species and 3 500 individuals, particularly during summer when there is an influx of migrants."*, making Marievale one of the most famous birding destinations in Gauteng [Madden, 2002]. Threats to the Marievale Bird Sanctuary include *inter alia* the building of road infrastructure, pipelines, power lines, pumping of excess water by mines, wastewaters from sewage plants, industries and residential areas [Madden, 2002]. Extensive reeds and encroachments that reduce *"... the amount of open-water and shoreline habitat for many ducks and wading birds—overall numbers of waterbirds were significantly lower during this period ..."* are the most common problems facing bird conservationists [Madden, 2002].

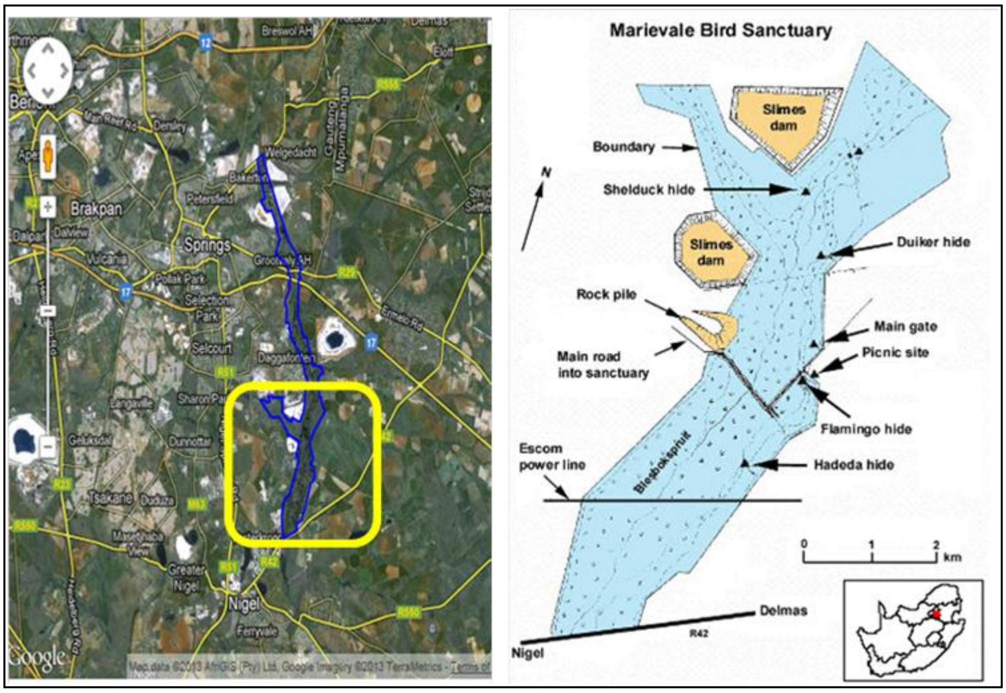

Figure 16: **Extent of the Marievale Bird Sanctuary (left and delineated in yellow) and its surrounding land-use (right) [Adapted from BirdLife South Africa, 1998; Madden, 2002; AfriGIS, 2013; Google Earth, 2013]**

Grootvaly/Blesbokspruit Wetland Reserve or Grootvaly/Blesbokspruit Wetland Environmental Education Centre is a protected 350 ha section of the Blesbokspruit wetland that has been privately owned by Anglo American Group [Ramsar, 1998; South African Wetland Conservation Programme, 1999]. The Grootvaly/Blesbokspruit Wetland Conservation Trust was established in 1995 with the *"… aim of conserving the Blesbokspruit ecosystem …"* [Swart, 1995]. The reserve is an important bird watching spot and receives many local and migratory bird species [BirdLife South Africa, 1998]. Grootvaly is used for scientific research and environmental education promoting the conservation of the Blesbokspruit ecosystem, including projects on the rehabilitation of the Blesbokspruit wetland [Swart, 1995]. The Trust also provides trails for bird watching, and other recreational activities (picnicking, and fishing) [Swart, 1995; South African Wetland Conservation Programme, 1999]. The threats to the centre are associated with the threats to the Blesbokspruit wetland and will be discussed in the following sub-sections.

Mining

Mining started in the East Rand region in the early 1900s because of the considerable gold deposits [Ramsar, 1998; South African Wetland Conservation Programme, 1999; Schoeman & Steyn, 2001; Thorius, 2004]. Historically, mining activities were operated, at first, by 31 small companies, but with time, these grew into larger and more diversified enterprises [Thorius, 2004]. Gold mining has contributed to the industrialisation and urbanisation of the region [Ramsar, 1998; South African Wetland Conservation Programme, 1999; Thorius, 2004; Muller, 2009]. In addition to gold, the underlying geology of the East Rand has encouraged the exploitation of other precious metals—silver, osmium, rhodium, iridium and platinum [Digby Wells and Associates, 1996; Haskins, 1998 Van der Merwe, 2003; De Wet & Prinsloo, 2004; Thorius, 2004].

Mining of different commodities like gold, clay, coal, uranium has triggered different mining methods in the area, ranging from open cast mining, quarrying, shallow undermining, and underground mining [Haskins, 1998; South African Wetland Conservation Programme, 1999; Ekurhuleni Metropolitan Municipality, 2003; 2004; Van der Merwe, 2003; Naledzi Environmental Consultants, 2007]. Underground mining was the most prominent mining method for gold ore recovery along the whole Witwatersrand Gold Belt. This gold-rich area includes the East Rand Basin where companies (East Rand Proprietary Mines, Anglo American Group, Marievale Gold Mining Company Limited and Grootvlei Mines Limited) [De Wet & Prinsloo, 2004; Thorius, 2004] have operated continuously in the area for a number of decades. Mining areas adjacent to the Blesbokspruit wetland (Figure 17) are characterised by the presence of slime dumps [Van der Merwe, 2003], resulting in a unique landscape (Figure 18) [Van der Merwe, 2003].

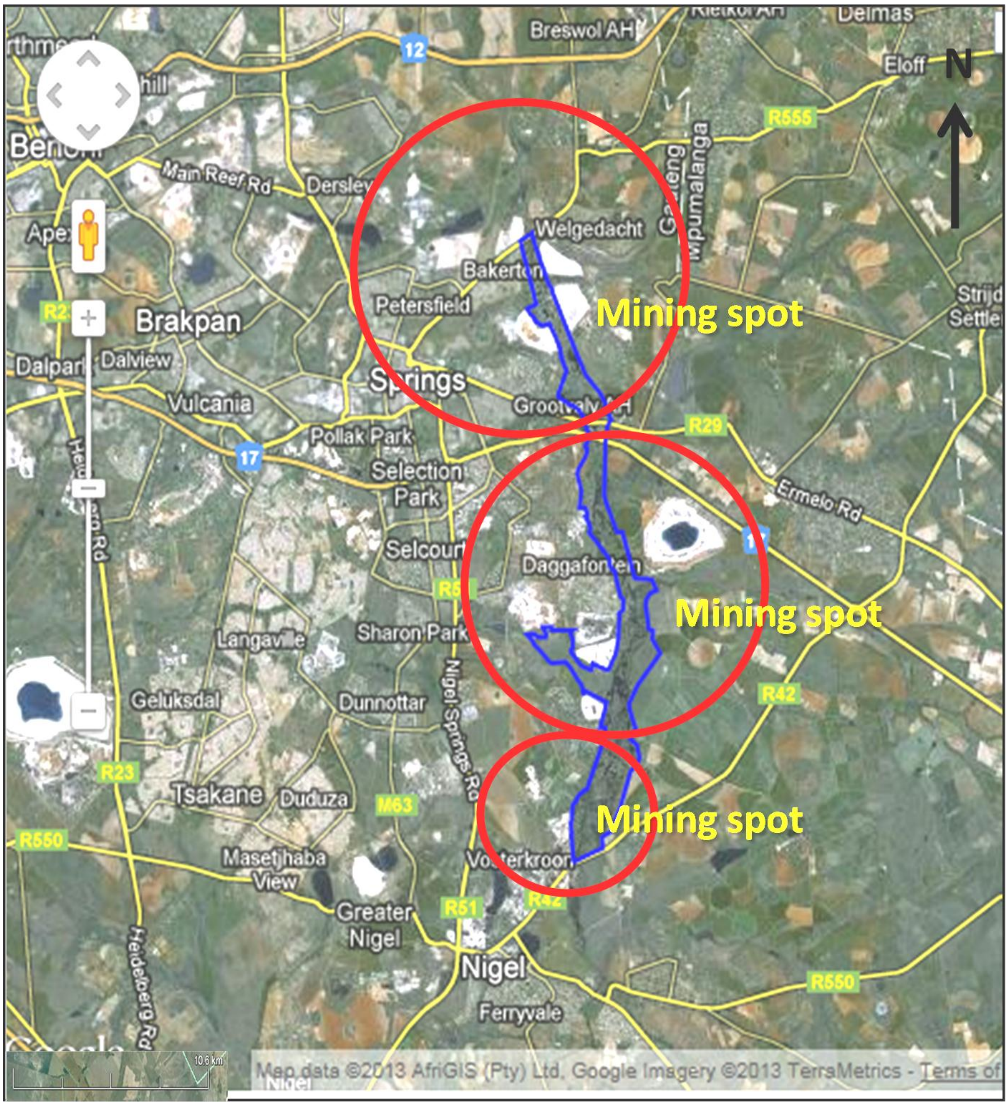

Figure 17: **Mining spots along the Blesbokspruit wetland [Adapted from AfriGIS, 2013; Google Earth, 2013]**

Figure 18: One of the slime dumps located on the western edge of the Blesbokspruit wetland. The pipe and road crossing point are also illustrated [Ambani, 2009]

Nowadays only a few mining companies are still operating in the areas surrounding the Blesbokspruit wetland—the majority of mines in the East Rand Basin ceased their operations in the 1950s because of the operating and management problems (Figure 19). The problems included the higher costs of underground water pumping [Wood & Reddy, 1998; Thorius, 2004]. Underground mine-water pumping, to allow access to the ore, has been an unavoidable and irreversible activity for gold mines in the region [Wood & Reddy, 1998; Thorius, 2004; Muller, 2009]. However, these mines could not continue to support the high costs of dewatering the mines by pumping out the underground mine-waters that were submerging their operations [Ramsar, 1998; Wood & Reddy, 1998; South African Wetland Conservation Programme, 1999; Thorius, 2004; Muller, 2009]. After the closure of most of the mines in the East Rand region, the last existing gold mine in the area surrounding the Blesbokspruit wetland was the Grootvlei Mine, a subsidiary of Petrex Ltd [Lea *et al*., 2003; Thorius, 2004].

Figure 19: Pamodzi Gold Mine, owner of Grootvlei Mine in the 2000s [Ambani, 2009].

The Grootvlei Mine was able to support the costs of pumping underground mine because this mine had been receiving financial assistance from the Department of Mineral and Energy since the 1990s [Thorius, 2004]. Financial aid to Grootvlei Mine was intended to prevent the flooding of the East Rand region and to avoid an environmental disaster from acid mine drainage (as it had been the case for most gold mining areas in the Witwatersrand) [Van Wyk & Munnik, 1998; Thorius, 2004). This situation prevailed until the so-called Grootvlei Mine 'incident' (see *Section 2.3.1*). It has been found that mining activities in the East Rand region, including in the Blesbokspruit River and associated wetland, are inherent to a number of environmental impacts [Thorius, 2004; Naledzi Environmental Consultants, 2007]. Negative effects of mining can occur upstream, downstream or along water resources—as at the Blesbokspruit River and its associated wetland (Figure 20) [Thorius, 2004]. These effects can be described as follows:

- acidification from high iron and sulphates water from dewatering of mine shafts [Ramsar, 1998; South African Wetland Conservation Programme, 1999; Thorius, 2004];
- death of aquatic species in the Blesbokspruit wetland because of "red iron precipitate" in discharged underground mine-water [Ramsar, 1998; South African Wetland Conservation Programme, 1999];
- change in the hydrological conditions of the Blesbokspruit wetland because of additional inputs from the discharge of underground mine-waters or ingress waters [Ramsar, 1998; Haskins, 1998; South African Wetland Conservation Programme, 1999];
- fragmentation and destruction of wetlands in the Ekurhuleni region, especially those surrounded by mining areas [Naledzi Environmental Consultants, 2007];
- leaching of slime dumps and toxic substances into the immediate open water of the Blesbokspruit River and wetland [Haskins, 1998; Van der Merwe, 2003; Ekurhuleni Metropolitan Municipality, 2003; 2004; De Wet and Prinsloo, 2004; AngloGold Ashanti, 2004];
- depletion of aquifers from the pumping of underground mine-water to accommodate ore extraction [Van der Merwe, 2003; Ekurhuleni Metropolitan Municipality, 2003; 2004];
- infiltration of surface water and groundwater ingress into underground mine [Thorius, 2004];
- previously uncontrolled gold mining activities that had transformed the landscape of the region [AngloGold Ashanti, 2004].

Figure 20: **Status of the surface water in the southern section (a) and northern section (b) of the Blesbokspruit wetland [Ambani, 2009]**

However, it should be acknowledged that, ironically, the self-same polluting mine-water is considered to have contributed to the development of what is now known as the Blesbokspruit wetland—through the continuous discharge of underground mine-waters [South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003].

Industries

Ekurhuleni Metropolitan Municipality is considered highly industrial [Thorius, 2004]. Those industries exist for the processing and transformation of raw minerals from mine exploration [Eastern Basin Catchment Task Team,, 2006]; for the manufacturing of other materials and products in the paper and pulp industry (e.g. SAPPI Enstra Mill) [Thorius, 2004; Eastern Basin Catchment Task Team, 2006]. Other industries found in the area are: engineering, machinery, equipment, chemical work and the manufacture of bricks and clay end-products (Figure 21) [South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Eastern Basin Catchment Task Team, 2006].

Figure 21: **Brick manufacturing in the southern section the Blesbokspruit wetland [Ambani, 2009]**

Industrial activities have made major contributions to the degradation of both the Blesbokspruit River and South Africa's wetland systems [South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Eastern Basin Catchment Task Team, 2006]. They have continuously been associated with:

- the release and runoff of toxic chemicals from industrial effluents into the immediate water systems, progressively deteriorating their water quality [South African Wetlands Conservation Programme, 1999; Thorius, 2004; Eastern Basin Catchment Task Team, 2006];
- consistent generation of solid and hazardous waste—ultimately leaching into the wetland's water system and changing the water quality and affecting the aquatic species [Ekurhuleni Metropolitan Municipality, 2003; 2004];
- the discharge of large amounts of industrial effluents causing eutrophication of the open water bodies and thereby posing a threat to their ecological character [Ekurhuleni Metropolitan Municipality, 2003; 2004].
- changes in the natural flow of the Blesbokspruit River and associated wetland by the additional water inputs from industries [South African Wetlands Conservation Programme, 1999].

Agricultural activities

Agriculture in Ekurhuleni Metropolitan Municipality plays a key role in addressing food security problems facing the whole of Gauteng Province [Ekurhuleni Municipality, 2008; Hoare *et al.*, 2008; Mail & Guardian, 2012]. For that reason, arable lands and farming areas have become strategically allocated and purposefully preserved in a region faced with other socioeconomic development projects—e.g. the need for more land for mining and residential development [Ekurhuleni Municipality, 2008; Hoare *et al.*, 2008; Mail & Guardian, 2012]. Agricultural lands extend across considerable areas; are mostly located at the outskirts of urban development or mixed with other land developments [Ekurhuleni Municipality, 2008]. Farming and cultivated lands within the region range from small to large-scale activities, dependent on the levels of output and expertise. These lands can be considered to be creating jobs for the local communities and contributing to the socioeconomic development of the Ekurhuleni Metropolitan Municipality [Eastern Basin Catchment Task Team, 2006; Naledzi Environmental Consultants, 2007]. The agricultural activities provide substantial food products to the whole of Gauteng Province [Van der Merwe, 2003 Thorius, 2004].

Agriculture is mainly practiced towards the eastern side of the region, (as previously illustrated in Figure 15) [Van der Merwe, 2003] and particularly close to wetlands [Naledzi Environmental Consultants, 2007]. Agriculture in the region includes livestock watering and irrigated crops, both of which depend on the Blesbokspruit River and wetland as sources of water [Naledzi Environmental Consultants, 2007; Muller, 2009]. Arable lands, in the form of smallholdings, are cultivated and/or irrigated for major crops—maize, vegetables, fodder for cattle—and horticultural needs (Figure 22) [South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Thorius, 2004].

Figure 22: Maize cultivated in land adjacent to the southern section of the Blesbokspruit wetland [Ambani, 2009]

Farming is an intensive activity, within the Blesbokspruit catchment and along its associated wetland [Van Der Merwe, 2003], which includes small to large-scale businesses breeding cattle and horses (Figure 23) [South African Wetlands Conservation Programme, 1999]. One of the top meat providers in Gauteng, Karan Beef, operates in the Blesbokspruit catchment and depends on the water running through this system [Ekurhuleni Metropolitan Municipality, 2007].

Figure 23: Cattle and horse breeding in areas surrounding the Blesbokspruit wetland [Ambani, 2009]

Water needed for crops and livestock farming comes from either the Blesbokspruit River or its associated wetland, depending on the relative location of the farms/plantations [Ramsar, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1999; Naledzi Environmental Consultants, 2007]. Most water is thus dammed (Figure 24).

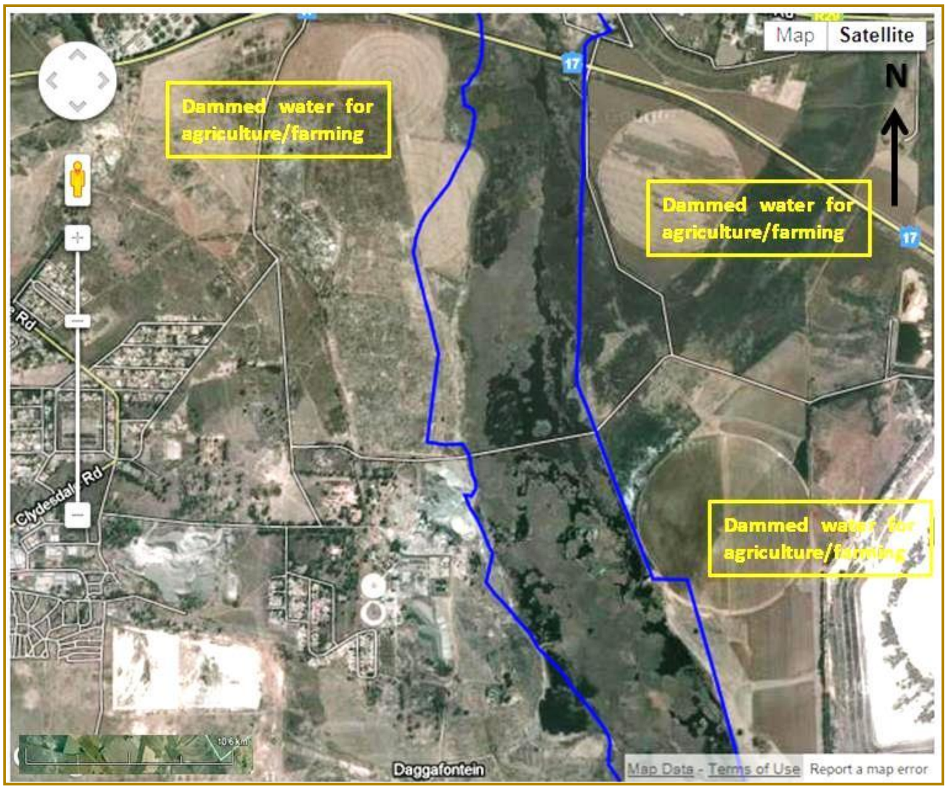

Figure 24: Dammed water for farming and cultivation purposes [Google Earth, 2003]

Agricultural activities are the source of a number of environmental problems for both the Blesbokspruit River and wetland [Ramsar, 1998; South African Wetlands Conservation Programme, 1999; Thorius, 2004; Eastern Basin Catchment Task Team, 2006; Naledzi Environmental Consultants, 2007]. Negative impacts of agriculture in the region include:

- eutrophication of the water bodies from fertiliser runoff [Van der Merwe, 2003] and mainly nitrogen and phosphorus elements [Godwin & Miner, 1996];
- runoff of livestock manure into the open water bodies [Godwin & Miner, 1996];
- fragmentation of the size area and shape of the Blesbokspruit wetland through encroachment of agricultural lands [Naledzi Environmental Consultants, 2007];
- alteration of the hydrological conditions of the Blesbokspruit River and wetland from the filling of dams for irrigation [Naledzi Environmental Consultants, 2007];
- creation of erosion and flooding in areas surrounding dams [Naledzi Environmental Consultants, 2007];
- overgrazing is predominant where the Blesbokspruit wetland becomes the only source of pastures for neighbouring livestock [Naledzi Environmental Consultants, 2007];
- wetland habitat disturbance and fragmentation from the construction of irrigation canals [Adair *et al.*, 2012];

- development of saline soils because of inadequate irrigation methods or overuse of fertilizers [Thorius, 2004];
- potential drying out of the Blesbokspruit wetland if continuous damming occurs without additional water inputs from other sources—mining, industries, and sewage works, [Naledzi Environmental Consultants, 2007].

Sewage treatment works

There are several sewage work treatments within the EMM, especially close to the Blesbokspruit wetland [South African Wetlands Conservation Programme, 1999]. The Blesbokspruit wetland thus receives treated sewage under ideal conditions (when there is no outburst or incident) [South African Wetlands Conservation Programme, 1999].

Since 1992, the major role player with regard to sewage treatment or wastewater management has been the East Rand Water Care Company (ERWAT) (Figure 25), whose major shareholder is the Ekurhuleni Metropolitan Municipality, followed by the Johannesburg Metropolitan Municipality and Lesedi Local Municipality [ERWAT, 2010]. This company serves more *"... 2 000 industries and more than 3.5 million people who have access to sanitation services ..."* with *"... 19 wastewater care works, treating a combined capacity of some 696 megalitres of wastewater per day ..."* [ERWAT, 2010]. ERWAT serves mainly EMM, and treats the sewage before discharge into the Blesbokspruit River and associated wetland [Thorius, 2004; ERWAT, 2010].

Figure 25: One of ERWAT sewage work treatment plants [ERWAT, 2010]

However, the discharge of sewage into the Blesbokspruit wetland has been linked to a number of environmental concerns:

- the eutrophic conditions of the Blesbokspruit wetland (Figure 26) [South African Wetlands Conservation Programme, 1999];
- outburst of pipes because of maintenance failure and thereafter contamination of the surface water quality in the Blesbokspruit wetland by raw sewage [South African Wetlands Conservation Programme, 1999; Tonkin, 2005];
- odours from inefficient sewage treatment plants [South African Wetlands Conservation Programme, 1999];
- additional inputs of water into the Blesbokspruit wetland and change in its natural hydrological conditions related to periodic higher demand in sewage treatments and discharges into wetland the system [South African Wetlands Conservation Programme, 1999];
- with the continued urban expansion in EMM, sewage discharges into both the Blesbokspruit River and wetland remains a concern and the solution requires more efficient sewage treatment plants [South African Wetlands Conservation Programme, 1999; Ekurhuleni Metropolitan Municipality, 2003 & 2004; Thorius, 2004].

Figure 26: Eutrophication from wastewater discharged and dumping of waste into the Blesbokspruit wetland [Ambani, 2009]

Urbanisation and residential expansion

Urban areas in the region cover over 45 per cent of the region (Figure 15 above), and include: residential expansion because of industrial development; commercialised agriculture and increasing population numbers [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Van der Merwe, 2003; Thorius, 2004; Tonkin, 2005]. More particularly, mining activities in the region have contributed to the establishment of formal and informal residential areas (Figure 27); these human settlements were previously meant to accommodate mineworkers [Thorius, 2004].

Figure 27: High-income houses next to the Blesbokspruit wetland [Ambani, 2009]

Residential expansion poses a number of socioeconomic and environmental problems, which in turn put different pressures on both the Blesbokspruit River and its associated wetland [Thorius, 2004; Naledzi Environmental Consultants, 2007]. Several pressures, on water resources such as the Blesbokspruit River and its wetland, emanating from human settlements and urbanisation are listed below and represent the different threats to the hydrology, morphology, water quality and the habit and ecology of both water systems [Ekurhuleni Metropolitan Municipality, 2003 and 2004; Naledzi Environmental Consultants, 2007]. These threats include:

- increased storm water runoff and the poor sewage treatment works for informal residential areas—in Springs, Daveyton—contributes to eutrophication of open water resources such as the Blesbokspruit wetland [Van der Merwe, 2003; Thorius, 2004; ERWAT, 2010];
- encroachment of the flood line of the Blesbokspruit wetland because of residential development in neighbouring towns—Nigel and Springs—making it difficult for its delineation [Uys, 2004; Thorius, 2004; Naledzi Environmental Consultants, 2007];
- changes in the drainage patterns and hydrology from the urban channel system for storm and wastewaters [South African Wetlands Conservation Programme, 1999; Ekurhuleni Metropolitan Municipality, 2003 and 2004; Naledzi Environmental Consultants, 2007; Hoare *et al.*, 2008];
- increased pollutant loads running through the Blesbokspruit wetland [Ekurhuleni Metropolitan Municipality, 2003 and 2004; Naledzi Environmental Consultants, 2007];
- reduction in the diversity of fish, avifauna, mammal species [BirdLife South Africa, 1998; Ekurhuleni Metropolitan Municipality, 2003 and 2004; Naledzi Environmental Consultants, 2007];
- increased stream bank erosion and sediment loads [Ekurhuleni Metropolitan Municipality, 2003 and 2004; Naledzi Environmental Consultants, 2007].

With industrialisation and urbanisation of the region on the increase, better water resource management has become necessary in a water scarce country like South Africa [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Naledzi Environmental Consultants, 2007]. Water resource management has become prominent with the creation of forums or catchment management agencies interested in the Blesbokspruit catchment and the whole of the Eastern Basin—including the Blesbokspruit Forum, the Eastern Basin Blesbokspruit Catchment Task Team, the Gauteng Wetland Forum [Blesbokspruit Forum, 2003a; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Gauteng Wetland Forum, 2010].

Other anthropogenic activities and their threats to the Blesbokspruit wetland

Many more anthropogenic activities take place in the Blesbokspruit catchment, especially close to the Blesbokspruit wetland [Ekurhuleni Metropolitan Municipality, 2003; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Naledzi Environmental Consultants, 2007; Ekurhuleni Metropolitan Municipality, 2008]. These activities range from: water abstraction to accommodate socioeconomic development; collection of thatching material; construction of drainage channel and diversion of water; illegal dumping of waste close or within the wetland system to the construction of transport infrastructure—roads, embankments, bridges, powerlines, pipelines [Ekurhuleni Metropolitan Municipality, 2003; Naledzi Environmental Consultants, 2007; Ekurhuleni Metropolitan Municipality, 2008].

The negative impacts of anthropogenic activities are similar to those in the above-mentioned list (Section 2.2.7), but other different problems include the following:

- introduction of alien species reducing in the numbers and habitat of indigenous species to the Blesbokspruit wetland [BirdLife South Africa, 1998];
- uncontrolled land-use around the Blesbokspruit wetland—e.g. informal residential settlements [Barbier *et al.*, 1997; Ramsar, 2000; Collins, 2001; Ekurhuleni Metropolitan Municipality, 2003; Naledzi Environmental Consultants, 2007; Ekurhuleni Metropolitan Municipality, 2008];
- uncontrolled extraction of Phragmites and bullrushes for use by local communities as artefact and crafts material—reducing the vegetation cover of the Blesbokspruit wetland [Naledzi Environmental Consultants, 2007];
- the waterlogged conditions of the Blesbokspruit wetland can prevent access to or work around it [Naledzi Environmental Consultants, 2007];
- dumping of waste into the Blesbokspruit wetland obstructs its surface (Figure 26) and can trigger its complete destruction if this problem is not rectified [Naledzi Environmental Consultants, 2007];

- concentration of water flow to a particular section of the Blesbokspruit wetland—mostly downstream, after a dam, bridge, pipeline, road structure has been established—diverted to another section [Naledzi Environmental Consultants, 2007];
- since the Blesbokspruit wetland is close to township informal settlement in Springs, there is a potential for any dry vegetation in this wetland to be burned by anthropogenic started fires [Naledzi Environmental Consultants, 2007];
- inability of the Blesbokspruit wetland to perform efficiently its purifying function before the water leaves the system—caused by the accumulation of inorganic and organic pollutants from direct and indirect points [Haskins, 1998; South African Wetlands Conservation Programme, 1999; AngloGold Ashanti, 2004; Bodenstein *et al.*, 2006].

Anthropogenic activities surrounding or within the Blesbokspruit wetland have been proven to alter the ecological character of the Blesbokspruit wetland from what it was when recorded into the Montreux Record in 1996 [Haskins, 1998; South African Wetlands Conservation Programme, 1999; AngloGold Ashanti, 2004]. However, only one specific activity has been cited as the main culprit of the loss of the health of the Blesbokspruit wetland—i.e. underground gold mining from the Grootvlei Mine [Haskins, 1998; South African Wetlands Conservation Programme, 1999; AngloGold Ashanti, 2004; Van Der Merwe, 2003; Thorius, 2004]. From the mid-1990s onwards, surface water contamination in the Blesbokspruit wetland has triggered much criticism from international, local key players and sectors of the public—all of whom are interested in environmental conservation issues (Bethlehem & Goldblatt, 1997; Ramsar, 1998; Haskins, 1998; South African Wetlands Conservation Programme, 1999; AngloGold Ashanti, 2004; Van der Merwe, 2003; Thorius, 2004].

2.2.8 *Legal and management status of the Blesbokspruit wetland*

Although considered legally as a non-binding international agreement, the Ramsar Convention still has its *raison d'être* for the *"wise use and conservation"* of international recognised wetlands [Barker, 1995; Adair *et al.*, 2012]. The Blesbokspruit wetland is "protected" under international law and, therefore is seen as a natural resource meant to benefit the global communities—not only South Africans [Barker, 1995; Adair *et al*., 2012].

The Department of Environmental Affairs (DEA) is responsible for implementing and administrating the Ramsar Convention at the national level, including the Blesbokspruit wetland [Cowan & Van Riet, 1998; Ramsar, 2000; Collins, 2005; Ramsar, 2012]. However, this national department shares its responsibilities with other national departments whose activities or decisions may be dependent on or affect wetlands [Collins, 2005]. At provincial level, the Department of Environmental Affairs delegates managerial powers to provincial governments, such as the Provincial Gauteng Department of Agriculture and Rural Development (GDARD), to assist with the implementation of the *"wise use and conservation"* Ramsar framework of the Blesbokspruit wetland [Macfarlane & Muller, 2011]. With the Blesbokspruit wetland located in Gauteng (more precisely in the East Rand), the Ekurhuleni Metropolitan Municipality answers to GDARD on issues relating to the Blesbokspruit wetland [Macfarlane & Muller, 2011]. In addition, groups of stakeholders—comprising governmental departments, private companies, environmental non-profit organisations and the public—have also come together as forums, committees or task teams to engage in and foresee water and land related issues in the whole Eastern Basin, including the Blesbokspruit catchment [Macfarlane & Muller, 2011].

Prior to the mid-1990s, because South Africa had outdated, weak or non-existent environmental legislation that could not enforce the *"wise use and conservation"* of the Blesbokspruit wetland, it was difficult for the relevant authorities to coerce companies to develop strategies or implement environmental best practices that would protect the ecological character of Blesbokspruit wetland [Macfarlane & Muller, 2011]. One of the requirements of the Ramsar Convention was that a management plan for the Blesbokspruit wetland should be developed to guide future activities around this wetland [South African Wetlands Conservation Programme, 1999; Meeuwis, 2009: Personal Communication, Senior Environmental Management Lecturer, University of Johannesburg; Macfarlane & Muller, 2011]. However, for more than a decade after the designation of the Blesbokspruit as a *Wetland of International Importance*, *Especially as a Waterfowl Habitat* in 1986, only drafts of this plan had been available, hence not sufficiently effective to guide any developments likely to affect the Blesbokspruit wetland [Macfarlane & Muller, 2011]. That is why, these dafted plans were criticised because they were too fragmented, sporadic, and ineffective, and cited as the main reason why Grootvlei Mine could continue to affect negatively the Blesbokspruit wetland [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Ramsar, 2007; Muller, 2009; Meeuwis, 2009; Macfarlane & Muller, 2011]. The requirements of the Ramsar Convention were thus not met [Macfarlane & Muller, 2011].

Between mid-1990s and 2000s, problems with drafting a comprehensive management plan for the Blesbokspruit wetland were linked to the following aspects:

- weakness of management plan or measures for the wise use, conservation and protection of the Blesbokspruit wetland by the government (as has happened around the world) [Barbier *et al*., 1997];
- too many landowners around the Blesbokspruit wetland; making its complete protection a complex task, heightened by the sporadic nature of management issues inherent in this wetland [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Eastern Basin Blesbokspruit Catchment Task Team, 2006];
- problems in the implementation of the drafted management plan because of the complex origin, development and location of the Blesbokspruit wetland [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Eastern Basin Blesbokspruit Catchment Task Team, 2006].

After the year 2000, with the changes in land-use policies and the passing of new pieces of environmental legislation, there was hope that the management of natural resources—like the Blesbokspruit wetland—would become more effective and bear positive fruit [Collins, 2005; Macfarlane & Muller, 2011]. Effective environmental legislation and management would assist in the delisting of the Blesbokspruit wetland from the Montreux Record [Ramsar, 1992; Macfarlane & Muller, 2011]. The new drafted management plans from the year 2000 to 2012, however, still failed in many regards [Ramsar, 2000; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Macfarlane & Muller, 2011]. The reasons for this lack of success still include:

- the management plan has not yet integrated all land-uses in an holistic manner; the plan still needs to incorporate accurate identification of all possible impacts inherent to the various land-uses; the plan needs to include proposals on how to monitor, mitigate and remediate or rehabilitate any possible detrimental effects for the protection and benefit of the wetland system [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Meewis, 2009; Macfarlane & Muller, 2011];
- there has been a long-term problem of commitment to the elaborated management plans (past and current) from the various stakeholders whose activities may, in one way or the other, be detrimental to the wetland [Eastern Basin Blesbokspruit Catchment Task Team, 2006; Meewis, 2009; Muller, 2009; Macfarlane & Muller, 2011];
- since the inclusion of the Blesbokspruit onto the Montreux Record, the competent authorities and stakeholders have encountered many challenges in the development and implementation of a management plan for the Blesbokspruit wetland [Muller, 2009; Macfarlane & Muller, 2011];
- the management of the Blesbokspruit wetland is still not fully active because this wetland is still relatively unknown —its values, functions and services are not fully defined—which contributes to it being discriminated against when considered against the socioeconomic development projects so much needed in the region [Macfarlane & Muller, 2011];
- a new unique and holistic management plan for the Blesbokspruit wetland is needed—because at present, different ownerships of the land surrounding this wetland make overall management ineffective [Macfarlane & Muller, 2011; BirdLife South Africa, 2013; Coughlan, 2013].

If South Africa wishes the Blesbokspruit wetland to be removed from the Montreux Record, because of successful restoration and management of this site, there are special studies to be completed [Ramsar, 1992; Ramsar, 1996a, 1996b; Smart, 1997; Adair *et al.*, 2012]. Studies should aim at providing scientific evidence to justify the theory that the ecological character of the Blesbokspruit wetland can now be maintained [Ramsar, 1992; Ramsar, 1996a, 1996b; Adair *et al.*, 2012]. For the Blesbokspruit wetland, since the loss of its ecological character was related to high saline underground mine-water contaminating the wetland system, only a continual improvement of the surface water quality of this wetland can be seen as a positive result [Ramsar, 1992; Macfarlane &

Muller, 2011; BirdLife South Africa, 2013; Coughlan, 2013]. Studies that can provide validation of a positive result could then be considered a motive for the Department of Environmental Affairs to apply to the Ramsar Committee for removal of the Blesbokspruit from the Montreux database [Ramsar, 1992; Adair *et al.*, 2012; Macfarlane & Muller, 2011; BirdLife South Africa, 2013; Coughlan, 2013]. Removal of the wetland from the Montreux database would therefore be based on a "legitimate reason", because South Africa has *"… an interest in maintaining a dignified standing in the international community …"* [Ramsar, 1992; Macfarlane & Muller, 2011; Adair *et al.*, 2012 ; BirdLife South Africa, 2013; Coughlan, 2013].

Other management interventions that have taken place in the Blesbokspruit catchment and wetlands include, *inter alia,* the designation of the southern portion of the Blesbokspruit wetland as a Nature Sanctuary; bird monitoring and counting; reed management; establishment of the Blesbokspruit Forum and the Eastern Basin Blesbokspruit Catchment Task Team [Madden, 2002; Blesbokspruit Forum, 2003a; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Macfarlane & Muller, 2011]. The Blesbokspruit Forum was created in 1996 as one of thirteen catchment management forums that currently exist in the Upper Vaal Catchment Management Area [Blesbokspruit Forum, 2003a]. The Blesbokspruit Forum was established because stakeholders perceived the need for a platform where consensus on effective catchment management strategy could be reached [Blesbokspruit Forum, 2003a]. This Forum would ultimately assist in the implementation of the National Water Act 36 of 1998 by putting in place water management strategies in the catchment since "… *the participation of all people in the protection, use, development, conservation, management and control of the water resources of the Blesbokspruit Catchment will be promoted through the Blesbokspruit Forum."* [Blesbokspruit Forum, 2003a]. Water management strategies already planned or implemented will be further summarised in *Section 2.4.2*.

2.3 The listing of the Blesbokspruit wetland onto the Montreux Record

Mining is the most important cause of the physicochemical contamination of water resources on both the global and national scales—including in South Africa [Haskins, 1998; Van der Merwe, 2003; Thorius, 2004; Naidoo, 2009]. This contamination has prevailed in South Africa, particularly in the gold mining areas of the Witwatersrand and where mines have been located close to water resources [Naidoo, 2009]. The pollution takes the form of acid mine drainage when natural waters come into contact with mine-waters rich in chemicals and heavy metals, pumped from underground mine works in Gauteng [Naidoo, 2009]. Underground mine-waters need to be pumped out to allow underground mine operations. Pumping is regulated according to water-use licenses issued by the Department of Water Affairs [Haskins, 1998; Wood & Reddy, 1998; Van der Merwe, 2003; Thorius, 2004].One of the license requirements, as part of water quality management measures, is that the mine-waters be treated before discharge [Wood & Reddy, 1998]. However, this has not always been the case—particularly with the early mining methods used by companies before the implementation of stricter and effective environmental legislation that could limit or require control of potential mining environmental impacts—i.e. methods in common practice before the 1990s [AngloGold Ashanti, 2004]. In addition, when faced with dilemmas because of financial, management difficulties and inadequate water treatment technologies versus the continuation of mining operations, certain mining companies took the risk to pollute adjacent water resources. Companies faced the possibility of having their water license withdrawn and/or having to cease completely their mining operations [Van Wyk & Munnik, 1998; Wood & Reddy, 1998]. This was the case for Grootvlei Mine from the mid-1990s until December 2010 [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetland Conservation Programme, 1998; Lea *et al*., 2003; Naidoo, 2009; Liefferink, 2011]. The main details of the story behind the so-called 'Grootvlei Mine incident' (or 'disaster') follow.

2.3.1 *The Grootvlei Mine 'incident' or 'disaster' as a driving force for the inclusion of the Blesbokspruit wetland onto the Montreux Record*

By 2010, Grootvlei Mine has had more than one owner during its period of operations [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetland Conservation Programme, 1998; Lea *et al*., 2003; Naidoo, 2009; Liefferink, 2011]. It was lastly owned by Aurora Empowerment Systems [Naidoo, 2009; Liefferink, 2011]. Grootvlei Mine is located along the Blesbokspruit wetland [Van Wyk & Munnik, 1998]. Grootvlei is one of the last operating gold mines in the Eastern Basin. Most mines in this region became financially marginal and were forced to cease their operations or were simply abandoned [Van Wyk & Munnik, 1998]. High operating costs or management problems, especially with the compulsory dewatering of underground mine-waters to keep the mines operational and facilitate the access to the ore, contributed to this situation [Scott, 1995; Van Wyk & Munnik, 1998].

Water in the Grootvlei Mine area originates from both its underground works and the surface or other sources of ingress [Lea *et al*., 2003; Jones & Wagener, 2011]; the latter increases the volume of water that needed to be pumped out by Grootvlei Mine [Van Wyk & Munnik, 1998; Lea *et al*., 2003]. To maintain its underground mining operations (when other mines in the areas had ceased their activities and the inherent pumping of underground mine-water) Grootvlei Mine had to discharge approximately 75 ML/d—which was directed into the Blesbokspruit wetland (Figure 28) [Van Wyk & Munnik, 1998; Lea *et al*., 2003]. Discharge of underground mine-water into the Blesbokspruit wetland had been authorised by the Department of Environmental Affairs on condition that appropriate water treatment measures be put in place "*…in the form of a desalination plant"* [South African Wetland Conservation Programme, 1998; Lea *et al*., 2003]. However, compliance with the permit was not always successful because of the financial, technical and management constraints faced by Grootvlei Mine [Wood & Reddy, 1998;]. Failures in treating underground, contaminated mine-water contributed to the so-called Grootvlei Mine 'incident' or 'disaster' [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; Thorius, 2004].

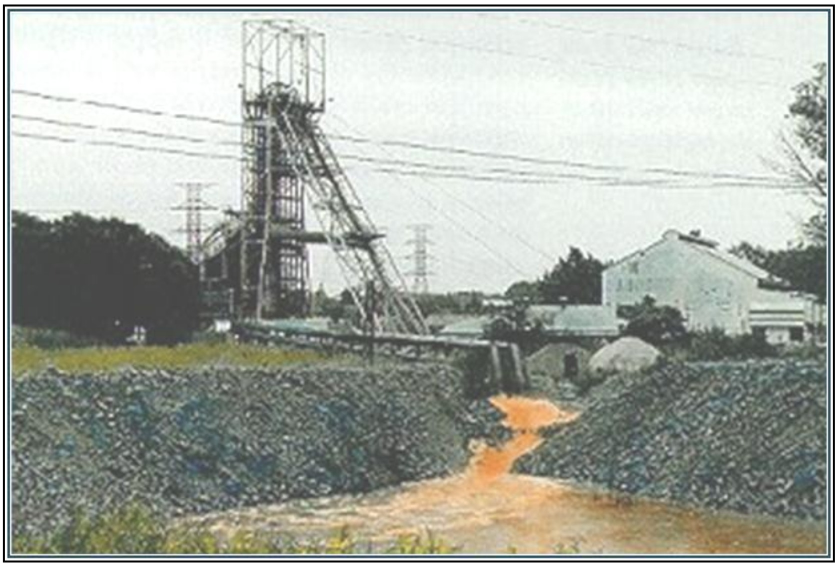

Figure 28: **Initial discharge of highly polluted water directly to the wetland by Grootvlei mine, December 1995 [South African Wetland Conservation Programme, 1998]**

As implied, the Grootvlei Mine 'incident' was seen as an environmental catastrophe by many parties [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1998]. The incident started in the second half of 1995, but reached its culmination in 1996 when acid mine drainage ran throughout the open waters of the Blesbokspruit wetland [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetland Conservation Programme, 1998]. This acid mine drainage was characterised by mine-water rich in iron hydroxide and sulphates [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1998]. Acid mine-water in the Blesbokspruit wetland resulted in the death of a considerable number of species—e.g. crabs, fish. It also caused a reduction in the diversity in aquatic avifauna species—particularly in the waterfowl that had been considered the rationale for ascending this wetland as a Ramsar site in 1986 [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; Ramsar, 1998; South African Wetlands Conservation Programme, 1998].

In May 1996, as a response to the prevailing situation and to criticisms made by different groups, the Department of Environmental Affairs requested that the Blesbokspruit wetland be placed on the Montreux Record [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1998; Richards, 2001; Thorius, 2004; Ramsar, 2012]. Having the Blesbokspruit wetland placed on the Montreux Record, on the grounds of saline water contamination negatively affecting the ecological character of this wetland, has many implications.

After the listing of the Blesbokspruit wetland onto the Montreux Record, the competent authorities (the Department of Environmental Affairs, the Department of Water Affairs and the Department of Minerals) requested that Grootvlei Mine investigate and implement water treatment options to minimise further impacts on the Blesbokspruit wetland [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1998; Thorius, 2004]. With the implementation of a pilot water treatment plant, iron hydroxide-rich water was pumped by Grootvlei Mine from their underground workings to a settling facility at the mine [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1998]. This process allowed iron compounds to precipitate in clarifying tanks before the partially treated mine-water was discharged into the Blesbokspruit wetland (Figure 29) [Van Wyk & Munnik, 1998; Wood & Reddy, 1998; South African Wetlands Conservation Programme, 1998].

Figure 29: A settling facility at Grootvlei Mine (a) and clarifying tanks (b) [Adapted from South African Wetlands Conservation Programme, 1998]

This procedure was necessary if Grootvlei Mine wished to resume its mining operations [Thorius, 2004]. The partial treatment (Figure 30) was revealed to be successful; just a few days later, Grootvlei Mine was operational again [Van Wyk & Munnik, 1998; South African Wetland Conservation Programme, 1998; Thorius, 2004].

Figure 30: Discharge of partially treated mine-water entering the Blesbokspruit wetland [South African Wetlands Conservation Programme, 1998]

2.3.2 *Implications of having the Blesbokspruit wetland still listed onto the Montreux Record*

The listing of the Blesbokspruit wetland onto the Montreux Record has provoked many debates from socioeconomic, political and environmental standpoints [Ramsar, 2000; Muller, 2009; Ramsar, 2012]. At the international level, South Africa had breached an international law or agreement relating to international wetland conservation [Ramsar, 1992]. This happened because, prior to 1990s, South African environmental legislation capable of enforcing the "wise use and conservation" of the Blesbokspruit wetland was either non-existent, outdated or too weak to coerce water polluters (such as the Grootvlei Mine) to apply environmental best practices when operating close to water bodies or natural resources [Ramsar, 1992].

Having the Blesbokspruit wetland listed on the Montreux Record also promoted a negative image of South Africa; it became a *"black mark"* for the country because of the then ineffective management of its international natural resources [Adair *et al*, 2012; International Institute for Sustainable Development, 2012; BirdLife South Africa, 2013; Coughlan, 2013]. The inefficiency was caused by the fragmented and sporadic management plan (which had taken over a decade post-1986 to be finalised, when the Blesbokspruit had become a Ramsar site of international interest [Ramsar, 2007; Muller, 2009; Meeuwis, 2009; Macfarlane & Muller, 2011]. In addition, South Africa, with the Blesbokspruit still under threat, cannot promote international cooperation for the preservation of other wetlands on the African continent or at the global scale [Ramsar, 2007; Muller, 2009; Meeuwis, 2009; Macfarlane & Muller, 2011; BirdLife South Africa, 2013; Coughlan, 2013]. The Blesbokspruit wetland, as habitat for migratory waterfowls or other endangered species, first needs to be restored and negative impacts by anthropogenic activities removed before South Africa can play a significant role on the world stage [Macfarlane & Muller, 2011; Adair *et al*., 2012; BirdLife South Africa, 2013; Coughlan, 2013].

The Blesbokspruit has become an *"impaired ecosystem"*—a definition applied to many wetlands included on the Montreux Record of *"wetlands in need of priority conservation*" [Macfarlane & Muller, 2011; Adair *et al*., 2012; BirdLife South Africa, 2013; Coughlan, 2013]. The Blesbokspruit wetland is not functioning at its full capacity, as it had been when it was initially recognised as a Ramsar site [Macfarlane & Muller, 2011; BirdLife South Africa, 2013; Coughlan, 2013]. Since the wetland was placed on the Montreux Record, there have been—and are still—problems in integrating *"…sustainability with ecology of this wetland…"* [Macfarlane & Muller, 2011; Adair *et al*., 2012; BirdLife South Africa, 2013; Coughlan, 2013]. Anthropogenic activities remain the principal threat to the ecological character of this wetland [Macfarlane & Muller, 2011; BirdLife South Africa, 2013; Coughlan, 2013]. Thus, the *"wise use and conservation"* framework of the Ramsar Convention has not been respected by socioeconomic developments or anthropogenic use surrounding the Blesbokspruit wetland [Ramsar, 1992; Macfarlane & Muller, 2011; Adair *et al*., 2012; BirdLife South Africa, 2013; Coughlan, 2013].

2.4 Summary of previous investigations on water quality and quantity issues in the Blesbokspruit wetland

Over the years, surface water quality and quantity in the Blesbokspruit catchment, including the wetland, have been investigated [Wood & Reddy, 1998]. Initially these investigations took place because of the many negative implications linked to poor water quality and flooding in this catchment and in Gauteng at large [Wood & Reddy, 1998]. Background details of the characteristics of water pollution in the Blesbokspruit wetland will be discussed below. A chronologically list of water quality and quantity related issues, the sources of pollutants and management interventions that are inherent to the Blesbokspruit wetland, will be included.

2.4.1 *Characteristics of water pollution in the Blesbokspruit wetland*

With regard to the Blesbokspruit wetland, special interest has been focused around salt concentrations and the acidification of the water system, concentrating on Grootvlei Mine as the point source [Wood & Reddy, 1998]. Saline water intrusion has been one of the main concerns because it contributed to a change in the ecological status of the Blesbokspruit wetland and led to the flagging of this wetland under the Montreux Record [Wood & Reddy, 1998; South African Wetland Conservation Programme, 1998; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006]. Saline water emanates from acid mine drainage or is the result of an accumulation or interaction between different salts—sulphate, magnesium, sodium and chloride—which negatively influence the aquatic life and dependent food chain of the Blesbokspruit wetland [South African Wetland Conservation Programme, 1998]. Saline water poses an ongoing threat to this Ramsar site and requires management action to restore desirable surface water quality conditions to encourage aquatic species abundance and diversity [South African Wetland Conservation Programme, 1998].

Saline and acidic waters in the Blesbokspruit wetland have been duly documented because the conditions also lowered the quality of the water used by downstream and surrounding users—e.g. for the irrigation of crops and livestock watering [Tonkin, 2005]. Extended impacts of surface water degradation in the Blesbokspruit have been associated with the accumulation of salt loads in the receiving Vaal River—a river system on which the whole of Gauteng depends for various water requirements, including domestic consumption [South African Wetland Conservation Programme, 1998; Wood & Reddy, 1998; Thorius, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006].

With saline water and acidic pollution the main challenges faced in the Blesbokspruit catchment, the selection of the best available control measures, to reduce the level of sulphates and other salt related pollutants in the discharged waters or effluents, is reliant on the application of certain evaluation criteria [Bowell, 2000] (Figure 31). Evaluation methods consist firstly of measuring both pH and sulphate levels to enable an appropriate decision to be reached [Bowell, 2000].

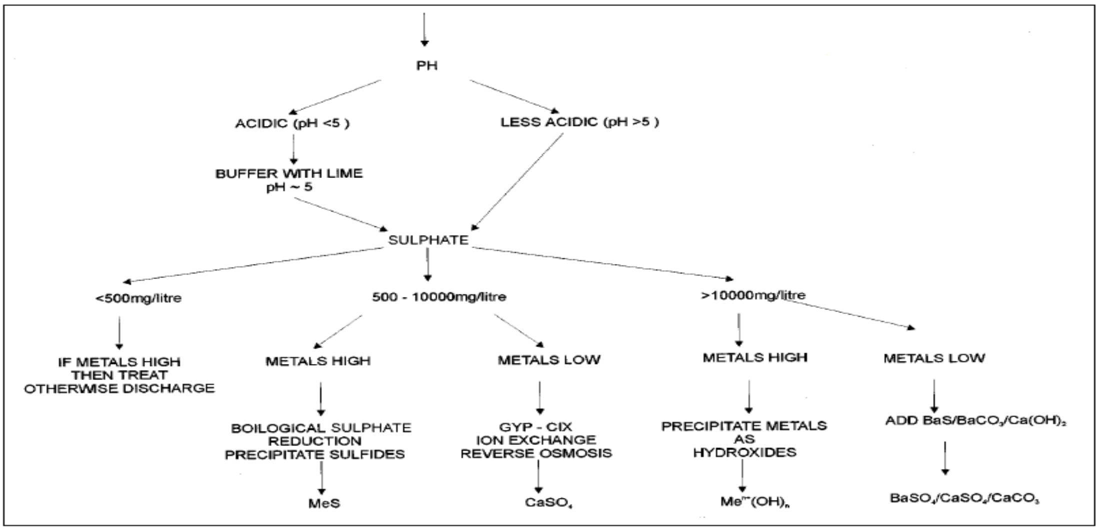

Figure 31: Mine-water fault tree for evaluation of sulphate treatment options [Bowell, 2000]

2.4.2 *Chronological water quality and quantity issues and management at the Blesbokspruit wetland*

The results of water quality and quantity investigations at the Blesbokspruit catchment, and its associated wetland are summarised in Table 6. The events impacting on surface water quality and quantity in the Blesbokspruit wetland from the early 1900s to December 2012 are highlighted. The major pollutants, the different water treatment and water ingress management options that had been proposed or implemented throughout the years are included.

Table 6: Chronological water related issues or management interventions at the Blesbokspruit catchment (based on literature review)

Date	Responsible party	Issues/Outcomes/Processes/Proposed solutions	Authors / References
1940s – 1950s	Operating Mines in the Far East Rand Mining Basin	In Far East Rand Mining Basin, there were 24 operating mines and at least 90 shafts up to the mid-1950s. “Most of these mines had to pump water from underground to either dewater areas where development was intended or to keep the existing workings from flooding”.	De Wet & Prinsloo, 2004
1950s – 1960s	Operating Mines in the Far East Rand Mining Basin	As more and more mines closed through the years it was left to fewer mines to pump the water out”.	Van Wyk & Munnik, 1998; De Wet & Prinsloo, 2004
1960	Operating Mines in the Far East Rand Mining Basin	“All pumping from the Far East Rand Mining Basin was being done by only three gold mines; Grootvlei, S.A. Lands and Exploration Gold Mining Company (Sallies) and Vlakfontein Gold Company (Vlakfontein)”.	Van Wyk & Munnik, 1998
1963 – onwards	Department of Minerals and Energy	“In recognition of the threat to the viability of these gold mines posed by the cost of pumping extraneous water from neighbouring mines and to prevent the sterilisation of the remaining gold reserves, the Government subsidised pumping cost from 1963 onwards”.	Van Wyk & Munnik, 1998
1967	Operating Mines in the Far East Rand Mining Basin	“A new pumping station and clarifier facility, jointly financed by Sallies, Grootvlei and Vlakfontein, were established on the deepest, Main Reef, mining horizon at Sallies No. 1 shaft in order to cater for most of the dewatering requirements of the Far East Rand Mining Basin”.	Van Wyk & Munnik, 1998
1990	Vaal River system	“Authorities' earlier health hazard warnings about serious sewage pollution in the upper reaches of tributaries to the Vaal River such as the Klip River, the Blesbokspruit and Natalspruit near Soweto at the East Rand, and the Rietspruit in the Westonaria region”.	US Department of Commerce, 1990

Date	Responsible party	Issues/Outcomes/Processes/Proposed solutions	Authors / References
June 1991	Sallies Mine	"Pumping ceased at Sallies Mine and the water level in the Far East Rand Mining Basin was allowed to rise".	Van Wyk & Munnik, 1998
1991	Operational Mines in the Far East Rand Mining Basin	"Today, there are only two larger gold mines, being The Grootvlei (Pty) Mines Ltd and Consolidated Modderfontein Mines 1979 Ltd (Cons Modder), and three small underground mining operations, being New Kleinfontein, Gravelotte and Pretklerk, operational in the FERB".	Van Wyk & Munnik, 1998
1992	Grootvlei Mine	"Grootvlei commenced construction of a brand new pumping station, entirely at their own cost, some 600 m shallower than the Sallies pumping station, on the Kimberley Reef mining horizon at their No. 3 shaft".	Van Wyk & Munnik, 1998
November 1995	Operating Mines in the Far East Rand Mining Basin	"The water level in the Far East Rand Mining Basin reached the elevation of the new pumping station in November 1995, at which time dewatering of the entire the Far East Rand Mining Basin via this pump station commenced".	Van Wyk & Munnik, 1998
1995 — onwards	Grootvlei Mine/ Operating Mines in the Far East Rand Mining Basin	"The underground mine water, then being discharged to the Riet Spruit at Sallies No. 1 shaft, would from now on be discharged at Grootvlei's No. 3 shaft to the Blesbokspruit and its associated wetlands."	Van Wyk & Munnik, 1998
1995	Grootvlei Mine/DWAF	Pumping and discharging of untreated underground water into the Blesbokspruit was permitted by the Department of Water Affairs and Forestry. Grootvlei Mine started pumping and discharging underground water in order to continue with its mining operations and "to maintain the water level below 740 m below surface".	Wood & Reddy, 1998; Lea *et al.*, 2003; Thorius, 2004
In December 1995	Grootvlei Mine	Water from Grootvlei mine is characterised by "elevated levels of iron and sulphate with additional contaminants in the form of manganese, chloride, sodium, and residual levels of zinc, cadmium, chromium, copper and cobalt". "Although the mine-water demonstrates the characteristic of being contaminated as a result of the oxidation of pyrites and associated AMD generation, the discharged pH 5.6-6.4 is relatively neutral, indicating a high level of background buffering."	Wood & Reddy, 1998
December 1995	Grootvlei Mine/DWAF	Following extensive contamination of the wetland with red iron oxide particulate matter, resulting in a number of fish and crab mortalities, this permit was withdrawn for non-compliance.	Van Wyk & Munnik, 1998; Wood & Reddy, 1998; Lea *et al.*, 2003; Thorius, 2004
15 May 1996	Grootvlei Mine/DWAF	"Withdrawal of the Mine's dewatering permit" by DWAF (Prof Kader Asmal, Minister of DWAF), because Mine had contributed to "…some 26 tons of iron and 316 tons of salts, mainly sulphates into the Blesbokspruit on a daily basis…". "Conditions of the succeeding permit required the construction of six temporary settling dams for the treatment of the effluent while a High Density Separation (HDS) plant was being constructed."	Van Wyk & Munnik, 1998; Lea *et al.*, 2003
1996	Grootvlei Mine	"The construction and installation of both the temporary settling ponds and the HDS plant resulted in a progressive improvement in the quality and reduction of the toxicity of the treated effluent. Although the HDS plant is effective in reducing the iron concentrations in the mine water from more than 180 mg/l to less than 1 mg/l, the water discharged into the Blesbokspruit still contains high dissolved salt concentrations, specifically sulphate, calcium, magnesium, sodium and chloride."	Lea *et al.*, 2003
28 May 1996	Grootvlei Mine/DWAF	Following the completion of this water treatment plant (HDS and six settling ponds), DWAF issued a second permit that allowed Grootvlei to discharge semi-treated mine water into the Blesbokspruit. This was for "… a further period of four months with the requirements that a permanent clarifier (HDS) plant had to be established and commissioned before the permit was to expire on 30 September 1996…".	Van Wyk & Munnik, 1998; Lea *et al.*, 2003; Thorius, 2004
30 September 1996	Grootvlei Mine/DWAF	A third permit was issued to Grootvlei to discharge underground mine-water that had been treated in the new HDS, which was valid for a period of six months.	Van Wyk & Munnik, 1998
1996	Grootvlei Mine/DWAF	Discharge of uncontrolled and excessive amount of salts into the water flowing through the Blesbokspruit wetland	Wood & Reddy, 1998; Lea *et al.*, 2003; Thorius, 2004

Date	Responsible party	Issues/Outcomes/Processes/Proposed solutions	Authors / References
1996	Grootvlei Mine/DWAF	Department of Environmental Affairs requested the Blesbokspruit wetland to be placed on the Montreux Record in terms of Article 3.2 of the Ramsar Convention, because of mine-water pollution.	Thorius, 2004
1996	Blesbokspruit Forum	"The Blesbokspruit Forum was established in the Upper Vaal Water Management Area, as a result of conflict around the effect of pollution of the Grootvlei mine on the Grootvlei wetland." The Blesbokspruit Forum was meant to oversee activities in the BBS catchment, monitor water quality/quantity and land uses and water users in the Blesbokspruit catchment	Blesbokspruit Forum, 2003a; Munnik, 2011
27 May 1997	Grootvlei Mine/DWAF	Extension of mine's water discharge permit for additional three months in order "… to allow the Cabinet to consider the conclusions and recommendations of the Grootvlei preliminary Cost-Benefit Analysis".	Van Wyk & Munnik, 1998
1 July 1997	Grootvlei Mine/DWAF	"Another permit issued to Grootvlei to discharge semi-treated underground mine-water in the Blesbokspruit for an additional 18 months on the condition that they conduct desalination pilot plant work and submit the results to the DWAF for consideration."	Van Wyk & Munnik, 1998
1998	Interdepartmental Committee for State Assistance to the Minerals Industry	Recommendation was made to Cabinet that "… the option of cessation of all mining operations in the Far East Rand Mining Basin should not be considered further, and the importance of conserving the Blesbokspruit wetland as a Ramsar site must be recognised and its Ramsar status should not be compromised."	Van Wyk & Munnik, 1998
1998	Gold mines in the Witwatersrand and the rest of South Africa	"At present most mines refrain from implementing desalination technology due to the associated implications and, therefore, the treatment of underground mine water is in general mainly restricted to pH correction and suspended solids and heavy metal removal."	Van Wyk & Munnik, 1998
1998	Gold Mines in the Witwatersrand Basin	Most active gold mines in the Witwatersrand add excessive amounts of "…saline underground mine water to an already salinated Vaal River system…", which poses "…a significant risk to the sustained fitness for use of South Africa's most strategic water resource, the Vaal River system…".	Van Wyk & Munnik, 1998
1998	Gold Mines in the Witwatersrand Basin	"If gold mining ceases, water levels in the major mining basins will rise and eventually decant at the lowest geographical points into the Vaal River system.".	Van Wyk & Munnik, 1998
1998	Grootvlei Mine	In 1998, there is more than sufficient water in the wetland since the natural water changes have been replaced by permanent flooding of the wetland.	Dini, 1998
1998	Blesbokspruit catchment Forum	By 1998, Rand Water and DWAF were working together to develop a policy to limit salt inputs in the Vaal River	Wood & Reddy, 1998
1998	Grootvlei Mine	TDS or sulphates measured downstream originate from discharge point at Grootvlei Mine – Grootvlei Mine has a direct impact on the water quality of monitoring point at closer distance to its discharge point. "Of significance is that the water quality remains relatively constant with distance downstream from the discharge point illustrating the dominance of the Grootvlei discharge flow and quality on the Blesbokspruit hydrodynamics."	Wood & Reddy, 1998
1998 - onwards	Grootvlei Mine	"Whether or not Grootvlei Mine remain in operation there will be the discharge of AMD contaminated water into the Vaal system " "It was also one of the first reports to predict that, should Grootvlei Mine stop pumping water, the mine-water would possibly decant at Nigel. Water ingress into mines is not new. Records of water ingress into these mines dates back to 1909 when Grootvlei abandoned the sinking of their No 1 shaft at 112 m due to an estimated 10 Ml/day ingress."	Wood & Reddy, 1998; De Wet & Prinsloo, 2004
1998	Grootvlei Mine	SO_4 pollution—Conceptualization of IX Process technology (Proposal). "Water quality is generally poor due to artificial inputs from mines, sewage treatment works and other industrial activities (i.e. point source discharges). The quality of the water is mainly influenced by total dissolved salts in the previously mentioned effluents. The "fingerprint" of the water chemistry is similar throughout the wetland (high sulphate, phosphate, nitrite/nitrate and ammonia concentrations)."	South African Wetland Conservation Programme, 1999

Date	Responsible party	Issues/Outcomes/Processes/Proposed solutions	Authors / References
1998	Grootvlei Mine	Construction of Savmin plant. “Acidic water is neutralized with lime and the heavy metal sludge has been settled out to provide a reasonably clear overflow.” “This overflow, saturated with calcium sulphate, will first be passed through a cation exchange resin in the hydrogen form followed by an anion exchange resin in the hydroxide (or free base) form. The chemical reactions are: 2RH + Ca++ = R2Ca + 2H+ 2R(OH) + SO_4 = = $R2SO_4$ + 2OH- 2H+ + 2OH- = 2H2O.”	Thorius, 2004
1998	Grootvlei Mine	Construction of Gyp-Cix plant—A novel precipitation technique developed by Mintek	Van der Merwe & Lea *et al.*, 2003
1998	Grootvlei Mine	Construction of biological sulphur removal plant—A resin based desalination technology developed by Chemeffco	Van der Merwe & Lea *et al.*, 2003
1998 - onwards	Grootvlei Mine	Construction of a reverse osmosis plant—Sulphur removal as proposed by Rhodes University “Acid mine drainage (AMD) from Grootvlei Mine in Springs is no longer neutralised in a biological process, using partially treated sewage. A patented co-treatment process was applied to Grootvlei effluent, charged for by Ekurhuleni based East Rand Water Care. Company, Erwat, in a test phase from 1998, and on a large scale from 2003 to May 2009.”	Van der Merwe & Lea *et al.*, 2003; Mining News, 2010
1998,	Grootvlei Mine	Neutralisation of Acid Mine Drainage—“…using selective precipitation techniques as pre-treatment for by-product recovery as proposed by Aqua-K technologies.”	Van der Merwe & Lea *et al.*, 2003
1 January 1999	Grootvlei Mine/DWAF	Predictions were made that the fifth permit that would be issued to Grootvlei would cover the “…full scale desalination process…”	Van Wyk & Munnik, 1998
2001	Grootvlei Mine	“During June 2001, serious pipe failures were reported at the Grootvlei No 3 Shaft pump station, which delivers underground water to the HDS treatment plant, before being discharged into the Blesbokspruit. Examination of failed pipe sections revealed nodules on the inner surfaces, with pits extending through the pipe wall.”	De Wet & Prinsloo, 2004
2002	Grootvlei Mine	Pamodzi Gold, owner of the Grootvlei mine, faced financial problems involving maintenance of pumping shafts – mining company was liquidated in 2009.	Mining news, 2009
2003	Grootvlei Mine	“In order to keep the mining basin dry, water is pumped from the underground workings at an average rate of 75 mega litres per day (Ml/d). The pumping rates vary seasonally between 30 and 120 Ml/d historically. Under the current water use license, the mine is allowed to release up to 96 Ml/d of HDS treated water.”	Lea *et al.*, 2003
2005	Eastern Basin	“Among other things, the study found that there are four main sources of recharge into mines. These are direct recharge from rainfall events; seepage recharge; surface water losses from dams or streams; and recharge from groundwater (for example, on the East Rand most of the mining area is overlain by dolomites resulting in dolomitic groundwater contributing to the bulk of the inflow).”	Lea *et al.*, 2003 ; De Wet & Prinsloo, 2004
2004	Grootvlei Mine	“One of the medium—to long-term objectives of the mine water license is the implementation of water treatment to produce water of improved quality.” “Grootvlei Mine is in the process of implementing measures to reduce the ingress of surface water into the underground workings. By doing so, the volume of water pumped from underground will be minimized, which will reduce long-term mine water treatment costs. Reduced pumping volumes and water treatment will further work towards improving the water quality in the Blesbokspruit and ultimately the Vaal River Barrage, which supplies water to Gauteng Province.”	Lea *et al.*, 2003

Date	Responsible party	Issues/Outcomes/Processes/Proposed solutions	Authors / References
2005	Grootvlei Mine/ERWAT	Commissioning of BioSURE pilot plant at ERWAT's Ancor works "The plant is now being extended to treat 10 Ml/day of mine-water from Grootvlei." "The process removes sulphate from the acid-rich mine-water. Instead of expensive carbon and electron donor sources, primary sewage sludge, a by-product from ERWAT, is being used. The process is reportedly cheaper than any other alternative that uses carbon or electron donor sources, reducing costs from around R5/kl to about R1/kl operational expenditure." "According to Irene Lea—the 10 Ml/day BIOSURE plant is on track to be operational by 1 September 2005. Results indicate that the pilot plant is operating very well, achieving sulphate concentrations of less than 200 mg/l consistently."	The Water Wheel March/April 2005
July 2005	Grootvlei Mine	Sulphide water contamination—"However, while the HDS plant is effective in reducing iron concentrations in the mine-water from more than 180 mg/l to less than 1 mg/l, the water discharged into the Blesbokspruit still contains high dissolved salt concentrations, specifically sulphate, calcium, magnesium, sodium and chloride, thus impacting on the downstream river water quality."	The Water Wheel March/April 2005
2005	Sappi Enstra	"SAPPI experienced water quality problems from Ancor as a result of two bio-filters not functioning properly. The water had a strong hydrogen sulphide smell and a greyish colour. Excessive costs were experienced to treat the water." "A meeting was held between the Metro, ERWAT, Petrex and SAPPI to discuss the issue. The water quality has since returned to normal."	Blesbokspruit Forum Minutes, 2005
2006	Eastern Basin Blesbokspruit Catchment Task Team	Creation of the Eastern Basin Blesbokspruit Catchment Task Team—Task team consisting of government representatives and other stakeholders whose findings will be used for reinforcement/ law.	Eastern Basin Blesbokspruit Catchment Task Team, 2006
2006	Sappi Enstra	Saline waters from SAPPI - SAPPI cannot desalinize the water—financial constraints and not a legal requirement.	Eastern Basin Blesbokspruit Catchment Task Team – Minutes, 2006
2009	Grootvlei Mine	Although mining operations were terminated, underground mine-water was still pumped out Shaft No. 3 by Grootvlei Mine, then owned by Pamodzi Gold in 2009. "Underground water is pumped from a large underground cavity linking surrounding mines. The cavity water level must be kept below 36.9 m to prevent flooding of the neighbouring mines. During summer periods Grootvlei 3 shaft needs to pump an average of 80 Ml per day to limit the cavity level from rising."	Mathews *et al.*, 2009
2009	Grootvlei Mine	"Underground water extracted from Grootvlei 3 shaft contains high iron, ferrous and other sulphate concentrations which reduces the pH level to less than 4. This water therefore needs to be chemically treated before being allowed to flow into the nearby Blesbokspruit. After the water is pumped from underground and reaches surface treatment starts. Oxygen is first added to the water through the delivery column. This process changes the ferrous or iron(II) cations, in solution to ferric or iron(III) cations. Lime is then added which combines with the iron(III) ions. In the final stage a flocculent is added to deposit the residues on the bottom of the settler dams. The clear water on top is then allowed to drain into the Blesbokspruit stream."	Mathews *et al.*, 2009
2009	Grootvlei Mine	Acquisition of Grootvlei Mine by new owners, Aurora Systems Empowerments.	Ryan, 2009
Oct. 2009	Grootvlei Mine	Pollution threats at Blesbokspruit wetland because of the financial constraints of Grootvlei Mine.	Ryan, 2009
2009	Grootvlei Mine	"The potential pumping of AMD into the Ramsar site has been prevented by late state financial intervention."	Gauteng Wetland Forum, 2009
2010	Grootvlei Mine	"An effluent co-treatment five-year contract ran out and was not renewed by Grootvlei's new owners, Aurora Empowerment Systems."	Mining news, 2010

Date	Responsible party	Issues/Outcomes/Processes/Proposed solutions	Authors / References
2010	Grootvlei Mine /ERWAT	Discharge of untreated underground mine-water from January to April 2010—"108 Mega Litres untreated mine void water (Eastern Basin) is currently discharged by Grootvlei Mine, into the Blesbokspruit." "Erwat is no longer contributing to removing AMD from Grootvlei effluent." "Chemical treatment was either not effective or not performed prior to discharge—Due to mine experiencing financial constraints—Not compliant with water license conditions."	Mining news, 2010; Liefferink, 2011
2010 - onwards	Grootvlei Mine	Nearby township is affected by this untreated underground mine-water because they do not have piped water. Sewage is also going into the spruit from another mine. They want to attend water forum meetings as well. There is a need to test the water and do want media exposure for the problems.	Gauteng Water Caucus Meeting 7 July 2012
December 2010	Grootvlei Mine/DWA	Cessation of pumping and activities at Grootvlei Mine in December 2010—Directive issued by DWA—still no compliance—Institution of legal proceeding against Grootvlei mine by DWA.	Mining news, 2010; Gauteng Wetlands Forum, 2011a
2011	Grootvlei Mine	The hydrological function of the wetland is still a major problem since 1996 with the pumping of additional underground waters from Grootvlei mines and other surrounding sources of effluents	Macfarlane & Muller, 2011
2011	Grootvlei Mine	"No further feedback on the Aurora issue and this seems to have become significantly political in terms of trying to find a solution. • The pump station was flooded in February but there has been no further information as to when a new pump station will be installed on site."	Gauteng Wetlands Forum, 2011a
2011	Grootvlei Mine	Reported that acid mine drainage has been decanting into the Blesbokspruit in the last 9 weeks.	Gauteng Wetlands Forum, 2011b
2011	Sappi Enstra	Decommissioning of pulp plant.	Sappi, 2012
2011	Eastern Basin	Trans-Caledon Tunnel Authority (TCTA) is also looking at solutions for the Eastern Basin, below the town of Nigel, where acid water levels are rising. The overall plan to tackle AMD in the short-term will see TCTA sinking submersible pumps and concrete pipes into the three basins to stem the rising water. The aim is to pump enough water out of the respective basins so that it is at safe distance below the surface, which is 290m for the Eastern Basin.	Nyeleti Network for built environment, 2011
2012	Department of Environmental Affairs—Natural Resource Strategy	Plans to delist the Blesbokspruit wetland from the Montreux Record by the year 2013 (in DEA strategic plan).	Department of Environmental Affairs, 2012

The methods used to achieve each objective of this study are presented in the following chapter.

3. METHODOLOGY

This chapter introduces the study area, the type of data required for this study and the methods used for the attainment of each objective of the study as well as any shortcomings, if relevant.

3.1 Study area description

The study area, the Blesbokspruit wetland, is situated to the south-east of Johannesburg, mainly in the Ekurhuleni Metropolitan Municipality (EMM) of Gauteng (Figure 32), formerly known as the East Rand [Van Eeden & Schoonbee, 1996; Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ramsar, 2000; AngloGold Ashanti, 2004; Eastern Basin Blesbokspruit Catchment Task Team, 2006; Peck, 2007; Ekurhuleni Metropolitan Municipality, 2008]. Ekurhuleni is one of the six metropolitan municipalities found in Gauteng [Naledzi Environmental Consultants, 2007].

The Blesbokspruit wetland is geographically located between 26° 12'S - 26° 23'S latitude and 28° 29'E - 28° 32'E longitude [Haskins, 1998; South African Wetlands Conservation Programme, 1999] and covers a surface area of 1 858 ha at an altitude of 1 585 m above sea level [Haskins, 1998; South African Wetlands Conservation Programme, 1999; Ekurhuleni Municipality, 2003, 2004]. Blesbokspruit wetland is surrounded by Springs in the east, Boksburg, Benoni and Brakpan in the north-west and Nigel at the south [South African Wetlands Conservation Programme, 1999; Blesbokspruit Forum, 2003a].

3.2 Acquisition of a comprehensive set of water quality data of the Blesbokspruit wetland

For the completion of this study, primary and secondary information was needed. Primary information was the record of surface water quality made available by the Rand Water's surface water monitoring network for the period 2000 to 2011. Secondary information was extracted from various sources—interviews with members of the Blesbokspruit Forum, published and unpublished reports and articles. The information covered events that took place, prior to the year 2000 and from 2000 to 2011, which impacted on the surface water quality in the Blesbokspruit wetland.

Water quality management involves four processes—sampling, measurement, recording and interpretation [Du Plessis, 2006]. If done successfully, the processes will obtain analytical and quantitative data and give indications of the physical, chemical and biological conditions of any specific water resource [Du Plessis, 2006]. For this study, only relevant physicochemical parameters were selected, based on the previous researched findings on water quality in the Blesbokspruit wetland (Table 7).

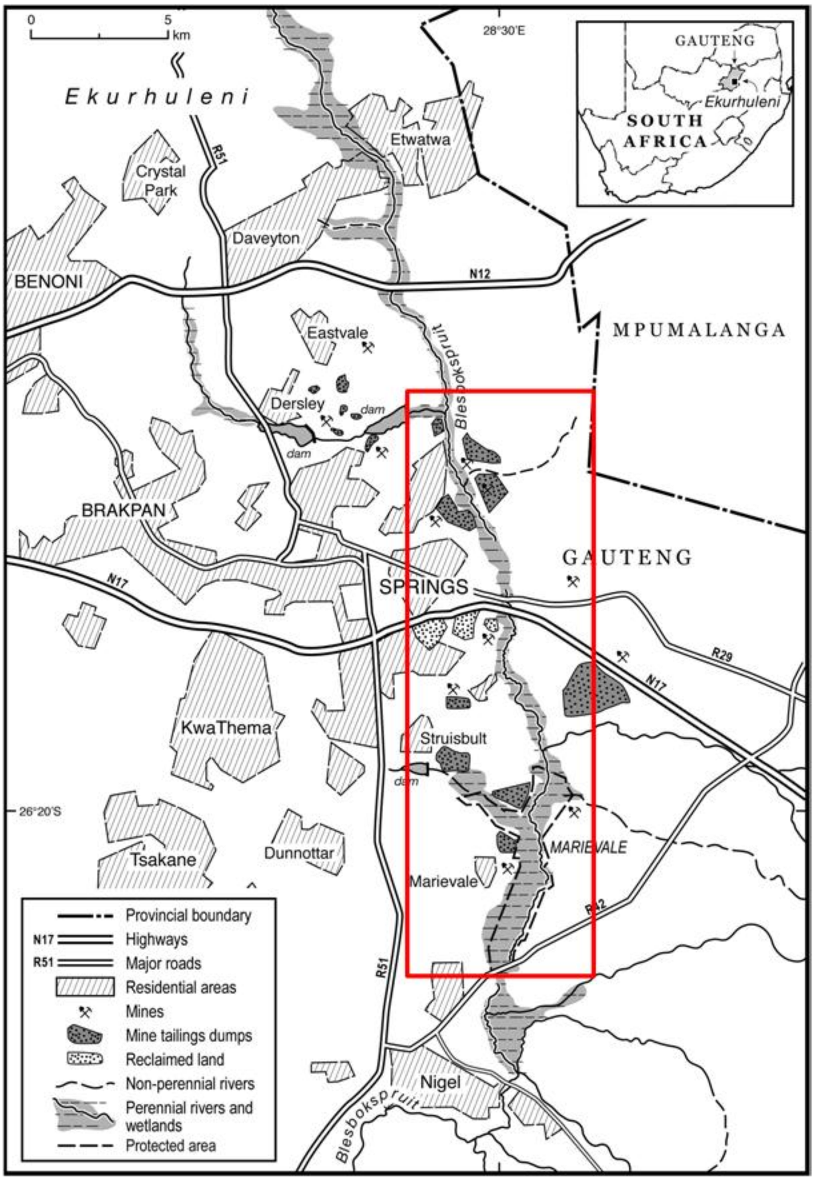

Figure 32: **Location of the study area demarcated in red (Wendy Job, 2013, University of Johannesburg)**

Selected physicochemical parameters were deemed adequate for determining the ecological integrity of the Blesbokspruit wetland and demonstrating how they can affect agricultural activities dependent on the water running through this wetland [Department of Water Affairs and Forestry, 1996a; 1996b; 1996c; Phaleng, 2009]. Biological determination of pathogens is critical for potable water supplies, but not necessary for routine monitoring of surface waters for the two other categories of usage—i.e. aquatic environment and agricultural activities (including irrigated crops and livestock watering) [Department of Water Affairs and Forestry, 1996a; 1996b; 1996c; De Fontaine, 2012].

The Blesbokspruit was placed on the Montreux record because of the physicochemical pollution and, accordingly, removal from the Montreux record would require focusing on these pollutants rather than on the biological parameters [Wood & Reddy, 1998]. Throughout this study only selected physicochemical parameters will be analysed to establish surface water quality conditions in the Blesbokspruit wetland [Wood & Reddy, 1998].

Table 7: Physical and chemical water quality constituents as monitored by Rand Water for the Blesbokspruit wetland (selected parameters are highlighted in light grey and in italics and bold)

WATER QUALITY PARAMETERS	
Physical Constituents	**Chemical Constituents**
pH	Aluminium (mg/l)
Total Dissolved Solids (mg/l)	***Chloride (mg/l)***
Total Dissolved Oxygen	***Sulphate (mg/l)***
Total Suspended Solids (Turbidity)	Iron (mg/l)
Electrical Conductivity (mS/m)	Manganese (mg/l)
	Nitrate (mg/l)
	Ortho-phosphate (mg/l)
	Magnesium (mg/l)
	Sodium (mg/l)
	Fluoride (mg/l)
	Ammonium (mg/l)

3.3 Representative surface water quality data for the Blesbokspruit wetland

The water quality data obtained from Rand Water covered an eleven-year period from January 2000 to December 2011, and represents the entire extant record for these sites at the time this study was undertaken. Monitoring took place from 1975 onwards—however the numerical data are no longer available; only graphical summaries exist. For this study, only computerised digital surface water quality data from 2000 to 2011 were used.

During 2010, a major event also took place that could have positive implications for the Blesbokspruit wetland. In December 2010, the Grootvlei Mine (then owned by Aurora Empowerment Systems) completely stopped pumping underground mine-waters because the mine was facing financial and management problems (Table 6). The cessation of pumping activities could be seen as a way out of the deleterious effects of acid mine-waters on the Blesbokspruit wetland since the so-called 'Grootvlei Mine incident' or 'disaster' (Table 6).

3.4 Location and description of the monitoring sites in and within the Blesbokspruit wetland

The Blesbokspruit wetland forms part of the Blesbokspruit catchment, a locality under the Upper Vaal Catchment Management Area section C21E (*Section 2.2.3*). This catchment is the responsibility of the Department of Water Affairs and Rand Water, and both parties have implemented a catchment-monitoring programme [De Fontaine, 2012]. Rand Water is a 'State Owned Enterprise' in charge of providing water for the Gauteng region [De Fontaine, 2012]. As part of this responsibility, the Rand Water Board carries out routine monitoring of treated and raw water resources within the

Vaal catchment, including its sub-catchments and tributaries. Under the different catchment-monitoring programmes, Rand Water assesses whether the quality of water in a catchment is compliant with the Catchment Forum Water Quality Guidelines [De Fontaine, 2012].

The different monitoring programmes assist Rand Water in assessing the fitness for use by households and other users in the Gauteng Province [De Fontaine, 2012]. Drinking water testing and provision are conducted on the water dispatched by the purification stations along the distribution chain to assess whether the water meets the SANS 241 potable standard [De Fontaine, 2012]. Surface waters are monitored on a routine basis, through sampling from an established network of sampling locations within the catchment areas, and using the Catchment Forum Water Quality Guidelines [De Fontaine, 2012]. Rand Water Catchment Water Quality Guidelines are very specific and set out the water quality goal and objectives of a catchment such as the Blesbokspruit [De Fontaine, 2012].

For this study, monitoring sites within the Blesbokspruit wetland and forming part of the Rand Water Board network will be examined, because they have compiled a continuous long-term record (covering 11 years) of monitoring data, with few missing measurements. The national Department of Water Affairs has also conducted sampling in the area on an intermittent basis during some years—a brief evaluation of the sampling record was sufficient to establish that these intermittent records were inadequate for purposes of establishing seasonal, inter-annual and spatial trends.

From the Rand Water network of monitoring sites for the whole Blesbokspruit Catchment, five monitoring localities were identified as lying within the designated boundary of the Blesbokspruit wetland (B5, B16, B15, B17 and B11) (Figure 33 shown as red dots). These five sampling points were strategically located at the inflow (B5) of the wetland, downstream of Grootvlei Mine Shaft No. 3 (B16, B15 and B17) and at the outflow point (B11) of the wetland. Closer to these montoring sites, point sources of water pollutants could be identified compared to the diffuse sources (Figure 33).

A sixth sampling site was selected, B6, (Figure 33 yellow dot), located to the western side of the wetland. Site B6 is located on a tributary, and is exposed to different pollutants before the water enters the Blesbokspruit wetland from the west half way along its length. The latitude and longitude of these locations are presented in Table 8.

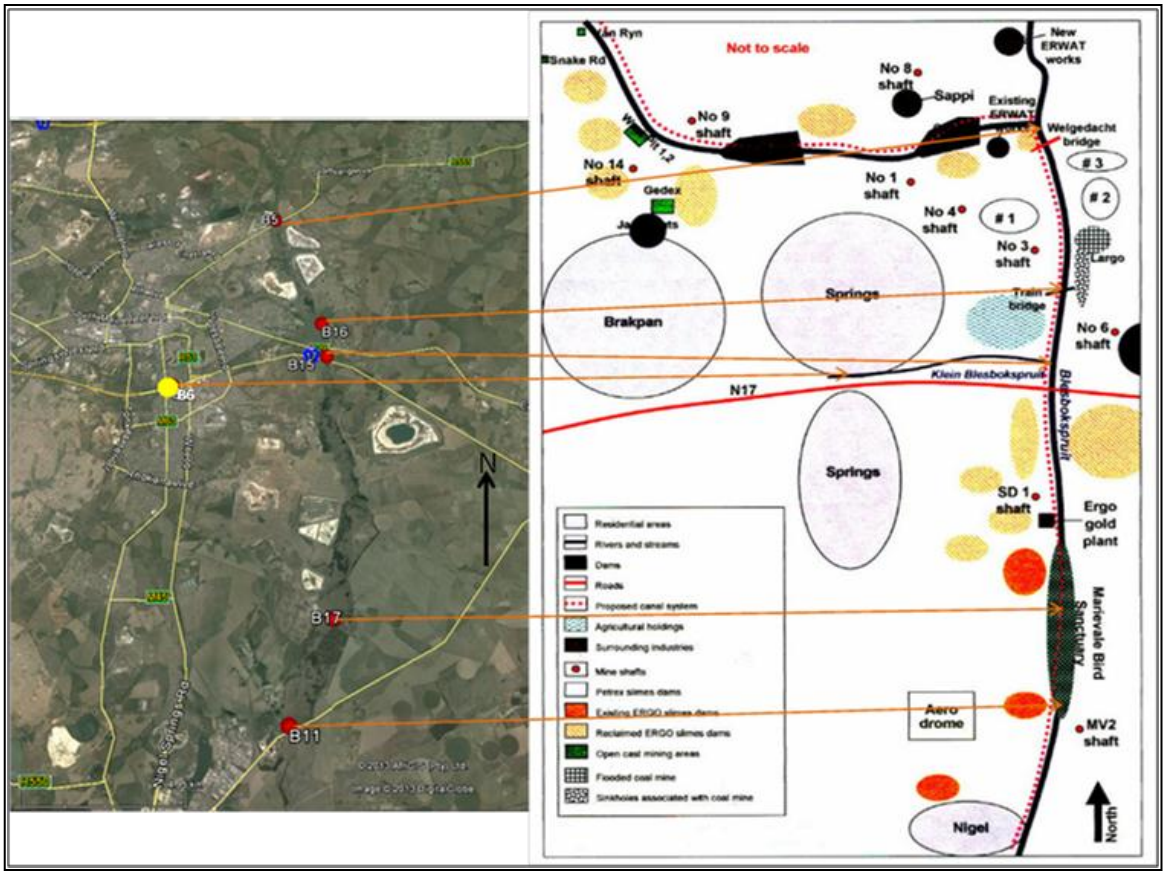

Figure 33: **Sampling locality points of Rand Water (illustrated by red and yellow dots on Google Earth Map) and their relative location along the Blesbokspruit wetland and on the side stream [Adapted from Thorius, 2004; Google Earth, 2013]**

Table 8: Location and description of water monitoring sites in the study area

Monitoring Site	Coordinates	Description and pollution influence
B5	28°28'48.22"E 26°12'52.63"S	Site located at the inflow of Blesbokspruit wetland—receives runoffs/outflows from upstream water users and land use such as Welgedacht sewerage works, Welgedacht road, Geduld Mine, tailings dam, Cowles dam; SAPPI Enstra and residential areas
B16	28°30'4.42"E 26°15'31.17"S	Site located below B5, and downstream of Grootvlei Mine Shaft No. 3—receives runoffs/outflows from upstream water users and land use such as Grootvlei Mine Shaft 3, tailings dams, Largo Colliery, Train Bridge, sewage waters from residential areas and some water pollutants from B5 upstream
B15	28°30'13.89"E 26°16'17.38"S	Site located below B5 and B16, and downstream of Grootvlei Mine Shaft No. 3—receives runoffs/outflows from upstream water users and land use such as residential areas in Springs, round N17 Toll Road Bridge, agricultural lands, and some water pollutants from B5, B16 upstream
B17	28°30'36.04"E 26°21'37.19"S	Downstream site located below B15, and downstream of Grootvlei Mine Shaft No. 3—receives runoffs/outflows from upstream water users and land use such as Daggafontein/ERGO Gold slime dams and mine operations, Springs residential areas, and agricultural lands, and some water pollutants from B5, B16, and B15 upstream—Site within the Marievale Bird Sanctuary

Monitoring Site	Coordinates	Description and pollution influence
B11	28°29'50.25"E 26°23'25.99"S	Downstream site located below B17 and at the outflow of Blesbokspruit wetland—receives runoffs/outflows from upstream water users and land use such as residential areas in Nigel, R42 Bridge , and some water pollutants from B5, B16,B15 and B17 upstream—Site within the Marievale Bird Sanctuary
B6	28°26'47.17"E 26°16'57.56"S	Site located on the side stream joining the Blesbokspruit wetland on its western section— receives runoffs/outflows from surrounding water users and land use such as Springs and Brakpan residential areas as well as industries

Figure 34, Figure 35 and Figure 36 pinpoint the potential sources of pollutants at sites within the Blesbokspruit wetland (from B5 to B11) and at B6 located aside of the wetland as summarised in Table 8.

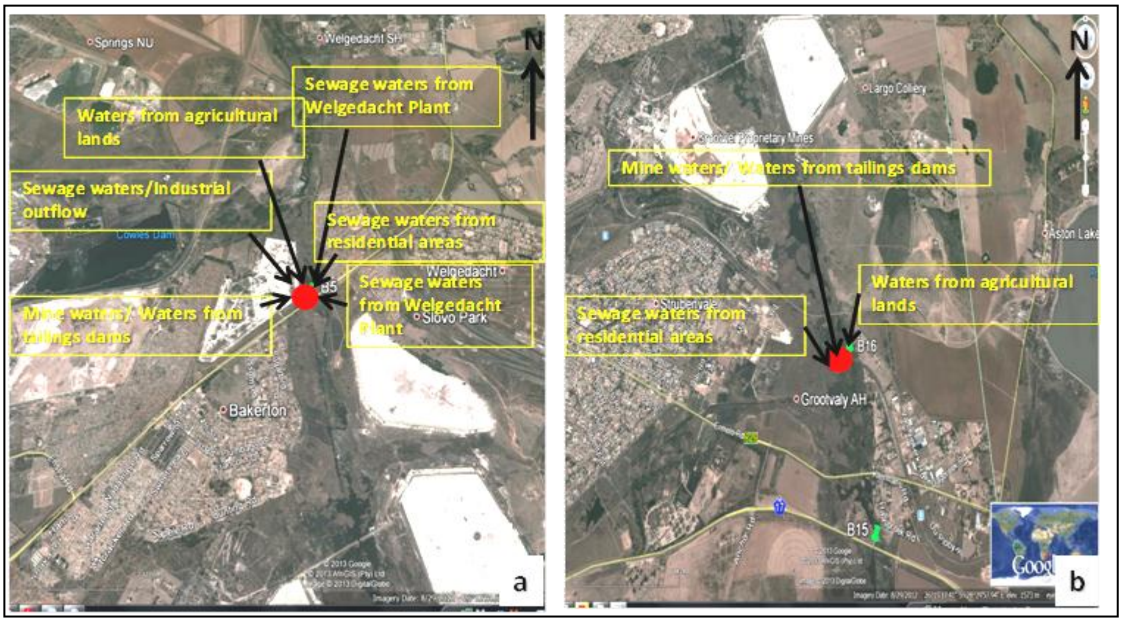

Figure 34: **Location of Sites B5 (a) and B16 (b) and their immediate sources of water pollutants [Adapted from Google Earth, 2013]**

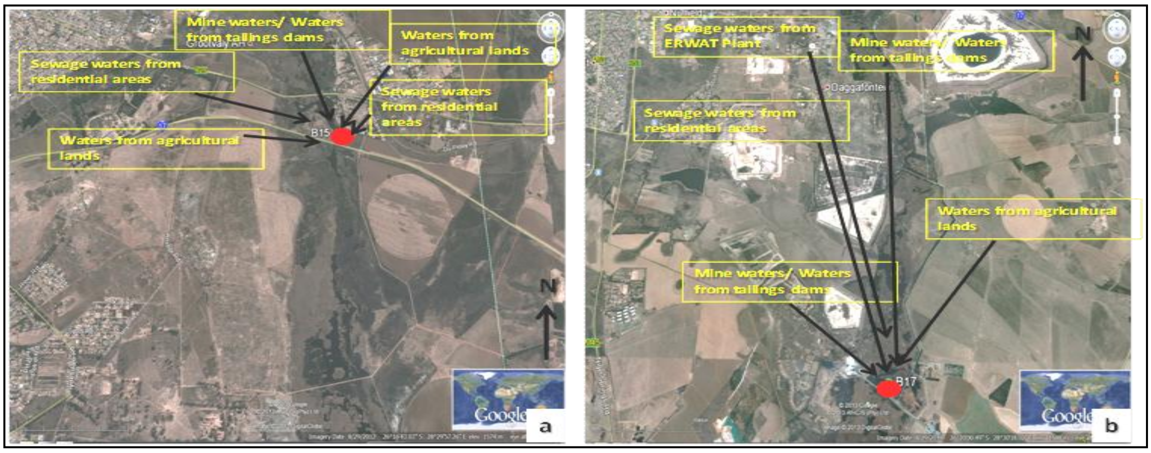

Figure 35: **Location of Sites B15 (a) and B17 (b) and their immediate sources of water pollutants [Adapted from Google Earth, 2013]**

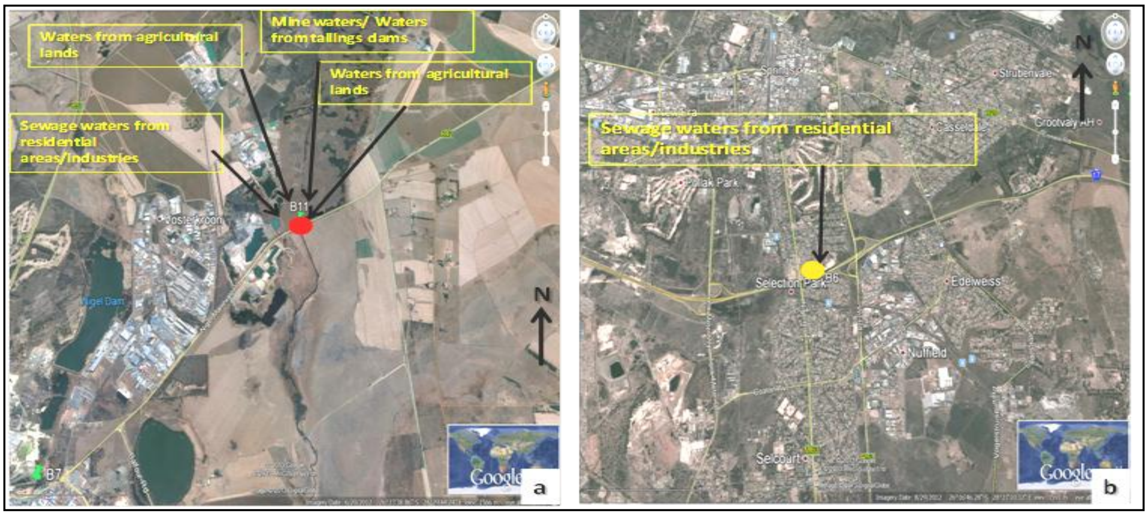

Figure 36: **Location of Sites B11 (a) and B6 (b) and their immediate sources of water pollutants [Adapted from Google Earth, 2013]**

3.5 Rand Water sampling procedures

Rand Water collects routine and non-routine samples, depending on the requirements of the day. For external testing (for instance: for customers with specific job requirements), Rand Water performs non-routine testing, whereas, as part of their normal monitoring programme for drinking, sewage and catchment water, Rand Water collects samples on a routine basis following established procedures. The sampling procedures for drinking, sewage and catchment water are each different.

Qualified technicians perform water sampling fieldwork and laboratory analyses. The technicians undergo two to six months training and evaluation until proven competent. Certified competency of the technicians, both in the field and at the laboratories, is an essential condition for the overall accreditation of Rand Water's sampling and analytical laboratory, and for the credibility of results provided to third parties.

Table 9 lists the ISO and SANS standard methods for which Rand Water is an accredited testing laboratory. Rand Water Laboratories are SANS 17025 accredited. Forty-six of the methods used by Rand Water Laboratories are fully accredited. The instruments used are calibrated according to SANS requirements prior to and during usage.

Table 9: Standard sampling procedure documents used by Rand Water [Rand Water Internal Document, 2012]

Document Title	Document	Location
Quality Management System Requirements	Quality Manual: 8.05.3	SQC Office
Water Quality – Sampling Part 1: Guidance on the Design of Sampling Programmes	ISO/SANS 5667 - 1	FQC Office
Water Quality – Sampling Part 2: Guidance on Sampling Techniques	ISO/SANS 5667 - 2	FQC Office
Water Quality – Sampling Part 5: Guidance on Sampling of Drinking Water from Treatment Works and Piped Distribution Systems	ISO/SANS 5667 - 5	FQC Office
Water Quality – Sampling for Microbiological Analysis	ISO 19458	FQC Office
Chlorine and monochloramine determinations with colorimeter	WI 3.3.1.06.1	FQC Office
General Sampling and Receiving Procedure	WI 3.3.1.09.1	FQC Office
Sampling Method		FQC Office

Surface water samples are taken at fortnightly intervals across the network. As part of the surface water sampling procedure, the field technician is required to carry out the following steps:

- inspect sample point for potential hazards;
- take four sample bottles to the sampling point and scan the labels;
- collect water sample by using a bucket grab sample;
- measure the temperature and pH of the water;
- fill the bottles by pouring water from the bucket;
- add stabilisers to selected bottles in accordance with intended test procedures;
- log temperature and pH readings into handheld recorder and collection list, together with any other observations (such as unusual discoloration of the water);
- seal samples and place samples into a cooler box.

Sampling bottles are recorded at specific location by using a Radix Field Worker FW300 a handheld recorder that incorporates a Global Positioning System and time stamp for data control and traceability purposes. In addition, as a prerequisite for testing dissolved oxygen, manganese sulphate solution is added to specific samples, as recommended in the standard operating procedures. Prior to and after the sampling campaign, the bar-coded sampling bottles are scanned at Rand Water for control and traceability purposes. The data are logged in a computer system for the records. The bottles are labelled by routing to one or more of the four Rand Water laboratories according to specific monitoring objectives—testing for chemical, biological, organic and inorganic parameters. Figure 37 illustrates how the sampling is conducted and gives a picture of the main equipment used in the process.

Figure 37: Grab method as performed by Rand Water technician (a) and bottles (b) and instrument (c) used during the water sampling campaign [Ambani, 2012]

3.6 Analytical procedures and result interpretation by Rand Water

Rand Water makes use of in-house laboratories to analyse their water samples. The company has four laboratories—Microbiology, Hydrobiology, Inorganic and Organic Laboratories. Each laboratory has its own method of analysing the collected water samples and interpreting their results according to each laboratory's accreditation and appropriate standard operating procedures.

For catchment management, Rand Water uses specific guidelines for the interpretation of the water quality results. As the Blesbokspruit wetland is part of the Blesbokspruit catchment area, in-stream water quality guidelines were developed by the Blesbokspruit Forum and made effective in June 2003 (Figure 38) [Blesbokspruit Forum, 2003b]. These guidelines are intended to assist the members of the forum (and other interested parties) to interpret the water quality monitoring results and for water quality management purposes [Blesbokspruit Forum, 2003b].

In-stream Water Quality Guidelines for the Blesbokspruit Catchment — **Effective: June 2003**

Variables	Measured as	Ideal Catchment Background	Acceptable Management Target	Tolerable Interim Target	Unacceptable
Physical					
Conductivity	mS/m	< 45	45 - 70	70 - 120	> 120
Dissolved Oxygen (O_2)	mg/l O_2		> 6.0	5.0 - 6.0	< 5.0
pH	pH units	6.5 - 8.5			< 6.5; > 8.5
Suspended Solids	mg/l	< 20	20 - 30	30 - 55	> 55
Organic					
Chemical Oxygen Demand (COD)	mg/l	< 20	20 - 35	35 - 55	> 55
Macro Elements					
Aluminium (Al)	mg/l		< 0.3	0.3 - 0.5	> 0.5
Ammonia (NH_4)	mg/l	< 0.1	0.1 - 1.5	1.5 - 5.0	> 5.0
Chloride (Cl)	mg/l	< 80	80 - 150	150 - 200	> 200
Fluoride (F)	mg/l	< 0.19	0.19 - 0.70	0.70 - 1.00	> 1.00
Iron (Fe)	mg/l	< 0.1	0.1 - 0.5	0.5 - 1.0	> 1.0
Magnesium (Mg)	mg/l	< 8	8 - 30	30 - 70	> 70
Manganese (Mn)	mg/l	< 0.2	0.2 - 0.5	0.5 - 1.0	> 1.0
Nitrate (NO_3)	mg/l	< 0.5	0.5 - 3.0	3.0 - 6.0	> 6.0
Phosphate (PO_4)	mg/l	< 0.2	0.2 - 0.4	0.4 - 0.6	> 0.6
Sodium (Na)	mg/l	< 70	70 - 100	100 - 150	> 150
Sulphate (SO_4)	mg/l	< 150	150 - 300	300 - 500	> 500
Bacteriological					
E.coli	counts/100ml	< 130	130 - 200	200 - 400	> 400
Faecal coliforms	counts/100ml		< 126	126 - 1,000	> 1,000
Biological					
Daphnia	% survival	100	90 - 100	80 - 90	< 80

Figure 38: In-stream water quality guidelines for the Blesbokspruit catchment used since June 2003 (selected parameters in red rectangles) [Blesbokspruit Forum, 2003b]

3.7 Data quality assurance

For quality purposes and uniform dataset, the following steps were taken:

- Fortnightly readings from 2000 to mid-2008 were obtained at a first request. A second request was made to obtain subsequent data in the same format for mid-2008 to 2011, but it appears that data are no longer kept as fortnightly values. The new dataset provided by Rand Water showed only average fortnightly values for the period after mid-2008. To establish a coherent and uniform database, across the entire time period, it was necessary to average all the fortnightly readings from the first 8.5 years into monthly readings.
- Analysis of the dataset was only possible after data quality and validity checks, by cleaning the dataset and removing any obvious outliers (e.g. negative concentrations or unconsistent high values), and deleting values below the analytical detection limits. Outliers were checked, missing values counted. Single missing single values were interpolated from their immediate neighbours.

3.8 Analysis of selected surface water quality data for seasonal, spatial and time trends from 2000 to 2011

Statistical analysis requires a complete dataset. For the purpose and scope of this thesis, only six physicochemical parameters were retained (sulphate, sodium, chloride, magnesium, electrical conductivity and pH) because their records were more complete, above the detection limits and greater than 1 (Appendix 1: Data cleanness and completeness & Appendix 2: Validated datasets of surface water quality parameters for the Blesbokspruit wetland 2000 to 2011.). These parameters are the most relevant and representative because they reflect the concentrations of salts useful for interpreting intermittent or episodic pollution events in the surface waters of the Blesbokspruit wetland. Different interpretive techniques from the statistical analysis to depict the time trends and spatial changes of the five selected parameters, over the period 2000 to 2011, were applied. The Excel® 2010 Descriptive Statistics tools were used throughout this study. These methods of analysis assisted in portraying whether there was an upward, downward or constant behaviour in the available values over the months and years.

3.9 Seasonal, spatial and long-term trends of selected physicochemical parameters

Summer and autumn months represent the rainy period; winter and spring months fall within the dry period of the Highveld climate. During the dry season, concentrations of chemicals tend to be higher than in the rainy season because there is a lower flow of water to dilute the chemicals from upstream to downstream.

Seasonal, spatial and long-term trends were analysed using pivot tables and box and whiskers applications. The constituents were then used to represent monthly average values over the selected period. Pivot tables and graphs were a useful tool to portray seasonal changes for each constituent at different locations, times, months, and years. Seasonal changes were used to identify any possible similarities and differences in surface water (as sampled at the selected monitoring sites of the study area) during each specific season including the rainy periods (i.e. summer and autumn months running from November through April) and dry periods (i.e. winter and spring months running from May through October). The spatial location of these sites were upstream (B5), middle stream (B16 and B15), downstream (B17 and B11) and on the side stream (B6). Long-term behaviour or changes of the selected water constituents were portrayed using annual averages to reveal long-term trends in the selected water constituents.

In addition to statistical analyses, qualitative information from previous work on the Blesbokspruit wetland and interviews with members of the Blesbokspruit Forum was linked to external events—commencement or cessation of large scale pumping of underground water, and commissioning of water treatment pilot plants etc. The events, which may have driven seasonal and long-term trends, were used to clarify the behaviour of the physicochemical parameters under investigation.

3.10 Sources and effects of the selected physicochemical parameters in freshwater wetland biota, irrigated crops and livestock

The presence of higher concentrations, of sulphate, sodium, magnesium and chloride and the inherent higher electrical conductivity values and varying pH, has been associated with both natural and anthropogenic point and non-point sources [Thorius, 2004; Du Plessis, 2006]. Table 10 provides a summary of the sources of salts (i.e. SO_4, Cl, Na and Mg), EC and pH, their behaviour and their possible effects on irrigated crops, livestock and aquatic biota in freshwater wetlands.

Table 10: Summary of sources, behaviour and negative effects of the selected physicochemical parameters found in freshwater wetland systems

Parameters	Sources	Behaviour / Interaction	Effects on Irrigated Crops/Soils, Livestock and Aquatic Biota
Salts (e.g. Sulphate (SO_4); Chloride (Cl); Magnesium (Mg) and Sodium (Na)	Atmospheric H_2SO_4 deposition (Kerekes *et al.*, 1986) Mine drainage (Kaksonen & Hakka, 2007) and Smelting operations (Kaksonen & Hakka, 2007) Urban runoff (US Geological Survey, 2011) Sewage Industrial effluents such as wastewaters from the paper and pulp industry (Stefen *et al.*, 1990; DWAF, 1996a,1996b, 1996c ; US Geological Survey, 2011) Oxidation of organic sulphur by microorganisms (Dillon & Evans, 2000) Sulphate minerals dissolution (Cortecci *et al.*, 2002) Sea level rise/Salt water intrusion (US Geological Survey, 2011) Fire (US Geological Survey, 2011) Agriculture runoff (US Geological Survey, 2011) Groundwater (US Geological Survey, 2011) "Road salt, effluent from industrial facilities, leachate from municipal landfills, effluent from private and municipal septic systems, and some agricultural chemicals." (Panno *et al.*, 2002) "Natural sources include	"Different soils tolerate sodium differently." (Salt Institute, 2011) Acidification of surface waters (Kerekes *et al.*, 1986) "Oxidation of oxidation of sulfide minerals leads to the formations of acidic metal- and sulfate-containing wastewaters" (Kaksonen & Puhakka, 2007) or acid mine drainage (AMD) Accumulation of sulphates and associated acidification in stagnant surface waters during dry season where there is low stream flow (Dillon & Evans, 2000; Eimers & Dillon, 2002; Eimers *et al.*, 2004; Clark *et al.* 2005, 2006) Lower sulphate concentrations in rainy season during high stream discharge or flow (Eimers *et al.*, 2008) "Exposure is a combination of concentration and duration." (Salt Institute, 2011) "Elevated soil levels of sodium and chloride decrease over the growing season due to leaching of the ions by rainfall and	"All of the plants and animals that make up freshwater aquatic communities are affected by salinity" (James *et al.*, 2003) Salts in higher concentrations may affect "plant growth by altering soil structure, permeability and aeration." (US Geological Survey, 2011; Salt Institute, 2011) Salts in higher concentrations are toxic to aquatic plants and animals (US Geological Survey, 2011; (Hunt *et al.*, 2012) Excess of salts in leaves can cause "leaf burn, necrotic (dead) patches and even defoliation." (Podmore, 2009) Excess of salts "inhibits the uptake of calcium, causing nutritional disorders." (Food and Agriculture Oganization, 2002). Different plant species tolerate salts differently (Salt Institute, 2011) High concentrations of salts in the soil may be "toxic or change water relationships such that the plant cannot easily

Parameters	Sources	Behaviour / Interaction	Effects on Irrigated Crops/Soils, Livestock and Aquatic Biota
	rock-water interactions, saline seeps, and minor atmospheric contributions." (Panno *et al.*, 2002) "Sodium chloride is added to many processed foods to delay spoilage while bringing out flavor." (Hunt *et al.*, 2012) "..more chlorides are entering groundwater through human waste. However, chlorides are not removed from waste by septic tank treatment processes and enter the leach field with the rest of the effluent, or wastewater. From there, chlorides can enter groundwater through septic systems and find their way into lakes, ponds, streams, and wetlands." (Hunt *et al.*, 2012) "Chloride ions in the environment can come from sodium chloride or from other chloride salts such as potassium chloride, calcium chloride and magnesium chloride." (Hunt *et al.*, 2012) "Chloride ions come into solution in water in underground aquifers, geological formations that contain groundwater. … Coastal flooding can also find its way into freshwater waters." (Hunt *et al.*, 2012)	run-off." (Salt Institute, 2011) "Exposures vary by season from the high chloride loadings of winter and spring to the low exposures during summer and fall." (Salt Institute, 2011) "When chloride enters a stream as runoff, it creates a chloride "pulse" which will travel down and out of the stream in a relatively short time (i.e., days to weeks, depending on the width, gradient and length of the stream) because the water is constantly flowing through the stream." (Salt Institute, 2011) "Different fish species exhibit a range of tolerance to different salts according to the time of exposure, salt concentration, temperature and character of the test water." (Salt Institute, 2011) "Elevated soil levels of sodium and chloride decrease over the growing season due to leaching of the ions by rainfall and run-off." (Salt Institute, 2011) "Once chlorides are in a water body, there are no biological processes that remove them. They are not typically removed at water treatment plants due to restrictively high cost. Natural spikes in chloride concentration can occur during summer "low flow" periods when evaporation exceeds precipitation." (Hunt *et al.*, 2012)	accumulate water and nutrients."(Goodrich & Jacobi, 2008) Salts promote eutrophication of freshwater systems (US Geological Survey, 2011) "The chlorides of calcium, magnesium and potassium are generally more toxic to fresh water species than sodium chloride." (Salt Institute, 2011) "Excessive salinity in livestock drinking water can upset the animals' water balance and cause death. High levels of specific ions in water can cause animal health problems and death." (Soltanpour & Raley, 2007) As the salinity of water increases, "intake also increases, except at very high content where the animals refuse to drink. Depressed water intake is accompanied by depressed feed intake." (Bagley *et al.,* 1997) "Increasing salinity of the irrigated soils is one of the main reasons for the current decrease in agricultural productivity" (Shirokova *et al.*, 2000)

Parameters	Sources	Behaviour / Interaction	Effects on Irrigated Crops/Soils, Livestock and Aquatic Biota
Electrical Conductivity (EC)	"Electrical conductivity (EC) is a measure of the ability of water to conduct an electrical current. This ability is a result of the presence in water of ions such as carbonate, bicarbonate, chloride, sulphate, nitrate, sodium, potassium, calcium and magnesium, all of which carry an electrical charge." (DWAF, 1996a, 1996b, 1996c)	"The TDSalts concentration is directly proportional to the electrical conductivity (EC) of water. Because EC is much easier to measure than TDSalts, it is routinely used as an estimate of the TDSalts concentration. Therefore, it has become common practise to use the total dissolved salts concentration, as a measure for the total dissolved solids." (DWAF, 1996a, 1996b, 1996c)	EC as triggered by the presence of salts has "effects on, and adaptations of, individual species; on community structure; and on microbial and ecological processes such as rates of metabolism and nutrient cycling." (DWAF, 1996c)
pH	Mining (Wiessner *et al.,* 2006; Kaksonen & Puhakka, 2007) "For surface water, pH values typically range between 4 and 11. The relative proportions of the major ions, and in consequence the pH, of natural waters, are determined by geological and atmospheric influences." (DWAF, 1996a, 1996b, 1996c) "Industrial activities generally cause acidification rather than alkalinization of rivers. Acidification is normally the result of three different types of pollution, namely: -low-pH point-source effluents from industries, such as pulp and paper and tanning and leather industries; -mine drainage, which is nearly always acid, leading to the pH of receiving streams dropping to below 2; and -acid precipitation resulting largely from atmospheric pollution caused by the burning of coal (and subsequent production of	Acid mine drainage – acidic water with low pH values (Wiessner *et al*., 2006) "Very dilute sodium-chloridedominated waters are poorly buffered because they contain virtually no bicarbonate or carbonate. If they drain catchments containing certain types of vegetation (for example, fynbos), the pH may drop as low as 3.9 owing to the influence of organic acids (for example, humic and fulvic acids)." (DWAF, 1996a, 1996b, 1996c) "Most fresh waters …are relatively well buffered and more or less neutral, with pH ranges between 6 and 8." (DWAF, 1996a, 1996b, 1996c) "The pH may also vary both diurnally and seasonally. Diurnal fluctuations occur in productive systems where the relative rates of photosynthesis and respiration vary over a 24-hour period, because photosynthesis alters the carbonate/bicarbonate equilibrium by removing	"The toxic effects of acid pH values on fish increase as the concentrations of calcium, chloride and sodium decrease" (DWAF, 1996c) "...high concentrations of dissolved oxygen may decrease the effect of high pH values on fish, particularly if alkaline conditions are the result of intense photosynthetic activity of aquatic plants, which is normally accompanied by high levels of dissolved oxygen." (DWAF, 1996c) "In poorly buffered waters, pH can change rapidly, which in turn may have severe effects on the aquatic biota." (DWAF, 1996c) "Streams with acidic pH values have different periphyton (micro flora and fauna living on solid surfaces) communities and lower overall production compared with less acidic streams." (DWAF, 1996c) For livestock, "highly alkaline waters may cause digestive upsets,

Parameters	Sources	Behaviour / Interaction	Effects on Irrigated Crops/Soils, Livestock and Aquatic Biota
	sulphur dioxide (SO_2)) and the exhausts of combustion engines (nitrogen oxides). Both sulphur oxides (SO_x) and nitrogen oxides (NO_x) form strong mineral acids when dissolved in water. When acid rain falls on a catchment, the strong acids leach calcium and magnesium from the soil and also interfere with nutrient availability." DWAF, 1996a, 1996b, 1996c)	CO from the water. Seasonal variability is largely related to the hydrological cycle, particularly in rivers draining catchments with vegetation such as fynbos, where the concentration of organic acids is consistently lower during the rainy season." (DWAF, 1996a, 1996b, 1996c)	diarrhea, poor feed conversion and reduced water/feed intake." (Bagley *et al.,* 1997)

In the Blesbokspruit wetland, the potential and identified sources of water pollution are also associated with natural and anthropogenic processes summarised in Table 11.

Table 11: Summary of potential and identified sources that may influence the selected physicochemical parameters in the Blesbokspruit wetland (Adapter from Figure 33)

Parameters	Potential and Identified Anthropogenic/Natural Source/Processes
Sulphate (SO_4)	Defunct mines (e.g. Largo Colliery); Underground minewater discharges (e.g.Grootvlei Mine); Industries (e.g. Sappi Enstra); Sewage Works (e.g. ERWAT); tailing dams; Implats Refinery; Agricultural Small Holdings
Sodium (Na)	Mines and Industries; Sewage Works; agricultural lands
Chloride (Cl)	Mines and Industries; Sewage Works; agricultural lands
Magnesium (Mg)	Grootvlei Mine; Industries); Sewage Works; tailing dams; agricultural lands
Electrical Conductivity (EC)	Mines and Industries; Sewage Works; tailing dams; agricultural lands
pH	Mines and Industries; Sewage Works; tailing dams; agricultural lands

Based on the negative effects of parameters—sulphate, chloride, magnesium, sodium, pH and electrical conductivity at certain levels on irrigated crops, livestock and aquatic biota—there was a need to develop targeted limits, applicable to South Africa, for use as reference points (Department of Water Affairs and Forestry, 1996a, 1996b, 1996c]. These targeted limits are meant to guide water users (dependent on the aquatic ecosystem) when assessing the suitability or fitness of freshwater resources like the Blesbokspruit wetland—especially when pollutants (from potential sources) are likely to lower the quality of these natural resources (Department of Water Affairs and Forestry, 1996a, 1996b, 1996c; Tonkin, 2005].

3.11 Water quality target limits for irrigation, livestock watering and aquatic environment

To evaluate the fitness of use of the surface water quality in the Blesbokspruit wetland by the selected users, the national *Target Water Quality Guideline Ranges* for irrigation, livestock watering and the aquatic environment was used (Table 12) (Department of Water Affairs and Forestry, 1996a; 1996b and 1996c]. Domestic guidelines were not used for this study because the surface water in the Blesbokspruit wetland is not used directly for domestic purposes.

Where no target value ranges were provided by the Department of Water Affairs, for some parameters, the limits of the Blesbokspruit catchment or previous findings were used to ascertain the suitability of the surface water in the Blesbokspruit wetland for the selected water users or requirements.

Table 12: Combination of Target Value Ranges for Irrigation, Livestock Watering and Aquatic Environment according to selected physicochemical parameters and stricter In-stream Water Quality Guidelines for the Blesbokspruit Catchment (Adapted from Department of Water Affairs and Forestry, 1996a, 1996b and 1996c; Blesbokspruit Forum, 2003b]

Parameters	DWA Target value range for irrigation	DWA Target value range for livestock watering	DWA Target value range for aquatic environment	Blesbokspruit Ideal Catchment Background	Blesbokspruit Acceptable Management Target
pH	6.5 - 8.4	*NTV*[3]	**0.5 of a pH unit variation**	6.5 - 8.5 (mg/L)	*NTV*
Electrical Cond. (EC)	0 - 40 (mS/m)	70 – 300 (mS/m)	*NTV*	<45 (mS/m)	45 - 70 (mS/m)
Cl as chloride	0 - 100 (mg/L)	0 - 1500 (mg/L) non-ruminants 0 - 3000 (mg/L) ruminants	**0 - 0.2 ug/L as limit of TDS, no separate limits for Na and Cl ions**	<80 (mg/L)	80 - 150 (mg/L)
Magnesium(Mg)	*NTV*	0 - 500 (mg/L)	*NTV*	<8 (mg/L)	8 - 30 (mg/L)
Sodium (Na)	0 - 70 (mg/L)	0 - 2 000(mg/L)	*NTV*	<70 (mg/L)	70 - 100 (mg/L)
Sulphate (SO_4)	*NTV*	0 - 1 000(mg/L)	*NTV*	<150 (mg/L)	150 - 300 (mg/L)

3.12 Evaluations of the water quality management interventions

A range of management interventions have been developed, by members of the Blesbokspruit Forum or by other stakeholders, to tackle the problem of surface water quality in the whole Blesbokspruit catchment, including the Blesbokspruit wetland (De Fontaine, 2012]. These interventions include, *inter alia,* in-stream water quality guidelines for the whole Blesbokspruit catchment; water treatment methods; and ingress water management (Wood & Reddy, 1998; Blesbokspruit Forum, 2003b; Lea *et al*, 2003].

[3] NTV means 'no target value' proposed by the Department of Water Affairs in their guidelines.

To evaluate the effectiveness of the past and current management interventions throughout the eleven-year period, the *"… in-stream Water Quality Guidelines for the Blesbokspruit Catchment"* document was used. This guideline document (Figure 38) was developed and based on the national *Target Water Quality Guideline Ranges* and endorsed by the Department of Water Affairs. Nevertheless, this water quality guideline for the Blesbokspruit is aimed at different water users in this catchment—i.e. domestic, irrigation, livestock, aquaculture, recreational, industrial activities and aquatic ecosystem—and represents water quality management objectives for the entire catchment, including all existing water resources (De Fontaine, 2012].

For this study, only the values representing '*ideal catchment background'* and *'acceptable management target'* ranges for the respective selected parameters (Table 12) were used to ascertain the success or failure of all water quality management interventions. If successful, inter-annual surface water quality results would be within both the '*ideal catchment background'* and *'acceptable management target'* ranges. Positive results would ultimately be used to motivate the reinstatement of the Blesbokspruit wetland as a Ramsar site, along with the re-evaluation of the Ramsar criteria and Montreux Record requirements for the Blesbokspruit wetland.

3.13 Importance of adequate water quality conditions under the Ramsar Convention

Ramsar documents pertaining to water quality and the guidelines of the Montreux Record for contaminated sites were consulted. This information served as evidence for using surface water quality as an acceptable approach to establish the ecological integrity of the Blesbokspruit wetland (Ramsar, 1996a; South African Wetlands Conservation Programme, 1999]. These documents also provide the tools to apply for the delisting of the Blesbokspruit wetland from the Montreux Record and its reinstatement as a Ramsar site—if all requirements are met (Ramsar, 1998]. However, the feasibility of a successful application could only be tested through using the outcomes of this study, (presented in Chapter 4—RESULTS AND DISCUSSION), together with an attempt to complete the Montreux Record questionnaire to test whether the site now fulfils all enumerated conditions.

3.14 Data reliability and shortcomings

Accurate spatial and temporal trends of a water resource have been proved to be intimately related to the frequency, time and size of the sampling (Department of Water Affairs and Forestry, 1996a; 1996b and 1996c]. For the dataset used, few shortcomings were identified during the sampling campaign and the archiving of data:

- few missing field visual observation of parameters—colour and turbidity or load to record immediate event necessary for result interpretation and decision making process;
- no record of flow of the Blesbokspruit wetland because Rand Water does not monitor flow levels, i.e. the flow of a water body could indicate the load particles and concentration. This is

important primarily for studies dealing with the volumes of sediment or particles in a water resource;

- data were not recorded for several locality points for specific months and specific water constituents, with no metadata on reasons for why the data is missing;
- Events that could be associated with the monthly surface water quality readings were very limited, thus preventing the full understanding of the behaviours and trends (seasonal and inter-annual) of the analysed water parameters.
- fortnightly readings were only provided for the period January 2000 to June 2008. The data had to be re-worked to portray monthly average values for this period to fit the remaining dataset (July 2008 to December 2011).

The results of applying these methods to the samples and obtained data are presented in the following chapter.

4. RESULTS AND DISCUSSION

In this chapter the results of the water sampling, performed from 2000 to 2011 for the Blesbokspruit Ramsar wetland, following the methods described in the previous chapter, are presented and discussed.

For this study, attention was only given to those constituents related to ions above the detection limits of salts (sulphate, chloride, magnesium and sodium), and to pH and electrical conductivity. Several other parameters form part of the routine analyses of the Rand Water Board (aluminium, ammonia, boron, bromide, calcium, copper, nitrate, nitrite, phosphate, phosphorus, zinc, selenium, chemical oxygen demand, dissolved organic carbon, total organic carbon, total silicates and total *Kjeldahl* nitrogen). However, most of these elements and compounds occurred at trace concentrations that were infrequently or intermittently above detection limits, or were not routinely monitored. Physical parameters being monitored, other than pH and electrical conductivity (hardness, suspended solids, temperature, turbidity), were either not entered onto the Rand Water Board database or, alternatively, were not made available to the researcher at the time of this study. The results presented and discussed represent the monthly mean concentrations of sulphate, sodium, chloride, magnesium and monthly mean pH and electrical conductivity values, for each of the six sites over the period 2000 – 2010. This time line covers the period when the pumping of underground mine-water prevailed until it was halted in December 2010. The year 2011, in contrast, is linked to the shutting down of the Grootvlei Mine and the absence of underground mine-water pumping activities by this mine.

Seasonal and inter-annual variations were interrogated for the parameters and concentrations where values were regularly above detection limits. These variations were presented in graphical format in the text (Tables of numerical values for each parameter were placed in the APPENDICES). Various trends were plotted by site, starting with Site B6, (located in a side stream flowing into the main Blesbokspruit channel from the west). Then, in spatial sequence, results were presented from the inflow into the designated Ramsar wetland, at Site B5, moving downstream through B16, B15 and B17, to the outlet at Site B11. This sequencing allowed for the detection of pollutants that might be added to or deposited from the flow at various intermediate points —e.g. the pumping of underground mine-water just upstream of Site B16, at Grootvlei Mine Shaft No. 3 (Figure 33).

The seasonal trends (period monthly averages) of constituents gave indications of variations of water quality within the seasonal cycles (rainy and dry seasons) and influence of possible intermittent anthropogenic events occurring in the study area. According to the season, the physicochemical nature of the water might change, for better or worse, dependent on the loads of chemicals, and quantities of precipitation and groundwater flow into the wetland system (Table 10). These seasonal variations set a baseline of the natural cycles, against which the timing and extent of pollution events and trends might become apparent. The baseline would also facilitate the identification of possible reasons for unusual events.

The inter-annual variations (long-term trends) of constituents were compared with the Department of Water Affairs Target Water Quality Guideline Ranges for agricultural use (irrigation, livestock watering) and the aquatic environment, as applicable and, the in-stream water quality guidelines developed for the Blesbokspruit catchment. These summarised trends would inform on the fitness for use of the water in the Blesbokspruit for downstream agricultural uses and dependent aquatic biota. These results would tell also whether the ecological integrity of the Blesbokspruit wetland had been restored to an adequate surface water quality (as stipulated by the Montreux Record Recommendations for this wetland and addressed in *Section 2.1.6*). Based on these trends, it was possible to establish whether the surface water of the Blesbokspruit wetland had been improving or deteriorating over the selected period. This, in turn, might motivate the delisting of the Blesbokspruit from the Montreux Record, and establish a basis for evaluating the management interventions of the Blesbokspruit Forum for protecting the Blesbokspruit wetland as a crucial water resource for the region.

4.1 Time trends in surface water quality

4.1.1 *Seasonal changes*

Average monthly concentrations will be presented in two time divisions: firstly, for the period 2000 to 2010 when the pumping of underground mine-water was still effective (until it stopped in December 2010); secondly, for the year 2011, considered to be the point when, in the absence of underground mine-water pollution, restoration of the Blesbokspruit wetland started. Results for 2011 are dealt with separately, because pumping of underground water ceased at the end of 2010, and the concentrations of several ionic species had dropped by a factor of two or more when compared with the preceding years (*Section 4.1.2)*. The year 2011 was thus atypical when compared with the previous years (2000-2010).

Spatially, Site B5 was considered the reference site, since it is located at the inlet of the wetland and is upstream of discharges of underground mine-water. Sites B16, B15, B17 are located downstream of Grootvlei Mine Shaft No. 3 and the discharge point. Site B11, situated at the outlet of the Blesbokspruit wetland, receives water from upstream sites B5 through B16, B15 and B17.

Seasonal variations in sulphate concentrations

Sulphate (SO_4) monthly average concentrations for the period 2000 - 2010 are presented in Figure 39 and Appendix 3: Mean seasonal and inter-annual results in tabular format. SO_4 levels decreased during the rainy period (from October through March) from the inlet B5, through B16, B15, B17 to the outlet B11. By contrast, during the dry season (from April through September), SO_4 concentrations increased by a factor of 0.5 to 1.5—especially the sites located downstream of the inlet

B5 (i.e. from B16 through B15, B17 to the outlet B11). Nevertheless a few exceptions in SO_4 seasonal trends were observed at Site B6 (located at the side stream).

Water that entered the wetland at B5 contained the lowest levels of SO_4 (from 94 – 134 mg/L) (Figure 39 & Appendix 3: Mean seasonal and inter-annual results in tabular format). As the water flowed south, it mixed with the discharges of SO_4-rich water from the Grootvlei Mine shaft No. 3 discharge point (located just upstream from Site B16). This mixing with the mine-water was reflected in the jump of concentration from ~134 mg/L to ~649 mg/L. In this water, now very high in SO_4 at Site B16, SO_4 concentrations progressively reduced in summer (particularly in February and March) at the downstream sites (B15, B17, and B11)—probably because of dilution by rainwater and surface runoff. In contrast, during late winter and spring (July through October), the sulphate concentrations relative to Site B16 increased downstream, indicating additional small inflows of SO_4-rich water, possibly from groundwater seepage from the adjacent slimes tailings impoundments.

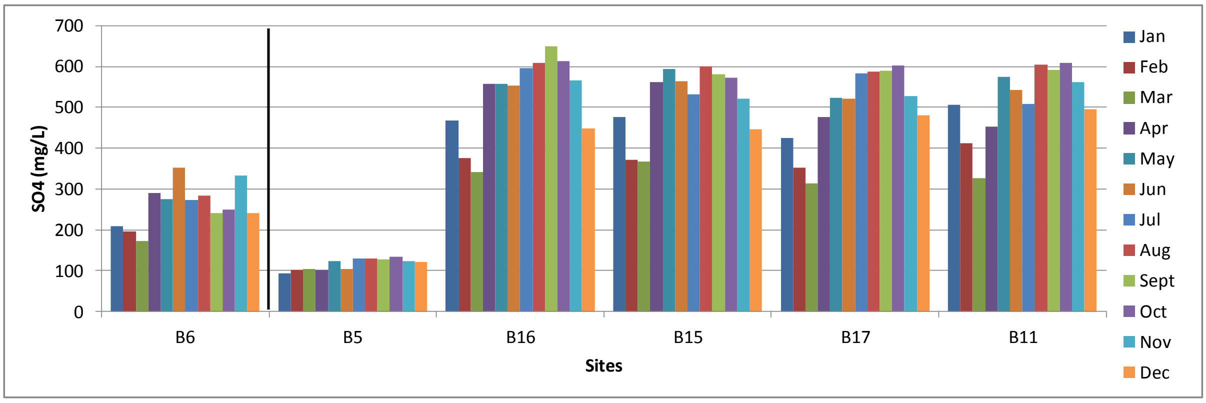

Figure 39: Seasonal average sulphate concentration from 2000 to 2010

Seasonal variations were apparent in the discharge from underground pumping at B16 (Figure 40) indicating that the underground water may have been influenced by short-term seasonal changes of precipitation at the surface. Similar seasonal variations in sulphate concentrations occurred at the three downstream sites (B15, B17 and B11)—emphasised in the set of normalised monthly average plots (Figure 40). During the summer months (December – March), SO_4 concentrations were low, with the lowest values occurring in March at all the sites along the wetland (From B16 through B15, B17 and B11). There was a sharp increase from April through May, with levels continuing to increase until reaching their highest values in August and September.

By contrast, Site B5 showed only slight seasonal variations, lower in late summer, higher in winter and spring (Figure 40). This could be explained by the location of the site at the inlet of the wetland and the likelihood it was less influenced by the same pollutants measured at sites B16, B15, B17 and B11—the latter four sites probably received wastewaters from mines and metallurgical operations (e.g. underground mine-water, slimes tailings, derelict mines, mineral processing).

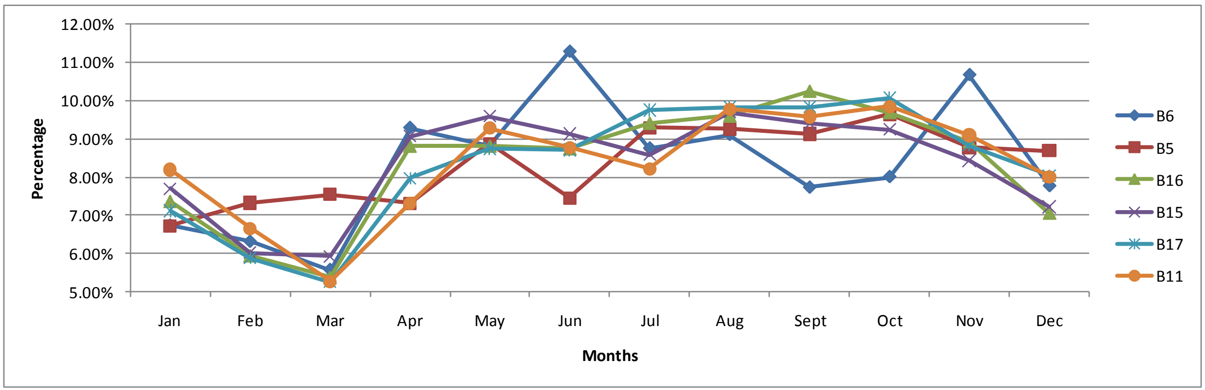

Figure 40: **Normalised seasonal differences and similarities in sulphate patterns at Sites B5, B16. B15, B17, B11 and B6 from 2000 to 2010**

At site B6, there was an irregular seasonal pattern, with low late summer concentrations and high winter concentrations of SO_4 (Figure 40). The maximum concentration in June at this site was because of a singularly high event in year 2000, for which there no explanation is available. B6 was (and remains) directly exposed to effluents from the town of Springs residential areas and surrounding sewerage works.

In 2011, no distinct seasonal pattern of SO_4 was observed at the inlet to the Blesbokspruit wetland (site B5) (Figure 41). In the downstream sites (from B16 to B11), summer months tended to show a progressive decrease in SO_4 concentration, with unexplained high events occurring in some months for sites B15, B17 and B11 (Appendix 3: Mean seasonal and inter-annual results in tabular format). No direct cause could be associated with these events since the pumping operations terminated in December 2010. SO_4 values in the wetland appeared to be relatively uniform (with the exception of these few high events). It is possible that SO_4 concentrations, present at the time samples were collected, were the result of an accumulation of SO_4 prior to 2011. Conversely, the side stream (Site B6) of the wetland system showed a decrease in SO_4 from April through August—with high events (that could not be linked to any specific activity) documented during the months of January, April, May and June (Appendix 3: Mean seasonal and inter-annual results in tabular format).

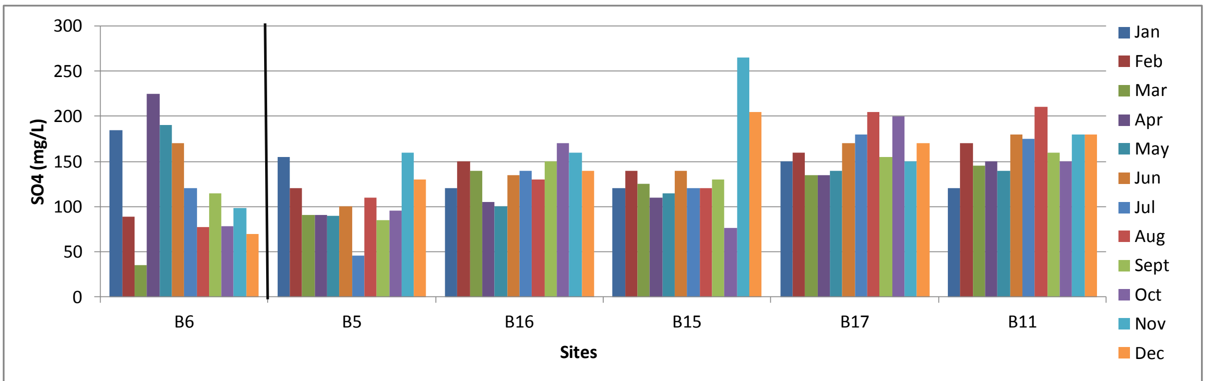

Figure 41: **Seasonal average sulphate concentration in 2011**

In summary, it could be concluded that elevated SO_4 concentrations in the Blesbokspruit wetland (from B16 to B11) were a direct result of the discharge of underground mine-water, high in salt content, from the Grootvlei Mine until the pumping activities ceased in December 2010. This observation correlated with the previous findings of SO_4 loads from the same mine from 1996 until the end of 2010 (*Section 2.4.2*). On a seasonal basis, SO_4 tended to fluctuate—dilution of SO_4 is high during rainy months, and low during dry months when there is little rainwater and surface flow available (Table 10). This fluctuation could be compared with the loading of salts continuously pumped from the Grootvlei Mine, regardless of the season (as portrayed by SO_4 concentration values at Site B16 and downstream). This explains why, when water exited the Blesbokspruit wetland at B11, SO_4 concentration values were still comparatively high (between 326 - 609 mg/L), especially for the period 2000 - 2010. Nevertheless after December 2010 (and the cessation of the pumping operations at Grootvlei Mine), SO_4 concentrations downstream along the flow of the Blesbokspruit wetland decreased to reach similar concentration levels (as noted at the inlet B5), with only a few high events. Surprisingly, after December 2010, B6 on the side stream also showed decreasing SO_4 concentrations. Neverthesss, over the last two to three months of 2011 (i.e. October, November and December), SO_4 concentrations downstream of Grootvlei Mine discharging point No.3 were still high, over 150 mg/L, even at the outlet point B11 in contrast to concentrations at the inlet B5. Therefore, SO_4 concentrations in the Blesbokspruit wetland after 2010 can be considered to be both residual—from SO_4-rich water accumulated in the system—and to include SO_4 originating from B5 and B6.

Seasonal variations in sodium concentrations

Sodium (Na) monthly average concentrations for the period 2000 - 2010 are presented in Figure 42 and Appendix 3: Mean seasonal and inter-annual results in tabular format. Na levels decreased during the rainy periods (from October through March) from the inlet B5 through B16, B15, B17 to the outlet B11. By contrast, during the dry season (from April through October), Na concentrations increased by a factor of 0.5 to 1.5 (from 97 - 173 mg/L)—particularly from July to September—from the inlet B5 to the downstream sites, with the only exception observed at B11 where Na concentrations were on the increase until October (Figure 42). Na concentrations at the inlet B5 contrasted with the SO_4 pattern, with concentrations being close to the downstream concentrations (Figure 42). Water that entered the wetland at B5 already contained a proportion of Na (from 97 – 156 mg/L) (Figure 42 & Appendix 3: Mean seasonal and inter-annual results in tabular format). As the water flowed south, it mixed with the discharges of SO_4-rich water and additional small inflows of Na from Grootvlei Mine shaft No. 3 discharging point (located just upstream from Site B16). The additional Na reflected as a minimal increase of Na concentrations from B16 to the remaining downstream sites B15, B17 and B11 when compared with levels at the inlet B5. Nevertheless, this is an anomaly—on the evidence collected the additional Na caused by pumped underground water was not nearly as high as for SO_4. The source of high Na concentrations in the inlet water has not been fully resolved yet—upstream sewerage works, abandoned mines and a pulp and paper industry are possible sources. The H^+ ion is not considered a likely possibility because the pH was consistently in the range above neutral pH 7.5; the underground mine-water being discharged by Grootvlei Mine was partially treated to increase pH values (*Section 4.1.1— Seasonal variations in pH).* For B6, on the side stream, Na also followed a seasonal pattern of lower concentrations during the rainy months and higher concentrations during the dry periods (Appendix 3: Mean seasonal and inter-annual results in tabular format).

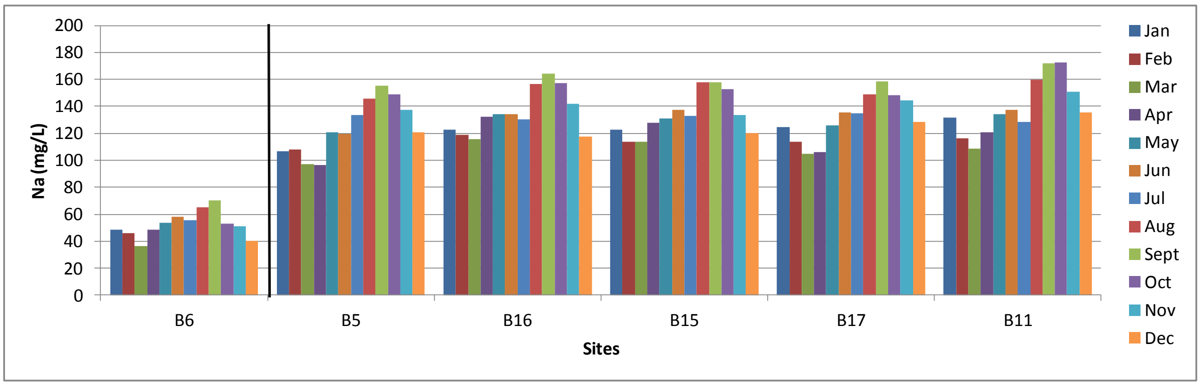

Figure 42: Seasonal average sodium concentration from 2000 to 2010

Seasonal variations of Na concentration behaved as expected (shown in the normalised graph in Figure 43). During the summer months (October - March), Na progressively decreased for sites B5, B16, B15, B17 and B11—in the dry winter months there was a gradual increase from April, reaching the highest values in August, September and October. Nevertheless, in July at the downstream sites (B16 B15 and B11), there was a minimal decrease in Na concentrations. At Site B5, considered the reference site (located upstream of the wetland), the inflow already contained a high Na load—only slightly lower on average than the downstream sites (Figure 42 & Appendix 3: Mean seasonal and inter-annual results in tabular format). This water became more concentrated in Na downstream from B16, picking up an additional Na load, in parallel with the SO_4 behaviour. Site B11, at the outlet of the wetland, had the highest Na concentrations overall (Figure 42 & Appendix 3: Mean seasonal and inter-annual results in tabular format). .

Conversely, at the site on the side stream, B6 had the lowest Na concentration values (Figure 42 & Appendix 3: Mean seasonal and inter-annual results in tabular format). B6 results followed the same seasonal patterns as the sites (B16, B15 and B11) along the Blesbokspruit wetland (i.e. a decrease in Na concentrations during the rainy period and an increase during the dry period, with July again featuring as a month with lower Na values). B6 has been directly exposed to urbanised effluents (different from the effluents affecting the main stream of the wetland) from the urban and industrial areas of Springs. These irregularities were identified in Figure 43.

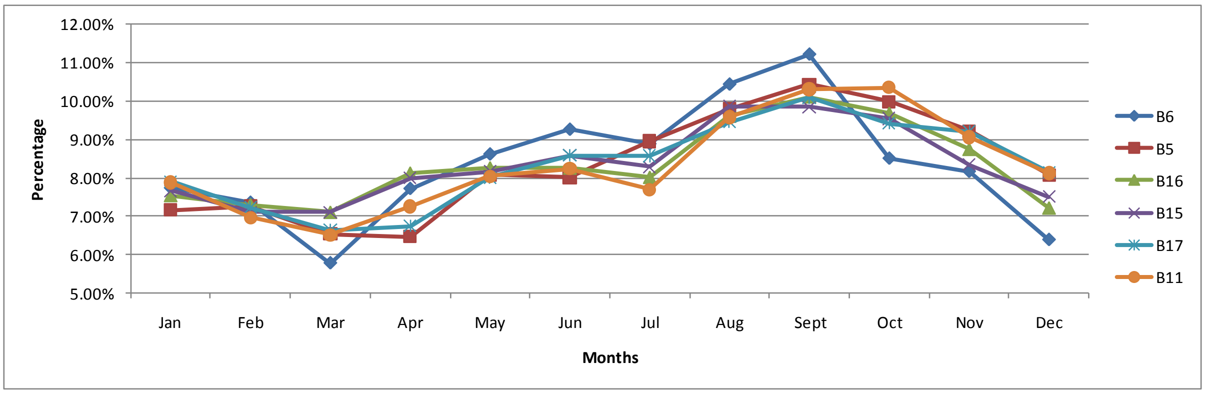

Figure 43: Normalised seasonal differences and similarities in sodium patterns at Sites B5, B16. B15, B17, B11 and B6 from 2000 to 2010

In 2011, Na concentrations tended to follow an erratic pattern with no real seasonal distinction for sites within the wetland (as it occurred with SO_4 concentrations). Na tended to increase during summer months, decreased in April, and again increased during May – July, showed a further decrease in August, and progressively increased in the following months. High events occurred in November or December (Figure 44 & Appendix 3: Mean seasonal and inter-annual results in tabular format). However, reasons for these high Na concentrations could not be linked to any particular events taking place around that time. Similar to the SO_4 variations obtained for 2011, Na values tended to be uniform or within the same range (25 - 100 mg/L) for the sites along the wetland. However, Site B6 had the lowest Na values (2 - 42 mg/L), which also tended to follow an erratic seesaw pattern, with no real seasonal distinction noted (Figure 44).

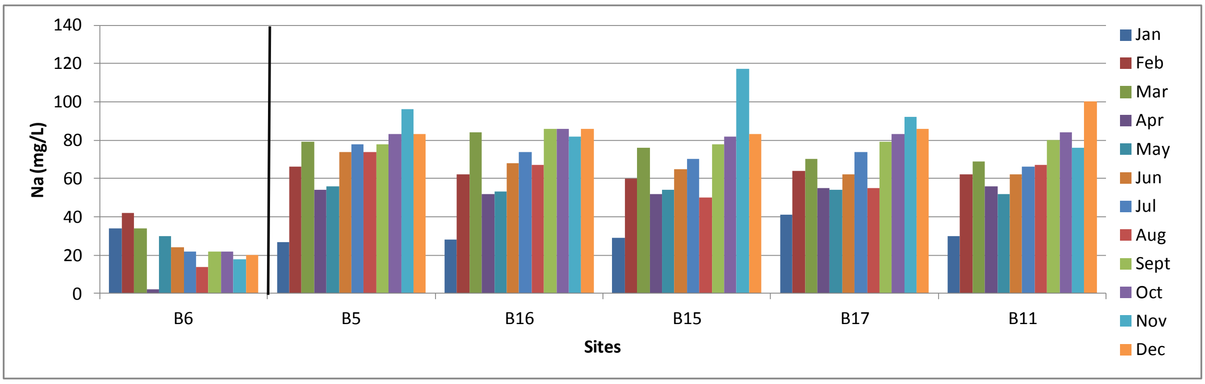

Figure 44: Seasonal average sodium concentration in 2011

To summarise: Na concentration levels at sites within the wetland were not predominantly from the discharged underground mine-water from Grootvlei Mine because the inlet at site B5 already showed high Na levels. Na found in the stream was an accumulation of the pollution upstream of Site B5 (because of the presence of pollutants from other industries—paper and pulp plants, sewage plants, delerict mines), plus small additions from:

- Grootvlei Mine groundwater pumping operations;
- seepage from adjacent tailings and irrigated farmland;
- Na water originating from the side stream (where B6 is located).

All these point and diffuse sources of Na resulted in water with higher Na concentrations when leaving the wetland at outlet B11, a major concern for water users downstream of B11.

Seasonal variations in chloride concentrations

Chloride (Cl) monthly average concentrations for the period 2000 - 2010 are presented in Figure 45 and Appendix 3: Mean seasonal and inter-annual results in tabular format. Cl levels decreased during the rainy period (from October through March), but increased in concentration during the dry season (from April through October), apart from a few exceptions. Cl appeared to vary in a seasonal pattern (similar to Na) for the sites along the main stream (B5 to B11) and the side stream (B6). Cl concentrations on the mainstream ranged from 100 - 180 mg/L. On the side stream (B6), the values were considerably lower, in the range 30 - 70 mg/L. From sites B5 to B11 (downstream), Cl concentrations were higher by a factor of three when compared with B6 at the side of the wetland.

However, in a manner similar to that of Na, Cl concentrations at the inlet B5 contrasted with the SO_4 pattern, with concentrations at the inlet being close to the downstream concentrations (Figure 45 & Appendix 3: Mean seasonal and inter-annual results in tabular format). This formed an anomaly—on the evidence that the additional Cl from pumped underground water was not nearly as high as with SO_4. This implies that Grootvlei Mine was not the exclusive point source for Cl. An accumulation of Cl element may have emanated from other sources of wastewaters upstream and surrounding the wetland. However, in parallel with Na and SO_4, higher Cl values were not reflected in lower (acidic) the pH values (from Site B5 and moving downstream) (*Section 4.1.1— Seasonal variations in pH).* This may imply that, even when the water was saline, measures had been taken to increase pH or else the natural purifier function of the Blesbokspruit wetland was still active.

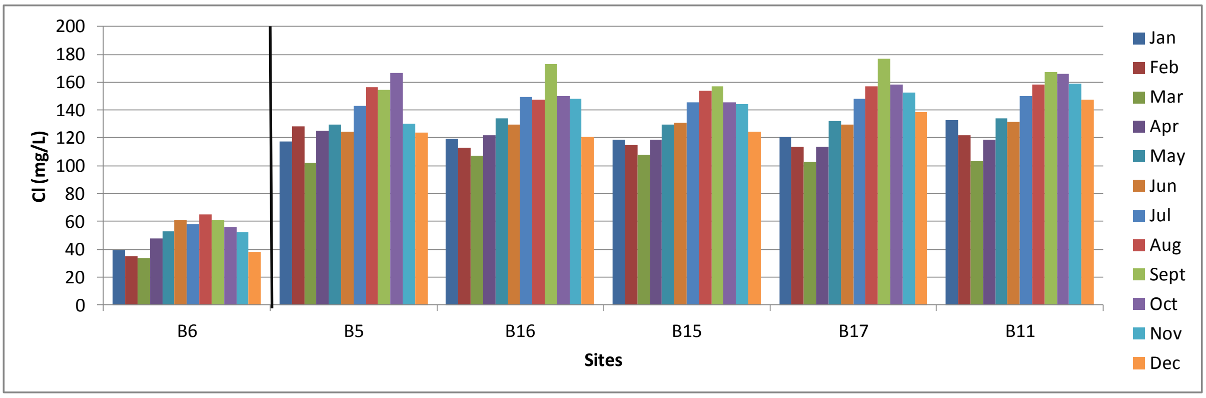

Figure 45: Seasonal average chloride concentration from 2000 to 2010

Seasonal behaviour of Cl concentrations was as expected—shown in the normalised graphs in Figure 46. During the summer months (October – March), Cl progressively decreased for sites B5, B16, B15, B17 and B11; in winter months there was a gradual but continuous increase from April, progressing until levels reached their highest values in August, September and October.

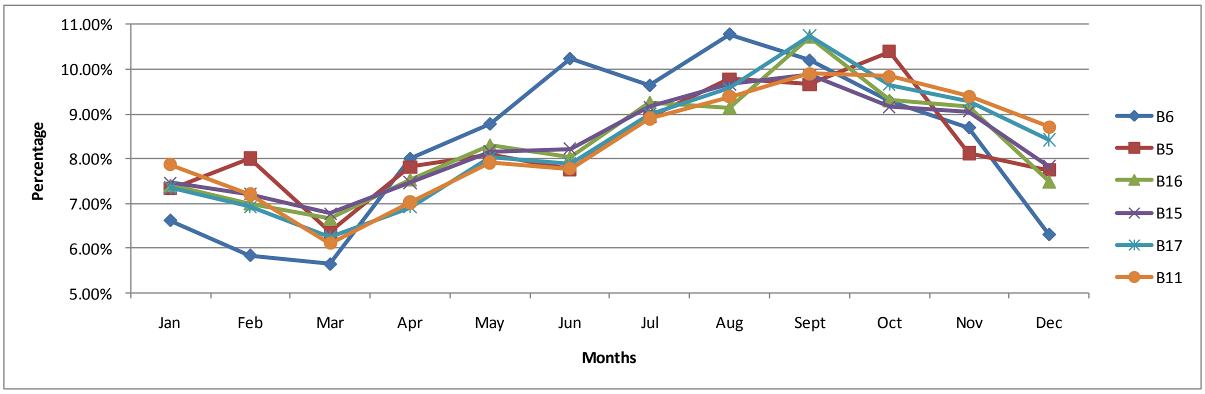

Figure 46: **Normalised seasonal differences and similarities in chloride patterns at Sites B5, B16. B15, B17, B11 and B6 from 2000 to 2010**

Noticeably in 2011, when there were no longer any underground mine-water discharges, there was a continuous decrease in Cl concentrations during summer months (from November throughout February). These decreases were followed by a sudden increase in March; then followed by another decline in Cl concentrations in April—at all the sites in the main stream, with only few exceptions (Figure 47 & Appendix 3: Mean seasonal and inter-annual results in tabular format). During the dry winter and spring months (from May through to October), Cl concentrations tended to be continuously on the increase from Site B16 to B11; Site B5 almost followed the same pattern, with the notable exception of lower Cl concentrations in September. Events related to high concentrations of Cl in either the summer or winter months could not be traced back. Similar to the patterns for SO_4 and Na in 2011, Cl values tended to be more uniform and within the same range (30 - 120 mg/L) for all the downstream sites, with the highest Cl values recorded in October, November and December. However, Site B6 on the side stream had the lowest Cl values (20 - 60 mg/L), which tend to follow an erratic seesaw pattern, with no real seasonal distinction.

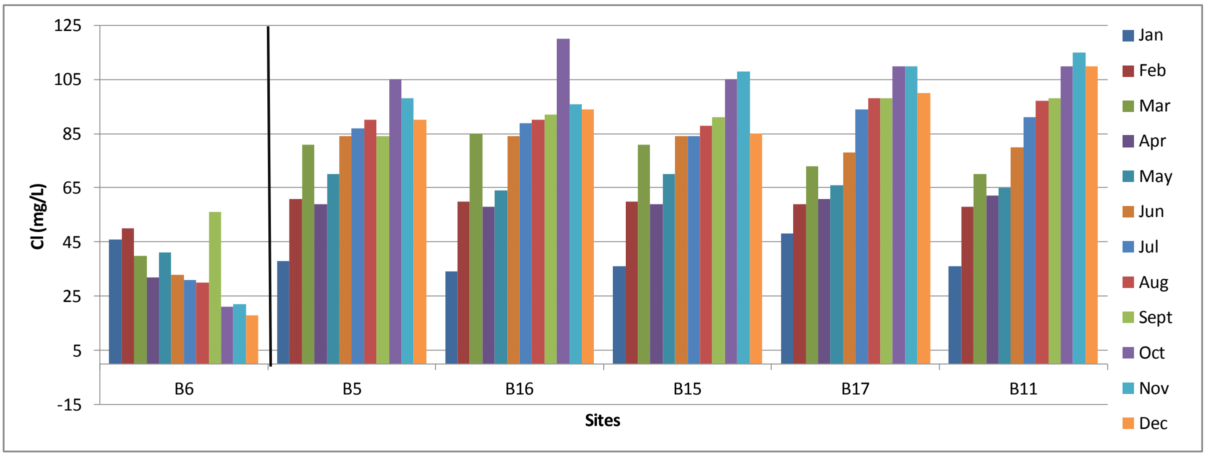

Figure 47: **Seasonal average chloride concentration in 2011**

At Site B5, considered the reference site located upstream of the wetland, the inflow already contained high Cl loading, with concentrations similar to those of the downstream sites (Figure 47 &

Appendix 3: Mean seasonal and inter-annual results in tabular format). Water from B5 was just a reflection of water found downstream at B11 throughout the year, with only slight differences, implying that the wetland could not clear itself of the extra Cl already added to it from upstream and surrounding pollution sources.

In summary, Cl concentration levels at sites within the wetland were not predominantly from the discharged underground mine-water from Grootvlei mine, since the inlet B5 was already showing high Cl levels. The same scenario occurred with Na concentrations. This means that Cl found in the stream was an accumulation of the pollution upstream, plus small additional input from Grootvlei and groundwater seepage from adjacent tailings and other sources. The Cl level was still high during December 2011—especially when leaving the wetland at outlet B11 (compared to Cl at the inlet B5), thus becoming a concern for water users downstream of B11.

Seasonal variations in magnesium concentration

Magnesium (Mg) monthly average concentrations for the period 2000 - 2010 are presented in Figure 48 and Appendix 3: Mean seasonal and inter-annual results in tabular format. Mg appeared to vary in a seasonal pattern similar to that of SO_4 for the sites along the main stream (B5 to B11) and the side stream (B6). Site B5, as the reference site, contained low levels of Mg (from 15 – 20 mg/L) (Figure 48 & Appendix 3: Mean seasonal and inter-annual results in tabular format). As the water flowed south, it mixed with the discharges of Mg-rich water from Grootvlei mineshaft 3 discharging point, close to Site B16. This mixing was reflected in the jump of concentration (by a factor of two) from ~40 mg/L to ~70 mg/L in all seasons. This water, which had become very high in Mg at Site B16, did not reduce in concentration at the downstream sites (B15, B17, and B11)—probably because of the very low dilution of Mg when it came into contact with other salts (SO_4, Na and Cl).

Seasonal variations were not always apparent at the inlet Site B5, which showed a uniform pattern (15 - 20 mg/L) throughout the year, compared to the rest of the sites downstream that showed an increase by a factor of three in Mg concentrations (Figure 48). It can be assumed that that the underground water, as monitored at Site B16, influenced water downstream of Shaft No. 3, Grootvlei Mine, even if seasonal changes in Mg concentrations at Site B16 and the remaining downstream sites were not well pronounced during the winter months. However, there was a noticeable seasonal pattern, especially during the summer months from B16 to B11, where rainwater assisted with the dilution of Mg (Figure 48 & Appendix 3: Mean seasonal and inter-annual results in tabular format).

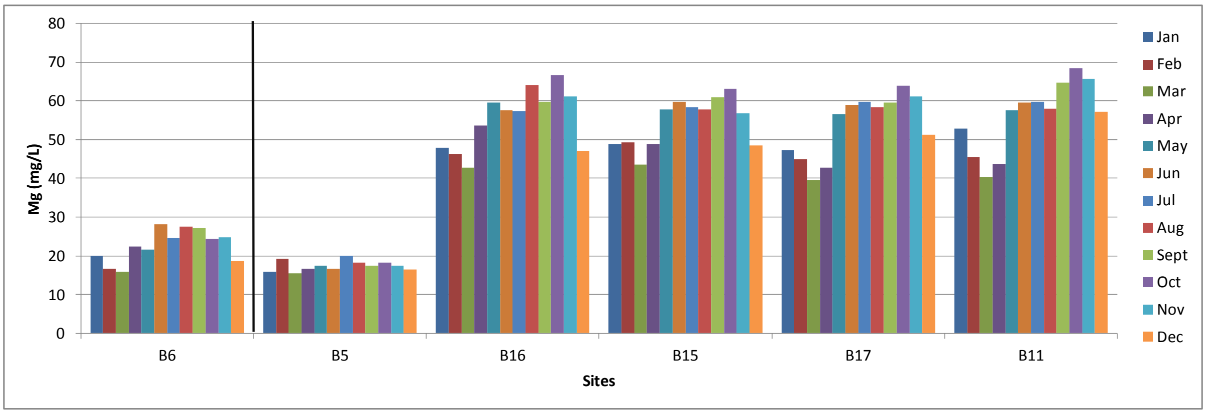

Figure 48: **Seasonal average magnesium concentration from 2000 to 2010**

Overall, Mg concentrations at the three downstream sites (B15, B17 and B11) had similar seasonal variations (normalised monthly average plots—Figure 49). During the summer months (December – March), Mg concentrations were low, with the lowest value in March. The same pattern was observed with SO_4 concentrations (Figure 39 Appendix 3: Mean seasonal and inter-annual results in tabular format&). There was a sharp increase in Mg from April through May, further increasing until the highest values were reached in October.

In contrast, for Site B5, a real seasonal pattern could not be established: the trend appeared to be irregular (Figure 49). This could be explained by the location of B5 at the inlet of the wetland — this site was less influenced by underground water from Grootvlei Mine. The same occurred with Site B6, at the side stream, where Mg concentrations did not show a seasonal difference, but rather followed an irregular or erratic seesaw pattern or had minimal concentrations (15 - 30 mg/L) in almost the same range as B5 (Figure 49).

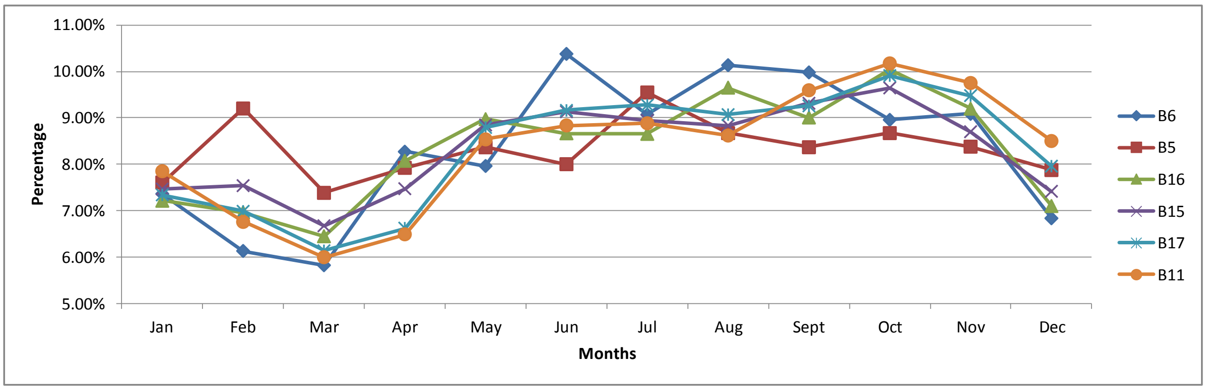

Figure 49: **Normalised seasonal differences and similarities in magnesium patterns at Sites B5, B16. B15, B17, B11 and B6 from 2000 to 2010**

In 2011, with no discharge of underground mine-water by Grootvlei Mine, Mg concentrations did not show a distinct seasonal fluctuation between the rainy and dry period at the in-stream sites (from B5 to B11) as well as the side stream site B6 (Figure 50 & Appendix 3: Mean seasonal and inter-annual results in tabular format). At Site B5 upstream, the inflow already contained Mg (Figure

50) before picking up additional Mg from Site B16 and the remaining sites downstream of Grootvlei Mine shaft No. This implies that, even after the cessation of underground pumping activities by Grootvlei Mine, Mg could still be present around the mine Shaft 3 (Site B16) and could accumulate throughout the downstream sites (From B15 to B11). In September 2011, Mg levels tended to remain high, especially for the three sites downstream (B15, B17 and B11). High events that occurred, specifically during the last three months of 2011 (i.e. October, November and December) (Figure 50 & Appendix 3: Mean seasonal and inter-annual results in tabular format), have not been documented in previous studies. Similar to SO_4, Na, and Cl in 2011, Mg concentrations at the outlet point B11 in the last months of 2011 tended to be higher than the preceding months. Such high Mg concentrations could still be a concern.

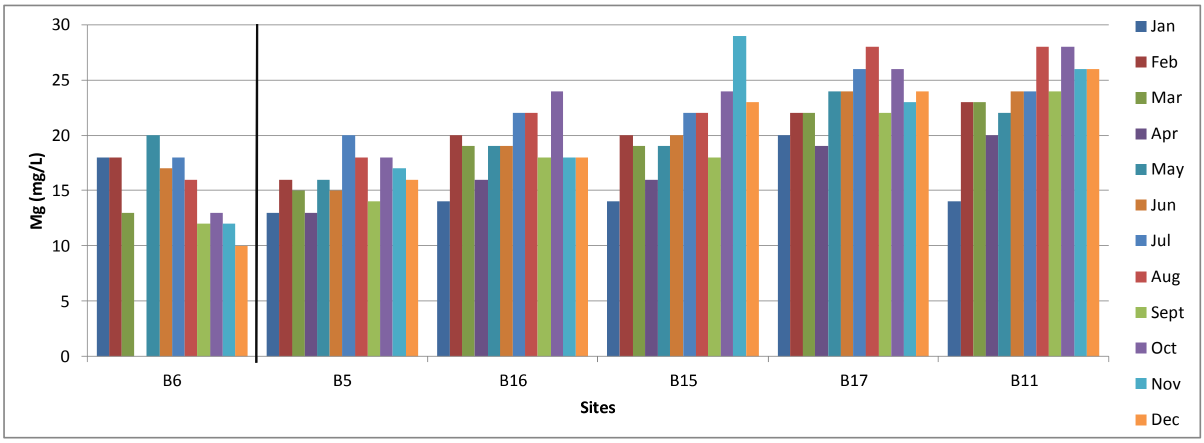

Figure 50: Seasonal average magnesium concentration in 2011

In summary, during summer months, particularly from November throughout March, probably because of dilution by rainwater surface runoff, Mg tended to decrease continuously for sites along the stream even prior to the cessation of underground mine-water pumping activities at Grootvlei Mine shaft No. 3. In contrast, from the onset of winter months (April through October), Mg concentrations tended to be high, with only slight decreases, indicating the addition of small flows of Mg-rich water, possibly because of groundwater seepage from the adjacent slimes tailings dams. Mg levels were still high during the last three months in 2011, especially at outlet B11 (when leaving the wetland) compared to Mg concentrations at the inlet B5, such high concentrations of Mg at the outlet could become thus a concen for downstream water users.

Seasonal variations in electrical conductivity

Electrical conductivity (EC) monthly average values for the period 2000 - 2010 are presented in Figure 51 and Appendix 3: Mean seasonal and inter-annual results in tabular format. EC varied on a monthly basis for the sites in - stream (B5 to B11) and on the side stream (B6). EC values on the main stream ranged from 85 - 210 mS/m; on the side stream (B6) the range was 60 - 90 mS/m. From Sites B5 to B11 downstream, EC values were higher by a factor of two when compared to levels at B6 on the side of the wetland.

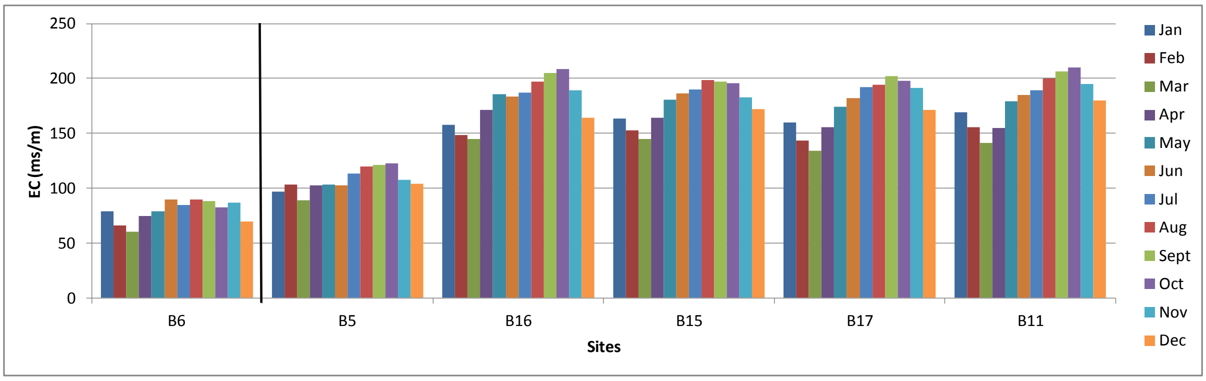

Figure 51: Seasonal average electrical conductivity measurement from 2000 to 2010

Electrical Conductivity (EC) followed the same seasonal patterns as Na, Cl, SO_4 and Mg constituents for sites B5, B16, B15, B17 and B11, as expected (Figure 51 & Appendix 3: Mean seasonal and inter-annual results in tabular format). During rainy months, EC decreased; in the dry season, it progressively increased. The only difference was at site B6 (the site at the side of the wetland), which did not have a regular and identifiable seasonal pattern (Figure 51). B6 was (and continues to be) directly exposed to effluents different from those of B5, B16, B15, B17 and B11. These irregularities are identified in the normalised Figure 52.

With respect to average concentration, EC was similar to SO_4 and Mg in that the value at the inlet site B5 was low; then a step function followed, increasing from Site B16 onwards. This possibly indicates that the increase in conductivity is associated with the increased concentrations of SO_4 and linked Mg. The higher level of salts resulted in an increase in the conductivity of the water in the Blesbokspruit wetland stream (Wood & Reddy, 1998).

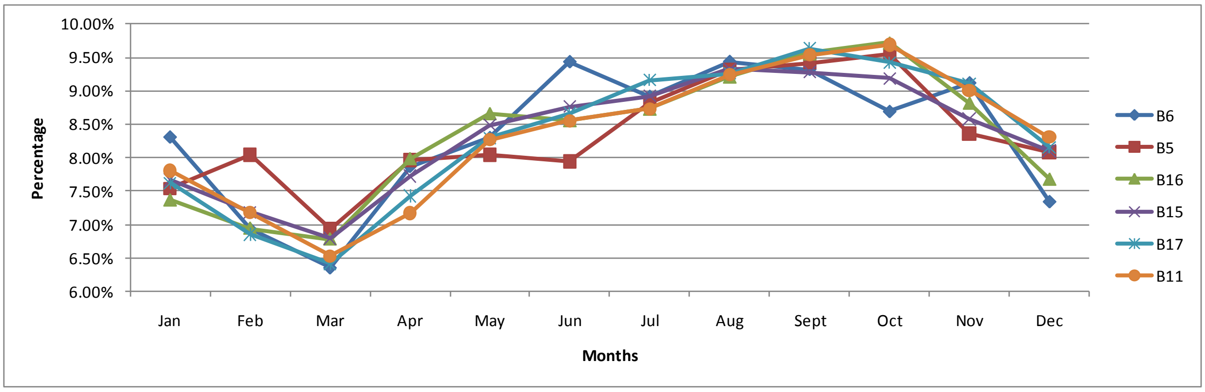

Figure 52: Normalised seasonal differences and similarities in electrical conductivity patterns at Sites B5, B16. B15, B17, B11 and B6 from 2000 to 2010

At Site B5, again considered the reference site because of its upstream location of the wetland, water was highly saline and the same occurred at the downstream sites. This water became slightly more saline downstream from Site B16 (located near the Grootvlei pumping point). This was reflected in the small increments in Na, Cl, Mg and SO_4. As a consequence, because of the high loads of salts in the stream, EC values for all the sites downstream were high, implying that the water was more saline from below Site B16 (Grootvlei Mine Shaft) to the outlet at B11 (Figure 52 & Appendix 3: Mean seasonal and inter-annual results in tabular format).

However, in 2011, when no underground mine-water discharge occurred, EC concentrations showed a distinctly different pattern between the rainy and dry periods for the in-stream sites when compared with B6 at the side of the wetland (Figure 53 & Appendix 3: Mean seasonal and inter-annual results in tabular format). At Site B5 upstream, the inflow already showed higher EC values (50 - 95 mS/m) (Figure 53 & Appendix 3: Mean seasonal and inter-annual results in tabular format). The same scenario happened at the downstream sites from B16 to B11, with EC values ranging from 50 to 110 mS/m. This implies that, even after the cessation of underground pumping activities by Grootvlei Mine, EC was still influenced by the presence of the salts (SO_4, Mg, Na and Cl) in the water. However, since EC was already high at the inlet point B5, the conclusion can be drawn that the higher EC values (at the downstream sites) had not been triggered by the persisting salts running off from Grootvlei Mine Shaft No. 3 alone. Other upstream or adjacent point and diffuse sources were also affecting EC levels throughout the wetland. This explains the change in EC levels noted from April 2011—EC levels tended to increase consistently for the sites in the wetlands (B5 to B11), and dropped or stabilised during the last three months of 2011. Nevertheless, higher EC values at the end of 2011 imply that the water leaving the wetland at B11 was still saline (Figure 53 & Appendix 3: Mean seasonal and inter-annual results in tabular format).

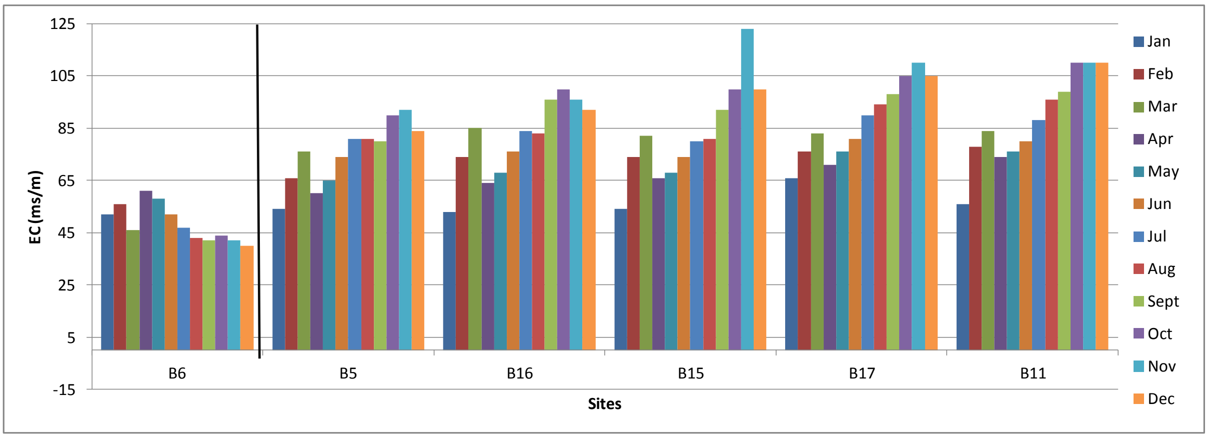

Figure 53: Seasonal average electrical conductivity measurement in 2011

It can be concluded that, because of the high concentrations of ions in the water, EC values tended to be high. During the winter months from April until October, values increased as surface and ground water flow reduced and salts become more concentrated. In summer, in contrast, the chemicals in water tended to dilute and become less concentrated because of the additional rainwater and runoff from adjacent areas (causing the EC levels to either drop or stabilise). Nevertheles, high EC values over the last months of 2011 from the inlet B5 to the outlet B11 poses a concern for the downstream water users, proving to effect that the water leaving the wetland at B11 was still saline.

Seasonal variations in pH

pH monthly average values for the period 2000 - 2010 are presented in Figure 54 and Appendix 3: Mean seasonal and inter-annual results in tabular format. For all the sites along the wetland (B5 to B11), pH tended to be neutral at 7.7 or slightly alkaline at 8.3. However, B6, at the side stream, showed the lowest pH, with values not exceeding 7.5—slightly more acidic water was found at that location. The same levels occurred at Site B5, upstream of the wetland, which tended to have most pH values below 8—in comparison with the other in-stream sites located in more alkaline waters (B16, B15, B17 and B11).

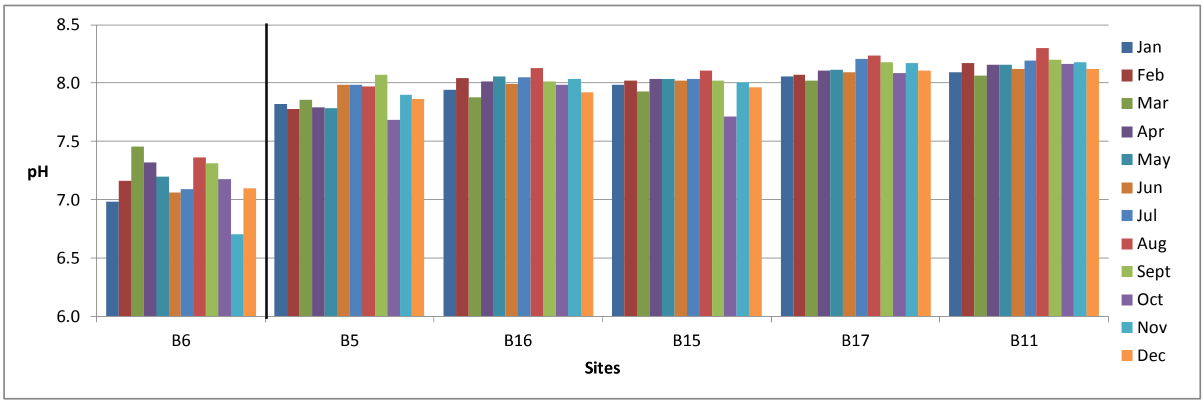

Figure 54: Seasonal average pH measurement from 2000 to 2010

During the summer wet months, pH at sites B5, B16, B15, B17 and B11 tended to be slightly lower, by ~0.2 pH points compared with the winter dry months. The pH seasonal variability was thus slight compared to the variations in the ionic concentrations. There was very minimal variability in the distribution of the pH values for the sites along the wetland, indicating that very little change occurred at sites B16 to B11—in contrast to sites B6 and B5 (Figure 55).

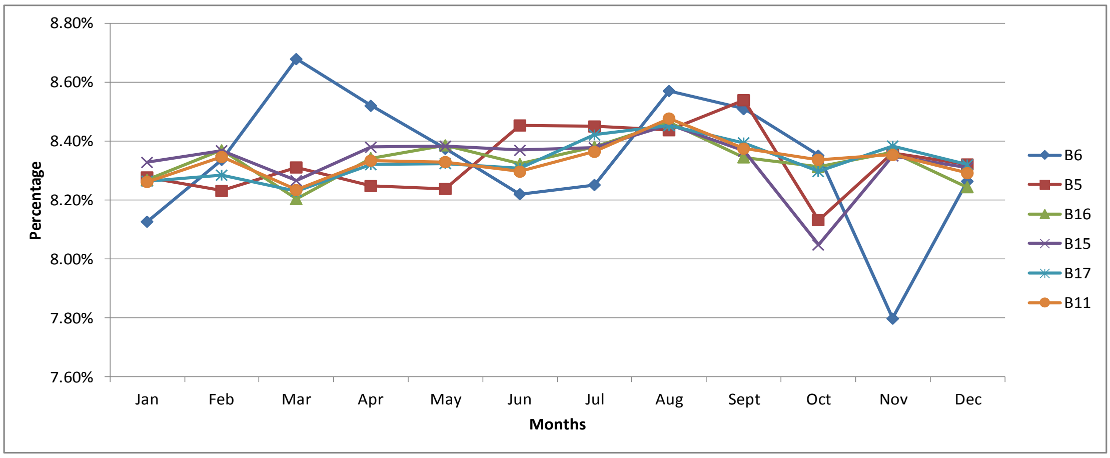

Figure 55: Normalised seasonal differences and similarities pH patterns at Sites B5, B16. B15, B17, B11 and B6 from 2000 to 2010

In 2011, with no additional underground mine-water being discharged in the Blesbokspruit wetland, pH values tended towards more acidic scenarios (below 7.5) as the water flowed from the inlet B5 to the sites close to Grootvlei Mine Shaft 3 (Sites B16 and B15). This also applied to B6 on the side stream. Very few exceptions or events of pH becoming higher than 7.5 (Figure 56 & Appendix 3: Mean seasonal and inter-annual results in tabular format) were noted. Downstream sites B17 and B11 portrayed higher pH values—above 7.5. Overall, there was no distinct seasonal pattern in pH readings, even when Grootvlei Mine was no longer operational. Nevertheless, compared to the previous years, pH decreased (mostly to below 7.5), raising concerns about the possibility of further acidification of the wetland caused since the stopping of underground water pumping.

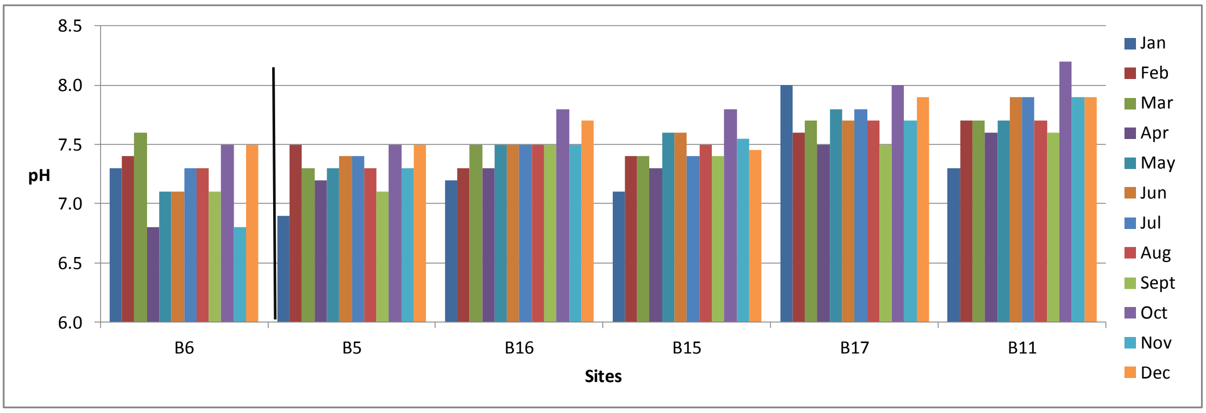

Figure 56: Seasonal average pH measurement in 2011

pH values represent a fundamental issue in terms of the conventional understanding of water discharge from the underground workings, widely referred to as *acid mine drainage* (Table 6 & Table 10). As the sampling point at B16 is located only a few metres downstream of the discharge point of the underground pumping, and the water has a high SO_4 load, the conventional understanding would be that this water is mildly acidic. Since the 1990s, however, the underground water has usually been treated, partially or fully, before being discharged into the wetland (Table 6)—the expectation would be for pH levels to become more neutral. The evidence from Figure 54 showed the pH values of the discharge water were neutral to slightly alkaline. The jump in EC at site B16 may have reflected an increase of H^+ ion concentrations, but this is not replicated in the pH values, most likely because the mine-water was already being treated. The different treatments modes included, *inter alia,* desalinisation plants, use of chemical treatments (including lime and desulphurisation—literature review—*Section 2.4*).

4.1.2 *Inter-annual variations*

The commissioning of water treatment plants for pumped underground water at Site B16 is marked on the inter-annual graphs (Figure 57 to Figure 62) by two green arrows. The dashed lines (blue and red) represent the in-stream surface water quality management guidelines/goals for the Blesbokspruit catchment (as established by the Blesbokspruit Forum).

Sulphate inter-annual variations

Sulphate annual average concentrations for the period 2000 - 2011 are presented in Figure 57 and Appendix 3: Mean seasonal and inter-annual results in tabular format. Site B5, at the inlet to the wetland, recorded constant low levels of SO_4 (86 - 142 mg/L), indicating the water entering the wetland was not SO_4 polluted (Figure 57). There was no specific pattern of change in SO_4 at Site B5 over the decade.

From 2003 to 2010, the levels of SO_4 at the discharge point of pumped underground water (B16) and for all downstream sites within the wetland (B15, B17 and B11) decreased progressively. A final sharp drop—from approximately 320 mg/L to 135 mg/L—was noted (in 2011) as the result of the cessation of pumping of underground water at the end of 2010. The decreasing SO_4 over the period 2003 to 2010 occurred because of interventions by Grootvlei Mine to mitigate its discharges, following the placing of the wetland onto the Montreux Record in the 1990s. However, from 2005 onwards, Grootvlei Mine faced major financial and technical constraints in maintaining the water treatment plants to operate at full capacity (Table 6) [Dini, 1998; Wood & Reddy, 1998; Lea *et al*., 2003; Thorius, 2004]; nevertheless, the SO_4 levels continued a decreasing trend (Figure 57).

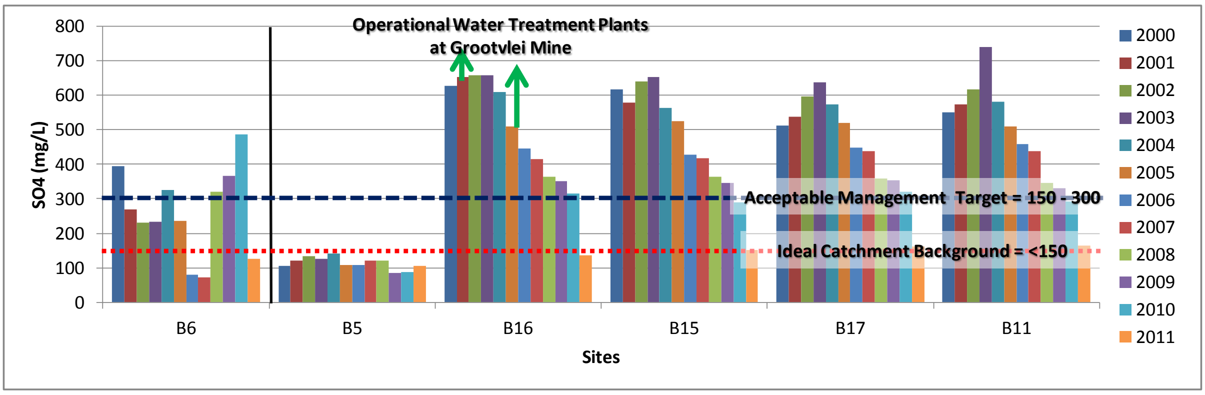

Figure 57: Sulphate inter-annual average concentrations from 2000 - 2011

Following the cessation of pumping of Grootvlei's underground waters in December 2010 (Table 6), a decrease in SO_4 concentrations for the sites located downstream of the wetland would be expected. This decrease, of the drop in SO_4 concentrations to ~150 mg/L in 2011, is shown in Figure 57.

Throughout the decade, until December 2010, SO_4 concentrations were well above the *'ideal catchment background'* and *'acceptable management target'* proposed for the management of water resources in the Blesbokspruit catchment. This was especially the case for the sites downstream of the Grootvlei Mine pumping point at shaft No.3—shown by higher and target-exceeding SO_4 values from B16 to B11 (Figure 57). By contrast, the inlet site B5 showed concentrations of SO_4 within both management target value ranges (less than 150 mg/L) (Figure 57). After 2010, SO_4 concentrations had decreased by a factor of two, thus implying that the underground mine-water from Grootvlei Mine was the main source of SO_4 loads in the wetland system. In 2011, surface water in terms of SO_4 concentrations tended towards the stricter *'ideal catchment background'* limits for all the in-stream sites. B6, on the side stream, showed some target-exceeding SO_4 concentrations over the decade, but in 2011, SO_4 values had dropped by a factor of three (Figure 57 & Appendix 3: Mean seasonal and inter-annual results in tabular format). However, no events in relation to yearly SO_4 trends at B6 had been documented in previous research.

Chloride inter-annual variations

Chloride annual average concentrations for the period 2000 - 2011 are presented in Figure 58 and Appendix 3: Mean seasonal and inter-annual results in tabular format. Cl decreased for all the sites over the 11-year period (Figure 58). However, from 2000 to 2002, Cl was increasing, thereafter it decreased monotonically until 2011. After 2010, there was only a slight drop in Cl concentrations in the wetland—not necessarily associated with the cessation of the pumping by Grootvlei Mine, since the *inlet site* (B5) showed only a slight decrease (Figure 58) in Cl. The slight change was not comparable to the factor two decrease in SO_4 concentrations. In contrast, B6 on the side stream showed the lowest Cl values with an erratic seesaw pattern (Figure 58 & Appendix 3: Mean seasonal and inter-annual results in tabular format).

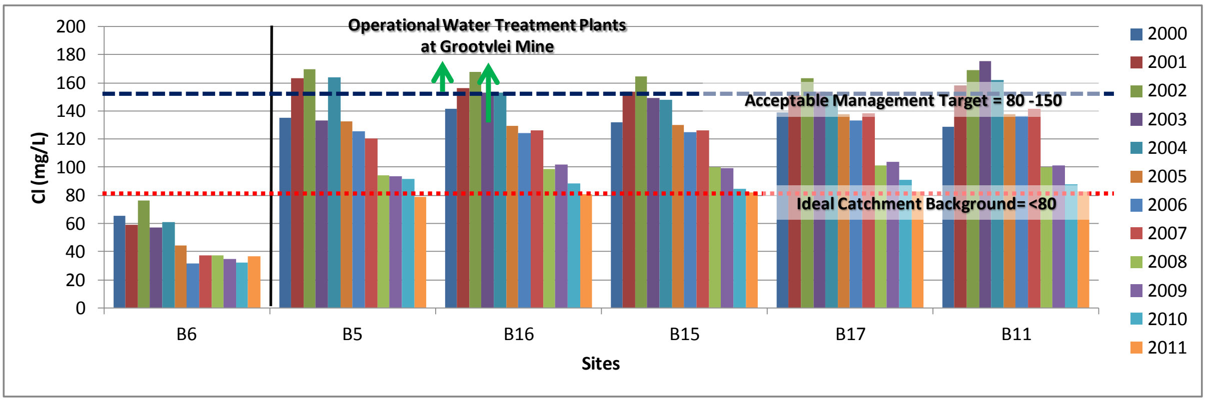

Figure 58: Chloride inter-annual average concentrations from 2000 – 2011

The inlet site (B5) showed the same inter-annual trend as the downstream sites, with only a few exceptions (from B16 through B11) (Figure 58 & Appendix 3: Mean seasonal and inter-annual results in tabular format). This may imply that Cl in the wetland did not originate in the water pumped by Grootvlei Mine that entered the system at Site B16. Rather, the chloride might have originated from the pulp and paper mill located a few kilometres upstream of the inlet B5. The pulp and paper industry processes (i.e. bleaching) result in effluents with high saline (Na and Cl) content, particularly in pulp processes used in South Africa, as reported by Steffen *et al.* (1990). The progressive reduction in Cl (and Na) from 2002 to 2011 may be because of improvements in the pulp and paper industry processes, resulting in a reduction of volumes of effluents and concentration of salts discharged into the Blesbokspruit stream. In 2006, the question of the high saline content in the Blesbokspruit stream was raised at a meeting held by the Eastern Basin Catchment Committee (Table 6). The response given was that removal of Na and Cl from industrial effluents was not a legal requirement, and that such a desalinisation treatment would be extremely costly. There appears to be no further recorded discussion of this issue in the subsequent minutes of the committee. Further investigation of the discharge water quality from the pulp and paper mill industry is outside the scope of the current thesis. However, this appears to be an important factor if an understanding of the inter-annual variation of the major ions is to be achieved. According to the paper company's 2012 annual report, the pulping plant was decommissioned in 2011 and, consequently, the water quality report of 2012 onwards should show a decline in Cl (and Na) concentrations.

Throughout the decade until December 2010, Cl concentrations were within the *'acceptable management target'*, except for a few exceeding events between 2001 and 2004. This was especially the case for all the in-stream sites, starting with the inlet B5 to the sites downstream of the Grootvlei Mine pumping point (Figure 58). At B6, Cl concentrations were well below the *'ideal catchment background'* limits for all years (less than 80 mg/L). After 2004, Cl concentrations became more manageable and decreased by a factor of two in 2011 for the in stream sites, thus implying that upstream runoffs carried less Cl pollutants (from the pulp and paper industry, sewage works), and minimal Cl flows were originating from underground mine-water at Grootvlei. In 2011, for all sites, the water began to adhere to the *'ideal catchment background'* limits in terms of Cl concentrations—a trend similar to that of the SO_4 concentrations (Figure 57, Figure 58 & Appendix 3: Mean seasonal and inter-annual results in tabular format). In contrast, over the 11-year period, Site B6 was well within the *'ideal catchment background'* limits, proving once more that this site was not affected by the same pollutants as the in-stream sites (Figure 57, Figure 58 & Appendix 3: Mean seasonal and inter-annual results in tabular format).

Sodium inter-annual variations

Sodium annual average concentrations for the period 2000 - 2011 are presented in Figure 59 and Appendix 3: Mean seasonal and inter-annual results in tabular format. Na concentrations (Figure 59) closely mirrored the concentrations of Cl (Figure 58) in magnitude, spatial pattern and time variation. For the period 2000 - 2011, the range of Na values at the inlet and within the wetland (65 - 180 mg/l) were similar and higher by a factor of two compared to the side stream (Site B6) (30 - 90mg/l) (Figure 59 & Appendix 3: Mean seasonal and inter-annual results in tabular format). This implies that, as Cl, Na-rich water originated from sources upstream of the Blesbokspruit wetland, (pulp and paper industry and sewage plants).

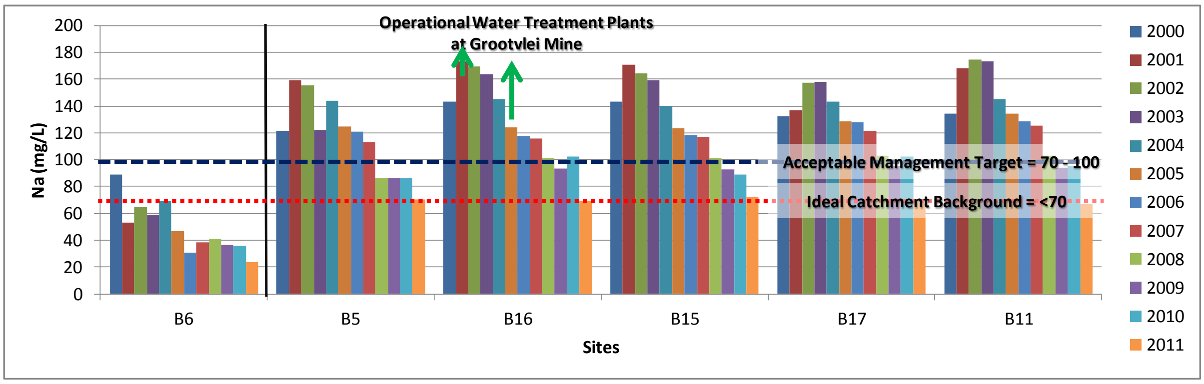

Figure 59: Sodium inter-annual average concentrations from 2000 - 2011

After the year 2010, there was a small drop in Na within the wetland (from B5 to B11) (Figure 59 & Appendix 3: Mean seasonal and inter-annual results in tabular format). Na concentrations in 2011 showed a uniform distribution, with little change from site to site along the wetland. Na, SO4 and Cl had similar pattern at sites downstream of the inlet point (B5). This may suggest that surface water entering the wetland may or may not influence Na, SO4 and Cl concentrations downstream when Grootvlei Mine was no longer a source of these pollutants. However, the fact that only SO_4 was lower at B5—and not Cl and Na—is an unresolved puzzle.

Throughout the decade until December 2010, Cl concentrations exceeded the *'acceptable management target'* limits, except for a few compliant events between 2008 and 2010. This was especially the case for all the in-stream sites, starting with the inlet B5 to the sites downstream Grootvlei Mine pumping point (Figure 59). In contrast, at B6, in a pattern similar to that of Cl, Na concentrations were well below the *'ideal catchment background'* limits for all years (less than 70 mg/L). After 2008, Na progressively decreased for most of the in-stream sites, with only a few non-compliant events (B16 and B17) in 2010, when Grootvlei Mine was making the final discharges of untreated mine-water before pumping was suspended (Figure 59) (Table 6). In 2011, for all the sites, the water was compliant with the *'ideal catchment background'* limits in terms of Na concentrations, a trend similar noted for both SO_4 and Cl concentrations (Figure 57, Figure 58, Figure 59 & Appendix 3: Mean seasonal and inter-annual results in tabular format).

Magnesium inter-annual variations

Magnesium annual average concentrations for the period 2000 - 2011 are presented in Figure 60 and Appendix 3: Mean seasonal and inter-annual results in tabular format. Mg showed inter-annual variations similar to SO4 (Figure 57). For the period 2000 - 2011, Mg concentrations ranged from 14 - 75 mg/L along the sites in the stream compared to the lower value range (14 - 43 mg/L) in water flowing in from the western side (site B6) (Figure 60). At the inlet B5, Mg values were sporadic, showing no distinct pattern over the years. Site B16 showed concentrations two to three times higher than the Mg levels recorded at the inlet B5 (Figure 60). The same pattern was observed for the remaining downstream sites. This implies that high Mg originated from underground mine-water discharged by Grootvlei Mine. After 2003, Mg decreased consistently, marking the effectiveness of water treatment measures by Grootvlei Mine before the mine-water was discharged.

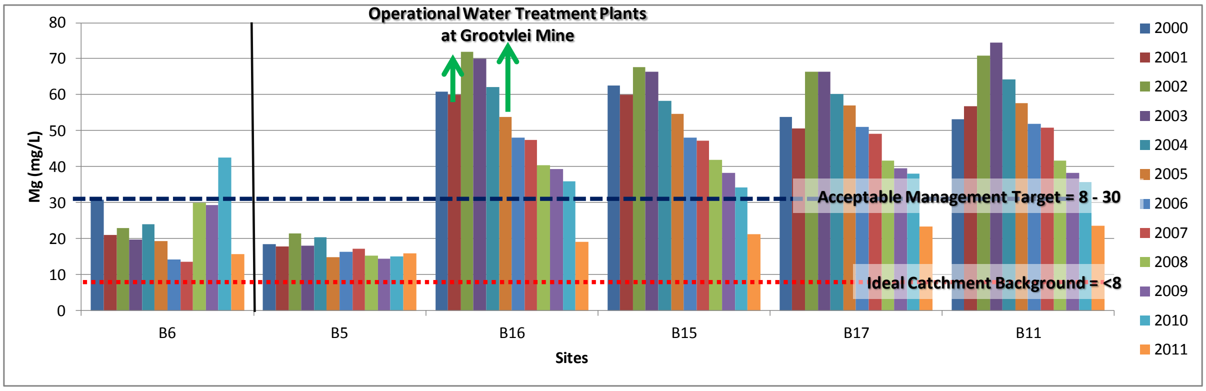

Figure 60: Magnesium inter-annual average concentrations from 2000 - 2011

After the cessation of pumping activities at Grootvlei Mine in 2010, Mg sharply decreased by a factor of 1.5 (Figure 60). This implies that Grootvlei Mine was indeed the main source of Mg found in the Blesbokspruit wetland—similar to the pattern of levels of SO_4 (Figure 57).

Throughout the decade until December 2010 (again similar to SO_4) Mg concentrations were well above the *'ideal catchment background'* and *'acceptable management target'* limits (Figure 57 & Figure 60). This applied especially to the sites downstream of the Grootvlei Mine pumping point at shaft No.3 as shown by the higher and target-exceeding SO_4 and Mg values from B16 to B11 (Figure 57 & Figure 60). In contrast, the inlet site B5 showed concentrations of Mg within the management target value ranges (less than 30 mg/L) (Figure 60). After 2010, Mg concentrations decreased by a factor of 1.5, thus implying that underground mine-water from Grootvlei Mine was the main source of Mg and SO_4 loads in the wetland system. In 2011, surface water Mg concentrations tended towards the *'acceptable management target'* limits for all the in-stream sites. B6, on the side stream, showed considerably higher Mg values close to or exceeding the *'acceptable management target'* limits until 2010. However, in 2011, Mg values considerably dropped by a factor of 2.5 at B6 (Figure 60 & Appendix 3: Mean seasonal and inter-annual results in tabular format). However, no explanation for high Mg concentrations in relation to B6 was available.

Electrical conductivity inter-annual variations

Electrical conductivity annual average values for the period 2000 - 2011 are presented in Figure 61 and Appendix 3: Mean seasonal and inter-annual results in tabular format. EC inter-annual variations were influenced by SO_4 and Mg concentrations (Figure 57 and Figure 60). This resulted in EC values from Site B16 to the outlet B11 being much higher (between two to three times) than EC values at the inlet Site B5 (Figure 61). From 2003, all the downstream sites showed a decline in EC values. By contrast, at Site B6, EC values did not show a declining trend (Figure 61). Although EC at the inlet

B5 was approximately 50 per cent of the values of B16 to B11, it followed a decreasing trend in parallel to the decrease in Na and Cl.

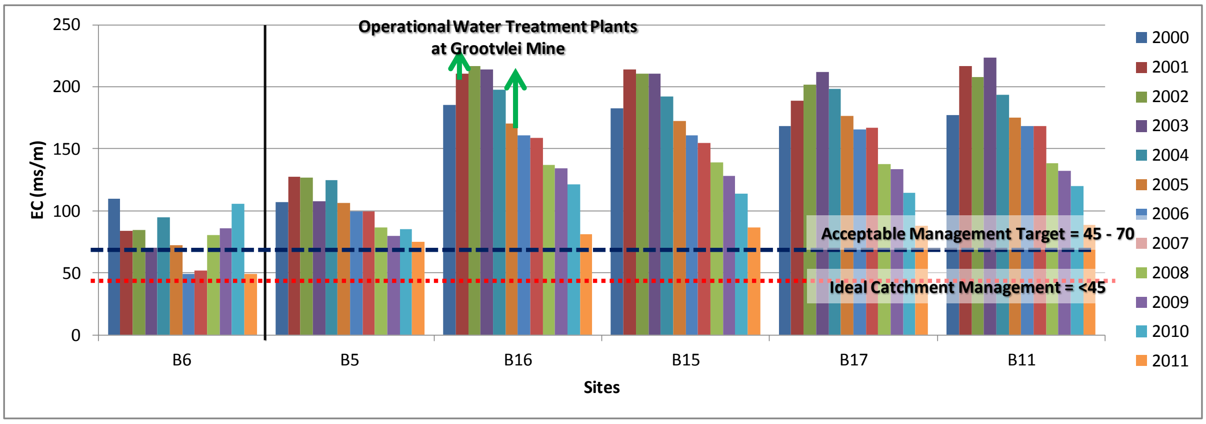

Figure 61: **Electrical conductivity inter-annual average variations from 2000 - 2011**

After the year 2010, with the cessation of the underground mine-water pumping, there was a sharp drop of EC for the sites downstream—closer to the concentrations measured at B5. This implied that there was a combination of reduction of EC from SO4 and Mg from Grootvlei Mine and from reduction of Na and Cl entering the wetland at site B5 (Figure 61).

Throughout the 11-year period, and as a result to the combined salts (SO_4 Mg, Cl and Na), EC values were well above the *'ideal catchment background'* and *'acceptable management target'* limits (Figure 61). This was especially the case for the in-stream sites B5 to B11, which showed higher—and target-exceeding—EC values (Figure 61 & Appendix 3: Mean seasonal and inter-annual results in tabular format). In contrast, non-compliant EC values, at B6 on the side stream, showed several episodes of compliance in particular years (Figure 61 & Appendix 3: Mean seasonal and inter-annual results in tabular format). However, explanations for high EC values at Site B6 were not recorded in previous studies. After 2010, EC values decreased by a factor of 1.5 from B16 to B11, thus implying that underground mine-water from Grootvlei Mine had been the main source of salts influencing EC values (i.e. Mg and SO_4). However, with EC values still high and exceeding the *'acceptable management target'* limits (Figure 61) at the inlet B5, it can be assumed that other salts, originating upstream of the wetland (Na and Cl), also contribute to high EC values within the Blesbokspruit wetland. In 2011, regardless of the overall drop of EC values, there was still non-compliance with the '*acceptable management target'* limits (Figure 61) for all the in-stream sites. B6 was the only site conforming to the required limits (Figure 61 & Appendix 3: Mean seasonal and inter-annual results in tabular format).

pH inter-annual variations

pH annual average values for the period 2000 - 2011 are presented in Figure 62 and Appendix 3: Mean seasonal and inter-annual results in tabular format. pH tended to be uniform over the years for all the sites, with the exception of the side stream (B6), which showed two anomalous years of lower (more acidic) pH, in 2000 and 2010 (Figure 62). pH values for the sites along the Blesbokspruit wetland were uniform, with values within the band pH = 7.7 to 8.2 (except for 2011, which showed a distinct drop of ~0.4 pH units—i.e. slight trend towards acidification, after cessation of pumping at the end of 2010). The water in the wetland was thus generally neutral to mildly alkaline—rather than the commonly held view that the wetland is inundated with acidic water (Table 6). In 2011, the spatial trend of pH tended to increase slightly from the inlet B5 (pH = 7.3) to the outlet B11 (pH = 7.8) (Figure 62), i.e. the water became slightly more alkaline as it flowed through the wetland.

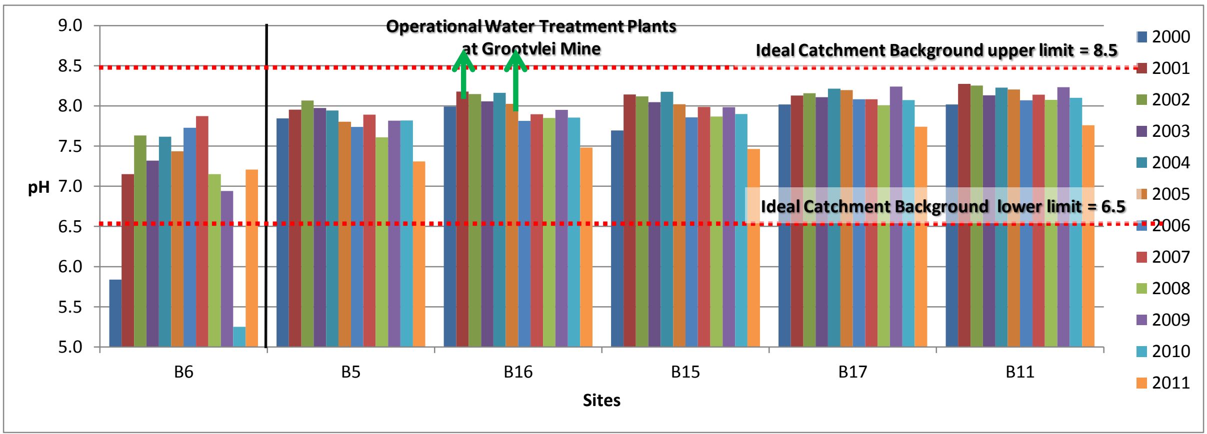

Figure 62: pH inter-annual average variations from 2000 - 2011

As the decrease in pH from 2010 to 2011 occurred at the inlet and at all sites downstream, it is hard to attribute the changes to the cessation of pumping of underground mine-water alone. The pulping plant at the paper mill was reported as decommissioned in 2011, and this might have been a contributory factor (taking into account the small step decreases in Na and Cl concentrations at the inlet (Site B5)).

Throughout the 11-year period, and as a result of the decreased in the salt loads (SO_4 Mg, Cl and Na) and associated EC values, pH values were well within the *'ideal catchment background'* limits (6.5 - 8.5) (Figure 62). This applied especially to the in-stream sites B5 to B11, which showed neutral to alkaline pH values (Figure 62 & Appendix 3: Mean seasonal and inter-annual results in tabular format). In contrast, alongside predominantly compliant pH values, B6 on the side stream showed several episodes of non-compliance in particular years (Figure 61 & Appendix 3: Mean seasonal and inter-annual results in tabular format). However, reasons for acidic pH values at Site B6 were not published. In 2011, overall pH values for all the in-stream sites and B6 tended towards lower values, but were still within the *'ideal catchment background'* limits (6.5 - 8.5) (Figure 62 & Appendix 3: Mean seasonal and inter-annual results in tabular format).

4.2 Water quality limits for irrigation, livestock watering and aquatic environment

The existing Department of Water Affairs (DWA) target limit values for agricultural use of water and aquatic ecosystem health are shown in tabular format for the respective inter-annual results. If no DWA limits were defined, the Blesbokspruit Catchment *'ideal catchment background'* limits were used as the reference—especially for aquatic ecosystems and *'acceptable management target'* for both irrigation and livestock watering activities. Green coding represents compliance with DWA/Blesbokspruit Catchment standards; and red coding indicates non-compliance (Table 13 to Table 29).

4.2.1 *Aquatic ecosystems*

pH values in the Blesbokspruit main stream were within DWA and Blesbokspruit catchment limits (Table 13) for ecosystem health and aquatic fauna for all years at all sites, with values between 6.5 and 8.5. For the side stream entering from the west (site B6); there were two deviant years (2000 and 2010) for which the pH annual average values dropped to 5.8 and 5.3 respectively. Exposure to such acidic levels might result in damage or death of species less tolerant to acidic water (Table 10). Water entering the wetland from the west has been exposed to urban and industrial runoff, but is not downstream either of the paper mill or of the underground water discharge point. Therefore the acidic episodes cannot be attributed to these two latter causes.

Table 13: Inter-annual pH results against Blesbokspruit *'ideal catchment background'* (pH = 6.5 - 8.5)

Inter-annual Average pH												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	5.8	7.2	7.6	7.3	7.6	7.4	7.7	7.9	7.2	6.9	5.3	7.2
B5	7.8	8.0	8.1	8.0	7.9	7.8	7.7	7.9	7.6	7.8	7.8	7.3
B16	8.0	8.2	8.1	8.1	8.2	8.0	7.8	7.9	7.9	8.0	7.9	7.5
B15	7.7	8.1	8.1	8.0	8.2	8.0	7.9	8.0	7.9	8.0	7.9	7.5
B17	8.0	8.1	8.2	8.1	8.2	8.2	8.1	8.1	8.0	8.2	8.1	7.7
B11	8.0	8.3	8.3	8.1	8.2	8.2	8.1	8.1	8.1	8.2	8.1	7.8

Annual average concentrations for salts (Table 14 to Table 17 respectively for SO_4, Na, Cl, and Mg) and EC (Table 18) showed that water in the Blesbokspruit wetland was not fit for healthy aquatic biota for the period 2000 - 2010 since the ionic concentrations and resulting EC values were well above the Blesbokspruit Catchment *'ideal catchment background'* or DWA 'a*quatic ecosystems'* target values. The only ion to improve to acceptable levels was SO_4, which was within limit at only specific locations (B6, B5 and B16) in 2011—i.e. after the cessation of underground pumping. This implies that aquatic biota were under pressure, and that saline waters in the Blesbokspruit wetland constituted a hazard to aquatic biodiversity.

Table 14: Inter-annual sulphate results against the Blesbokspruit *'ideal catchment background'* (SO_4 = <150 mg/L)

Inter-annual Average Sulphate (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	393	268	231	232	326	237	81	72	321	366	487	121
B5	104	122	134	125	142	108	109	122	121	86	87	106
B16	627	652	659	657	609	508	446	416	363	352	315	137
B15	616	577	640	652	564	525	427	417	363	345	289	153
B17	512	537	598	638	574	520	447	439	360	354	321	163
B11	551	573	617	739	582	510	457	439	345	330	291	163

Table 15: Inter-annual sodium results against the Blesbokspruit *'ideal catchment background'* (Na = <70 mg/L)

Inter-annual Average Sodium (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	89	53	65	59	69	47	31	39	41	36	36	24
B5	121	159	155	122	144	125	121	113	86	86	87	71
B16	143	173	170	164	145	124	118	116	101	94	102	69
B15	144	171	165	159	140	123	118	117	101	93	89	73
B17	132	137	157	158	144	129	128	122	103	95	102	68
B11	134	168	175	173	145	134	129	126	103	94	95	67

Table 16: Inter-annual chloride results against the Blesbokspruit *'ideal catchment background'* (Cl = <80 mg/L)

Inter-annual Average Chloride (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	65	59	76	57	61	44	32	37	38	34	32	35
B5	135	163	169	133	164	132	126	120	94	94	92	79
B16	142	156	168	153	153	129	124	126	99	102	88	81
B15	132	153	164	149	148	130	125	126	100	99	84	82
B17	139	151	164	154	151	137	133	138	101	104	91	83
B11	129	158	169	175	162	138	136	142	100	101	88	83

Table 17: Inter-annual magnesium results against the Blesbokspruit 'ideal catchment background' (Mg = <8 mg/L)

Inter-annual Average Magnesium (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	31	21	23	20	24	19	14	14	30	29	43	16
B5	19	18	21	18	20	15	16	17	15	14	15	16
B16	61	60	72	70	62	54	48	48	41	39	36	19
B15	63	60	68	66	58	55	48	47	42	38	34	21
B17	54	51	66	66	60	57	51	49	42	40	38	23
B11	53	57	71	75	64	58	52	51	42	38	36	24

Table 18: Inter-annual electrical conductivity results against the Blesbokspruit 'ideal catchment background' (EC = <45 mS/m)

Inter-annual Average Electrical Conductivity (mS/m)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	110	84	84	70	95	72	49	52	81	86	106	49
B5	107	127	127	108	125	106	100	100	86	80	85	75
B16	186	211	216	214	197	170	161	159	137	135	122	81
B15	183	214	210	210	192	172	161	155	139	129	114	87
B17	168	189	202	212	198	177	166	167	138	133	115	88
B11	177	217	208	223	193	175	168	169	139	133	120	88

The effects of reduced biodiversity within the wetland, possibly resulting from the high saline content, were mentioned in Table 10. In the long-term, a decrease in salts would enhance better aquatic conditions for species depending on the Blesbokspruit wetland because of lesser negative effects (Table 10), and would contribute to desirable water conductivity. The closure of the pulping plant of the paper industry in 2011 might become a factor and lead to an improvement in the future—this should be followed up in subsequent studies.

4.2.2 *Irrigated crops*

pH values in the Blesbokspruit main stream were within DWA and Blesbokspruit catchment limits (Table 13) for irrigated crops for all years at all sites, with values between 6.5 and 8.4. For the side stream entering from the west (site B6), there were two deviant years (2000 and 2010) for which the pH annual average values dropped to 5.8 and 5.3 respectively. Exposure to such acidic levels might result in damage to crops less tolerant to acidic water (Table 10).

Table 19: Inter-annual pH results against DWA Target values for irrigated crops (pH = 6.5 - 8.4)

Inter-annual Average pH												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	5.8	7.2	7.6	7.3	7.6	7.4	7.7	7.9	7.2	6.9	5.3	7.2
B5	7.8	8.0	8.1	8.0	7.9	7.8	7.7	7.9	7.6	7.8	7.8	7.3
B16	8.0	8.2	8.1	8.1	8.2	8.0	7.8	7.9	7.9	8.0	7.9	7.5
B15	7.7	8.1	8.1	8.0	8.2	8.0	7.9	8.0	7.9	8.0	7.9	7.5
B17	8.0	8.1	8.2	8.1	8.2	8.2	8.1	8.1	8.0	8.2	8.1	7.7
B11	8.0	8.3	8.3	8.1	8.2	8.2	8.1	8.1	8.1	8.2	8.1	7.8

pH was conform to the target ranges for irrigated crops, regardless of the presence of saline waters.

Salt load results showed that SO_4 concentrations, despite a decrease, only reached *'acceptable management target'* in 2010 (Table 20) after Grootvlei Mine had ceased to discharge underground mine-water into the Blesbokspruit wetland.

Table 20: Inter-annual sulphate results against the Blesbokspruit 'acceptable management target' (SO_4 = 150 - 300 mg/L)

Inter-annual Average Sulphate (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	393	268	231	232	326	237	81	72	321	366	487	121
B5	104	122	134	125	142	108	109	122	121	86	87	106
B16	627	652	659	657	609	508	446	416	363	352	315	137
B15	616	577	640	652	564	525	427	417	363	345	289	153
B17	512	537	598	638	574	520	447	439	360	354	321	163
B11	551	573	617	739	582	510	457	439	345	330	291	163

Chloride concentrations became adequate for irrigated crops after 2007 for the sites along the wetland, with only few exceeding episodes between 2008 and 2009 (at sites B16, B17 and B11). Overall, the water was Cl compliant in 2010 and 2011 for all locations (Table 21). Nevertheless, water on the side stream has been fit for irrigation since 2010, with Cl concentrations always within the acceptable requirements (Table 21).

Table 21: Inter-annual chloride results against DWA irrigated crops target range (Cl = 0 - 100 mg/L)

Inter-annual Average Chloride (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	65	59	76	57	61	44	32	37	38	34	32	35
B5	135	163	169	133	164	132	126	120	94	94	92	79
B16	142	156	168	153	153	129	124	126	99	102	88	81
B15	132	153	164	149	148	130	125	126	100	99	84	82
B17	139	151	164	154	151	137	133	138	101	104	91	83
B11	129	158	169	175	162	138	136	142	100	101	88	83

Sodium concentrations started well above the limits; only in 2011 did Na decrease to within the limits for water quality requirements for irrigation at the sites within the wetland. However, at the side stream, B6 had Na values compliant to the standard limits after the year 2000 (Table 22).

Table 22: Inter-annual sodium results against DWA irrigated crops target range (Na = 0 - 70 mg/L)

Inter-annual Average Sodium (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	89	53	65	59	69	47	31	39	41	36	36	24
B5	121	159	155	122	144	125	121	113	86	86	87	71
B16	143	173	170	164	145	124	118	116	101	94	102	69
B15	144	171	165	159	140	123	118	117	101	93	89	73
B17	132	137	157	158	144	129	128	122	103	95	102	68
B11	134	168	175	173	145	134	129	126	103	94	95	67

Like Sulphate, Mg concentrations were well above the limits at locations downstream of Grootvlei Mine and only dropped to reach acceptable ranges after 2010, when the cessation of pumping of underground mine-water took place. However, except for only a few non-compliance episodes, water at B6 became as fit for irrigation as that at B5 where magnesium was concerned (Table 23).

Table 23: Inter-annual magnesium results against the Blesbokspruit *'acceptable management target'* (Mg = 8 - 30 mg/L)

Inter-annual Average Magnesium (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	31	21	23	20	24	19	14	14	30	29	43	16
B5	19	18	21	18	20	15	16	17	15	14	15	16
B16	61	60	72	70	62	54	48	48	41	39	36	19
B15	63	60	68	66	58	55	48	47	42	38	34	21
B17	54	51	66	66	60	57	51	49	42	40	38	23
B11	53	57	71	75	64	58	52	51	42	38	36	24

Electrical conductivity values, representing the combined effects of all the major ions, were well above standard limits (Table 24); this was despite the reduction in the concentrations of the individual ions/salts. Electrical conductivity remained above the target values, even in 2011, when no pumping of underground mine-water took place. This implies that water conductivity was not adequate for irrigation activities because of the presence of different salts in higher concentrations.

Table 24: Inter-annual electrical conductivity results against DWA irrigated crops target range (EC = 0 - 40 mS/m)

Inter-annual Average Electrical Conductivity (mS/m)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	110	84	84	70	95	72	49	52	81	86	106	49
B5	107	127	127	108	125	106	100	100	86	80	85	75
B16	186	211	216	214	197	170	161	159	137	135	122	81
B15	183	214	210	210	192	172	161	155	139	129	114	87
B17	168	189	202	212	198	177	166	167	138	133	115	88
B11	177	217	208	223	193	175	168	169	139	133	120	88

4.2.3 *Livestock watering*

pH guideline values for the Blesbokspruit catchment were used (‘*ideal catchment background*’). Compared to this target value range (6.5 - 8.5) (Table 13), pH was not a real concern for the water consumed by the surrounding livestock. However, with pH values lower than 6.5 (as in the case of B6), acidic water posed a threat to the dependent livestock (Table 10).

Sulphate values were within DWA limits for livestock at all locations. Thus, the water requirements in terms of SO_4 were met from Site B5 to B11 and B6 at the side stream (Table 25).

Table 25: Inter-annual sulphate results against DWA livestock watering target range (SO_4 = 0 - 1000 mg/L)

Inter-annual Average Sulphate (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	393	268	231	232	326	237	81	72	321	366	487	121
B5	104	122	134	125	142	108	109	122	121	86	87	106
B16	627	652	659	657	609	508	446	416	363	352	315	137
B15	616	577	640	652	564	525	427	417	363	345	289	153
B17	512	537	598	638	574	520	447	439	360	354	321	163
B11	551	573	617	739	582	510	457	439	345	330	291	163

Sodium values showed that the water was also fit for consumption by livestock, and did not pose a threat at any of the different locations (Table 26).

Table 26: Inter-annual sodium results against DWA livestock watering target range (Na = 0 - 2000 mg/L)

Inter-annual Average Sodium (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	89	53	65	59	69	47	31	39	41	36	36	24
B5	121	159	155	122	144	125	121	113	86	86	87	71
B16	143	173	170	164	145	124	118	116	101	94	102	69
B15	144	171	165	159	140	123	118	117	101	93	89	73
B17	132	137	157	158	144	129	128	122	103	95	102	68
B11	134	168	175	173	145	134	129	126	103	94	95	67

Chloride concentrations, both within the Blesbokspruit wetland and on the side stream, were adequate for the surrounding livestock, which includes non-ruminants and ruminants (Table 27).

Table 27: Inter-annual chloride results against DWA livestock watering target ranges (Cl = 0 - 1500 mg/L for non-ruminants & Cl = 0 - 3000 mg/L for ruminants)

Inter-annual Average Chloride (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	65	59	76	57	61	44	32	37	38	34	32	35
B5	135	163	169	133	164	132	126	120	94	94	92	79
B16	142	156	168	153	153	129	124	126	99	102	88	81
B15	132	153	164	149	148	130	125	126	100	99	84	82
B17	139	151	164	154	151	137	133	138	101	104	91	83
B11	129	158	169	175	162	138	136	142	100	101	88	83

Magnesium results showed that the water was fit for consumption, with values well within the required limits (Table 28).

Table 28: Inter-annual magnesium results against DWA irrigated crops target range (Mg = 0 - 500 mg/L)

Inter-annual Average Magnesium (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	31	21	23	20	24	19	14	14	30	29	43	16
B5	19	18	21	18	20	15	16	17	15	14	15	16
B16	61	60	72	70	62	54	48	48	41	39	36	19
B15	63	60	68	66	58	55	48	47	42	38	34	21
B17	54	51	66	66	60	57	51	49	42	40	38	23
B11	53	57	71	75	64	58	52	51	42	38	36	24

Since all the analysed salts were within the required standards for all sites, it was expected EC would follow the same trends (Table 29). However, for B6, several values were below the required limits for reasons that have not been defined at this stage.

Table 29: Inter-annual electrical conductivity results against DWA irrigated crops target range (EC = 70 - 300 mS/m)

Inter-annual Average Electrical Conductivity (mS/m)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	110	84	84	70	95	72	49	52	81	86	106	49
B5	107	127	127	108	125	106	100	100	86	80	85	75
B16	186	211	216	214	197	170	161	159	137	135	122	81
B15	183	214	210	210	192	172	161	155	139	129	114	87
B17	168	189	202	212	198	177	166	167	138	133	115	88
B11	177	217	208	223	193	175	168	169	139	133	120	88

Salt loads, associated EC values and pH showed that the surface water in the Blesbokspruit wetland was of adequate quality for the dependent livestock. This was especially true for those limits found to be well below their respective DWA or Blesbkspruit catchment limits. Regardless of the progressive decline in the concentrations of SO4, Mg, and EC, the water only reached acceptable limits for aquatic biota and irrigated crops after 2010. Nevertheless, there is still concern about the levels of other salts (i.e. Na and Cl) which were measured during certain years at levels beyond the targeted limits for either aquatic biota or irrigation. A slight drop in the concentrations of Na and Cl after 2010, proved that these pollutants did not originate from the underground mine-water discharges (as previously investigated *Section 2.4*) but emanated from other upstream industrial effluents (e.g. Sappi Enstra and ERWAT). pH findings proved that there was no risk to the selected water users and the receiving environment; nevertheless, alkaline pH levels would have to be maintained to remain within the targeted limits required for aquatic biota and agricultural activities.

4.3 Evaluation of the water quality management interventions at the Blesbokspruit wetland

There has been an overall improvement of surface water quality in the Blesbokspruit wetland, which implies that historical (pre-2000) and current water management interventions have been successful. When compared with previous investigations (which pointed out the acidification and salinisation of the Blesbokspruit wetland) (Table 6), the treatment of underground mine-water by Grootvlei Mine had successfully contributed to a decrease in SO_4, Mg and associated EC levels in the mine-water that was discharged into this wetland. Grootvlei Mine had also successfully limited the volume of ingress water to the pumping system to reduce the amount of underground mine-waters being pumped and discharged into the Blesbokspruit wetland (Table 6). Nevertheless, because of the mixing of effluents high in salts, the need to reconcile and reassess the quality of the water remained. Water discharged by other sources (e.g. paper industry plant, sewage treatment plant, mine seepage, etc.) still needs to be quality assessed for the ecological and agricultural activities (irrigation and livestock watering depending on the water in the Blesbokspruit wetland). This should include reviewing the concentrations of the salts mainly associated with the respective processes or activities prior to discharge into the stream; hence, pollutants from the Blesbokspruit wetland end up in the Vaal River system, considered the life-giver for the socioeconomic activities in Gauteng and beyond.

The observed inter-annual improvement of the surface water quality in the Blesbokspruit wetland could also be attributed to the cessation of Grootvlei's underground pumping activities in 2010, which refutes previous views on this issue (Table 6).

4.4 Reinstatement of the Blesbokspruit wetland as a Ramsar Site

Since the pumping of underground water stopped in 2010 (when Grootvlei mine met financial troubles—the mine was still under liquidation in 2011-2012), the pollution load from this source has reduced. Drastic drops in SO_4, Mg and associated EC levels after 2010 confirm this. Nevertheless, Na and Cl concentrations proven to originate from other effluents (i.e. pulp plant and sewage plant), have, in part, negated conclusions drawn by previous investigations which used to link all Na and Cl to just the underground mine-water pumping operations. After 2010, with the closure of the pulp plant at Sappi Enstra, Na and Cl showed a further slight drop in levels across the samples taken from the water entering the Blesbokspruit wetland to the exit point at B11.

On the grounds of the progressive inter-annual decline in all the salts and combined EC, as well as with pH values being above neutral, it is now possible to consider making application to the Ramsar Committee requesting the delisting of Blesbokspruit wetland from the Montreux Record.

However, possible future threats of surface decanting, from underground works because of rising water levels in the absence of underground pumping operations or from derelict mines (Table 6), could still pose an ecological hazard with socioeconomic repercussions (Table 6). The need for a viable and holistic management plan still exists—a plan that will embrace underground mine-water pumping requirements with environmental conservation.

The conclusions and recommendations are provided in the next chapter.

5. CONCLUSION AND RECOMMENDATIONS

This study provides evidence that surface water quality in the Blesbokspruit wetland has been improving since the Grootvlei Mine 'incident' that contributed to the listing of this wetland, because of the considerable degradation of the water system on the Montreux Record in 1996. Surface water deterioration from the pumping of underground water high in salts was enough to make this Ramsar site lose its international status and ecological integrity.

The surface water quality monitoring results for the period 2000 to 2011 (for parameters pH, EC, SO_4, Na, Cl and Mg) showed that there were seasonal, spatial and long-term patterns in the behaviour of these physicochemical parameters. From the inlet site B5 to the site downstream of Grootvlei Mine (B16) and the downstream sites B15, B17 and B11, the salts loads were found to follow a similar seasonal pattern, with higher concentrations occurring during the dry season (winter months), and lower concentrations in the rainy season (summer). Lower salt loads were because of the dilution effect of additional water entering the wetland from summer rains and surface flows. These study results show how the pollution load varied within the wetland from upstream to downstream: site B5 (selected as the reference site located at the inflow point to the wetland) showed overall lower salt concentrations and less variability of physical parameters (EC and pH). B6 was an exceptional case, located on a side stream flowing into the wetland from an industrial and residential area. B6 showed an entirely different pattern of behaviour by the selected physicochemical elements from the sites along the main stream.

The long-term inter-annual trends over the eleven years covered in this study support the hypothesis that the surface water quality in the Blesbokspruit wetland has been improving, primarily because a range of water quality management interventions have taken place subsequent to the Grootvlei Mine 'incident' in 1996. From 2001, with the installation of more effective water treatment plants by Grootvlei Mine, the salt load downstream of the mine discharge point had been decreasing until 2010—when that mine ceased pumping operations. From 2000 to 2010, a progressive decline in the salt levels correlated with lesser conductivity values as well as a neutral to alkaline pH levels (7.6 - 8.3) throughout the sites along the Blesbokspruit wetland. The improvement in the surface water quality of the Blesbokspruit wetland is ultimately linked to the closure of the Grootvlei mine (lastly owned by Aurora Empowerment Systems) in December 2010. It can be concluded that this mine was the main culprit through the discharge of its high-in-salts underground mine-waters. However, the concentrations of Na and Cl showed a different story, with similar higher concentrations of these two elements recorded in the water entering the Blesbokspruit wetland at site B5 and exiting at site B11. This means that the majority of the Na and Cl loading did not originate from the underground mine-water pumping operations at Grootvlei Mine, but came from other sources (e.g.

paper and pulp industry, sewage plant) using Cl and Na in their processes prior to the discharge of waste water into the stream.

The year 2011—during which there was no pumping of mine-water from Grootvlei Mine and after Sappi Enstra had decommissioned its pulp plant—was marked by a consistent decrease in all the salts; EC dropped in parallel with the reduced salt load. pH values for the sites along the Blesbokspruit wetland were uniform over the ten years 2000 to 2010, with values within the band pH = 7.6 to 8.2. However, in 2011, a distinct drop of ~0.5 pH units occurred—i.e. indicating a slight trend towards acidification, in coincidence with the cessation of underground pumping and the closure of the pulp plant. This consistent improvement in the Blesbokspruit water quality challenges previous views that surface water quality would deteriorate after discontinuation of underground pumping. However, the decanting of underground water may occur in future since it is reported that the water table is rising rapidly in this water compartment. The signature of high Na and Cl in the inlet water also challenges the view that high salinity of Blesbokspruit water was primarily caused by the mine discharges—inflow of saline surface water from upstream industries has also been shown to be a major contributor to the pollution load.

When evaluated against DWA target ranges, combined with water quality guidelines for the Blesbokspruit catchment for pH, EC, SO_4, Cl, Na, and Mg, it appeared that surface water quality in the Blesbokspruit wetland was not completely fit for use for irrigation and for the aquatic biota in the wetland. Only water quality requirements for livestock watering were met during that period. With the continuous decrease of the salt load over the years and the discontinuation of discharge by Grootvlei Mine and Sappi Enstra in 2011, surface water quality in the Blesbokspruit wetland can be expected to gradually reach desirable conditions for—mainly—the aquatic biota, including the return of abundant waterfowl (through which the wetland first gained its international accreditation). If desirable water conditions are to continue in the Blesbokspruit wetland, it is necessary to control the different sources of water pollutants and eliminate conflict with agricultural and aquatic ecosystem water requirements (i.e. in terms of salts and inherent EC). Effective management of the Blesbokspruit wetland and better water treatment technologies/desalination plants (by industries or users of the Blesbokspruit water) remain essential to the good health of this important water source.

The improvement of surface water quality in the Blesbokspruit wetland may constitute a milestone in water resource management and environmental conservation as a whole, as defended by the various pieces of legislation in South Africa. However, future decantation and associated flooding threats in the Blesbokspruit catchment may arise because the Grootvlei Mine underground mine-water pumping operations into the Blesbokspruit wetland had completely stopped (Table 6). The loss of water input from pumping activities may also have an impact on the downstream water users. In particular, the irrigation of cultivable lands and livestock watering is dependent on the availability of sufficient supply of water at volumes associated with the permanent state of flooding inherent in the

Blesbokspruit wetland (South African Wetlands Conservation Programme, 1999; Thorius, 2004). Less water in the Blesbokspruit wetland could lead to water shortages through a return of the normal wetland conditions that existed prior to the addition of mine-waters—i.e. as a shallow, non-perennial stream (South African Wetlands Conservation Programme, 1999; Thorius, 2004).

Plans have been made, since the 2000s, for the removal of the Blesbokspruit from the Montreux Record. However, until 2012, the Blesbokspruit was still listed as a wetland under threat because of saline contamination and acidification of its surface water from results recorded in past investigations (Table 6). The current improvement in the quality of the surface water in the Blesbokspruit wetland could thus become a motivation for the delisting of the Blesbokspruit wetland from the Montreux Record and its reinstatement as a Ramsar site. This would only be feasible if based on scientific evidence that the desirable surface water quality in the Blesbokspruit wetland would be able to enhance similar or approximate ecological conditions of 1986 (when the Blesbokspruit gained its international status). Based on the positive findings of this study, the Montreux Questionnaire could be completed with confidence since the high levels of salts from Grootvlei underground mine ceased to be a problem after December 2010. Since 2010, the saline conditions of the Blesbokspruit wetland improved considerably with a consistent decline in the salt loads, EC and the maintenance of alkaline conditions. If the removal of the Blesbokspruit wetland from the Montreux Record turns out to be successful, South Africa, as a pioneer to one of the oldest environmental treaties, could also become one of the few countries to successfully restore and have one of their threatened Ramsar sites reinstated.

The Blesbokspruit Forum, as part of the greater Blesbokspruit Catchment Management, should continue with the monitoring of the water quality in the Blesbokspruit wetland. A start, if possible, should be made to measure the water flow to assist sound management decisions. The Blesbokspruit and its associated wetland are freshwater resources that ultimately flow into the Vaal River system (on which the whole of Gauteng depends to nurture its socioeconomic activities). Saving the Blesbokspruit wetland from continuous saline pollution could benefit many downstream users. Given the very limited availability of freshwater resources in South Africa the sustainable use of all water resources is of utmost importance. To avoid the Blesbokspruit wetland being turned into a wasteland or destroyed (as it has been the case for other wetlands in Gauteng) the value of the Blesbokspruit wetland should be promoted to a wider audience, especially to businesses whose activities are likely to negatively impact on the surface water quality of this wetland. This would assist in the conservation and wise use of the Blesbokspruit as encouraged by the Ramsar Convention.

Finally, if South Africa cannot succeed in restoring the Blesbokspruit wetland because of the much-needed socioeconomic developments that negatively influence this site, it may still be possible for South Africa to approach the Ramsar Bureau by applying the *"…urgent national interest…"* route to have the Blesbokspruit deleted from the Ramsar List (Ramsar, 1992; Smart, 1997). Nevertheless, this would be a first in the Ramsar Convention history since:

> *"No Ramsar sites have ever been "de-listed"... on only three occasions, Parties have invoked the "urgent national interest" clause to restrict the boundaries of Ramsar site, in Belgium in the 1980s, in Australia in 1997 (although in this case the restriction of boundaries did not in fact occur), and in Germany in 2000"* [Cliquet, 2005].

South Africa will have thus to compensate for the loss of the Blesbokspruit wetland resources [Ramsar, 1992; Smart, 1997]:

> *"When considering such compensation, a Contracting Party may take into account, inter alia, the following:*
>
> - *The maintenance of the overall value of the Contracting Party's wetland area included in the Ramsar List at the national and global level;*
> - *the availability of compensatory replacement;*
> - *the relevance of the compensatory measure to the ecological character, habitat, or value of the affected Ramsar site(s);*
> - *scientific and other uncertainties;*
> - *the timing of the compensatory measure relative to the proposed action; and*
> - *the adverse effect the compensatory measure itself may cause."*

Entirely removing the Blesbokspruit wetland from the Ramsar List is not desirable for a country (such as South Africa) that wishes to embrace sustainable development [BirdLife South Africa, 2013; Coughlan, 2013]. As a footnote, it can be reported that the re-instatement of the Blesbokspruit as a Ramsar wetland is still debatable. The issue has been addressed within the strategic planning of the Department of Environmental Affairs (as well as on various agendas for workshops held by interested parties such as the Blesbokspruit Forum and the Gauteng Wetland Forum) [Gauteng Wetland Forum, 2012; De Fontaine, 2013; Coughlan, 2013].No details on the progress towards this objective are available at the time of writing [Gauteng Wetland Forum, 2012; Coughlan, 2013].

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References

Abbott Grobicki (2002). *Cultivation of plants in restores urban wetlands for income generation in local communities*. WRC Report No. 1054/1/02. Pretoria: Water Research Commission.

Acocks, J.P.H. (1988). *Veld Types of South Africa*. Memoirs of the Botanical Survey of South Africa, No.57: 1-146. Pretoria: Botanical Research Institute.

Adair, C., Mora, N.B., Laing, J., Rogers, Z. (2012). Restoration of the Wetlands in Palo Verde National Park: A Legal and Ecological Analysis. Final Report. http://www.law.ufl.edu/_pdf/academics/academic-programs/study-abroad/costa-rica/Ramsar-Report.pdf (Accessed on 20 February 2013).

AfriGIS (2013). Google Earth Map of Important Bird Area http://www.birdlife.org.za/conservation/iba/iba-directory/229-blesbokspruit (Accessed on 20 February 2013).

AngloGold Ashanti (2004). Report to society: Case studies: South Africa—The Blesbokspruit Ramsar Wetland site. http://www.anglogold.co.za/subwebs/informationforinvestors/reporttosociety04/values_bus_principles/environment/e_cs_sa_7_18.htm (Accessed on 28 March 2012).

Bagley, C.V.; Amacher, J.K.; Poe, K.F. (1997). Analysis of Water Quality for Livestock. *All Archived Publications*. Paper 106. http://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1105&context=extension_histall&sei-redir=1&referer=http%3A%2F%2Fscholar.google.co.za%2Fscholar%3Fstart%3D10%26q%3Dsalinity%2Band%2Blivestock%26hl%3Den%26as_sdt%3D0%2C5#search=%22salinity%20livestock%22 (Accessed on 28 March 2012).

Baker, C.M. (1992). *Atilax Paludinosus*. *The American Society of Mammalogist.* Mammalian Species No. 408, 1–6. http://www.science.smith.edu/msi/pdf/i0076-3519-408-01-0001.pdf (Accessed on 25 April 2012)

Barbier, E.B. (1993). Sustainable Use of Wetlands – Valuing Tropical Wetland Benefits: Economic Methodologies and Applications, *The Geographical Journal*, *159(1)*, 22-32.

Barbier, E.B., Acreman, M., Knowler, D. (1997). *Economic valuation of wetlands: A guide for policy makers and planners*. Gland: Ramsar Convention Bureau.

Barker, H. (1995). And God saw that it was good. *Juta's Business Law, 3*, 147-148. http://heinonline.org/HOL/LandingPage?collection=journals&handle=hein.journals/jutbusil3&div=62&id=&page= (Accessed on 22 February 2013).

Bethlehem , L., Goldblatt, M. (1997). *The bottom line: industry and the environment in South Africa.* Cape Town: International Development Research Centre, University of Cape Town Press.

BirdLife South Africa (1998). Important Birds Areas of Gauteng. http://www.birdlife.org.za/images/stories/conservation/iba/PDF/Blesbokspruit_p88_90.pdf (Accessed on 20 February 2013).

BirdLife South Africa (2013). Wetlands prioritisation project brings positive impact on birdlife. http://www.sagoodnews.co.za/index2.php?option=com_content&do_pdf=1&id=5512 (Accessed on 20 May 2012).

Blesbokspruit Forum (2003a). Terms of reference for the Blesbokspruit Forum. http://www.reservoir.co.za/catchments/vaal%20barrage/blesbok%20forum/blesbok%20documents/blesbok__tor_oct2003.pdf (Accessed on 20 May 2012).

Blesbokspruit Forum (2003b). In-stream water quality guidelines for the Blesbokspruit catchment. http://www.reservoir.co.za/catchments/vaalbarrage/blesbok_forum/blesbok_documents/blesbok_guidelines.PDF (Accessed on 15 February 2012).

Bodenstein, J.A., van Eeden, P.H., Legadima, J., Chaka, J. (2005). A preliminary assessment of the present ecological state of the major rivers and streams within the northern service delivery region of the Ekurhuleni Metropolitan Municipality. http://www.ewisa.co.za/literature/files/213%20van%20Eeden.pdf (Accessed on 20 May 2012).

Bowell, R.J. (2000). Sulphate and salt minerals: The problem of treating mine waste. http://www.srk.co.za/files/File/UK%20PDFs/pubart_sulphat1.pdf (Accessed on 10 August 2012).

Bowman, M. (2002). The Ramsar Convention on wetlands: Has it made a difference? In *Yearbook of International Co-operation on Environment and Development 2002/2003.* London: Earthscan Publications, pp. 61–68. http://ramsar.rgis.ch/pdf/key_law_bowman2.pdf (Accessed 20 May 2012).

Castañeda, C., Herrero, J. (2008). Assessing the degradation of saline wetlands in an arid agricultural region in Spain. *Catena*, *72*, 205-213.

Clark, J.M., Chapman, P.J., Adamson, J.K., Lane, S.N. (2005). Influence of drought-induced acidification on the mobility of dissolved organic carbon in peat soils. *Global Change Biology*, *11*, 791–809.

Clark, J.M., Chapman, P.J., Heathwaite, A.L., Adamson, J.K. (2006). Suppression of dissolved organic carbon by sulfate induced acidification during simulated droughts. *Environmental Science and Technology, 40*, 1776–1783.

Cliquet, A. (2005). International legal possibilities and obligations for nature conservation in ports. In Herrier J.-L., J. Mees, A. Salman, J. Seys, H. Van Nieuwenhuyse and I. Dobbelaere (Editors). p. 393-404. *Proceedings 'Dunes and Estuaries 2005' – International Conference on Nature Restoration Practices in European Coastal Habitats*, Koksijde, Belgium, 19-23 September 2005. VLIZ Special Publication 19, xiv + 685 pp.

Collen, B. (2004). A generic environmental management plan for the lacustrine wetlands of the East Rand of Gauteng. Unpublished MSc minor dissertation in Environmental Management. Johannesburg: University of Johannesburg.

Collins, J. (2001). Environmental Facts: Wetlands. Bellville: University of the Western Cape. http://www.botany.uwc.ac.za/Envfacts/facts/wetlands.htm (Accessed on 20 May 2012).

Collins, N.B. (2005). Wetlands: The basics and some more. Bloemfontein: Free State Department of Tourism, Environmental and Economic Affairs. http://www.dwaf.gov.za/iwqs/rhp/provinces/freestate/wetlands_basics&more.pdf. (Accessed on 20 May 2012).

Cortecci, G., Dinelli, E., Bencini, A., Adorni-Branccesi, A., La Ruffa, G. (2002). Natural and anthropogenic SO4 sources in the Arno river catchment, northern Tuscany, Italy: A chemical and isotopic reconnaissance. *Applied Geochemistry, 17*, 79–92.

Coughlan, S. (2013). The future of the Blesbokspruit. http://springsadvertiser.co.za/76507/the-future-of-the-blesbokspruit/ (Accessed on 8 September 2013).

Cowan, G.I., Van Riet, W. (1998). *A Directory of South African Wetlands*. Pretoria: Department of Environmental Affairs and Tourism.

Davies, B., Day, J. (1998). *Vanishing Waters*. Cape Town: University of Cape Town Press.

De Fontaine, M. (2012). Personal Communication. Member of the Blesbokspruit Forum and Water Quality Specialist at Rand Water.

De Fontaine, M. (2013). Blesbokspruit Wetland Ramsar Status Review 2013. http://discussion.wetlands.za.net/viewtopic.php?f=6&t=434&sid=f6f9040ca4b534cce723ec86de33bdf6 (Accessed 4 September 2013).

Dely, J.L., Kotze, D.C., Quinn, N.W., Mander, J.J. (1999). *A pilot project to compile an inventory and classification of wetlands in the Natal Drakensberg Park*. Technical report. Pretoria: Department of Environmental Affairs and Tourism.

Department of Water Affairs and Forestry (1996a). *South African Water Quality Guidelines. Volume 4: Agricultural Water Use: Irrigation (2nd Edition).* Pretoria: Department of Water Affairs and Forestry.

Department of Water Affairs and Forestry (1996b). South African Water Quality Guidelines. *Volume 5: Agricultural Water Use: Livestock Watering (2nd Edition).* Pretoria: Department of Water Affairs and Forestry.

Department of Water Affairs and Forestry (1996c). South African Water Quality Guidelines. *Volume 7: Aquatic Ecosystems (2nd Edition)*. Pretoria: Department of Water Affairs and Forestry.

Department of Water Affairs and Forestry (2004) *National Water Resource Strategy*. Pretoria: Department of Water Affairs and Forestry.

Department of Environmental Affairs and Tourism (2005). Background Research Paper: Biodiversity and Ecosystem Health. Pretoria: Department of Environmental Affairs and Tourism. http://s3.amazonaws.com/zanran_storage/soer.deat.gov.za/ContentPages/42728136.pdf (Accessed on 16 May 2012).

De Wet, L.P.D., Schoonbee, H.J., Pretorius, J., Bezuidenhout, L.M. (1990). Bioaccumulation of selected heavy metals by the water fern, *Azolla filiculoides* Lam. in a wetland ecosystem affected by sewage, mine and industrial pollution. *Water SA, 16(4)*, 281-286.

De Wet, L.P.D. & Prinsloo, J.Z. (2004). Bio-corrosion of underground to surface delivery pipes at the Grootvlei Mine, Springs: Water quality, microbiological and management aspects. Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference, Cape Town. http://www.ewisa.co.za/literature/files/243.pdf (Accessed on 16 May 2012).

Digby Wells and Associates (1996). DWAF: Department of Water Affairs and Forestry. The Grootvlei Proprietary Mines Limited: Environmental Management Programme Report. Report no. 222699/1. Randburg: Digby Wells and Associates.

Dillon, P.J., Evans, H.E. (2000). Long-term changes in the chemistry of a soft-water lake under changing acid deposition rates and climatic fluctuations. *Verhandlungen Internationale Vereinigung für Theoretische und Angewandte Limnologie*, *27*, 2615–2619.

Dini, J. (1999). Blesbokspruit – South Africa. http://www.environment.gov.za/soer/nsoer/resource/wetland/index.htm (Accessed on 10 May 2012).

Dugan, P. (1990). *Wetland Conservation: A Review of Current Issues and Required Action.* Gland: IUCN.

Du Plessis, J. (2006). The assessment of the water quality of the Hex River Catchment- North West Province. Unpublished MSc minor dissertation in Environmental Management. Johannesburg: University of Johannesburg.

Durand, J.F. (2012). The impact of gold mining on the Witwatersrand on the rivers and karst system of Gauteng and North West Province, South Africa. *Journal of African Earth Sciences*, *68*, 24–43.

ERWAT (2010). The East Rand Water Care Company (ERWAT) http://www.erwat.com/page.php?pageID=4 (Accessed on 20 March 2012).

Eastern Basin Blesbokspruit Catchment Task Team (2006). Discussion Document. First Document for Comments. http://www.reservoir.co.za/catchments/vaalbarrage/blesbok_forum/ebwg/500798_EBBCTT_Draft_DD_2006.pdf (Accessed on 23 January 2012).

Eimers, M.C., Dillon, P.J. (2002). Climate effects on sulphate flux from forested catchments in south-central Ontario, Canada. *Biogeochemistry*, *61*, 337–355.

Eimers, M.C., Dillon, P.J., Watmough, S.A. (2004). Long-term (18-year) changes in sulphate concentrations in two Ontario headwater lakes and their inflows in response to decreasing deposition and climate variations. *Hydrological Processes*, *18*, 2617–2630.

Eimers, M.C. Watmough, S.A., Buttle, J.M., Dillon, P.J. (2008). Examination of the potential relationship between droughts, sulphate and dissolved organic carbon at a wetland-draining stream. *Global Change Biology,14,* 938–948.

Ekurhuleni Metropolitan Municipality (2003). *First Year State of the Environment Report 2003*. Kempton Park: Ekurhuleni Metropolitan Municipality.

Ekurhuleni Metropolitan Municipality (2004). *State of the Environment Report 2004*. Kempton Park: Ekurhuleni Metropolitan Municipality.

Ekurhuleni Metropolitan Municipality (2008). *Environmental Management Framework 2007*. Kempton Park: Ekurhuleni Metropolitan Municipality.

Environmental Protection Agency (2001). Functions and Values of Wetlands. EPA Report 843-F-01-002c. United States.

Food and Agriculture Organization (2002). *Agricultural Drainage Water Management in Arid and Semi-Arid Areas.* Fao Irrigation and Drainage Paper 61. Food and Agriculture Organization Of the United Nations: Rome. http://www.fao.org/docrep/005/y4263e/y4263e07.htm

Gauteng Water Caucus Meeting (2012). Minutes of 7th July 2012. http://forums.wetlands.za.net/gauteng/minutes/gwc_minutes_07jul2012.pdf (Accessed on 23 January 2013).

Gauteng Wetland Forum (2009). Minutes of 8th May 2009. http://forums.wetlands.za.net/gauteng/minutes/gwf_minutes_08may2009.pdf (Accessed on 23 January 2013).

Gauteng Wetland Forum (2010).Gauteng Wetland Forum Constitution. http://forums.wetlands.za.net/gauteng/documents/gwf_constitution.pdf (Accessed on 23 January 2013).

Gauteng Wetland Forum (2011a). Minutes of 1st July 2011 http://forums.wetlands.za.net/gauteng/minutes/gwf_minutes_01jul2011.pdf (Accessed on 23 January 2013).

Gauteng Wetland Forum (2011b). Minutes of 4th November 2011. http://forums.wetlands.za.net/gauteng/minutes/gwf_minutes_04nov2011.pdf (Accessed on 23 January 2013).

Gauteng Wetland Forum (2012). Minutes of 28th September 2012. http://forums.wetlands.za.net/gauteng/minutes/gwf_minutes_28sep2012.pdf (Accessed on 23 January 2013).

Godwin, D.C., Miner, J.R. (1996). The potential of off-stream livestock watering to reduce water quality impacts. *Bioresource Technology, 58*, 285-290.

Goodrich, B.A. Jacobi, W.R. (2008). Magnesium Chloride Toxicity in Trees. Factsheet No. 7.425. http://www.ext.colostate.edu/pubs/garden/07425.html (Accessed on 23 January 2013).

Gopal, B., Kvet, J., Loffler, H., Masing, V., Patten, B.C. (1990). Definition and classification. In Patten, B.C. (Editor) *Wetlands and Shallow Continental Water Bodies. Volume 1: Natural and Human Relationships.* The Hague: SPB Academic Publishing.

Haskins, C. (1998). *Information sheet on Ramsar Wetlands*. Pretoria: Gauteng Nature Conservation.

Haskins, C.A., Compaan, P.C. (1998). A historical review of the changing nature of the Blesbokspruit wetland, South Africa. Pretoria: Gauteng Nature Conservation.

Hoare, D., Van der Merwe, E., Claasen, P. (2008). *Ekurhuleni Metropolitan Municipality: Biodiversity Report, 2008*. Kempton Park: Ekurhuleni Metropolitan Municipality.

Hunt, M., Herron, E., Green, L. (2012). Chlorides in Fresh Water. The University of Rhode Island Watershed Watch, Cooperative Extension. College of the Environment and Life Sciences (CELS). (Accessed on 23 June 2013).http://www.uri.edu/ce/wq/ww/Publications/Chlorides.pdf

International Institute for Sustainable Development, (2012). Summary of the eleventh conference of the parties to the Ramsar Convention on wetlands: 6-13 July 2012. *Earth Negotiations Bulletin*, *17 (39),* 1-17. http://www.iisd.ca/download/pdf/enb1739e.pdf (Accessed on 23 March 2013).

International Union for the Conservation of Nature (1980). *World Conservation Strategy*. Switzerland: International Union for the Conservation of Nature.

James, K.R., Cant, B., Ryan, T. (2003). Responses of freshwater biota to rising salinity levels and implications for saline water management: a review. *Australian Journal of Botany, 51, (6),* 703 – 713.

Jones and Wagener (2011). Remediation of ingress to old gold workings linked to Grootvlei Mine. Technical Report, Jones and Wagener Consulting Civil Engineers. http://www.jaws.co.za/projects/remediation-ingress-old-gold-workings-linked-grootvlei-mine) (Accessed on 23 March 2013).

Kaksonen, A.H., Puhakka, J.A. (2007). Sulfate Reduction Based Bioprocesses for the Treatment of Acid Mine Drainage and the Recovery of Metals. *Engineering in Life Sciences, 7, (6),* 541–564.

Kerekes, J., Beauchamp, S., Tordon, R. (1986). Sources of sulphate and acidity in wetlands and lakes in Nova Scotia. *Water, Air, and Soil Pollution, 31*, 207-214.

Kotze, D.C. (2000). *Wetland Use: A wetland management decision support system for South African freshwater palustrine wetlands. Part 2: Organizational assessment and development and a structure for planning wetland management.* South African Wetlands Conservation Programme. Pretoria: Department of Environmental Affairs and Tourism. http://www.wetland.org.za/ckfinder/userfiles/files/3_6_2-%20Wetland%20Use2.pdf (Accessed December 2012).

Larivière, S. (2002). *Lutra maculicollis*. *The American Society of Mammalogists* Mammalian Species No. 712, 1–6. http://www.science.smith.edu/msi/pdf/712_Lutra_maculicollis.pdf (Accessed on 23 January 2013).

Lea, I., Waygood, C., Duthie, A. (2003). Water management strategies to reduce long-term liabilities at Grootvlei gold mine. 8th International Congress on Mine Water & the Environment, Johannesburg, South Africa. http://www.imwa.info/docs/imwa_2003/imwa_2003_441-449.pdf (Accessed on 23 October 2012).

Liefferink, M. (2011). Alleged Human Right violations by Aurora Mine (Grootvlei). *ww.pea.org.za/latestnews/upload/news_doc_295.doc* (Accessed on 23 January 2013).

Madden, S. (2002). Marievale Bird Sanctuary. http://web.uct.ac.za/depts/stats/adu/marie.htm (Accessed on 23 April 2013).

Macfarlane, D.M., Muller, P.J. (2011). *Blesbokspruit Ramsar Management Plan*. Draft Report prepared for the Department of Environmental Affairs. Presentation made at the stakeholder workshop for developing a management plan for the Blesbokspruit Ramsar Site on 24th January.

Mail & Guardian (2012) Gauteng Agriculture and Rural Development. Supplement to the Mail & Guardian, pp. 36-37.

Maione, U., Majone-Lehto, B., Monti, R. (2000). *New Trends in Water and Environmental Engineering for Safety and Life*. Rotterdam: Balkema.

Marti, A. (2011). Wetlands: A review with three case studies: The People's Republic of China, the United States of America, and Ethiopia. http://www.uwsp.edu/forestry/StuJournals/Documents/IRM/aMarti.pdf (Accessed on 20 December 2012).

Mathews, E. H., Hasan, A., Pelzer, R.P. (2009). Case Studies: The Environmental Impact Of Dsm Projects. http://active.cput.ac.za/energy/past_papers/ICUE/2009/PDF/Paper%20-%20Mathews%20E.pdf (Accessed on 20 July 2012).

Mitsch, W.J., Gosselink, J.G. (1993). *Wetlands (2nd Edition)*. New York: Van Nostrand Reinhold.

Mitsch, W. J., Wu, X., Nairn, R.B., Weihe, P.E., .Wang, N., Deal, R., Boucher, C.E. (1998). Creating and restoring wetlands: A whole-ecosystem experiment in self-design. *Bioscience*, *48(12)*, 1019-1030.

Mouton, J. (2001). *How to succeed in your Master's and Doctoral Studies: A South African guide and resource book.* Pretoria: Van Schaik.

Muller, P. (2009). Personal Communication. Manager of the Gauteng Nature Conservation and the Blesbokspruit Ramsar Site. Johannesburg: Gauteng Department of Agriculture, Conservation and Environment.

Mulungufhala, T. (2008). *Healthy wetlands, Healthy people*. Pretoria: South African National Biodiversity Institute.

Naidoo, B. (2009). Mining & Environment—Acid mine drainage single most significant threat to SA's environment. 8th May 2009. http://www.watermarkglobalplc.com/documents/news/2009_05_09_mining_environment.pdf (Accessed 13 April 2013).

Naledzi Environmental Consultants (2007). Wetland Inventory Report, 2007 – Identification, classification, assessment & delineation of wetlands within the Ekhuruleni Metropolitan Municipality. https://www.ekurhuleni.gov.za/business/useful-resources/enviro-reports/doc_download/311-wetland-inventory-report-2007 (Accessed on 29 December 2012).

Nyeleti Network for Built Environment (2011). Acid mine drainage. Issue No. 8. http://thenetworks.co.za/wp-content/uploads/2012/03/Nyeleti_Network_8thEdition.pdf (Accessed on 20 April 2013).

Panno, S.V., Hackley, K.C., Hwang, H.H., Greenberg, S., Krapac, I.G., Landsberger, S., O'Kelly, D.J. (2002). Source identification of sodium and chloride contamination in natural waters: preliminary results. http://www.water-research.net/Waterlibrary/privatewell/nacl.pdf (Accessed on 20 December 2012).

Phaleng, D.M. (2009). Anthropogenic impacts on the integrity of the Blesbokspruit catchment: A case study of surface water pollution. Unpublished MSc Dissertation in Environmental Sciences. Pretoria: University of South Africa.

Podmore, C. (2009). Irrigation salinity – causes and impacts. Primefact 937. Industry & Investment NSW. http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0018/310365/Irrigation-salinity-causes-and-impacts.pdf (Accessed on 20 December 2012).

Potgieter, M. (2002). The role wetlands play in water reclamation. Technical report, Department of Hydrology, University of Zululand. http://www.scienceafrica.co.za/2002/January/wetland.htm (Accessed on 20 May 2011).

Quental, N., Lourenço, J.M., da Silva, F.N. (2009). Sustainable development policy: goals, targets and political cycles. *Sustainable Development*, *19*, 15–29.

Ramsar (1992). Ramsar Advisory Missions. Report No. 29 St Lucia, South Africa. Gland: Ramsar Convention Bureau. http://www.ramsar.org/cda/en/ramsar-documents-rams-ramsar-advisory-missions-15893/main/ramsar/1-31-112%5E15893_4000_0__ (Accessed on 20 December 2012).

Ramsar (1996a). Guidelines for operation of the Montreux Record. http://www.ramsar.org/cda/en/ramsar-documents-montreux-guidelines-for-operation-20983/main/ramsar/1-31-118%5E20983_4000_0__ (Accessed on 9 November 2012).

Ramsar (1996b). Montreux Record – Questionnaire. http://www.ramsar.org/cda/en/ramsar-documents-montreux-montreux-record-21007/main/ramsar/1-31-118%5E21007_4000_0__(Accessed on 9 November 2012).

Ramsar (1998). A Directory of Wetlands of International Importance. South Africa Ramsar Site 343;(WI Site 1ZA004) http://www.wetlands.org/RSIS/_COP9Directory/Directory/RIS/1ZA004en.pdf. __(Accessed on 9 November 2012).

Ramsar (2000). Briefing document on the Convention on Wetlands. http://www.environment.gov.za/PolLeg/Conventions/ramsarbriefing.htm (Accessed on 20 April 2011).

Ramsar (2005). A Conceptual Framework for the wise use of wetlands and the maintenance of their ecological character. The 9th Meeting of the Conference of the Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971) Kampala, Uganda, 8-15 November 2005. http://www.ramsar.org/cda/en/ramsar-documents-cops-cop9-9th-meeting-of-the-17274/main/ramsar/1-31-58-82%5E17274_4000_0__(Accessed on 18 August 2013).

Ramsar (2007). The Montreux Record and the Ramsar Advisory Missions. http://www.ramsar.org/pdf/about/info2007-06-e.pdf (Accessed on 10 May 2011).

Ramsar (2010). *Managing wetlands: Frameworks for managing Wetlands of International Importance and other wetland sites (4th Edition).* Ramsar handbooks for the wise use of wetlands, Vol. 18. Gland: Ramsar Convention Secretariat.

Ramsar (2011a). Message from Ahmed Djoghlaf, Executive Secretary of the Convention on Biological Diversity on the Occasion of the Fortieth Anniversary of the Ramsar Convention on Wetlands. http://www.ramsar.org/pdf/wwd/11/wwd11-reports/wwd11_canada2_cbd.pdf (Accessed on 17 June 2012).

Ramsar (2011b). The Montreux Record. http://www.ramsar.org/cda/en/ramsar-documents-montreux-montreux-record/main/ramsar/1-31-118%5E20972_4000_0__(Accessed on 17 December 2012).

Ramsar (2012). The Ramsar Convention on Wetlands: About the Ramsar Convention. http://www.ramsar.org/cda/ramsar/display/main/main.jsp?zn=ramsar&cp=1-36^7804_4000_0__(Accessed on 20 May 2012).

Richards, L.T. (2001). A guide to wetland identification, delineation, and wetland function. Unpublished MSc minor dissertation in Geography and Environmental Management. Johannesburg: Rand Afrikaans University.

Rogers, K.H. (1995). Riparian wetlands. Centre for Water in the Environment. University of the Witwatersrand: Johannesburg. http://wetlands.sanbi.org/articles2/File/wetlandssa04.pdf (Accessed on 20 April 2011).

Ryan, B. (2009). Grootvlei counts on last-minute reprieve. http://www.miningmx.com/news/gold_and_silver/grootvlei-counts-on-last-minute-reprieve.htm (Accessed on 20 April 2011).

Salt Institute (2011). Salt and the natural environment. http://www.saltinstitute.org/Issues-in-focus/Road-salt/Road-salt-our-environment/Natural-environment (Accessed on 19 November 2012).

Saving Water SA (2010). Gold mine pumps acidic water into stream. http://www.savingwater.co.za/2010/03/03/14/gold-mine-pumps-acidic-water-into-stream/ (Accessed on 19 November 2012).

Schuyt, K., Brander, L. (2004) *The Economic Values of the World's Wetlands*. Gland: World Wild Fund.

Schoeman, J.J., Steyn, A. (2001). Investigation into alternative water treatment technologies for the treatment of underground mine water discharged by Grootvlei Proprietary Mines Ltd into the Blesbokspruit in South Africa. CSIR Environmentek. *Desalination*, *133*, 13-30.

Scott, R. (1995). Flooding of Central and East Rand gold mines: An investigation into controls over the inflow rate, water quality and the predicted impacts of flooded mines. Report No. 486/1/95. Pretoria: Water Research Commission.

Semeniuk, C.A., Semeniuk, V. (1995). A geomorphic approach to global classification for inland wetlands. *Vegetatio*, *118*, 103-124.

Shirokova, Y., Forkutsa, I., Sharafutdinova, N. (2000). Use of electrical conductivity instead of soluble salts for soil salinity monitoring in Central Asia. *Irrigation and Drainage Systems*, *14*, 199–205.

Smart, M. (1997). Chapter 2: The Ramsar Convention: Its role in conservation and wise use of wetland biodiversity. In (eds) *Wetlands, Biodiversity and the Ramsar Convention*. Hails, A.J. (1997). Ramsar Convention Bureau: Gland. http://www.ramsar.org/cda/en/ramsar-documents-cops-cop8-wetlands-biodiversity-21181/main/ramsar/1-31-58-128%5E21181_4000_0__ (Accessed on 17 December 2012).

Soltanpour, P.N., W.L. Raley, W.L. (2007). Livestock Drinking Water Quality. Quick Facts No. 4.908. http://amlportal.state.wy.us/eqc/Cases%20on%20Appeal/05-3102%20PRBRC%20WQD%20Ch%202%20Petition/Livestock%20Drinking%20Water%20Quality.CSU.PAW.pdf (Accessed on 17 December 2012).

South Africa National Water Act (1998). National Water Act No 36 of 1998. Government Gazette, 26 August 1998, Vol. 398, No. 19182.

South African National Assembly, (2009). Question No. 114 - Internal question paper no 2 of 2009. https://www.environment.gov.za/sites/default/files/parliamentary_updates/question114_0.pdf (Accessed on 20 April 2013).

South African River Health Programme, (2001). *State of the Rivers Report: Crocodile Sabie-Sand and Olifants River systems.* WRC Report No. TT 147/01. Pretoria: Water Research Commission. http://www.dwaf.gov.za/iwqs/rhp/state_of_rivers/state_of_crocsabieolif_01/info_wetlands.html (Accessed on 17 December 2012).

South African Wetlands Conservation Programme (1998). Status of two South African Wetlands of International Importance listed on the Montreux Record. http://www.ngo.grida.no/soesa/nsoer/resource/wetland/montreux_rep.htm (Accessed on 19 November 2012).

South African Wetlands Conservation Programme (1999). Blesbokspruit http://www.ngo.grida.no/soesa/nsoer/resource/wetland/blesbokspruit.htm (Accessed on 19 November 2012).

Spash, C.L. (1998). *Environmental Values and Wetland Ecosystems: CVM, Ethics and Attitudes*. Cambridge Research for the Environment. Cambridge: University of Cambridge.

Steffen, Robertson, Kirsten (1990). Water and wastewater management in the paper and pulp industry. Water Research Commission Project No. 145 TT 49/90. Pretoria: Water Research Commission.

Swart, F. (1995). Grootvaly/Blesbokspruit Environmental Education Centre. News Release. Springs: Department of Public Relations and Marketing, Springs City Council.

Thorius, A. (2004) The effect of Grootvlei mine water on the Blesbokspruit. Unpublished MSc minor dissertation in Environmental Management. Johannesburg: University of Johannesburg.

Tonkin, I. (2005). World Recognised Site Under Threat. *Borehole Water Journal*, *63(4)*, 16-18. http://www.bwa.co.za/past_issues.htm (Accessed on 19 November 2012).

United Nations (2009). World Heritage: iSimangaliso Wetland Park. http://whc.unesco.org/en/list/914 (Accessed on 20 May 2011).

US Department of Commerce (1990). Environmental Issues. Report JPRS-TEN-90-016. National Technical Information Service: Springfield. www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA344000 (Accessed on 19 November 2012).

US Geological Survey (2011). Sulfate as a Contaminant in Freshwater Ecosystems: Sources, Impacts and Mitigation. http://conference.ifas.ufl.edu/ncer2011/Presentations/Wednesday/Waterview%20C-D/am/0850_Orem.pdf (Accessed on 19 November 2012).

Uys, M.C. (2004). Development of a Framework for the Assessment of Wetland Ecological Integrity in South Africa. Phase 1: Situational Analysis. Pretoria: Department of Water Affairs and Forestry.

Van der Merwe, C. (2003). The assessment of the influence of treated underground mine water on the benthic fauna on a portion of the Blesbokspruit Ramsar site. Unpublished MSc minor dissertation in Environmental Management. Johannesburg: University of Johannesburg.

Van der Merwe, C. (2009). Personal Communication. Member of the Blesbokspruit Forum, and Environmental Manager at Xtrata Ltd.

Van der Merwe, W., Lea, I. (2003).Towards sustainable mine water treatment at Grootvlei mine. *8th International Congress on Mine Water & the Environment, Johannesburg, South Africa*. http://www.imwa.info/docs/imwa_2003/imwa_2003_025-036.pdf (Accessed on 19 November 2012).

Van Eeden, P.H., Schoonbee, H.J. (1996). Metal concentrations in liver, kidney, bone and blood of three species of birds from a metal-polluted wetland. *Water SA, 22*, 351-357.

Van Wyk, J.J., Munnik, R. (1998). Dewatering of the Far East Rand mining basin. A critical evaluation of the government's approach towards solving the associated environmental problems. WISA biennial conference Cape Town. http://www.ewisa.co.za/literature/files/1998%20-%20151.pdf (Accessed on 20 May 2011).

Walmsley, R.D. (1988). *A description of the Wetlands Research Programme.* South African National Scientific Programmes Report No. 145. Pretoria: CSIR, 26 pp.

Water Wise (2012). World wetland day 2012: Wetlands and tourism. Rand Water. http://www.waterwise.co.za/export/sites/water-wise/water/Downloadable_Posters/Environmental_Days/Environmental_Days_posters/WWD_Poster_1_Rev3.pdf (Accessed on 20 May 2013).

Wetlands International (2007). Ramsar Sites Information Service: Welcome to the Ramsar Sites Information Service. http://ramsar.wetlands.org/ (Accessed on 23 April 2011).

Whitten, S., Bennett, J. (2005). *Managing Wetlands for Public and Social Good*, Cheltenham: Edward Elgar New Horizon in Environmental Economics Series.

Whyte, C.R., Shepherd, J.K. (1999). An Inventory of the wetlands in the Mkomazi Catchment of KwaZulu-Natal. Pietermaritzburg: Town and Regional Planning Commission.

Wiessner, A., Kuschk, P. Buddhawong, S., Stottmeister, U., Mattusch, J., Kästner, M. (2006). Effectiveness of Various Small-Scale Constructed Wetland Designs for the Removal of Iron and Zinc from Acid Mine Drainage under Field Conditions. *Engineering in Life Sciences*, 6 (6), 584–592.

Wikipedia (2013a). Great Crested Grebe. http://en.wikipedia.org/wiki/Great_Crested_Grebe (Accessed on 20 May 2013).

Wikipedia (2013b). Yellow-billed Duck. http://en.wikipedia.org/wiki/Yellow-billed_Duck (Accessed on 20 May 2013).

Wikipedia (2013c). Spur-winged Goose. http://en.wikipedia.org/wiki/Spur-winged_Goose (Accessed on 20 May 2013).

Willoughby, N., Grimble, R., Ellenbroek, W., Danso, E., Amatekpor, J. (2001). The wise use of wetlands: identifying development options for Ghana's coastal Ramsar sites. *Hydrobiologia, 458*, 221–23.

Wood, A., Reddy, V. (1998). Acid mine drainage as a factor in the impacts of underground minewater discharges from Grootvlei gold mine. IMWA Proceedings 1998. International Mine Water Association. http://www.mwen.info/docs/imwa_1998/IMWA1998_Wood_387.pdf (Accessed on 20 March 2012).

Woodward, R.T., Wui, Y.-S. (2001). The economic value of wetland services: a meta-analysis. *Ecological Economics, 37(2)*, 257-270.

APPENDICES

Appendix 1: Data cleanness and completeness

The dataset of surface water readings for the period 2000 – 2011 was received from Rand Water Board in an Excel Spreadsheet format. After the cleaning process, parameters with values below 1 (e.g. Al, F, Fe, Mn, NO_3, PO_4) and less than 97 per cent complete (e.g. NH4, COD, DO, SS) were not selected for analysis. This was because these parameters were not considered representative of the dataset and of less influence when compared to the remainder parameters (EC, pH, SO_4, Na, Cl and Mg). Outliers were removed, averages were calculated where more than one sample per month was analysed.

	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
Count of non-zero cells	1349	1350	626	1330	1325	1227	1323	1322	1323	324	442	1014	1329	415	1209	69
Number of missing values per parameter	14	13	737	33	38	136	40	41	40	1039	921	349	34	948	154	1294
Existing value %	99%	99%	46%	98%	97%	90%	97%	97%	97%	24%	32%	74%	98%	30%	89%	5%

Appendix 2: Validated datasets of surface water quality parameters for the Blesbokspruit wetland 2000 to 2011.

The following data represents the average concentration values or readings for surface water within the study area from January 2000 to December 2011. Blank cells indicate either missing values or values below the detection limit of the respective parameters. Nevertheless, for statistical analysis, only complete datasets (with better than 97% records) and with values greater than 1 were used.

YEAR 2000

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B5	10-Jan-00	105	7.9		120	0.37	0.06	15	0.89	110	4.2		3.5	77		2.8	
B5	24-Jan-00	45	7.8		36	0.25	0.04	9.9	0.1	30	1.2		0.37	48		3.8	
B5	7-Feb-00	105	7.8		125	0.43	0.07	16	0.13	110	1	0.25	0.92	105		2.9	
B5	21-Feb-00	78	8		76	0.24	0.04	14	0.17	70	7.4		1.8	62		3.7	
B5	6-Mar-00	86	7.7		95	0.39	0.08	13	1.2	105		1	0.38	130	76	3.3	
B5	20-Mar-00	63	7.5		63	0.32	0.04	11	0.28	65				115		4	
B5	10-Apr-00	97	7.2		105	0.24	0.06	16	0.33	105		1	0.96	74			
B5	8-May-00	105	7.5		130	0.4	0.4	13	0.72	98	5.5	0.4	3.4	79		1.5	
B5	22-May-00	140	7.7		195	0.4	0.1	21	0.57	175			0.27	140		1.2	
B5	5-Jun-00	92		0.05	100	0.31	0.15	18	0.33	92	2.6		0.44	110	61	3.5	42
B5	19-Jun-00	81	8.6	0.05	100	0.38	0.22	19	0.26	100	1.2	1.3	0.52	91	66	2.4	
B5	10-Jul-00	85	7.8	0.05	99	0.3	0.05	43	0.05	51	1.8			100	36		
B5	24-Jul-00	120	8.1	0.05	170	0.36	0.21	23	0.03	170			0.21	115	58	2.3	
B5	7-Aug-00	125	8.1	0.05	175	0.27	1.4	29	0.61	180	3.1		0.85	100	92	1.2	30
B5	21-Aug-00	120	7.7	0.07	140	0.22	0.4	13	0.38	145	0.79	0.27	0.25	135		2.4	
B5	4-Sep-00	150	8.1	0.11	215	0.32	0.14	26	0.24	140	2.6	0.23	0.51	110	92	2.7	
B5	18-Sep-00	155	8.5	0.11	235	0.24	0.15	16	0.15	260	3	0.64	0.52	125		3	
B5	9-Oct-00	170	7.8	0.11	235	0.29	0.12	23	0.24	275	4.4	0.26	0.64	165			
B5	23-Oct-00	155	7.8	0.05	230	0.33	0.14	24	0.28	74				155	56	1.4	
B5	6-Nov-00	82	7.8	0.02	100	0.33	0.03	16	0.12	99		0.59	0.76	74		6	
B5	20-Nov-00	94	7.7	0.04	115	0.31	0.06	14	0.32	120	0.6	0.89	1.3	105	83	3.9	
B5	4-Dec-00	105	7.8		130	0.3	0.04	18	0.29	115	1.4	0.33	3.5	92		2.4	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B5	**18-Dec-00**	98	7.7		120	0.28	0.12	15	1.5	105		0.84	0.47	95		3.7	
B16	**10-Jan-00**	125	8.4	0.05	100	0.32	0.05	37	0.16	110				750	26		
B16	**24-Jan-00**	99	8.4	0.05	76	0.32	0.05	28	1	76	2			100	24		
B16	**7-Feb-00**	150	7.9	0.11	100	0.26	0.05	44	0.05	125				5	29		
B16	**21-Feb-00**	57	8.1	0.05	35	0.27	0.06	16	0.16	36				100	23		
B16	**6-Mar-00**	150	7.8	0.05	100	0.32	0.07	49	0.41	115				155	24		
B16	**20-Mar-00**	150	7.6	0.05	91	0.25	0.12	50		105				140	13		
B16	**10-Apr-00**	195	8.2	0.05	58	0.29	0.04	74	0.6	135		0.49	0.09	1000	19		
B16	**8-May-00**	150	7.9	0.05	110	0.26	0.05	48	0.05	110			0.13	90	21		
B16	**22-May-00**	210	7.8	0.05	130	0.26	0.01	77	0.19	160		1.2	0.08	1000	26		
B16	**5-Jun-00**	170	7.9	0.05	100	0.27	0.05	64	0.64	135				720	14	3	
B16	**19-Jun-00**	190	8	0.05	135	0.28	0.01	67	0.36	155				900	20	6.6	
B16	**10-Jul-00**	200	7.8	0.05	150	0.3	0.02	69	0.32	175		1.8	0.14	930	29	4.3	
B16	**24-Jul-00**	245	7.9	0.05	185	0.31	0.06	88	0.63	200		1.9	0.13	1000	27	6.2	
B16	**21-Aug-00**	285	8	0.05	175	0.29	0.01	135	0.12	205		0.5	0.11	760	23		
B16	**4-Sep-00**	260	8.1	0.05	465	0.32	0.08	94	0.2	220		0.28	0.17	1620	24		
B16	**18-Sep-00**	270	7.8	0.05	200	0.31	0.03	26	0.13	220		0.33	0.16	1300	25		
B16	**9-Oct-00**	235	7.9		190	0.34	0.05		0.37				0.15	930	25	0.8	
B16	**23-Oct-00**	265	8.4		175	0.31	0.05		0.69				0.35	175	25		
B16	**6-Nov-00**	180	8	0.53	145	0.29	0.03	50	1.6	150		0.24	0.2	520	24	3.4	
B16	**20-Nov-00**	235	7.9	0.05	160	0.34	0.05	90	0.15	175			0.23	660	19		
B16	**4-Dec-00**	140	8	0.17	140	0.38	0.05	50	0.62	115				550	22	2.6	
B16	**18-Dec-00**	120	8		95	0.35	0.03		0.6				0.25	395	20	1.2	
B15	**10-Jan-00**	140	8.4	0.05	100	0.3	0.05	43	0.96	120				960	21		
B15	**24-Jan-00**	125	8.3		92	0.3									20		
B15	**7-Feb-00**	185	7.8	0.05		0.31	0.05	145	0.66	145	2			5	23		
B15	**21-Feb-00**	87	8.1	0.05	49	0.27	0.05	27	1.6	53				100	21		
B15	**6-Mar-00**	135	7.8	0.05	94	0.34	0.05	44	0.82	97				155	22		

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B15	**20-Mar-00**	96	7.7	0.05	72	0.24	0.05	30	0.51	69				77	12		
B15	**10-Apr-00**	115	8.1	0.05	77	0.26	0.05	36	0.16	77		0.72	0.14	740	17		
B15	**8-May-00**	155	7.7	0.05	115	0.27	0.05	50	0.05	120		1.1	0.14	620	20		
B15	**22-May-00**	190	7.8	0.05	120	0.26	0.05	67	0.05	145		1.2	0.08	860	24		
B15	**5-Jun-00**	220	7.8	0.05	135	0.29	0.05	81	0.05	180		1.5	0.07	860	17	5.2	
B15	**19-Jun-00**	220	7.8	0.05	140	0.3	0.05	77	0.05	170		1		870	19	6.2	
B15	**10-Jul-00**	215	7.8	0.05	165	0.3	0.05	72	0.05	175		1.7	0.08	650	21	8.3	
B15	**24-Jul-00**	235	8	0.05	165	0.31	0.05	86	0.1	190		1.4	0.14	950	23	5.1	
B15	**7-Aug-00**	230	7.8	0.05	170	0.32	0.05	82	0.14	190		0.61	0.11	970	21	2.5	
B15	**21-Aug-00**	255	8	0.05	160	0.3	0.05	20	0.1	185		0.29		620	20	4.3	
B15	**4-Sep-00**	235	7.9	0.05	180	0.31	0.05	80	0.27	205			0.13	880	22		
B15	**18-Sep-00**	250	7.8	0.05	200	0.31	0.05	85	0.32	210			0.09	1020	22		
B15	**9-Oct-00**	230	7.8		190	0.31							0.17	1050	29	1.2	
B15	**23-Oct-00**	230	3.1		170	0.33							0.18	180			
B15	**6-Nov-00**	175	8	0.53	140	0.3	0.05	50	0.05	150		0.33	0.16	540	31	5	
B15	**20-Nov-00**	215	7.9	0.05	160	0.36	0.05	80	0.2	160			0.19	690	18	3.3	
B15	**4-Dec-00**	140	7.7	0.14	115	0.39	0.29	35	0.05	86				420	25	1.7	
B15	**18-Dec-00**	120	7.9		96	0.36							0.26	345	18	6.1	
B6	**10-Jan-00**	200	4.1	1.4	100	0.29	0.32	41	3.8	145	19			100	14		
B6	**24-Jan-00**	91	4.7	2.1	60	0.38	0.05	25	4.9	51				52	12		
B6	**7-Feb-00**	77	4.9	1	36	0.34	0.05	19	2.3	42				100	16		
B6	**21-Feb-00**	80	6.9	0.05	31	0.31	0.05	28	1.9	40				100	19		
B6	**6-Mar-00**	77	6.9	0.05	30	0.43	0.05	23	0.8	42				205	20		
B6	**20-Mar-00**	76	6.7	0.05	36	0.31	0.05	20	1.6	40	1.9			340	15		
B6	**10-Apr-00**	150	6	0.18	81	0.29	0.05	40	3.9	82	13	8.6		970	11		
B6	**8-May-00**	115	5.8	0.59	69	0.34	0.05	31	2.3	66	0.83	8.7		520	11	9	
B6	**22-May-00**	125	5.1	0.74	77	0.35	0.13	36	2.3	77		8.7		890	14		
B6	**5-Jun-00**	165	4.9	1.9	110	0.54	0.05	44	3.3	99	3.7	16		850		10	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B6	**19-Jun-00**	175	4.7	2.6	115	0.65	0.05	46	3.8	105	5.8	15		750	11	10	
B6	**10-Jul-00**	120	4.8	1.1	79	0.32	0.05	37	1.5	64		13		325		12	
B6	**24-Jul-00**	93	4.9	0.05	61	0.33	0.15	28	0.57	150		5.4		480		10	
B6	**7-Aug-00**	88	5.8	0.28	81	0.27	0.05	25	1.1	145		3.5		330	14	8.2	
B6	**21-Aug-00**	89	6.5	0.05	74	0.27	0.05	23	1.2	58		2		290	12	7.8	
B6	**4-Sep-00**	84	6.3	0.05	64	0.26	0.19	26	1.1	170		0.3		270	11		
B6	**18-Sep-00**	70	6.6	0.05	48	0.21	0.05	27	0.75	175				225	13		
B6	**9-Oct-00**	79	6.8		53	0.25					4.7			255	21	3.2	
B6	**23-Oct-00**	57	6.7		23	0.34						0.21		205			
B6	**6-Nov-00**	120	6.8	0.55	62	0.28	0.22	28	1.1	66	3.3	2.2		395	17	6.3	
B6	**20-Nov-00**	230	4.8	0.9	130	0.33	0.05	51	5.8	130		6.3		880	12	8	
B6	**4-Dec-00**	73	6	0.2	35	0.26	0.34	17	1.7	33		1.8		275		6.6	
B6	**18-Dec-00**	86	7.6		42	0.48						2		240	16	3.4	
B17	**10-Jan-00**	120	8.4	0.05	100	0.31	0.05	32	1.8	110				100	21		
B17	**24-Jan-00**	105	8.3	0.05	89	0.31	0.05	29	1.3	89					22		
B17	**7-Feb-00**	155	8	0.05	100	0.22	0.05	48	0.66	125				5	27		
B17	**21-Feb-00**	88	8.1	0.05	52	0.27	0.05	28	1.1	59				100	22		
B17	**6-Mar-00**	64	7.7	0.05	40	0.23	0.05	19	0.05	42	2.1			170	30		
B17	**20-Mar-00**	120	7.9	0.05	84	0.27	0.05	41	0.11	88				19	15		
B17	**10-Apr-00**	96	8.2	0.05	66	0.27	0.05	32	0.05	64		0.22	0.15	440	21		
B17	**8-May-00**	125	7.8	0.05	100	0.27	0.05	40	0.22	105		1	0.17	560	22		
B17	**22-May-00**	165	8.1	0.05	110	0.27	0.05	52	0.12	125		0.22	0.1	640	28		
B17	**5-Jun-00**	225	7.7	0.05	160	0.3	0.05	86	1.5	185		1.7		930	21	5.2	
B17	**19-Jun-00**	240	7.8	0.05	145	0.31	0.05	83	0.96	180		1.1		1000	23	5	
B17	**10-Jul-00**	200	8	0.05	100	0.29	0.05	68	0.05	155				440	17	6.1	
B17	**24-Jul-00**	210	8.1	0.05	145	0.29	0.05	76	0.19	170		0.22	0.1	810	25	7.7	
B17	**21-Aug-00**	260	8.1	0.05	165	0.3	0.05	48	0.33	185				750	17	5.9	
B17	**4-Sep-00**	230	8.3	0.05	490	0.31	0.05	83	0.53	200			0.07	860	21		

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B17	**18-Sep-00**	240	7.9	0.05	200	0.33	0.05	86	0.52	205				960	20		
B17	**9-Oct-00**	175	7.8		150	0.32					1.5		0.23	560	25	1.7	
B17	**23-Oct-00**	235	8.4		170	0.31							0.18	340			
B17	**6-Nov-00**	185	8.2	0.54	160	0.32	0.05	53	0.05	160				560	33	4.4	
B17	**20-Nov-00**	195	8	0.05	145	0.35	0.05	69	0.05	150			0.14	470	19	5.7	
B17	**4-Dec-00**	140	7.6	0.12	145	0.38	0.05	49	0.05	115				660	25	2.7	
B17	**18-Dec-00**	130	8			0.37							0.16	385	20		
B11	**10-Jan-00**	140	8.4	0.05	100	0.4	0.05	41	1.3	115				1440	23		
B11	**24-Jan-00**	120	7.9	0.05	93	0.34	0.05	36	1.4	90				100	27		
B11	**7-Feb-00**	140	8	0.05	100	0.34	0.05	42	1.5	110				100	23		
B11	**21-Feb-00**	77	8	0.05	44	0.29	0.05	25	1.1	41				100	21		
B11	**6-Mar-00**	97	7.8	0.05	65	0.33	0.05	30	0.3	66				90	25		
B11	**20-Mar-00**	115	7.9	0.05	80	0.28	0.05	37	0.3	84				380			
B11	**10-Apr-00**	91	8.2	0.05	67	0.27	0.05	30	0.12	60			0.22	350			
B11	**22-May-00**	155	8	0.05	110	0.17	0.05	52	0.2	120		0.23		570	22		
B11	**5-Jun-00**	220	7.6	0.05	140	0.3	0.05	75	1.4	190		1.7		980	20	5.5	
B11	**19-Jun-00**	180	7.9	0.05	130	0.28	0.05	65	0.05	145				650		7.4	
B11	**10-Jul-00**	200	7.9	0.05	110	0.29	0.05	71	0.11	155				350		8.5	
B11	**24-Jul-00**	205	8.1	0.05	180	0.29	0.05	75	0.23	170		0.98		870		8.6	
B11	**21-Aug-00**	260	8.1	0.05	170	0.29	0.05	22	0.29	180				620		7.7	
B11	**4-Sep-00**	265	8.1	0.05	180	0.3	0.05	82	0.36	195	0.67			740			
B11	**18-Sep-00**	235	8.1	0.05	180	0.32	0.05	86	0.54	200				800			
B11	**9-Oct-00**	235	8.1		185	0.33								910	22	12	
B11	**23-Oct-00**	235	8.1		180	0.35							0.11	180	21		
B11	**6-Nov-00**	210	8.2	0.56	165	0.33	0.05	61	0.05	185				660	24	2.7	
B11	**20-Nov-00**	200	8.1	0.05	155	0.35	0.05	71	0.3	180				590	21		
B11	**4-Dec-00**	200	7.9	0.16	155	0.39	0.05	56	0.1	130				690		5.4	
B11	**18-Dec-00**	145	8		110	0.37							0.14	395	21	1	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	8-Jan-01	81	7.8	0.02	93	0.23	0.06	13	0.81	88	1.4	0.53	2.5	61		3.3	
B5	22-Jan-01	120	8	0.05	160	0.18	0.14	18	0.23	140	3.1		0.66	115	105	2.2	33
B5	5-Feb-01	135	7.9	0.05	175	0.28	0.18	27	1	175	3.9		1.1	130	65		
B5	19-Feb-01	105	7.6	0.05	135	0.21	0.06	16	0.21	110		0.21	0.19	110		4.3	
B5	5-Mar-01	120	8.4	0.03	130	0.24	0.1	11	0.14	160		0.66	2.2	98		0.92	
B5	19-Mar-01	105	7.7	0.05	120	0.24	0.05	24	0.41	125	3.6	2.5	0.55	115	23	3.1	
B5	9-Apr-01	105	7.9	0.05	120	0.3	0.12	17	0.35	105	3		0.69	105	39		20
B5	23-Apr-01	120	8	0.05	155	0.32	0.05	10	0.05	52		0.88		110	11	2.4	22
B5	7-May-01	190	8	0.1	285	0.26	0.15	25	0.17	260	2.7	0.26	0.36	180		2.5	
B5	21-May-01	105	8.5	0.05	125	0.29	0.09	11	0.43	135	0.59	0.45	1	97		5.6	
B5	4-Jun-01	125	7.9	0.05	165	0.1	0.1	20	0.45	140	4.8	0.22	0.85	100	91		64
B5	18-Jun-01	120	7.8	0.18	140	0.23	0.08	11	0.13	140		1.3	0.94	100		1.1	
B5	9-Jul-01	120	7.9	0.19	140	0.28	0.07	10	0.04	150		0.47	1.1	105		6.6	
B5	23-Jul-01	99	7.9	0.15	105	0.33	0.58	16	0.21	120	1.2	0.65	0.33	120	28	4.9	
B5	6-Aug-01	175	8.4	0.19	270	0.25	0.11	24	0.23	255	0.71		0.59	100	135	2.7	
B5	20-Aug-01	200	7.9	0.33	295	0.25	0.24	25	0.23	255	3.5	0.49	0.57	180		2.5	
B5	3-Sep-01	220	8.3	0.86	265	0.27	0.18	18	0.1	360	2.3		1.2	180			
B5	17-Sep-01	85	7.7		71	0.33					0.65	0.52	0.16	135	16	5.7	
B5	8-Oct-01	145	8	0.05	220	0.11	0.06	21	0.03		2.8		0.8	120	86		
B5	22-Oct-01	165	7.9	0.2	240	0.32	0.23	22	0.25	220	2	0.37	0.37	165		1.3	
B5	5-Nov-01	105	7.8	0.05	125	0.26	0.05	24	0.26	125	2.2	1.3	0.47	190	50	6.5	22
B5	19-Nov-01	71	7.8	0.02	79	0.39	0.13	11	0.34	76		0.3	0.14	82		3.8	
B5	3-Dec-01	110	7.8		135	0.32	0.05	18	0.46	150	0.71	0.42	3.1	105		4.2	
B16	8-Jan-01	140	8.1		145	0.31	0.03		0.03					495	20	1.7	
B16	22-Jan-01	200	8.1	0.05	93	0.34		56		165				540	25	3.2	
B16	5-Feb-01	240	8.2	0.12	165	0.37	0.01	71	0.51	235			0.25	800	33	2.8	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B16	**19-Feb-01**	165	7.7		130	0.5	0.01		0.32		1.6		0.65	370	30		
B16	**5-Mar-01**	190	8	0.05	140	0.36	0.01	53	0.45	160			0.11	365	27	4.4	
B16	**19-Mar-01**	210	8	0.05	155	0.34	0.01	56	0.14	165			0.25	500	35	1.5	
B16	**9-Apr-01**	210	7.9	0.05	150	0.36	0.05	57	0.24	170			0.23	570	37	2.4	21
B16	**23-Apr-01**	175	7.9	0.05	140	0.51	0.03	45	0.24	130			0.32	1030	29	2.3	
B16	**7-May-01**	215	8.3	0.05	155	0.32	0.11	58	0.8	170			0.1	1420	20	7.7	
B16	**21-May-01**	245	8.4	0.05			0.01	56	0.68	165					19		
B16	**4-Jun-01**	250	8.5	0.51			0.06	62	0.55	185					20	7.8	
B16	**18-Jun-01**	250	8.2	0.05			0.01	65	0.29	185					17	6.9	
B16	**9-Jul-01**	265	8	0.05	175	0.26	0.05	65	1.3	64				99	17	4.3	
B16	**23-Jul-01**	235	8.3	0.05	190	5.6	0.02	74	0.16	69		1	0.16	1990	21	1.2	
B16	**6-Aug-01**	180	8	0.05	145	4.3	0.04	51	0.63	145		1.8	0.19	400	26	2.6	
B16	**20-Aug-01**	265	8.4	0.1	240	0.5	0.05	77	0.26	280		0.22	0.1	990	27		
B16	**3-Sep-01**	240	8.4	0.05	220	0.44	0.05	71	0.53	205		1.1	0.17	420	24	1.6	
B16	**17-Sep-01**	255	8.4	0.1	210	0.45	0.01	68	0.64	205		0.24		570	20	5.9	24
B16	**8-Oct-01**		7.9	0.05	115	0.29	0.01	69	0.53	235			0.16	520	25	3.5	
B16	**22-Oct-01**		8.1	0.05			0.01	68	0.73	265			0.12		24	5.1	22
B16	**5-Nov-01**		8.1	0.05	175	0.35		60		155	1	0.27	0.32	495	29	4.4	24
B16	**19-Nov-01**	135	8.5	0.05	120	0.33	0.09	35	0.53	170		0.45	0.29	395	21	3.5	39
B16	**3-Dec-01**	145	8.7	0.05	110	0.38	0.02	45	0.99	120			0.17	425	28	3.4	
B15	**8-Jan-01**	190	8.2		145	0.31							0.22	580	17	3.3	
B15	**22-Jan-01**	240	8	0.05	98	0.32	0.05	65	0.59	190				660	24	3.1	
B15	**5-Feb-01**	215	8.2	0.18	150	0.37	0.05	55	0.46	165			0.24	445	29	4.5	
B15	**19-Feb-01**	210	7.7		160	0.23							0.3	560	32	2.5	
B15	**5-Mar-01**	165	7.9	0.05	130	0.36	0.2	45	0.45	140			0.23	370	22	1.5	
B15	**19-Mar-01**	200	7.9	0.05	150	0.36	0.19	54	1.2	160			0.25	550	32	3	
B15	**9-Apr-01**	210	7.9	0.05	140	0.37	0.05	55	0.42	155			0.23	580	36	2	
B15	**23-Apr-01**	230	8	0.05	160	0.39	0.05	63	0.14	190			0.18	1530	32	2.2	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**7-May-01**	200	8.1	0.05	155	0.35	0.05	52	0.1	160		0.69	0.11	1120	18	3.4	
B15	**21-May-01**	205	8.4	0.05			0.05	53	0.05	160					20	0.74	
B15	**4-Jun-01**	245	8.6	0.56			0.03	66	0.03	190					15	3.9	
B15	**18-Jun-01**	255	8.1	0.05			0.03	63	0.07	190					21	3	
B15	**9-Jul-01**	220	7.7	0.05	170	0.34	0.03	65	0.18	64			0.09	81	19	3.3	
B15	**23-Jul-01**	250	8.3	0.05	115	0.28	0.03	70	0.09	65		0.36	0.16	620	19		
B15	**6-Aug-01**	255	8	0.05	190	2.9	0.03	73	0.15	220		0.34	0.07	395	22	4.5	
B15	**20-Aug-01**	255	8.4	0.1	235	0.49	0.06	77	0.14	250		0.38	0.08	970	22		
B15	**3-Sep-01**	245	8.4	0.05	215	0.43	0.03	72	0.2	200		0.86	0.17	620	26	3.2	20
B15	**17-Sep-01**	225	8.4	0.1	205	0.46	0.05	58	0.25	180		1.1	0.19	355	25	3.8	
B15	**8-Oct-01**	220	7.7	0.05	88	0.24	0.1	72	0.6	215			0.26	500	28	1.6	
B15	**22-Oct-01**	220	7.9	0.05			0.33	70	1.8	255			0.22		28	4.2	
B15	**5-Nov-01**	165	8.3	0.05	170	0.36	0.43	47	2	140		0.38	0.32	310	28	5	
B15	**19-Nov-01**	135	8.5	0.05	120	0.33	0.11	35	0.52	170		0.61	0.29	395	22	2.7	
B15	**3-Dec-01**	165	8.7	0.05	120	0.37	0.2	48	1.1	125		0.23	0.26	330	24	6.6	
B6	**8-Jan-01**	90	7.9		51	0.4								305	13	5.7	
B6	**22-Jan-01**	83	7.4	0.05	38	0.44	0.05	21	0.59	48				260	24	6.7	
B6	**5-Feb-01**	97	6.6	0.19	63	0.32	0.05	16	0.2	175		1.6		285	14	9	
B6	**19-Feb-01**	93	6.8		65	0.5								295	11	8.3	
B6	**5-Mar-01**	69	6.9	0.05	39	0.42	0.05	16	0.26	37				210	13	9.1	
B6	**19-Mar-01**	65	7.1	0.05	38	0.44	0.05	15	0.29	35				205	14	4.4	
B6	**9-Apr-01**	68	7.1	0.05	51	0.58	0.05	15	0.28	39				190	27	6.2	
B6	**23-Apr-01**	63	7.2	0.05	46	0.57	0.05	15	0.2	40				165	13	7.8	
B6	**7-May-01**	76	7.3	0.3	62	0.44	0.05	17	0.24	52				210		9.9	
B6	**21-May-01**	64	7	0.05			0.05	15	0.25	37							
B6	**4-Jun-01**	105	9.3	0.25			0.32	14	1.1	36	3				36	5.9	
B6	**18-Jun-01**	56	7.4	0.05			0.03	15	0.32	34					13	6.8	
B6	**9-Jul-01**	66	6.7	0.05	42	0.42	0.03	18	0.34	12				185	15	6.5	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B6	**23-Jul-01**	100	7.4	0.05	83	4.1	0.03	28	0.58	19		4.4		340		10	
B6	**6-Aug-01**	110	7	0.05	100	3.4	0.03	31	0.33	73		0.54		365		11	
B6	**20-Aug-01**	140	7.1	0.1	115	0.35	0.07	40	0.1	115		0.24		360	15		
B6	**3-Sep-01**	145	7	0.05	155	0.41	0.03	36	0.15	91		0.21		235	19	6.1	
B6	**17-Sep-01**	86	6.8	0.1	58	0.39	0.05	23	0.48	45		1.3		310	11	7.8	
B6	**8-Oct-01**	93	7.1	0.05	62	0.42	0.06	29	0.37	67				365	15	1.2	
B6	**22-Oct-01**	84	6.5	0.05	32	0.33	0.06	26	0.31	54				380		6.7	
B6	**5-Nov-01**	62	7.1	0.12	21	0.32	0.07	18	0.29	38			0.07	245		6.7	
B6	**19-Nov-01**	56	6.6	0.05	22	0.36	0.11	14	0.28	33		0.67		220		6.2	25
B6	**3-Dec-01**	65	7.2	0.05	33	0.5	0.17	20	0.8	34				235	17	6.7	
B17	**8-Jan-01**	140	8.1		120	0.31					1.1		0.32	365	20	2.5	
B17	**22-Jan-01**	225	8	0.05	95	0.33	0.17	60	0.98	175				610	22	1.9	
B17	**5-Feb-01**	220	8.2	0.05	185	0.36	0.62	68	3	200			0.18	510	31	5.4	
B17	**19-Feb-01**	165	7.6		130	0.51					1.7		0.65	390	31		21
B17	**5-Mar-01**	135	7.8	0.1	110	0.44	0.53	35	0.91	105	0.62		0.26	225	25	4.6	
B17	**19-Mar-01**	195	8	0.05	155	0.38	0.05	52	0.15	160			0.21	440	35	2.5	
B17	**9-Apr-01**	205	8	0.05	100	0.39	0.05	23	0.05	46			0.16	530	34	2.8	
B17	**23-Apr-01**	175	7.9	0.05	140	0.51	0.05	45	0.38	125	0.61		0.32	1000	25	1.9	
B17	**7-May-01**	140	8	0.05	155	0.36	0.05	35	0.05	91		0.78	0.07	385	16	5.2	
B17	**21-May-01**	205	8.5	0.05			0.05	52	0.05	165					15		
B17	**4-Jun-01**	165	8.6	0.52			0.32	42	0.37	120	1.1				22	2.6	
B17	**18-Jun-01**	175	8.1	0.05			0.03	45	0.06	135	0.52				24	1.3	
B17	**9-Jul-01**	280	7.8	0.05	170	0.32	0.03	66	0.19	65			0.12	51	24	2.9	
B17	**23-Jul-01**	220	8.3	0.05	185	3.9	0.03	67	0.18	62		1.1	0.08	1900	15	2.2	
B17	**6-Aug-01**	175	8	0.05	145	4.5	0.03	50	0.03	140		1.8	0.27	390	26	1.4	
B17	**20-Aug-01**	250	8.4	0.1	240	0.47	0.05	77	0.05	235		0.41	0.08	880	19	3.8	
B17	**3-Sep-01**	245	8.3	0.05	230	0.35	0.03	80	0.11	265		0.23		405	23		22
B17	**17-Sep-01**	215	8.4	0.1	205	0.45	0.05	58	0.24	180		1.1	0.18	475	24	3.9	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B17	**8-Oct-01**		7.7	0.05	115	0.3	0.03	29	0.03	56			0.29	640	25	2.7	
B17	**22-Oct-01**	170	7.8	0.05			0.49	49	2.7	165	0.97		0.4		24	5.3	
B17	**5-Nov-01**	190	8.4	0.05	170	0.34	0.03	58	0.12	145		0.21	0.17	340	20	5.6	
B17	**19-Nov-01**	170	8.5	0.05	145	0.36	0.03	46	0.08	170			0.15	415	20	4	21
B17	**3-Dec-01**	97	8.6	0.05	72	0.43	0.26	26	1.3	63			0.31	250	22	2.2	
B11	**8-Jan-01**	175	8.5		150	0.35								500	22	7.3	
B11	**22-Jan-01**	195	8.2	0.11	93	0.37	0.61	52	3.3	160				455	29	2.7	
B11	**5-Feb-01**	210	8.3	0.05	170	0.39	0.19	20	0.41	170			0.1	570	25	9.4	21
B11	**19-Feb-01**	215	8.1		165	0.21							0.11	550	39	5.7	22
B11	**5-Mar-01**	200	8.1	0.05	145	0.38	0.44	58	1.1	170				410	29	5.1	
B11	**19-Mar-01**	200	8.2	0.05	46	0.39	0.05	13	0.05	32		0.4	0.99	26	42	2	
B11	**9-Apr-01**	205	8.2	0.05	150	0.39	0.05	55	0.49	160				570	45	7.8	24
B11	**23-Apr-01**	210	8.2	0.05	170	0.41	0.14	58	0.76	175				1380	29	6.5	
B11	**7-May-01**	210	8.2	0.05	160	0.32	0.05	56	0.51	175				1350	24	8.4	33
B11	**21-May-01**	210	8.5	0.05			0.05	54	0.16	165					21	6.5	
B11	**4-Jun-01**	230	8.6	0.54			0.03	65	0.03	185						3.7	
B11	**18-Jun-01**	240	8.2	0.05			0.03	63	0.22	195						3.5	20
B11	**9-Jul-01**	255	8	0.05	175	0.3	0.03	63	0.18	63				120	21	5.8	22
B11	**23-Jul-01**		8.4	0.05	185	4.9	0.03	68	0.22	64		4.3				9.7	34
B11	**6-Aug-01**	270	8.1		190	2.9						0.82		620		12	61
B11	**20-Aug-01**	245	8.4	0.1	180	0.34	0.07	78	0.38	245		0.37		940	20		23
B11	**3-Sep-01**	255	8.3	0.05	230	0.36	0.03	76	0.09	230		0.21		720	22	4.8	
B11	**17-Sep-01**	255	8.4	0.1	210	0.46	0.05	67	0.17	210		0.27		310	23	6.1	25
B11	**8-Oct-01**		7.8	0.05	95	0.24	0.07	69	0.42	230				420	31		
B11	**22-Oct-01**		8	0.05	200	0.33	0.06	68	0.35	270				650	24	5.7	29
B11	**5-Nov-01**	235	8.3	0.05	175	0.34	0.06	63	0.24	170		0.22	0.13	400		7.7	
B11	**19-Nov-01**	170	8.5	0.05	145	0.36	0.03	46	0.08	170			0.18	450		4.7	
B11	**3-Dec-01**	155	8.8	0.05	125	0.38	0.07	45	0.22	130			0.1	445	27	6.1	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	**7-Jan-02**	78	8	0.02	94	0.46	0.01	13	1.4	82	1.2	0.28	0.34	82			
B5	**21-Jan-02**	125	7.9	0.05	175	0.27	0.18	24	0.36	185	3.4		0.74	110	76	1.1	
B5	**4-Feb-02**	125	8	0.05	140	0.18	0.1	17	0.9	125	15		1.9	100	115	3.5	
B5	**18-Feb-02**	93	7.8		105	0.32	0.03	55	0.23	81	4.6	0.3	7	80		3.2	
B5	**4-Mar-02**	110	8.4		140	0.27	0.09	14	0.49	110	0.7	1.8	0.43	120		6.6	
B5	**18-Mar-02**	92	7.9	0.03	110	0.32	0.07	12	0.51	125	0.62	0.6	1.5	98	77	4	
B5	**8-Apr-02**	140	8	0.05	195	3.5	0.13	22	0.37	57	4.1	8.7	0.73	140	67		30
B5	**22-Apr-02**	170	8.7	0.05	240	0.39	0.22	27	0.52	195	5.6		0.93	150	100		34
B5	**6-May-02**	100	8	0.08	99	0.31	0.06	16	0.49	125	0.53	4.1	0.42	155		6	
B5	**20-May-02**	135	7.9	0.15	195	0.41	0.17	19	0.6	180	0.5	0.29	0.35	130		1.7	
B5	**3-Jun-02**	125	7.8	0.05	165	0.33	0.24	26	0.74	165	6		0.92	170	93		26
B5	**8-Jul-02**	135	8	0.05	180	0.21	0.09	22	0.55	125	6.2		1.4	110	120		32
B5	**22-Jul-02**	175	8.4	0.12	260	0.36	0.27	29	0.8	255	2.6	0.33	0.17	210	105	1.2	38
B5	**5-Aug-02**	125	8.3	0.07	150	0.3	0.08	17	0.18	180		0.86	0.65	145		18	
B5	**19-Aug-02**	150	8.1	0.13	200	0.25	0.11	20	0.1	180	1.4	0.87	0.34	155		2.5	
B5	**2-Sep-02**	130	8.1	0.15	190	0.38	0.09	19	0.19	185	1.7		0.42	130	215	1.3	
B5	**16-Sep-02**	135	8.2	0.05	195	0.29	0.15	19	0.4	165	3.4		0.77	120	70	1.7	37
B5	**7-Oct-02**	155	7.9	0.05	235	0.33	0.13	27	0.27	270	2.3		0.16	190	60	3.2	
B5	**21-Oct-02**	115	7.6	0.1	135	0.21	0.17	14	4	120	1.9	0.38	0.3	125		2.2	
B5	**4-Nov-02**	115	8.1	0.19	92	0.31	0.05	14	0.22	160	0.72		0.13	130	65	1.2	27
B5	**18-Nov-02**	160	8	0.11	260	0.55	0.19	29	0.44	245	5.5	0.74	0.84	160	105		33
B5	**2-Dec-02**	105	8.4	0.05			0.14	17	0.4	105	2.5				66		
B16	**7-Jan-02**	175	7.8	0.05	140	0.32	0.03	51	3.9	120	0.74	0.2	0.35	510	22	2.2	
B16	**21-Jan-02**	200	7.9	0.05	155	0.36	0.02	59	0.26	160			0.3	650	21	3.3	
B16	**4-Feb-02**	165	8.3	0.05	135	0.47	0.05	50	1.2	145			0.32	470	20	1.4	
B16	**18-Feb-02**	155	8.6	0.05	145	0.33	0.01	52	0.17	170			0.4	390	24	2.8	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B16	**4-Mar-02**	185		0.05	130	0.3	0.02	59	0.64	155			0.39	495	18	2	
B16	**18-Mar-02**	160	8.3	0.05	120	0.45	0.03	50	0.39	135			0.22	470	19	2.7	
B16	**8-Apr-02**	200	8.2	0.05	155	0.38	0.35	65	1.5	200			0.24	540	17	2.6	
B16	**22-Apr-02**	230	7.9	0.05	170	0.32	0.05	70	0.86	220	0.65	0.48	0.28	800	20	2.3	
B16	**6-May-02**	220	8.4	0.05	180	0.27	0.01	88	0.22	205		0.47	0.37	840	17	2.2	
B16	**20-May-02**	225	8.2	0.05	175			78	1.6	170			0.14		17	2	
B16	**3-Jun-02**	215	8.1	0.05	170		0.05	74	0.39	175	1.7		0.43	180	32	2.5	
B16	**8-Jul-02**	215	8.1	0.05	170	0.18	0.05	69	0.16	125		0.48	0.23	580	18	3.9	
B16	**22-Jul-02**	215	8.2	0.05	200	0.26	0.01	76	0.3	170				640	16	4.4	
B16	**5-Aug-02**	245	8.1	0.05	180	0.18	0.02	88	0.29	195		0.58	0.2	920	28	2.9	
B16	**19-Aug-02**	255	8.2	0.05	185	0.16	0.01	85	0.19	200	0.98	0.26	0.44	830	14	2.6	
B16	**2-Sep-02**	215	8.2	0.05	185		0.04	65	0.42	205			0.18	530	22	3.8	
B16	**16-Sep-02**	225	8	0.05	180	0.23	0.01	82	0.14	160		0.6	0.36	700	22	2	
B16	**7-Oct-02**	265	7.9	0.05	190	0.42	0.01	95	2.6	175	0.96	0.28	0.42	870	23	1.9	
B16	**21-Oct-02**	240	8.2	0.05	175	0.31	0.02	71	2.1	165			0.45	770	27	3.7	
B16	**4-Nov-02**	240	8.2	0.05	185	0.3	0.01	87	2.6	165			0.25	760	31	4	
B16	**18-Nov-02**	265	8.3	0.05	185	0.37	0.02	87	0.4	155		1.6	0.17	1030	44	5.8	21
B16	**2-Dec-02**	250	8	0.05	180	0.35	0.21	80	0.9	165			0.46	860	54	3.6	
B15	**7-Jan-02**	170	7.9	0.05	145	0.32	0.21	48	1.2	125			0.34	355	19	2.6	
B15	**21-Jan-02**	200	8	0.05	160	0.37	0.24	58	1.3	155			0.29	480	21	2.6	
B15	**4-Feb-02**	160	8.2	0.05	135	0.44	0.24	48	1.4	130			0.35	465	20	3.2	
B15	**18-Feb-02**	160	8.6	0.05	140	0.4	0.84	53	1.8	165			0.38	360	37	2.6	
B15	**4-Mar-02**	185		0.05	125	0.3	0.55	58	1.2	145			0.39	425	18	2.2	
B15	**18-Mar-02**	180	8.3	0.05	135	0.43	0.23	55	0.95	155			0.35	590	19	2.2	
B15	**8-Apr-02**	220	8.2	0.05	150	0.4	0.31	67	0.12	205		0.21	0.36	660	15	2.4	
B15	**22-Apr-02**	215	8	0.05	160	0.31	0.08	66	0.36	200		0.36	0.32	780	15	2.5	
B15	**6-May-02**	220	8.4	0.05	175	0.27	0.03	89	0.42	205		0.51	0.38	810	17	1.4	
B15	**20-May-02**	235	8.1	0.05	165		0.03	78	0.03	155		0.32	0.23		17	2.6	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**3-Jun-02**	210	8.1	0.05	165	0.16	0.03	71	0.03	165			0.31	790	26	4	
B15	**8-Jul-02**	215	8	0.05	165	0.16	0.03	70	0.13	115		0.48	0.21	640	17	3.2	
B15	**22-Jul-02**	220	8.1	0.05	185	0.22	0.03	76	0.14	175		0.81	0.12	710	23	4.2	
B15	**5-Aug-02**	220	8.1	0.05	175	0.13	0.03	78	0.37	175		0.33	0.21	810	21	4.1	
B15	**19-Aug-02**	230	8.3	0.05	180	0.12	0.03	73	0.34	195		0.46	0.35	740	28	3.7	
B15	**2-Sep-02**	205	8.1	0.05	185	0.14	0.03	57	0.46	195		0.45	0.39	540	24	1.8	
B15	**16-Sep-02**	210	8.1	0.05	185	0.42	0.03	72	0.28	145		0.38	0.37	590	25	3.3	
B15	**7-Oct-02**	240	8	0.05	185	0.32	0.03	79	0.48	185		0.4	0.4	680	23	3.1	
B15	**21-Oct-02**	240	8.2	0.05	180	0.29	0.03	70	0.03	185			0.45	790	24	4.1	
B15	**4-Nov-02**	210	8	0.05	160	0.17	0.03	56	0.53	135		0.28	0.42	560	27	3.9	
B15	**18-Nov-02**	235	7.7	0.05	180	0.36	0.03	81	0.39	140		0.21	0.43	840	27	4.4	
B15	**2-Dec-02**	250	8.1	0.05	180	0.37	0.14	85	0.87	170		0.32	0.46	830	28	3.2	
B6	**7-Jan-02**	64	6.9	0.05	38	0.48	0.03	19	0.16	33				225		5.7	
B6	**21-Jan-02**	66	8.3	0.05	27	0.48	0.03	14	0.07	26				160		5.2	
B6	**18-Feb-02**	61	7.7	0.05	33	0.53	0.34	19	0.76	35				230		2.4	
B6	**4-Mar-02**	45		0.05	22	0.39	0.34	14	0.85	21				135	13	5.3	
B6	**18-Mar-02**	74	7.8	0.05	50	0.5	0.17	21	0.75	50				205	11	6.7	
B6	**8-Apr-02**	81	7.6	0.05	57	0.54	0.19	24	0.08	63				230		5.2	22
B6	**22-Apr-02**	83	7.5	0.05	73	0.43	0.07	24	0.3	72				215		5.6	
B6	**6-May-02**	85	7.8	0.05	77	0.42	0.33	31	0.32	92	0.51	0.24		220		5.1	
B6	**20-May-02**	88	7.8	0.05	79	0.23	0.03	22	0.11	70				205	12	7.1	
B6	**3-Jun-02**	81	7.6	0.05	67	0.1	0.03	22	0.03	54		1		220	19	7.1	26
B6	**8-Jul-02**	85	7.9	0.05	61	0.25	0.05	22	0.41	61				260		9.5	
B6	**22-Jul-02**	90	7.8	0.05	68	0.32	0.03	27	0.37	65				280		9.4	
B6	**5-Aug-02**	91	7.9	0.05	74	0.2	0.03	30	0.22	83				275		7.1	
B6	**19-Aug-02**	100	7.8	0.05	86	0.26	0.03	28	1	75		0.41		305	12	8.3	
B6	**2-Sep-02**	100	7.5	0.05	110	0.35	0.03	25	0.21	78		0.27		260	17	7.2	
B6	**16-Sep-02**	99	7.4	0.05	110	0.48	0.03	25	0.21	83				255	33	6.7	25

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B6	**7-Oct-02**	115	7	0.05	165	0.38	0.03	25	0.13	97		0.51		260	21	6.9	
B6	**21-Oct-02**	110	7.8	0.05	150	0.42	0.03	25	0.31	94		0.29		245	18	5.8	
B6	**4-Nov-02**	92	7.5	0.05	96	0.46	0.03	25	0.17	81				250	20	6.4	
B6	**2-Dec-02**	79	7.4	0.05	77	0.45	0.03	18	0.73	62	0.65	0.56		180	29	3.2	
B17	**7-Jan-02**	165	7.9	0.05	120	0.38	0.03	49	0.6	115			0.32	445	24	2.2	
B17	**21-Jan-02**	195	7.9	0.05	165	0.37	0.19	57	0.93	165			0.2	520	21	2.3	
B17	**4-Feb-02**	84	8.1	0.05	82	0.42	0.03	23	0.37	54			0.5	210	13	2	
B17	**18-Feb-02**	155	8.6	0.05	140	0.49	0.27	55	1.2	160			0.26	560	19	2.3	
B17	**4-Mar-02**	150		0.05	120	0.35	0.09	48	0.38	130			0.31	410	21	1.7	
B17	**18-Mar-02**	125	8.2	0.05	100	0.42	0.15	35	0.55	94			0.38	295	17	1.6	
B17	**8-Apr-02**	170	8.1	0.05	120	0.41	0.52	51	0.19	155		0.32	0.95	390	20	2.2	
B17	**22-Apr-02**	210	8	0.05	165	0.31	0.03	67	0.1	205		0.33	0.23	700	19	2	
B17	**6-May-02**	220	8.4	0.05	175	0.27	0.15	95	0.15	205		0.36	0.21	880	34	1.6	
B17	**20-May-02**	225	8.1	0.05	165	0.2	0.03	74	0.03	155			0.25			2	
B17	**3-Jun-02**	225	8.2	0.05	170	0.1	0.03	81	0.03	180			0.16	190	25	3.9	22
B17	**8-Jul-02**	210	8.2	0.05	175	0.29	0.03	73	0.03	125		0.41	0.13	590		4.3	
B17	**22-Jul-02**	220	8.1	0.05	170	0.3	0.03	77	0.15	175		0.68	0.13	670	20	5.6	
B17	**5-Aug-02**	215	8.2	0.05	185	0.29	0.03	69	0.23	69			0.15	760	21	3.7	
B17	**19-Aug-02**	225	8.3	0.05	185	0.32	0.03	73	0.32	205			0.23	690		3.7	
B17	**2-Sep-02**	205	8.1	0.05	180		0.03	59	0.52	220		0.41	0.42	520	23	2.2	21
B17	**16-Sep-02**	215	8.2	0.05	195	0.26	0.03	74	0.4	165		0.2	0.24	580	24	4.2	
B17	**7-Oct-02**	245	8.1	0.05	200	0.28	0.03	83	0.7	195		0.22	0.41	890	25	2.9	
B17	**21-Oct-02**	250	8.2	0.05	200	0.23	0.03	79	0.03	165			0.48	870	29	3.8	
B17	**4-Nov-02**	210	8	0.05	165	0.33	0.03	71	0.7	140		0.2	0.43	600	28	1.5	
B17	**18-Nov-02**	255	8.2	0.05	205	0.19	0.03	82	0.97	190			0.35	960	30	5.9	
B17	**2-Dec-02**	270	8.2	0.05	215	0.29	0.03	86	1.3	190		0.33	0.35	820	36	2.4	
B11	**7-Jan-02**	175	8	0.05	140	0.37	0.1	51	0.71	130			0.13	430	25	3.4	
B11	**21-Jan-02**	195	7.9	0.05	165	0.39	0.18	57	0.92	160				510		3.1	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B11	**4-Feb-02**	175	8.3	0.05	100	0.7	0.12	54	0.82	150		0.23	0.16	490	25	4.9	
B11	**18-Feb-02**	145	8.6	0.05	125	0.39	0.16	48	0.59	135			0.18	355	25	4.6	
B11	**4-Mar-02**	150		0.05	120	0.35	0.09	46	0.37	120			0.35	430	24	1.5	
B11	**18-Mar-02**	150	8.3	0.05	115	0.46	0.24	48	0.5	130			0.21	450	22	5.3	
B11	**8-Apr-02**	180	8.3	0.05	140	0.53	0.21	58	0.09	175		0.29	0.18	450	21	5.3	
B11	**22-Apr-02**	200	8.2	0.05	160	0.32	0.16	64	0.68	200		0.25	0.15	440		6.2	
B11	**6-May-02**	215	8.2	0.05	170	0.23	0.03	99	0.16	210		0.43	0.21	860		1.6	
B11	**20-May-02**	225	8.4	0.05	170		0.03	76	0.18	160					28	7.2	
B11	**3-Jun-02**	215	8.3	0.05	170		0.03	79	0.03	175				870	25	8.2	22
B11	**8-Jul-02**	210	8.2	0.05	175	0.13	0.06	70	0.03	120		0.23	0.11	560		5.3	
B11	**22-Jul-02**	215	8.2	0.05	175	0.25	0.03	75	0.27	175				650	21	6.8	56
B11	**5-Aug-02**	215	8.3	0.05	190	0.29	0.03	82	0.46	210				740	24	8.6	
B11	**19-Aug-02**	220	8.4	0.05	185	0.32	0.03	72	0.39	200				650	25	8	40
B11	**2-Sep-02**	215	8.2	0.05	185		0.03	73	0.64	215			0.13	620	30	6.7	42
B11	**16-Sep-02**	220	8.3	0.05	200	0.3	0.03	64	0.45	210			0.11	640	35	6.9	37
B11	**7-Oct-02**	235	8.2	0.05	205	0.35	0.03	82	0.78	220			0.17	670	37	6	24
B11	**21-Oct-02**	250	8.2	0.05	205	0.3	0.03	77	0.03	210			0.48	860	55	4.5	
B11	**4-Nov-02**	245	8.3	0.05	195	0.33	0.03	91	0.62	165			0.25	430	63	7	
B11	**18-Nov-02**	255	8.3	0.05	215	0.23	0.03	100	1.1	185			0.18	900	55	7.9	
B11	**2-Dec-02**	270	8.2	0.05	210	0.39	0.03	95	1.5	190		0.38	0.36	960	62	4	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	6-Jan-03	60	7.5		58	0.31	0.02	14	0.08	53	0.68	0.28	0.21	72		2.9	
B5	20-Jan-03	135	8	0.1	170	0.24	0.09	19	0.11	155	2.6	0.23	0.57	145		3.2	
B5	3-Feb-03	105	7.6	0.06	135	0.23	0.05	16	0.22	130				115		2.5	
B5	17-Feb-03	120	8.6	0.1	155	0.27	0.09	18	0.19	130	0.91	0.39	0.39	135		4.4	
B5	3-Mar-03	97	8		120	0.45	0.07	17	0.18	99	1.7		1.7	105		2.9	
B5	17-Mar-03	110	7.7		125	0.3	0.19	17	0.37	140		0.49		160		4.6	
B5	7-Apr-03	115	7.7		140	0.25	0.08	18	2.4	145	6		3.8	96		1.7	
B5	5-May-03	105	7.9		170	0.34	0.03	20	0.19	120	2.3	0.24	1.6	110		3.4	
B5	19-May-03	120	7.8	0.05	150	0.26	0.12	27	0.56	150	2.9	1.3	0.51	230	70	1.8	
B5	2-Jun-03	115	8.6	0.33			0.15	20	0.38	135	3.6				76	1.2	
B5	7-Jul-03	125	8	0.05	150		0.13	24	1.1	155	3.3	0.68	0.96	140	48		
B5	21-Jul-03	95	8	0.54	105	0.28	0.05	19	0.05	96	3.2		0.2	155	33	3	
B5	4-Aug-03	125	8.5	0.12	150	0.23	0.09	18	0.24	150	0.57		0.33	140		2.6	
B5	18-Aug-03	125	8.3	0.09	165	0.35	0.11	16	0.35	135	1.4	1.4	0.65	130		7	
B5	1-Sep-03	92	7.8	0.08	110	0.34	0.13	14	0.22	100	2		0.19	110		2.6	
B5	15-Sep-03	94	8.5		100	0.29					3.3		0.34	110	39	2.1	
B5	6-Oct-03	125	7.8		165	0.29					2.9		0.88	135	23		
B5	20-Oct-03	60	7.5	0.05	49	0.25	0.05	15	0.78	54	1.3			100	29		
B5	3-Nov-03	84	7.6	0.08	105	0.27	0.07	13	0.2	93			0.09	110		1.6	
B5	17-Nov-03	110	7.9		125	0.45					2.1		0.52	95	41	2.7	
B5	1-Dec-03	120	8	0.05	170	0.14	0.08	19	0.35	150	4.2	0.35	0.76	120	83	1.1	35
B5	15-Dec-03	130	8.1	0.05	175	0.12	0.03	18	0.03	135	5.7	0.31	0.86	115	120	1.4	54
B16	6-Jan-03	250	8.1	0.05	175	0.31	0.02	92	0.36	200		3.6	0.44	860	31	2.6	
B16	20-Jan-03	245	8.1	0.05	170	0.45	0.01	91	0.09	205		0.44	0.51	640	57	2.9	21
B16	3-Feb-03	195	8	0.05	140	0.59	0.01	77	0.95	135		0.54	0.72	660	28	1.2	
B16	17-Feb-03	215	8.3	0.05	175	0.36	0.02	88	0.68	175			0.49	550	42	1.1	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B16	**3-Mar-03**	165	8.1		125	0.31	0.49	46	2.3	155	0.82	0.86	0.68	450	31	5.2	
B16	**7-Apr-03**	180	8		135	0.3	0.02	60	1.3	155			0.78	520	25	2.2	
B16	**5-May-03**	230	7.8	0.02	160	0.34	0.06	79	1.1	115		7.7	0.48	800	25	3	
B16	**19-May-03**	220	8.4	0.02	160	0.33	0.03	78	4	140		0.45	0.43	650	26	8	
B16	**2-Jun-03**	240	8.4	0.05	165	0.35	0.05	87	0.88	180				760	24	4.4	
B16	**7-Jul-03**	200	7.7	0.04	165	0.35		55	0.2	175		1.2	0.22	560		4.3	
B16	**21-Jul-03**	200	7.8	0.02	160	0.35	0.05	65	0.49	215		0.42	0.26	560		12	
B16	**4-Aug-03**	79	8.1	0.02	65	0.3	0.09	11	0.25	98		3.3	0.48	120		27	
B16	**18-Aug-03**	245	8.4	0.02	165	0.5	0.02	79	0.06	195		0.22	0.31	850		15	
B16	**1-Sep-03**	220	7.7		160	0.45	0.03	67	1.4	220			0.33	800		10	
B16	**15-Sep-03**	245	8.2		180	0.42	0.03	67	1.4	210		0.44	0.23	880			
B16	**6-Oct-03**	245	8.1	0.03	200	0.46		96	0.46	210			0.43	870		4.5	
B16	**20-Oct-03**	250	8	0.06	175	0.44	0.03	89	0.66	170		0.24	0.51	1010		1.5	
B16	**3-Nov-03**	225	8.2		155	0.45	0.4	76	1.8	140			0.54	690		3.6	
B16	**17-Nov-03**	225	8		170	0.39		78	0.42	150			0.44	670		4.6	
B16	**1-Dec-03**	195	7.9	0.18	54	0.26	0.04	20	0.94	48		3.2	0.57	215		1.1	
B16	**15-Dec-03**	225	7.9		160	0.39	0.09	71	0.49	150			0.71	680		3.9	
B15	**6-Jan-03**	240	8.1	0.05	155	0.28	0.03	89	4.9	175		0.25	0.56	780	24	3.1	
B15	**20-Jan-03**	225	8.1	0.05	165	0.46	0.03	81	4	180		0.36	0.63	590	29	2	
B15	**3-Feb-03**	180	7.9	0.05	135	0.62	0.03	48	4.6	105		0.61	0.61	650	27	2.8	
B15	**17-Feb-03**	190	8.3	0.05	155	0.35	0.03	64	6.1	165			0.72	560	40	1.5	
B15	**3-Mar-03**	150	8.2		110	0.33	0.02	45	1	135			0.34	415	34	5.9	
B15	**17-Mar-03**	205	8.1		135	0.33		72	7.3	165			0.69	630	23	2.8	
B15	**7-Apr-03**	180	7.7		135	0.3	0.04	51	0.04	155			0.78	530	26		
B15	**5-May-03**	220	7.8	0.03	150	0.34	0.04	75	0.85	125		0.5	0.66	750	25	2.6	
B15	**19-May-03**	220	8.4	0.02	160	0.32	0.11	82	0.29	160			0.43	780	21	3.1	
B15	**2-Jun-03**	225	8.6	0.05	155	0.38	0.01	82	0.58	175		0.26		700	24	4.3	
B15	**7-Jul-03**	200	7.7	0.04	160	0.47	0.01	56	0.16	160		1	0.26	660		4.9	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**21-Jul-03**	200	7.7	0.02	160	0.35	0.01	58	0.13	225		0.43	0.26	570		9.2	
B15	**4-Aug-03**	215	8.1		155	0.34	0.01	60	0.15	190		0.24	0.31	850		12	
B15	**18-Aug-03**	215	8.4		160	0.37	0.03	66	0.24	190		0.24	0.34	610		13	
B15	**1-Sep-03**	220	7.8		160	0.43	0.03	72	0.17	195			0.33	750		12	
B15	**15-Sep-03**	230	8.1		165	0.36	0.02	63	0.2	195			0.43	830		4.8	
B15	**6-Oct-03**	230	8	0.02	170	0.49	0.04	90	0.51	185			0.53	760		6.8	
B15	**20-Oct-03**	230	8	0.05	175	0.45	0.01	79	0.2	145		0.22	0.48	820		4.5	
B15	**3-Nov-03**	220	8.2		155	0.52	0.02	75	0.31	140			0.53	690		3.5	
B15	**17-Nov-03**	210	7.9		160	0.43	0.02	66	0.22	140			0.61	540		4.2	
B15	**1-Dec-03**	195	7.9	0.2	44	0.22	0.02	14	0.34	37		3.3	0.65	150		3.3	
B15	**15-Dec-03**	225	8		160	0.39	0.01	71	0.18	155			0.7	730		4.3	
B6	**6-Jan-03**	98	6.6	0.05	56	0.29	0.03	26	0.6	73		0.2		360	13	5.8	
B6	**20-Jan-03**	73	6.7	0.05	35	0.45	0.03	19	0.4	51		0.33		275	21	6	
B6	**3-Feb-03**	73	6.7	0.05	45	0.44	0.03	15	0.15	43				245	13	4.3	
B6	**17-Feb-03**	49	6.5	0.05	21	0.38	0.03	12	1.4	24		0.26		185	21	5.7	
B6	**3-Mar-03**	62	7.8		30	0.45	0.01	15	0.44	44		0.24		195	12	6.5	
B6	**17-Mar-03**	56	7.6		25	0.46	0.02	10	0.55	27				145	17		
B6	**7-Apr-03**	74	7.4		51	0.41	0.03	18	0.41	52				230	13		
B6	**5-May-03**	80	7	0.02	60	0.33	0.03	21	0.36	62	0.71	0.55		250	15	4.2	
B6	**19-May-03**	91	7.9		82	0.33	0.07	20	0.08	72				260	14	6.2	
B6	**2-Jun-03**	94	7.5	0.04	165	0.33	0.04	85	0.35	190				740	16	7.2	40
B6	**7-Jul-03**	76	7.3	0.03	83	0.51	0.01	15	0.04	70				190		8.8	
B6	**21-Jul-03**	72	7.3		72	0.5	0.04	18	0.03	82				170		16	
B6	**4-Aug-03**	73	7.7	0.02	66	0.47	0.01	16	0.05	66				170		24	
B6	**18-Aug-03**	73	8	0.02	56	0.48	0.05	20	0.11	70				180		15	
B6	**1-Sep-03**	69	7.5	0.02	53	0.45	0.04	16	0.13	62				180			
B6	**15-Sep-03**	67	7.6	0.03	44	0.46	0.07	14	0.21	53		0.48		155		5.6	
B6	**20-Oct-03**	26	7.3	0.14		0.34	0.05	5.6	0.43	12		0.81		56		4.8	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B6	**17-Nov-03**	28	7.2			0.43	0.16	6.5	0.1	12				46		3.8	
B6	**1-Dec-03**	88	7.5	0.12	46	0.5		22	0.26	61				320		4	
B6	**15-Dec-03**	86	7.3	0.02	42	0.49	0.01	22	0.64	57				295		4	
B17	**6-Jan-03**	240	8.1	0.05	160	0.29	0.03	76	5	180		0.23	0.56	810	26	3.9	
B17	**20-Jan-03**	180	8.1	0.05	125	0.49	0.03	59	1.5	140			0.31	420	32	2.7	35
B17	**3-Feb-03**	200	8.1	0.05	150	0.57	0.03	96	1.2	135		0.27	0.37	720	29	1.8	
B17	**17-Feb-03**	140	8	0.05	115	0.39	0.03	42	2.7	120	1.4		0.93	365	42		
B17	**3-Mar-03**	135	8.1		99	0.33	0.03	36	0.96	125			0.42	375	28	1.7	
B17	**17-Mar-03**	185	8.1		140	0.35	0.01	57	1.2	170			0.58	530	35	4.1	
B17	**7-Apr-03**	195	8.1		140	0.33	0.03	20	0.11	51			0.47	600	29	3.2	
B17	**5-May-03**	215	7.9	0.02	160	0.33	0.05	75	0.38	120		0.97	0.39	670	26	2.8	
B17	**19-May-03**	230	8.5	0.02	165	0.3	0.11	87	0.38	150			0.26	730	27	3.9	
B17	**2-Jun-03**	225	8.6	0.04	66	0.22	0.01	68	0.22	160		0.21		180		5.9	
B17	**7-Jul-03**	215	8	0.03	170	0.44	0.01	63	0.6	180		0.29	0.17	530		7.2	
B17	**21-Jul-03**	210	8	0.02	170	0.41	0.01	67	0.63	235			0.12	760		17	
B17	**4-Aug-03**	220	8.1		170	0.41	0.01	65	0.49	195			0.2	750		19	
B17	**18-Aug-03**	225	8.5		175	0.43	0.03	71	0.8	195			0.19	760		15	
B17	**1-Sep-03**	230	7.8		180	0.44	0.01	74	1	215			0.18	920		19	
B17	**15-Sep-03**	225	8.1		165	0.43	0.01	60	0.15	195			0.44	710		4	
B17	**6-Oct-03**	230	8	0.03	170	0.46	0.06	83	0.49	175			0.52	800		3.1	
B17	**20-Oct-03**	245	8.2	0.02	195	0.48	0.01	86	0.55	160			0.27	840		7.8	
B17	**3-Nov-03**	235	8.2		175	0.44	0.02	81	1.5	160			0.46	790		3.6	
B17	**17-Nov-03**	210	7.9		160	0.43	0.03	66	0.22	140			0.6	550		2.9	
B17	**1-Dec-03**	230	8.1	0.15	140	0.33		54		120		0.92		550		2	
B17	**15-Dec-03**	235	7.9		195	0.36	0.05	73	1.1	160			0.73	680		3.4	
B11	**6-Jan-03**	260	8.1	0.05	210	0.31	0.03	110	1.5	210			0.31	810	53	6.6	23
B11	**20-Jan-03**	215	8.2	0.05	180	0.33	0.03	83	1	180			0.22	700	52	6	22
B11	**3-Feb-03**	215	8.3	0.05	165	0.44	0.03	65	0.81	120		0.29	0.3	930	43	3.7	

Site	**Date**	**EC**	**pH**	**AL**	**Cl**	**F**	**Fe**	**Mg**	**Mn**	**Na**	**NH_4**	**NO_3**	**PO_4**	**SO_4**	**COD**	**DO**	**SS**
B11	**17-Feb-03**	220	8.2	0.05	185	0.37	0.03	105	3.9	185			0.4	620	180	3.9	20
B11	**3-Mar-03**	155	8		120	0.33	0.02	48	5.8	155	0.68	0.63	0.67	425	63	2.1	
B11	**17-Mar-03**	185	8.1		140	0.35	0.01	57	1.6	170			0.59	520	82	1.9	
B11	**7-Apr-03**	195	8		140	0.33	0.03	10	0.08	42			0.46	610	68		
B11	**5-May-03**	210	8	0.02	165	0.34	0.03	77	0.83	135		0.3	0.31	650	77	7.2	46
B11	**19-May-03**	230	8.4	0.02	165	0.32	0.1	64	0.3	165		4.2	0.27	740	62	3.2	
B11	**2-Jun-03**	235	8.3	0.04	165	0.34	0.02	83	0.59	165				740	55	5.8	32
B11	**7-Jul-03**	220	8	0.03	175	0.43	0.01	69	0.46	170				570		9.6	
B11	**21-Jul-03**	210	7.9		170	0.41	0.01	67	0.61	220			0.12	580		21	
B11	**4-Aug-03**	220	8.2		170	0.4	0.01	67	0.28	195			0.1	930		22	
B11	**18-Aug-03**	225	8.4		180	0.35	0.01	83	0.6	200			0.1	730		8.4	
B11	**1-Sep-03**	230	7.9		175	0.43	0.01	72	1.1	220			0.18	870		11	
B11	**15-Sep-03**	240	8.2		190	0.38	0.02	69	0.46	215				850		7.7	
B11	**6-Oct-03**	245	8.2	0.03	205	0.45	0.03	100	0.83	210			0.19	930		6.7	
B11	**20-Oct-03**	250	8.2	0.05	205	0.41	0.01	90	0.85	170		0.23		860		7.3	
B11	**3-Nov-03**	235	8.2		180	0.49	0.02	82	1.5	170			0.47	870		5.2	
B11	**17-Nov-03**	235	8		185	0.41	0.02	84	1.2	165			0.26	830		7.2	
B11	**1-Dec-03**	245	8.2	0.03	195	0.41		81	1.3	175			0.33	750		3.6	
B11	**15-Dec-03**	240	7.9		195	0.38	0.01	73	1	175		8	0.8	750		3.5	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	5-Jan-04	135	8.1	0.05	200	0.1	0.15	19	0.2	185	1	0.4	0.27	140	72	3.5	23
B5	19-Jan-04	135	7.9		170	0.27					3.7	24	0.61	155	47	3.2	
B5	9-Feb-04	205	8.1	0.28	325	0.28	0.17	35	0.26	295	3.9	0.36	0.44	215		2.3	
B5	23-Feb-04	125	7.6	0.05	165	0.26	0.03	19	0.07	8.5	0.71		0.18	140		1.9	
B5	8-Mar-04	105	8.1	0.05	125	0.31	0.13	21	0.31	68	2		0.37	155	46	5.2	20
B5	26-Apr-04	74	7.5	0.02	77	0.55	0.04	16	0.67	72	4.6		0.6	130		2.6	
B5	10-May-04	120	7.9	0.05	150	0.27	0.2	25	1	145	2.6	0.8	0.79	130	58	2.2	
B5	24-May-04	120	7.9	0.05	170	0.33	0.06	22	0.03	150	1.8		0.41	130	27	2.1	35
B5	7-Jun-04	94	7.9	0.04	99	0.37	0.03	15	2.2	120		0.46	0.26	110		1.8	
B5	21-Jun-04	125	8.5	0.04	155	0.3	0.07	21	0.53	165	1.4	1.3	0.58	135		21	
B5	12-Jul-04	120	7.7	0.05	145	0.29	0.03	25	0.38	120	3.3	1.1	0.57	170	95	3.1	
B5	26-Jul-04	165	8	0.26	245	0.33	0.32	23	0.24	225	1.5	0.5	0.4	150		2	
B5	23-Aug-04	115	8	0.11	150	0.31	0.14	20	0.3	145	3.5	0.51	0.82	98	12	0.95	
B5	6-Sep-04	155	8.6	0.68	190	0.37	0.19	17	0.11	205	0.72		0.77	150		1.6	
B5	20-Sep-04	95	7.7	0.05	125	0.3	0.1	18	0.38	93	2.2		0.78	100	51	2.4	
B5	11-Oct-04	135	8.1	0.05	155	0.3	0.06	17	0.2	200	1.3	1.8	0.53	150		7	
B5	25-Oct-04	155	7.9	0.08	225	0.29	0.03	22	0.23	180	1.5		0.39	170			
B5	8-Nov-04	160	8.2	0.13	245	0.26	0.13	27	0.46	220		0.59	3.1	135	115	3.1	
B5	22-Nov-04	73	7.7	0.05	70	0.23	0.05	19	0.76	63	0.97		0.22	200	34		
B5	6-Dec-04	90	7.6	0.19	98	0.35	0.32	16	0.05	74	1.4			130	28	1.5	
B5	20-Dec-04	115	7.8	0.05	150	0.45	0.07	12	0.32	145	1.6	0.38	1	96		3.7	
B16	5-Jan-04	210	8.2	0.09	150	0.4	0.01	61	1.6	150			0.73	720		3	
B16	19-Jan-04	225	8	0.1	175	0.37	0.02	71	2.4	185			0.5	750		1.5	
B16	9-Feb-04	185	8.2		155	0.42	0.1	52	0.48	140			0.63	450		2.5	
B16	23-Feb-04	175	7.9	0.07	130	0.36		47	1.3	125			0.54	470		3.1	
B16	8-Mar-04	130	7.8		115	0.4	0.01	34	1.1	140			0.51	315			

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B16	**26-Apr-04**	205	8.4		135	0.53	0.01	68	3.6	140			0.27	630		2.9	
B16	**10-May-04**	200	8.2		135	0.34	0.02	66	0.94	125			0.38	670			
B16	**24-May-04**	190	8.2			0.35	0.02	63	0.53	145			0.3	590		5.7	
B16	**7-Jun-04**	200	7.9		140	0.37		62		120		0.2		690		3.8	
B16	**21-Jun-04**	190	8.1		140	0.5	0.04	63	2	115		0.65	0.21	660		3.9	
B16	**12-Jul-04**	195	8.4		155	0.35	0.03	61	0.03	130		0.47	0.28	680		5	
B16	**26-Jul-04**	190	8.5		160	0.38		59	3.5	140			0.09	560		4.6	
B16	**23-Aug-04**	200	8.5		155	0.4	0.01	62	1.6	170			0.3	640		4.8	
B16	**6-Sep-04**	200	8.2		170	0.42	0.02	59	0.3	165			0.21	500		3.1	
B16	**20-Sep-04**	220	8.5		160	0.39	0.05	72	0.12	185			0.42	720		3.5	
B16	**11-Oct-04**	225	7.9	0.02	165	0.38	0.02	79	2.1	175			0.45	680		4.9	
B16	**25-Oct-04**	225	8.5		165	0.47	0.07	77	1.7	150			0.51	760		4.3	
B16	**8-Nov-04**	215	8.2		200	0.4	0.04	78	0.72	185			0.49	700		3.5	
B16	**22-Nov-04**	230	8		160	0.44		81	0.92	135			0.46	750		4.6	
B16	**6-Dec-04**	165	7.7		140	0.61	0.03	43	0.19	100			0.8	435		1.9	
B16	**20-Dec-04**	170	8.1		150	0.53	0.01	45	2.3	135			0.56	425		3.3	
B15	**5-Jan-04**	210	8.1	0.08	150	0.42	0.03	61	0.21	145			0.71	710		2.3	
B15	**19-Jan-04**	210	7.9	0.09	155	0.28	0.02	60	0.2	165			0.8	600		2.3	
B15	**9-Feb-04**	190	8.1		150	0.28	0.01	54	0.83	145			0.77	530		1.8	
B15	**23-Feb-04**	155	8	0.07	125	0.4	0.02	42	0.55	125			0.75	390		1.7	
B15	**8-Mar-04**	130	7.8		115	0.43	0.02	34	0.79	140			0.55	320		2.8	
B15	**26-Apr-04**	180	8.5		125	0.37	0.02	56	0.1	130			0.4	490		3.4	
B15	**10-May-04**	200	8.2		130	0.34	0.01	66	0.14	125			0.37	720		4.7	
B15	**24-May-04**	190	8.1		135	0.43		62	3	110		0.36	0.32	630		5.2	
B15	**7-Jun-04**	180	8.1		135	0.42	0.01	52	0.13	115		0.28	0.26	570		2.9	
B15	**21-Jun-04**	190	8		140	0.51	0.11	61	0.05	110		0.67	0.22	510		1	
B15	**12-Jul-04**	195	8.4		155	0.34	0.02	61	0.11	130		0.49	0.28	610		5.4	
B15	**26-Jul-04**	175	8.4		155	0.38	0.01	51	0.04	135		0.7	0.19	510		4.6	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**23-Aug-04**	200	8.5		155	0.4	0.03	62	0.25	160			0.29	500		5.2	
B15	**6-Sep-04**	200	8.1		155	0.35	0.01	59	0.18	155			0.37	580		3.4	
B15	**20-Sep-04**	210	8.5	0.1	155	0.34	0.03	67	0.52	175			0.36	730		5.9	
B15	**11-Oct-04**	215	7.9	0.02	160	0.42	0.03	72	0.23	170			0.39	650		5.4	
B15	**25-Oct-04**	220	8.6		160	0.48	0.04	76	0.32	150			0.49	670		3.3	
B15	**8-Nov-04**	205	8.3		175	0.38	0.01	70	0.25	155			0.46	660		3.2	
B15	**22-Nov-04**	210	8.1		160	0.36	0.01	63	0.19	135			0.53	700			
B15	**6-Dec-04**	185	7.9		160	0.64	0.03	52	0.11	130			0.58	330		2.5	
B15	**20-Dec-04**	185	8.2		155	0.53	0.01	45	0.18	140			0.65	435		2.6	
B6	**5-Jan-04**	110	7.7	0.16	49	0.45	0.02	27	0.17	77				395		5.6	
B6	**19-Jan-04**	85	7.3	0.1	36	0.47	0.01	21	0.67	58				290		3.9	
B6	**9-Feb-04**	86	7.7	0.14	39	0.46	0.04	19	0.26	71				295		6.9	
B6	**8-Mar-04**	64	7.3	0.08	25	0.39	0.05	15	0.62	40		0.23		230		7.8	
B6	**26-Apr-04**	79	7.5	0.07	40	0.41	0.01	20	0.67	50				285		5.4	
B6	**10-May-04**	82	7.7		43	0.35	0.02	21	0.31	52				285		6.6	
B6	**24-May-04**	105	7.6	0.05	70	0.23	0.1	14	1.2	110				400		5.8	
B6	**7-Jun-04**	96	7.5		58	0.32		24	0.39	55				350		6.6	
B6	**21-Jun-04**	95	7.5		59	0.43	0.02	26	0.48	64				335		8	
B6	**12-Jul-04**	115	7.7		96	0.3	0.01	26	0.32	81	0.62		0.09	385		8.1	
B6	**26-Jul-04**	115	7.8	0.04	99	0.38	0.01	27	0.11	82				405		5.7	
B6	**23-Aug-04**	120	8.1		85	0.51	0.08	32	2.3	91				380		4.9	
B6	**6-Sep-04**	110	7.7		76	0.5	0.04	30	2.2	75				385		4.1	
B6	**20-Sep-04**	120	8.2		76	0.5	0.02	34	1.9	87				400		6.8	
B6	**11-Oct-04**	110	7.7	0.04	71	0.76	0.08	31	1.5	87				315		5.8	
B6	**25-Oct-04**	72	8.2		28	0.65	0.03	18	1.4	47		0.26		220		4.1	
B6	**8-Nov-04**																
B6	**22-Nov-04**	90	7.4		87	0.51	0.02	36	0.45	75		3.8	0.41	345		5.1	
B6	**6-Dec-04**	89	7		80	0.62	0.08	19	0.29	68				275		5.7	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B6	**20-Dec-04**	64	7.1	0.04	36	0.55	0.01	16	1.3	39			0.08	220		6.2	
B17	**5-Jan-04**	230	8.2	0.1	180	0.41	0.03	74	1.3	165			0.51	700			
B17	**19-Jan-04**	210	8	0.12	155	0.37	0.01	60	0.21	165			0.81	640		2.7	
B17	**9-Feb-04**	190	8.1		150	0.41	0.02	54	0.82	145			0.77	530		3.1	
B17	**23-Feb-04**	180	8.1	0.07	145	0.44	0.02	47	0.86	150			0.67	440		3	
B17	**8-Mar-04**	130	8		105	0.36	0.03	35	0.58	125			0.46	330		4.3	
B17	**26-Apr-04**	175	8.5		130	0.46	0.01	56		125			0.47	500		4.2	
B17	**10-May-04**	190	8.1		135	0.42		65	5	120			0.36	620		3.8	
B17	**24-May-04**	190	8		135	0.33	0.02	63	0.39	110		0.37	0.32	560		4.9	
B17	**7-Jun-04**	200	8.1		145	0.35		63	0.81	170			0.21	730		4.4	
B17	**21-Jun-04**	195	8.1		140	0.47	0.02	65	0.51	115				630		7.6	
B17	**12-Jul-04**	195	8.5		155	0.39	0.02	64	0.37	130				530		5.3	
B17	**26-Jul-04**	175	8.4		155	0.38	0.01	49	0.06	130		0.67	0.19	460		3.4	
B17	**23-Aug-04**	205	8.5		170	0.41	0.02	66	0.66	170			0.17	520		4.8	
B17	**6-Sep-04**	200	8.1	0.02	71	0.3	0.02	23		64		2.8	0.37	495		2.7	
B17	**20-Sep-04**	215	8.5	0.02	175	0.4	0.04	69	0.92	185			0.32	680		5.9	
B17	**11-Oct-04**	225	8	0.03	180	0.56	0.03	80	0.87	185			0.25	780		5.4	
B17	**25-Oct-04**	230	8.5		180	0.49	0.04	82	0.9	165			0.27	660		5.3	
B17	**8-Nov-04**	230	8.3		170	0.33	0.01	71	0.23	160			0.47	570		2	
B17	**22-Nov-04**	230	8.3		180	0.44	0.02	76	0.78	155			0.45	700		2.8	
B17	**6-Dec-04**	200	8		160	0.51	0.02	60	0.89	140			0.51	550		2.6	
B17	**20-Dec-04**	165	8.2		155	0.52	0.01	44	0.22	140			0.63	435		2.7	
B11	**5-Jan-04**	230	8.2	0.08	175	0.36	0.03	73	0.79	170			0.49	750			
B11	**19-Jan-04**	245	8.1	0.13	195	0.4	0.02	79	1.1	200			0.25	820		3.9	
B11	**9-Feb-04**	190	8.2		160	0.38	0.02	60	0.82	145			0.39	640		5	
B11	**23-Feb-04**	185	8.1	0.04	150	0.46	0.02	49	0.92	140			0.42	540		4.4	
B11	**8-Mar-04**	130	7.9		105	0.42	0.02	35	0.53	125			0.45	330		4	
B11	**26-Apr-04**	170	8.5	0.02	125	0.39	0.01	52	0.29	135			0.28	420		4.7	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B11	**10-May-04**	190	8		135	0.4		63	5.2	125			0.35	630		3.9	
B11	**24-May-04**	190	8		140	0.45	0.01	63	0.93	120			0.27	580		4.9	
B11	**7-Jun-04**	195	8.2		145	0.43	0.02	62	0.29	125				520		3.9	
B11	**21-Jun-04**	195	8.1		140	0.49	0.02	66	0.56	120				590		7.1	
B11	**12-Jul-04**	200	8.5		155	0.4	0.01	63	0.42	130				710		6.8	
B11	**26-Jul-04**	190	8.5		160	0.41	0.01	61	0.31	140			0.1	490		7.6	
B11	**23-Aug-04**	205	8.5		165	0.37	0.02	66	0.75	165			0.19	570		3.9	
B11	**6-Sep-04**	205	8.2		170	0.36	0.01	63	0.36	165			0.2	570		4.1	
B11	**20-Sep-04**	215	8.5		175	0.37	0.03	70	0.55	195			0.19	670		8.2	
B11	**11-Oct-04**	225	8.2	0.02	185	0.42	0.03	79	0.6	170			0.23	710		7.9	
B11	**25-Oct-04**	230	8.6	0.02	180	0.43	0.03	82	0.74	160		0.84	0.34	710		10	
B11	**8-Nov-04**	125	8.1		165	0.4	0.01	69	0.17	120			0.46	660		1.8	
B11	**22-Nov-04**	230	8.2		185	0.42	0.01	79	1	155			0.32	700		5.2	
B11	**6-Dec-04**	220	8.1		235	0.46	0.03	68	0.95	140			0.3	190		2.2	
B11	**20-Dec-04**	96	8.1		150	0.54	0.01	45	0.37	105			0.56	430		3.4	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	**10-Jan-05**	64	7.8	0.03	62	0.22	0.08	11	0.9	56	2.9		1.4	62		1.3	
B5	**24-Jan-05**	96	7.6		105	0.23	0.05	14	0.28	110	12		0.96	76		1.2	
B5	**7-Feb-05**	90	7.3		99	0.22	0.05	12	0.34	105	8.3		2	75		0.78	
B5	**21-Feb-05**	105	7.7		140	0.21	0.06	16	0.03	110		1.1	0.12	105		6.7	
B5	**7-Mar-05**	96	7.7		110	0.42	0.11	15	0.39	93	7.2	0.25	1.2	120		0.92	
B5	**11-Apr-05**	86	7.9		110	0.49	0.04	15	0.09	100			0.14	88		2.3	
B5	**25-Apr-05**	100	7.9		120	0.37	0.14	16	0.57	115	3.8		2.8	88		1.7	
B5	**9-May-05**	92	7.9		100	0.25	0.25	14	0.42	110	2.6		1.9	85		1.2	
B5	**23-May-05**	105	7.1		130	0.24	0.02	15	0.22	125	4.7		1.1	105		1.3	
B5	**6-Jun-05**	78	7.7	0.05	90	0.42	0.04	12	0.44	78				99		2.1	
B5	**20-Jun-05**	105	7.9		130	0.4	0.04	19	0.92	125	2.4	0.26	3.6	90			
B5	**11-Jul-05**	86	7.7	0.05	94	0.34	0.03	11	0.06	115		0.42	0.22	100		3	
B5	**25-Jul-05**	140	8.1	0.05	210	0.12	0.1	18	0.23	180	1.8	0.21	0.37	140	99	2.7	29
B5	**8-Aug-05**	98	7.7	0.09	130	0.43	0.12	14	0.23	100	1.9		0.31	110		1.9	
B5	**22-Aug-05**	82	7.6	0.03	100	0.24	0.04	13	0.32	90		0.35		135		1.7	
B5	**5-Sep-05**	89	7.9	0.03	110	0.32	0.04	12	0.21	99		0.24	0.12	115		3.6	
B5	**19-Sep-05**	155	7.5	0.11	235	0.47	0.44	16	0.19	175	2.7	0.55	0.07	190		2.3	
B5	**10-Oct-05**	115	7.7	0.18	160	0.4	0.13	12	0.21	145	1.9	0.5	0.36	120		1.9	
B5	**24-Oct-05**	85	7.6	0.05	100	0.22	0.03	16	0.27	58	0.85	0.35	1.8	71		3.2	
B5	**7-Nov-05**	170	8.2	0.39	235	0.35	0.12	14	0.08	250	4.5	1.2	0.6	155		3.2	
B5	**21-Nov-05**	130	8.3	0.43	190	0.32	0.12	19	0.16	180				105	105	5.8	34
B5	**5-Dec-05**	145	8.1	0.14			0.16	22	0.35	190	0.91				47	1.6	20
B5	**19-Dec-05**	130	8.6	0.11	150	0.32	0.08	14	0.19	165	0.75	1.1	0.94	140		5.4	
B16	**10-Jan-05**	145	8.1		120	0.53	0.07	45	0.59	105			0.59	390		1.4	
B16	**24-Jan-05**	135	7.9		105	0.51	0.14	38	1.1	115			0.21	380		3.1	
B16	**7-Feb-05**	135	8.1		97	0.4	0.03	40	1.9	105			0.46	365		2.7	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B16	**21-Feb-05**	145	8.1		110	0.42		43	0.18	115			0.36	415		2	
B16	**7-Mar-05**	145	8.3		115	0.33	0.04	43	0.07	115			0.41	395		2.5	
B16	**11-Apr-05**	145	7.8		120	0.35	0.05	41	0.05	93			0.28	410		2.7	
B16	**25-Apr-05**	130	8		110	0.35		37		110			0.33	355		1.9	
B16	**9-May-05**	140	7.9		110	0.32	0.01	40	2.2	99			0.53	400		4.1	
B16	**23-May-05**	180	7.9		120	0.27	0.05	59	0.05	110			0.23	580		2.2	
B16	**6-Jun-05**	145	8.1		125	0.23	0.03	65	0.17	130			0.28	510		4.6	
B16	**20-Jun-05**	175	7.9		135	0.25	0.01	52	0.02	125			0.11	540		3.5	
B16	**11-Jul-05**	165	7.8		140	0.21	0.02	48	0.29	115		0.27	0.08	455		2.1	
B16	**25-Jul-05**	160	8.5		125	0.26	0.02	42	0.77	110	2.4	0.37	1.2	455		4.7	
B16	**8-Aug-05**	185	8.6		140	0.27		59	0.37	130			0.22	475		3	
B16	**22-Aug-05**	225	8.1		150	0.32	0.13	82	0.53	150			0.14	870		2.7	
B16	**5-Sep-05**	160	7.8		120	0.36	0.03	40	0.09	100	2.4		1.5	400		3.2	
B16	**19-Sep-05**	195	8.1		145	0.34	0.02	64	0.31	145			0.3	520		1.6	
B16	**10-Oct-05**	215	8		150	0.34	0.01	71	0.14	155			0.32	720		2.3	
B16	**24-Oct-05**	230	8		150	0.31	0.02	83	0.22	150			0.35	720		3.5	
B16	**7-Nov-05**	215	8		160	0.37		73	2.2	165			0.39	820		2.2	
B16	**21-Nov-05**	215	8		155	0.42	0.06	72	0.11	160		0.36	0.33	670		1.5	
B16	**5-Dec-05**	170	7.8		135	0.41	0.01	54	0.05	125			0.36	440		0.88	
B16	**19-Dec-05**	165	7.8		135	0.5	0.55	46	1.2	130	2.3		2.2	410		0.75	
B15	**10-Jan-05**	155	7.9		120	0.54	0.02	47	1.6	105			0.58	420		2.7	
B15	**24-Jan-05**	110	8.1		96	0.44	0.03	26	0.41	97			0.45	240		3.1	
B15	**7-Feb-05**	135	8		100	0.4	0.02	41	1.8	105			0.47	380		1.3	
B15	**21-Feb-05**	160	7.9		115	0.45	0.01	49	0.67	99			0.46	445		2.3	
B15	**7-Mar-05**	150	8.2		115	0.33		47	0.24	99			0.48	430		3	
B15	**11-Apr-05**	145	7.8		120	0.31	0.01	42	0.38	96			0.35	425		3	
B15	**25-Apr-05**	130	8		100	0.35		36	0.6	105			0.31	345		3.9	
B15	**9-May-05**	150	8		110	0.33	0.01	44	0.21	105			0.26	440		4.6	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**23-May-05**	175	7.9		120	0.25	0.05	59	0.28	105			0.25	560		5.2	
B15	**6-Jun-05**	150	7.9		125	0.2	0.04	65	0.29	120			0.52	520		3.5	
B15	**20-Jun-05**	180	7.9		130	0.24	0.01	56	0.17	125			0.28	640		4.6	
B15	**11-Jul-05**	185	7.9		140	0.19	0.01	58	0.09	120			0.17	640		4.8	
B15	**25-Jul-05**	185	8.5		150	0.27	0.01	57	0.18	120			0.3	590		5	
B15	**8-Aug-05**	180	8.6		135	0.25	0.03	58	0.23	135			0.28	600		4	
B15	**22-Aug-05**	185	8.1		140	0.3	0.01	58	2.2	130			0.35	620		3.9	
B15	**5-Sep-05**	190	8		140	0.27	0.02	59	0.51	135			0.47	530		0.87	
B15	**19-Sep-05**	190	8		140	0.32	0.01	61	0.39	140			0.63	520		3.2	
B15	**10-Oct-05**	205	8		145	0.32	0.03	66	0.38	155			0.53	680		3.6	
B15	**24-Oct-05**	210	8.1		150	0.28	0.04	71	0.63	145			0.7	670		4.2	
B15	**7-Nov-05**	205	7.9		155	0.37	0.01	68	0.31	155			0.67	690		3.5	
B15	**21-Nov-05**	205	7.9		150	0.38	0.02	67	0.37	150		0.26	0.54	480		2.9	
B15	**5-Dec-05**	175	7.9		135	0.43	0.01	57	0.45	125			0.57	540		3.5	
B15	**19-Dec-05**	205	8		155	0.52	0.01	63	0.66	165			0.69	670		1.6	
B6	**10-Jan-05**	67	7.1	0.04	34	0.55	0.02	17	0.94	41			0.1	240		7	
B6	**7-Feb-05**	67	7.6	0.02	29	0.45	0.02	18	0.92	44				230		5.3	
B6	**21-Feb-05**	50	6.8	0.03	21	0.44	0.01	14	1.9	22				180		3.1	
B6	**7-Mar-05**	72	7.9		39	0.41	0.01	17	0.64	41				245		6.9	
B6	**11-Apr-05**	70	7.8	0.03	44	0.36	0.01	17	0.35	46				240		4.7	
B6	**25-Apr-05**	49	6.9	0.03	23	0.4	0.01	14	1.4	25				170		7.2	
B6	**9-May-05**	67	7.4	0.03	35	0.39	0.03	18	0.57	44				235		7.7	
B6	**23-May-05**	77	7.3		41	0.4	0.01	22	0.57	49				295		5.3	
B6	**6-Jun-05**	89	7.2		52	0.26	0.08	28	0.57	65				330		8.1	
B6	**20-Jun-05**	82	7.4	0.05	49	0.33	0.02	22	0.37	54				300		9.3	
B6	**11-Jul-05**	85	7.4	0.03	67	0.31		21	0.19	59				275		8.4	
B6	**25-Jul-05**	85	7.9		64	0.4	0.02	21	0.4	57				265		8.1	
B6	**8-Aug-05**	83	7.8		58	0.37	0.01	22	0.33	56				265		7.1	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B6	**22-Aug-05**	82	7.6		60	0.43	0.04	23	0.35	54				255		6.6	
B6	**5-Sep-05**	85	7.6		57	0.41	0.01	24	0.45	57				260		6	
B6	**19-Sep-05**	85	7.6		57	0.38	0.02	25	0.6	60				270		2.2	
B6	**10-Oct-05**	72	7.3	0.02	35	0.62	0.06	19	1.4	43	1.3	0.65		200		4.6	
B6	**21-Nov-05**	79	7.1	0.03	70	0.6	0.05	17	0.37	62		0.31		240		4.1	
B6	**5-Dec-05**	49	7.4	0.02	24	0.81	0.04	13	0.46	28				115		5.3	
B6	**19-Dec-05**	51	7.6		22	0.7	0.02	15	0.18	33				120		5.8	
B17	**10-Jan-05**	155	7.9		120	0.53	0.02	46	1.7	105			0.6	420			
B17	**24-Jan-05**	115	8.2		97	0.47	0.04	29	0.41	100			0.4	260		4.9	
B17	**7-Feb-05**	125	8.3		98	0.4	0.01	38	0.43	105			0.46	320		1.3	
B17	**21-Feb-05**	165	8.4		120	0.45	0.03	48	0.67	120			0.47	415		5.8	
B17	**7-Mar-05**	160	8.4		125	0.34	0.01	53	0.33	100			0.42	360		4.5	
B17	**11-Apr-05**	155	8.1		125	0.33	0.01	46	0.54	98			0.35	390		2.4	
B17	**25-Apr-05**	130	8		100	0.36		37	0.63	105			0.3	345		3	
B17	**9-May-05**	145	8.1		115	0.33	0.02	44	0.62	110			0.33	405		5.1	
B17	**23-May-05**	160	8.1		120	0.27	0.01	50	0.29	105			0.23	495		2.1	
B17	**6-Jun-05**	150	8		125	0.21	0.03	67	0.22	125		0.59	0.29	580		5.3	
B17	**20-Jun-05**	180	8		135	0.25		59	0.28	120			0.17	520		6.3	
B17	**11-Jul-05**	195	8.6		145	0.22	0.02	57	0.26	120			0.13	740		4.9	
B17	**25-Jul-05**	190	8.6		155	0.25	0.01	59	1.3	91			0.13	570		6.4	
B17	**8-Aug-05**	185	8.6		140	0.24	0.02	60	0.23	135			0.16	560		4.7	
B17	**22-Aug-05**	190	7.9		145	0.33	0.11	63	4.1	135			0.29	660		3.2	
B17	**5-Sep-05**	195	8.2		150	0.39	0.01	62	0.68	140			0.28	570		5	
B17	**19-Sep-05**	205	8.2		155	0.37	0.02	67	1.2	155			0.45	550		4.1	
B17	**10-Oct-05**	215	8.2		165	0.32	0.01	71	1.4	180			0.37	640		1.7	
B17	**24-Oct-05**	220	8.1		170	0.28	0.01	79	1.8	150			0.6	660		5.5	
B17	**7-Nov-05**	220	8.1		175	0.39	0.01	78	1.2	180			0.39	720		6.2	
B17	**21-Nov-05**	210	8.1		165	0.4	0.02	72	0.86	165		0.34	0.24	600		2.2	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B17	**5-Dec-05**	190	8.1		145	0.43	0.01	63	0.66	140			0.37	640		3.1	
B17	**19-Dec-05**	210	8.3		170	0.52	0.02	65	0.56	175			0.65	530		1.6	
B11	**10-Jan-05**	145	8.1	0.02	120	0.6	0.05	43	0.29	110			0.59	390		5.1	
B11	**24-Jan-05**	125	8.2		105	0.49	0.02	34	1.7	105			0.38	315		6.6	
B11	**7-Feb-05**	125	8.3		105	0.41	0.02	37	0.75	110			0.42	315		2.3	
B11	**21-Feb-05**	145	8	0.02	110	0.45	0.02	42	0.38	99			0.38	410		5.7	
B11	**7-Mar-05**	160	8.4		125	0.35	0.01	54	0.51	105			0.36	375		6	
B11	**11-Apr-05**	155	7.9		96	0.33	0.01	48	0.48	105			0.28	87		2.4	
B11	**25-Apr-05**	130	8.1		105	0.38	0.01	37		100			0.32	350		6.3	
B11	**9-May-05**	145	8.1		115	0.34	0.01	43	0.26	100			0.23	415		8.1	
B11	**23-May-05**	155	8.2		120	0.28	0.01	49	0.16	120			0.14	425		3.5	
B11	**6-Jun-05**	145	8		125	0.24	0.03	64	0.18	125			0.23	470		7.9	
B11	**20-Jun-05**	180	8.1		130	0.23	0.01	58	0.42	120				445		7	
B11	**11-Jul-05**	175	8.1		145	0.22		58	0.34	120				470		7.8	
B11	**25-Jul-05**	185	8.6		150	0.32	0.01	60	0.43	140				690		8.3	
B11	**8-Aug-05**	190	8.6		145	0.28	0.01	62	0.35	140				600		7	
B11	**22-Aug-05**	190	8.2		150	0.32	0.02	61	0.76	145			0.12	620		6.3	
B11	**5-Sep-05**	195	8.2		150	0.32	0.01	62	0.54	150			0.19	610		7.1	
B11	**19-Sep-05**	200	8.3		155	0.31	0.03	67	0.46	175			0.25	620		7.1	
B11	**10-Oct-05**	215	8.3		165	0.31	0.01	72	0.54	150			0.18	840		7.5	
B11	**24-Oct-05**	215	8.2		170	0.28	0.01	77	1.1	225			0.32	670		5	
B11	**7-Nov-05**	225	8.2		180	0.36	0.01	80	1	180			0.23	730		6.2	
B11	**21-Nov-05**	220	8.2		175	0.41	0.02	77	0.88	155		0.4	0.1	600		5.7	
B11	**5-Dec-05**	200	8.1		155	0.41	0.02	69	0.73	175			0.24	660		6.5	
B11	**19-Dec-05**	215	8.3		170	0.48	0.01	71	0.87	135			0.32	620		4.7	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	**9-Jan-06**	115	7.7	0.05	150	0.3	0.05	16	0.39	145	1.7	2.1	0.55	125		5.8	
B5	**23-Jan-06**	96	7.8		110	0.3	0.06	18	0.42	115	3.1	0.22	3.3	66		2	
B5	**6-Feb-06**	56	7.7		64	0.37	0.02	12	0.08	54	1		0.52	57		2.7	
B5	**20-Feb-06**	74	7.6		86	0.3	0.02	15	0.68	81	1.6	0.25	0.98	66		1.9	
B5	**6-Mar-06**	82	7.7		105	0.44	0.04	16	0.77	110	2.5		0.94	76		1.1	
B5	**20-Mar-06**	100	7.7		110	0.21	0.07	14	0.29	120	0.91	1.5	0.47	125		2.9	
B5	**10-Apr-06**	80	7.9		94	0.33	0.04	12	0.12	87		0.32	0.1	98		5	
B5	**24-Apr-06**	96	7.6		130	0.45	0.05	16	0.35	105	0.58	0.21	0.83	86		3.9	
B5	**8-May-06**	98	7.8		120	0.27	0.05	14	0.27	115		0.58	0.45	83		2.1	
B5	**22-May-06**	77	7.5	0.05	77	0.26	0.11	18	0.59	76	1.4			125	53		20
B5	**5-Jun-06**	91	7.8		115	0.26	0.02	13	0.36	110		2.1	0.16	96		3.8	
B5	**19-Jun-06**	85	7.7		100	0.31	0.04	16	0.3	99		0.32	0.63	96		1.6	
B5	**10-Jul-06**	84	8.3	0.04	105	0.36	0.06	11	0.14	94	0.57	0.56	0.18	100		3.1	
B5	**24-Jul-06**	125	8	0.05	155	0.28	0.06	18	1.8	115		0.25	0.25	180	74	1.5	45
B5	**7-Aug-06**	69	8.2	0.1	73	0.32	0.07	12	0.28	69			0.12	79		0.93	
B5	**21-Aug-06**	155	7.8	0.05	210	3.6	0.21	26	0.46	220	5.2	1.4	0.85	155	100	2.1	46
B5	**4-Sep-06**	135	7.9	0.05	170	0.27	0.19	26	1.1	170	3.5		1.3	150	91		
B5	**18-Sep-06**	110	8.4	0.03	140	0.25	0.12	14	0.31	130	3.3	4.2	1.5	110	81	5.2	
B5	**9-Oct-06**	80	7.8	0.05	62	0.32	0.05	18	0.71	86	2.2			96	48		
B5	**23-Oct-06**	140	5.5	0.19	290	0.41	0.09	15	0.26	245	1.2	0.27	0.42	205		1.7	
B5	**6-Nov-06**	100	7.8	0.05	94	0.31	0.05	20	0.3	120	2.1		0.41	120	39		
B5	**20-Nov-06**	125	8.1	0.05	170	0.25	0.19	21	0.46	160	5		0.88	120	83	1	35
B5	**4-Dec-06**	120	7.8		160	0.17	0.07	17	0.3	175		0.56		120		1.6	
B5	**18-Dec-06**	100	7.6		125	0.33	0.08	15	0.73	95	6	7.2	4.3	82		0.73	
B16	**9-Jan-06**	175	7.7		135	0.38	0.02	53	0.74	120			0.46	475		2	
B16	**23-Jan-06**	140	7.8		120	0.31	0.25	35	0.08	100			0.42	340			

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B16	**6-Feb-06**	105	8		87	0.25	0.01	25	0.11	76	1.5		1.4	230		1.3	
B16	**20-Feb-06**	85	7.5		57	0.29	0.05	23	0.05	63	0.84		0.24	210		2.4	
B16	**6-Mar-06**	99	7.4		92	0.43	0.01	25	0.38	93	1.6		0.24	225		2.1	
B16	**20-Mar-06**	97	7.9		73	0.33	0.02	26	0.15	66	0.96		0.44	225		1.2	
B16	**10-Apr-06**	145	8		115	0.31	0.01	44	0.09	110			0.47	435		1.4	
B16	**24-Apr-06**	185	8.2		130	0.32	0.02	62	0.62	130			0.39	560		3.5	
B16	**8-May-06**	170	8		125	0.33	0.02	54	0.91	130			0.41	420		2.2	
B16	**22-May-06**	165	8		125	0.31	0.02	51	0.52	135			0.32	420		2.3	
B16	**5-Jun-06**	190	7.8	0.03	130	0.37	0.05	66	0.05	145		0.2	0.27	570		2.2	
B16	**19-Jun-06**	145	7.9	0.02	120	0.36	2	38	0.05	90		0.41	0.31	335		2.7	
B16	**10-Jul-06**	165	7.9		135	0.28	0.01	48	0.18	160		0.25	0.93	435		3.8	
B16	**24-Jul-06**	175	7.9		150	0.3	0.03	53	0.04	120		0.29	1.2	410		0.76	
B16	**7-Aug-06**	215	7.8		150	0.39	0.04	67	0.53	155	0.96	0.91	1.2	810		1.1	
B16	**21-Aug-06**	150	7.8		135	0.34	0.01	38	0.02	93	3.9	0.4	1.4	310		1.5	
B16	**4-Sep-06**	180	7.8		130	0.31	0.03	56	0.07	125	9.6	1.3	2.7	435		1.3	
B16	**18-Sep-06**	215	7.7		150	0.26	0.02	73	0.18	140	0.67	0.29	1.7	970		2.9	
B16	**9-Oct-06**	195	7.7		145	0.35	0.03	60	0.08	130			2	550		2.3	
B16	**23-Oct-06**	195	7.8		145	0.31		63	0.05	135	1		1.7	540		1	
B16	**6-Nov-06**	210	7.8		150	0.33	0.03	66	0.03	135	1.5		2.2	630		0.79	
B16	**20-Nov-06**	130	7.6		130	0.16	0.02	33	0.57	120	1.7		2.5	270		1.8	
B16	**4-Dec-06**	145	7.7		120	0.24	0.01	37	0.1	115	0.53		1.9	335		1.4	
B16	**18-Dec-06**	190	7.8		130	0.41	0.11	59	0.71	135			1.8	570		2.2	
B15	**9-Jan-06**	165	7.8		115	0.37	0.02	52	0.77	100			0.62	410		2.8	
B15	**23-Jan-06**	140	7.9		120	0.31	0.01	35	2.3	99			0.67	350		1.8	
B15	**6-Feb-06**	110	8.1		97	0.24	0.01	28	0.73	90			0.45	245		1.9	
B15	**20-Feb-06**	93	7.6		62	0.31	0.1	26	3.5	68	0.67		0.45	235		2.4	
B15	**6-Mar-06**	105	7.4		91	0.44	0.02	28	1	92	1.5		0.25	255		2.3	
B15	**20-Mar-06**	125	7.9		93	0.33	0.02	35	1	100			0.32	355		2.4	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**10-Apr-06**	145	8.2		110	0.3	0.02	45	0.67	115			0.4	435		3.4	
B15	**24-Apr-06**	165	8.2		120	0.31	0.02	52	0.6	135			0.44	455		3.2	
B15	**8-May-06**	170	8		125	0.33	0.02	53	0.29	140			0.4	445		4.1	
B15	**22-May-06**	160	7.9		125	0.31	0.01	48	0.19	140			0.33	405		3.8	
B15	**5-Jun-06**	175	7.8	0.03	125	0.36	0.03	58	0.21	130			0.23	510		3	
B15	**19-Jun-06**	165	7.9	0.04	130	0.39	0.03	51	0.46	115			0.34	435		3	
B15	**10-Jul-06**	180	7.9		135	0.29	0.02	55	0.27	150		0.43	0.52	475		1.1	
B15	**24-Jul-06**	180	7.9		150	0.31	0.02	55	0.23	125		0.22	0.77	415		3.3	
B15	**7-Aug-06**	180	7.9	0.02	155	0.37	0.02	52	0.18	125		1	1.1	500		1.8	
B15	**21-Aug-06**	180	7.8		145	0.35	0.02	54	0.25	120	1.7	2.2	1.2	520		3.1	
B15	**4-Sep-06**	180	7.8		135	0.34	0.03	57	0.47	125	5.4	1.9	2.2	440			
B15	**18-Sep-06**	185	7.8		150	0.25	0.01	56	0.77	125	0.57	0.41	2	610		2.6	
B15	**9-Oct-06**	200	7.8		145	0.34	0.01	60	0.45	120			1.5	510		1.5	
B15	**23-Oct-06**	195	7.8		150	0.32	0.02	64	0.67	140	1.1		1.8	510		1.6	
B15	**6-Nov-06**	200	7.9		150	0.36		60	4	130	0.81	0.2	1.9	570		1.2	
B15	**20-Nov-06**	140	7.7		120	0.16	0.01	41	1.9	105		0.49	0.7	330		2.5	
B15	**4-Dec-06**	145	7.7		120	0.24	0.02	36	2.6	115	0.5		1.9	340		1.8	
B15	**18-Dec-06**	185	7.9		135	0.45	0.01	54	2	130	0.74		2	500			
B6	**23-Jan-06**	53	7.2		27	0.38	0.04	13	0.21	31				155		6	
B6	**6-Feb-06**	45	7.8	0.06	26	0.32	0.03	9.9	0.11	26				105		6.3	
B6	**20-Feb-06**	55	7.6	0.02	29	0.5	0.03	15	0.2	35				145		7.5	
B6	**6-Mar-06**	49	6.9	0.06	28	0.49	0.06	15	0.24	31				130		6.4	
B6	**20-Mar-06**	54	7.7	0.06	38	0.39	0.03	15	0.11	37				120		7.3	
B6	**10-Apr-06**	56	7.6	0.03	40	0.32	0.05	17	0.19	41				135		6.7	
B6	**24-Apr-06**	51	8.2	0.06	38	0.4	0.04	15	0.14	37				84		7.7	
B6	**8-May-06**	47	7.7	0.04	35	0.39	0.04	14	0.1	36			0.08	53		11	
B6	**22-May-06**	45	7.7	0.03	35	0.3	0.03	13	0.06	33		1.1		46		8.2	
B6	**5-Jun-06**	44	7.6	0.14	32	0.24	0.03	14	0.15	32		0.49		52		7.4	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B6	**19-Jun-06**	44	7.8	0.13	31	0.29	0.02	13	0.18	29				58		7.6	
B6	**10-Jul-06**	47	7.7	0.07	30	0.33	0.02	14	0.26	30	0.62			64		1.9	
B6	**24-Jul-06**	45	7.8	0.09	30	0.3	0.02	14	0.27	27				56		8.2	
B6	**7-Aug-06**	49	8	0.06	36	0.36	0.03	14	0.09	29				60		5.4	
B6	**21-Aug-06**	47	8	0.03	32	0.35	0.04	14	0.06	25				54		7.2	
B6	**4-Sep-06**	51	8.1	0.04	33	0.35	0.04	16	0.89	30				61		6.3	
B6	**18-Sep-06**	52	7.8		30	0.45	0.03	16	0.2	28				58		7.7	
B6	**23-Oct-06**	50	7.8	0.02	21	0.38	0.04	16	0.19	28			0.11	46		6.7	
B6	**6-Nov-06**	54	8		37	0.43	0.03	15	0.08	32				52		5.8	
B6	**4-Dec-06**	44	7.7		21	0.38	0.03	12	0.16	23			0.13	77		6.5	
B6	**18-Dec-06**	49	7.6	0.03	36	0.39	0.04	13	0.1	28				91			
B17	**9-Jan-06**	190	8		145	0.37	0.01	61	0.42	160			0.48	490		5	
B17	**23-Jan-06**	150	8		135	0.35	0.01	39	0.37	120			0.58	355		6.6	
B17	**6-Feb-06**	150	8.2		125	0.25		43	0.17	110			0.46	395		2	
B17	**20-Feb-06**	83	7.6		66	0.35	0.04	22	0.71	67			0.32	165		6.9	
B17	**6-Mar-06**	110	7.8		86	0.49		33	0.49	86			0.21	295		1.7	
B17	**20-Mar-06**	125	8.1		99	0.34	0.02	34	0.14	105			0.38	320		1.7	
B17	**10-Apr-06**	130	8.2		110	0.29	0.02	39	0.14	105			0.4	345		4	
B17	**24-Apr-06**	155	8.3		115	0.32	0.01	47	0.22	130			0.57	440		3.3	
B17	**8-May-06**	170	8		125	0.33	0.02	54	0.68	145			0.35	450		2.1	
B17	**22-May-06**	170	8.2		130	0.33	0.01	54	0.17	145			0.31	385		5.1	
B17	**5-Jun-06**	175	8	0.02	130	0.37	0.02	58	0.08	130			0.21	500		9.2	
B17	**19-Jun-06**	170	8	0.02	135	0.38	0.01	52	0.1	120			0.21	480		3.3	
B17	**10-Jul-06**	175	8.1		140	0.28	0.01	56	0.33	160			0.2	490		6.1	
B17	**24-Jul-06**	185	8.1		150	0.31		59	0.26	125			0.31	460		5.8	
B17	**7-Aug-06**	185	8.2		155	0.35	0.01	56	0.11	140			0.37	560		2.7	
B17	**21-Aug-06**	180	8.4		155	0.33	0.02	57	0.12	125			0.49	550		8.5	
B17	**4-Sep-06**	180	8.4	0.02	140	0.29	0.02	61	0.2	135			0.64	445		4.6	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B17	**18-Sep-06**	185	8.3		160	0.25	0.01	57	0.21	135			1.1	650		1	
B17	**9-Oct-06**	205	8.2		160	0.37		62	0.79	140			1.3	570			
B17	**23-Oct-06**	210	8		165	0.34	0.04	73	1.7	160			1.3	590		6.5	
B17	**6-Nov-06**	200	8.2		160	0.34	0.01	61	0.88	145			1.4	550			
B17	**20-Nov-06**	160	7.8		130	0.16	0.01	52	0.42	120	2.6		2.5	415		2	
B17	**4-Dec-06**	160	7.9		140	0.24	0.01	45	0.29	125				405		3.7	
B17	**18-Dec-06**	175	8		140	0.44	0.02	52	1.3	130			1.8	430		1.8	
B11	**9-Jan-06**	195	8		155	0.39	0.02	62	0.71	135			0.27	510		6.5	
B11	**23-Jan-06**	170	8		145	0.36	0.01	48	0.63	125			0.35	425		4.3	
B11	**6-Feb-06**	155	8.2		135	0.27	0.01	47	0.31	75			0.34	415		4.8	
B11	**20-Feb-06**	93	7.9		74	0.34	0.03	25	0.33	77			0.35	200		5.6	
B11	**6-Mar-06**	99	7.7		73	0.49	0.02	30	0.26	99			0.29	245		4.8	
B11	**20-Mar-06**	115	8		93	0.33	0.02	31	0.11	120			0.33	290		3.1	
B11	**10-Apr-06**	130	8.1		120	0.3	0.03	38	0.29	125				355		6	
B11	**24-Apr-06**	145	8.3		110	0.32	0.04	43	0.16	130			0.34	395		3.7	
B11	**8-May-06**	170	8		125	0.34	0.02	55	0.64	145			0.34	435		9	
B11	**22-May-06**	170	8.1		125	0.32	0.01	51	0.14	135			0.15	500		8.6	
B11	**5-Jun-06**	170	8	0.03	130	0.38	0.02	58	0.06	125			0.11	445		5.9	
B11	**19-Jun-06**	175	8.1	0.02	135	0.39	0.01	54	0.09	160				495		6.6	
B11	**10-Jul-06**	175	8.1		140	0.3	0.01	56	0.21	120				570		1.5	
B11	**24-Jul-06**	180	8.1		150	0.31	0.01	57	0.36	135			0.13	520		9	
B11	**7-Aug-06**	185	8.1		155	0.36	0.01	57	0.24	125				530		5.6	
B11	**21-Aug-06**	185	8.2		160	0.34	0.02	58	0.29	135			0.19	590		8	
B11	**4-Sep-06**	185	8.2		145	0.31	0.02	62	1.1	135			0.3	455		7.5	
B11	**18-Sep-06**	185	8.1		170	0.25	0.01	59	0.4	140			0.4	540		1.2	
B11	**9-Oct-06**	205	8.1		165	0.35	0.01	60	0.5	165			0.67	540		5.8	
B11	**23-Oct-06**	210	8.2		170	0.3	0.01	71	0.49	160			0.75	570		5.3	
B11	**6-Nov-06**	210	8.2		165	0.36	0.01	67	0.32	150	3		3.6	610		5.6	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B11	**20-Nov-06**	175	7.9		135	0.15		57	0.11	130	1.3		0.27	465		1.5	
B11	**4-Dec-06**	160	8		140	0.25	0.02	44	0.25	130			1.7	400		2.8	
B11	**18-Dec-06**	190	8.1		155	0.45	0.01	56	0.14	115			0.87	475		5.1	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B5	**8-Jan-07**	90	7.7		92	0.23	0.11	14	0.44	100	2.5		1.5	79			
B5	**22-Jan-07**	105	7.8		125	0.41	0.07	18	0.21	115	1.5	0.21	1.3	110		4.2	
B5	**5-Feb-07**	88	7.6		105	0.27	0.06	15	0.13	99			0.3	100		1.4	
B5	**19-Feb-07**	105	7.7		130	0.34	0.1	15	0.66	110	5.4		6.7	88		1.5	
B5	**5-Mar-07**	105	7.9		140	0.26	0.03	19	0.11	110	0.66	0.41	1.9	115		1.4	
B5	**19-Mar-07**	44	8.1	0.05	36	0.34	0.05	13	0.05	35				27			
B5	**23-Apr-07**	120	7.8	0.02	145	0.11	0.02	26	1.3	68	2.1	0.54	0.28	130		6	
B5	**7-May-07**	84	8	0.05	100	0.29	0.06	11	0.11	86	1	0.35	0.21	96		3.1	
B5	**21-May-07**	91	7.8	0.05	100	0.26	0.05	22	0.15	105	1.3	0.28	0.17	170	40	3.5	
B5	**4-Jun-07**	125	8.5	0.04	165	0.49	0.08	12	0.45	130	2.4	0.65	1.2	115		3.7	
B5	**18-Jun-07**	130	8.2	0.05	175	0.2	0.11	18	0.69	175	1.2	0.25	1.1	105	94	2.5	31
B5	**9-Jul-07**	105	7.8	0.05	120	0.25	0.05	26	1.3	125	3.5	0.53	0.81	180	74	5	
B5	**23-Jul-07**	110	8.1	0.05	130	0.3	0.03	18		140				90	72	2	
B5	**6-Aug-07**	120	7.9		170	0.32	0.05	21	0.1	130		0.35	0.7	130			
B5	**20-Aug-07**	94	7.8	0.05	100	0.29	0.05	23	0.47	105	2.7	0.45	0.55	240	44		
B5	**3-Sep-07**	98	8.3	0.05	120	0.29	0.03	18	0.03	120				105	59	4	
B5	**17-Sep-07**	91	8.5	0.05	115	0.35	0.05	18	0.12	105		0.49		140	56	2.4	
B5	**8-Oct-07**	94	8	0.05	120	0.3	0.06	17	0.03	165	0.78	0.4	0.08	135	13	3.2	
B5	**22-Oct-07**	120	7.8		125	0.25	0.1	17	0.65	120	16		2.6	145		0.97	
B5	**5-Nov-07**	93	7.5		110	0.26	0.13	12	0.55	105	1.9		1.7	120		1.3	
B5	**19-Nov-07**	100	7.9	0.02	120	0.31	0.1	15	0.18	135	0.68	1.1	0.49	110		8.3	
B5	**3-Dec-07**	82	6.9	0.02	105	0.41	0.01	12	0.2	105		1		145		2.9	
B16	**8-Jan-07**	115	7.7		98	0.41	0.04	28	0.16	93			0.96	270			
B16	**22-Jan-07**	125	7.5		99	0.29	0.01	35	0.35	94			1.3	290		1.3	
B16	**5-Feb-07**	140	8		115	0.27	0.17	43	0.14	105	0.55		1.3	345		0.71	
B16	**19-Feb-07**	175	7.9		115	0.22	0.02	57	0.39	120			0.82	490		2.2	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B16	**5-Mar-07**	185	8		125	0.26	0.08	60	0.26	125			1.1	560		1.9	
B16	**19-Mar-07**	195	7.9		135	0.22	0.19	64	1.2	140			1	590		2.5	
B16	**23-Apr-07**	165	7.9		130	0.6	0.05	51	0.05	115			0.88	435		1.2	
B16	**7-May-07**	175	7.8		140	0.51	0.27	52	1.3	140			0.71	470		3	
B16	**21-May-07**	175	7.9		140	0.49	0.11	52	0.03	130			0.75	470		3.8	
B16	**4-Jun-07**	175	7.9		140	0.33	0.02	50	0.49	125		0.33	0.24	485		1.7	
B16	**18-Jun-07**	165	7.9		140	0.41	0.06	51	0.11	120			0.44	425		0.72	
B16	**9-Jul-07**	170	7.8		155	0.31	0.02	52	0.27	130		0.23	0.37	470		3.6	
B16	**23-Jul-07**	150	7.9		135	0.33	0.01	41	0.14	110	1.9	0.74	0.59	335		1.8	
B16	**6-Aug-07**	185	8		140	0.37		59	0.03	130			1.1	540		3.6	
B16	**20-Aug-07**	165	8.1		130	0.27	0.05	50	0.2	115			2.2	430		3.1	
B16	**3-Sep-07**	160	8		145	0.31	0.1	52	0.28	150			2	520			
B16	**17-Sep-07**	150	8.1		130	0.35	0.01	39	0.15	96	6		3.7	210		2.3	
B16	**8-Oct-07**	140	7.8		115	0.41	0.03	38	0.17	100	0.96		2.1	360		1.7	
B16	**22-Oct-07**	110	7.9		93	0.36	0.01	26	0.2	86	1.4		0.9	230		2.1	
B16	**5-Nov-07**	140	7.9		115	0.4		46	0.3	87	1.2		1.3	380		1.9	
B16	**19-Nov-07**	160	8		115	0.42	0.03	48	4.4	110	0.67		1.4	425		1.5	
B16	**3-Dec-07**	170	7.8		120	0.43	0.02	51	0.32	120			1.1	420		1.4	
B15	**8-Jan-07**	115	7.7		100	0.4	0.03	28	2.5	92		0.45	1.1	265		1.4	
B15	**22-Jan-07**	135	7.9		99	0.29	0.04	39	1.8	94	0.53		1.3	330		1	
B15	**5-Feb-07**	140	8.1		115	0.27	0.03	42	2	105	0.5	0.27	1.3	345		1.3	
B15	**19-Feb-07**	170	7.9		115	0.23	0.01	53	2.4	115			1.2	435		1.2	
B15	**5-Mar-07**	170	8.1		130	0.26	0.01	53	1.9	120			1.4	470		1.9	
B15	**19-Mar-07**	185	8.1		135	0.21	0.01	59	1.3	125			1.1	540		2.4	
B15	**23-Apr-07**	165	7.9		130	0.59	0.01	50	0.49	105			0.88	440		4.5	
B15	**7-May-07**	180	7.9		135	0.5	0.01	52	0.17	140			0.71	495		3.6	
B15	**21-May-07**	175	7.9		145	0.47	0.02	51	0.16	135			0.77	435		2.7	
B15	**4-Jun-07**	180	8		140	0.31	0.02	49	0.13	135	0.96	0.23	0.68	520		7.7	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B15	**18-Jun-07**	165	8		140	0.38	0.01	52	0.26	120			0.44	420			
B15	**9-Jul-07**	165	8.1		150	0.29	0.01	46	0.16	135		0.24	0.42	410		4.7	
B15	**23-Jul-07**	170	7.9		140	0.31	0.02	50	0.15	135		0.24	0.52	440		1.7	
B15	**6-Aug-07**	175	8.1		140	0.33	0.02	53	0.15	125			0.78	435			
B15	**20-Aug-07**	165	7.9		130	0.27	0.01	48	0.2	125			1.3	435		1.5	
B15	**3-Sep-07**	150	8		140	0.31	0.01	51	0.25	140			1.8	420		2.4	
B15	**17-Sep-07**	175	8.2		135	0.38	0.03	51	0.55	130	1.4		2.3	490		2.4	
B15	**8-Oct-07**	140	7.8		115	0.39	0.03	39	0.25	100	0.89		1.9	355		1.4	
B15	**22-Oct-07**	19	8.4		89	0.37	0.03	28	0.36	86	0.74		1.2	225		1.5	
B15	**5-Nov-07**	140	7.9		115	0.4	0.03	45	0.42	84	1.2		1.3	375		1.8	
B15	**19-Nov-07**	160	7.9		115	0.42	0.05	48	0.11	110	0.67		1.4	425		2.6	
B15	**3-Dec-07**	170	8		120	0.44	0.01	53	0.94	125			1.2	475		2.1	
B6	**8-Jan-07**	50	7.9		29	0.38	0.02	13	0.2	31			0.08	96		6.2	
B6	**22-Jan-07**	44	7.6	0.02	24	0.32	0.05	12	0.09	27				82		4.7	
B6	**5-Feb-07**	49	8	0.03	34	0.35	0.03	13	0.02	35				64		5.5	
B6	**19-Feb-07**	51	7.9		35	0.34	0.03	12	0.18	39				52		6	
B6	**5-Mar-07**	53	8.1		46	0.41	0.06	12	0.13	42			0.07	31		7.5	
B6	**19-Mar-07**	49	8.2		42	0.47	0.08	12	0.18	44				24		7.6	
B6	**23-Apr-07**	53	7.8	0.09	38	0.55	0.03	13	1.2	41				95		7.6	
B6	**7-May-07**	52	7.9		39	0.49	0.11	12	0.18	43				75		3.1	
B6	**21-May-07**	50	7.8		32	0.54	0.11	12	0.63	35				67		8.3	
B6	**4-Jun-07**	50	7.9		31	0.47	0.08	13	0.37	32				70		0.92	
B6	**18-Jun-07**	61	7.9		47	0.4	0.05	14	0.07	42	1.7	1.4		94			
B6	**9-Jul-07**	59	8		52	0.4	0.02	13	0.8	44	4.6	3.6		48		2.2	
B6	**23-Jul-07**	57	7.9		45	0.37	0.02	12	0.15	42	2.3	6	0.07	36		2	
B6	**6-Aug-07**	51	7.9	0.07	47	0.4	0.09	25	0.41	43		0.97		36		1.2	
B6	**20-Aug-07**	52	8		42	0.42	0.03	13	0.27	39				34			
B6	**3-Sep-07**	52	8.1		42	0.54	0.01	15	0.4	41				30			

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B6	**17-Sep-07**	47	8		22	0.44	0.01	13	0.6	29				33		7.8	
B6	**8-Oct-07**	50	7.9	0.07	36	0.47	0.08	14	0.21	35				96		7.1	
B6	**22-Oct-07**	56	7.8	0.04	29	0.39	0.02	14	0.3	39				150		6.1	
B6	**5-Nov-07**	48	7.5	0.02	29	0.4	0.06	14	0.59	42			0.09	115		6	
B6	**19-Nov-07**	59	8.1		45	0.43	0.03	15	0.11	50				145		4.9	
B6	**3-Dec-07**	46	7		28	0.39	0.04	12	1.2	35		0.2		105		6.6	
B17	**8-Jan-07**	130	7.9		115	0.31	0.02	34	0.85	95			3.2	290			
B17	**22-Jan-07**	140	7.8		115	0.31	0.02	41	0.34	105			1.4	335			
B17	**5-Feb-07**	145	8.2		125	0.3	0.02	45	0.34	115			1.4	350		3	
B17	**19-Feb-07**	165	7.9		125	0.26	0.01	52	1.2	125		0.28	1.4	405		1.6	
B17	**5-Mar-07**	180	8.1		145	0.29		58	0.9	130			1.4	485		1.7	
B17	**19-Mar-07**	190	8	0.02	150	0.36	0.02	61	0.78	145			1.2	510			
B17	**23-Apr-07**	180	7.9		140	0.58	0.01	56	0.27	125			1.3	465			
B17	**7-May-07**	180	7.9		145	0.55	0.01	59	0.23	135			1.2	495		1.9	
B17	**21-May-07**	190	8		155	0.53		56	0.04	145			0.69	550		5.2	
B17	**4-Jun-07**	185	8.2		150	0.34	0.01	56	0.36	140			0.62	560		2.2	
B17	**18-Jun-07**	170	8.2		145	0.43	0.01	53	0.2	125			0.52	435			
B17	**9-Jul-07**	175	8.1		160	0.31		53	0.31	130			0.42	450		1.4	
B17	**23-Jul-07**	175	8.1		150	0.31		52	0.47	155			0.49	440		8.2	
B17	**6-Aug-07**	175	8.2		155	0.33	0.02	54	0.36	130			0.53	445			
B17	**20-Aug-07**	175	8.2		145	0.27		53	0.37	145			0.63	490		5	
B17	**3-Sep-07**	190	8.1		155	0.33	0.02	17	0.12	40			0.99	540			
B17	**17-Sep-07**	180	8.3		150	0.4		56	0.93	145			1.3	560		5.1	
B17	**8-Oct-07**	165	8.1		135	0.41		49	0.47	120			1.3	430		5.6	
B17	**22-Oct-07**	130	8.2		115	0.39	0.01	35	0.23	110			1.2	280		4.7	
B17	**5-Nov-07**	140	8.1		120	0.42	0.02	45	0.64	89			1.4	345		5.2	
B17	**19-Nov-07**	145	8.2		115	0.42	0.01	43	0.38	105			1.3	355		5.2	
B17	**3-Dec-07**	165	8.1		125	0.45	0.01	51	0.67	125			1.2	440			

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH4	NO3	PO4	SO4	COD	DO	SS
B11	**8-Jan-07**	140	8.1		120	0.34	0.01	38	0.15	105			1.1	325		4.7	
B11	**22-Jan-07**	145	7.9		120	0.35	0.01	42	0.11	115			1.1	320			
B11	**5-Feb-07**	145	8.2		125	0.3	0.02	45	0.39	125			1.3	350		5.1	
B11	**19-Feb-07**	165	8.1		130	0.29	0.01	50	0.39	135			0.97	375		4.1	
B11	**5-Mar-07**	175	8.2		150	0.31	0.02	57	2.5	155			0.99	425		3.9	
B11	**19-Mar-07**	195	8.1		165	0.3	0.02	64	1.5	120			0.76	490			
B11	**23-Apr-07**	180	7.9		145	0.56	0.02	56	0.29	145			1.3	485		6.6	
B11	**7-May-07**	190	8.1		150	0.52	0.02	61	0.42	135			0.73	530		2.1	
B11	**21-May-07**	185	8		150	0.49	0.01	58	0.17	150			0.68	540		6.9	
B11	**4-Jun-07**	190	8.2		155	0.35		57	0.28	125			0.38	600		3.2	
B11	**18-Jun-07**	170	8.1		145	0.39		53	0.07	130			0.5	435			
B11	**9-Jul-07**	185	8.2		160	0.32		56	0.15	150			0.3	460		2.9	
B11	**23-Jul-07**	175	8.1		155	0.32	0.01	53	0.21	83			0.33	495		2.8	
B11	**6-Aug-07**	180	8.3		160	0.33	0.03	35	0.37	145			0.35	450		8.2	
B11	**20-Aug-07**	180	8.3		150	0.27		55	0.23	150			0.41	495		3.8	
B11	**3-Sep-07**	165	8.1		160	0.39	0.01	56	0.25	150			0.6	500		7.8	
B11	**17-Sep-07**	185	8.3		155	0.38	0.01	57	0.43	115			0.85	500		4.7	
B11	**8-Oct-07**	165	8.2		135	0.42		48	0.45	110			1.4	435		6.3	
B11	**22-Oct-07**	145	8.2		125	0.4	0.04	40	0.27	84			1.1	325		4.4	
B11	**5-Nov-07**	140	8.2		120	0.42	0.02	44	0.64	105		0.34	1.5	345		4.8	
B11	**19-Nov-07**	145	8.2		115	0.42	0.01	42	0.25	120			1.3	355		7	
B11	**3-Dec-07**	165	8.1		125	0.46	0.01	50	0.29	110			1.1	415		6.4	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	**1-Jan-08**	97	7.8		125	0.21	0.03	19	0.12	105	1.9		0.34	100		4.3	
B5	**1-Feb-08**	76	7.8		66	0.38	0.02	14	0.02	79		0.24	0.07	76		3.2	
B5	**1-Mar-08**	80	7.5		83	0.24	0.04	13	0.64	76	9.4	0.27	1.6	65		3.9	
B5	**1-Apr-08**	78	7.1		74	0.3	0.01	12	0.23	67	1.9	0.36	0.12	120		6	
B5	**1-May-08**	54	6.9		38	0.28	0.01	13	0.12	27		0.5		155		1.8	
B5	**1-Jun-08**	77	7.5		92	0.44	0.04	16	1.6	84	1.7		0.7	82		1.9	
B5	**1-Jul-08**	91	8.2		110	0.27	0.04	17	0.23	110		0.43	0.19	115		3	
B5	**1-Aug-08**	88	7.6		110	0.33	0.21	12	0.8	98	3.8		3.1	73		2.5	
B5	**1-Sep-08**	130	7.7	0.02	125	0.32	0.11	16	0.91	115			4.2	175		1.2	
B5	**1-Oct-08**	115	7.6		165	0.25	0.1	17	0.25	120			0.15	115		3.7	
B5	**1-Nov-08**	88	7.7	0.05	96	0.63	0.15	17	0.62	99	3.7			100	60		
B5	**1-Dec-08**	63	7.9		44	1.3	0.02	18	0.15	56	1.4	0.36	0.51	280		5.2	
B16	**1-Jan-08**	89	7.6		67	0.47	0.24	24	1.1	68	0.8		0.7	200		4	
B16	**1-Feb-08**	96	8.2		68	0.49	0.04	32	0.23	70	1.2	0.2	0.82	240		2.1	
B16	**1-Mar-08**	110	7.9		83	0.5	0.02	31	0.34	75	0.67		0.52	270		2.4	
B16	**1-Apr-08**	130	7.7		84	0.37	0.02	41	1.1	82			0.3	380		3.3	
B16	**1-May-08**	140	7.8		98	0.42	0.03	40	0.48	100			0.21	370		3.7	
B16	**1-Jun-08**	140	7.8		105	0.38		41		105			0.21	360		3.8	
B16	**1-Jul-08**	160	7.9		110	0.37	0.03	46	0.03	110		0.22	0.4	420		4.6	
B16	**1-Aug-08**	170	7.9		120	0.43	0.03	50	0.03	130			0.5	520		5.2	
B16	**1-Sep-08**	180	7.9		120	0.38	0.03	56	2.5	140		0.24	1.1	500		5.2	
B16	**1-Oct-08**	180	7.8		120	0.44	0.03	53	2.8	115			1.9	460		2.4	
B16	**1-Nov-08**	115	8.1		115	0.41		32	0.66	110	0.68		1.4	265		4.4	
B16	**1-Dec-08**	135	7.6		96	0.4	0.03	40	0.42	110	0.75		1.5	370		1.6	
B15	**1-Jan-08**	115	7.8		87	0.48	0.02	35	1.6	96			0.96	290		1.7	
B15	**1-Feb-08**	100	8.1		69	0.52	0.01	32	1.2	69		0.25	0.71	275		2.1	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**1-Mar-08**	120	7.8		82	0.51	0.01	42	0.52	88			0.59	330		2.8	
B15	**1-Apr-08**	120	7.8		78	0.39	0.01	36	0.18	87			0.36	335		3.2	
B15	**1-May-08**	145	7.8		100	0.38	0.01	42	0.1	100			0.55	380		4.2	
B15	**1-Jun-08**	145	7.9		105	0.39		47	0.1	105			0.3	370		4.5	
B15	**1-Jul-08**	155	8		110	0.36	0.02	46	1.2	105			0.18	400		5.5	
B15	**1-Aug-08**	155	7.9		120	0.4	0.01	45	0.26	115		0.2	0.42	445		4.4	
B15	**1-Sep-08**	170	7.9	0.02	120	0.36	0.04	51	0.45	130			0.68	405		4.2	
B15	**1-Oct-08**	170	7.9		120	0.42	0.01	48	0.34	110	0.56		1.6	450		2.6	
B15	**1-Nov-08**	140	7.8		115	0.44	0.01	42	0.61	110	0.68	0.36	2.1	350		3.2	
B15	**1-Dec-08**	130	7.7		93	0.4	0.01	36	2.1	100	0.78		1.7	330		2.2	
B6	**1-Jan-08**	50	7.2	0.13	28	0.47	0.03	14	0.44	32			0.09	140		6.4	
B6	**1-Feb-08**	60	8	0.08	32	0.5	0.01	18	0.46	35			0.07	145		4.6	
B6	**1-Mar-08**	50	7.7	0.08	36	0.46	0.04	14	0.28	34				115		6.2	
B6	**1-Apr-08**	64	7.2		72	0.38	0.02	32	0.84	52	2.3	0.98	0.56	500		3.1	
B6	**1-May-08**	74	7.3	0.03	41	0.52	0.01	25	3.4	36				260		7	
B6	**1-Jun-08**	85	7		30	0.28		22	0.21	26	0.67	0.82	0.27	185		8.5	
B6	**1-Jul-08**	105	6.7		36	0.5		44	8.2	46			0.34	485		7.4	
B6	**1-Aug-08**	110	6.9		42	0.56		46	6.1	50				490		7.1	
B6	**1-Sep-08**	110	7.1		42	0.44		48	3.6	57				400		7	
B6	**1-Oct-08**	90	6.9		32	0.63	0.04	34	1.5	44		0.32		380		4.4	
B6	**1-Nov-08**	85	7		34	0.5		30	2.8	38				370		4.4	
B6	**1-Dec-08**	86	6.8		26	0.42	0.01	32	2.1	38				380		6.2	
B17	**1-Jan-08**	120	8		96	0.5	0.02	37	0.12	97			0.9	320			
B17	**1-Feb-08**	76	7.7		60	0.5	0.01	26	0.16	60			0.73	200		4.6	
B17	**1-Mar-08**	110	8		58	0.41	0.01	28	0.2	58			0.47	200		4.6	
B17	**1-Apr-08**	120	7.9		78	0.4	0.01	35	0.12	86			0.5	320		4.8	
B17	**1-May-08**	140	8		97	0.41	0.01	40	0.14	105			0.4	370		5.8	
B17	**1-Jun-08**	145	8		105	0.4		45	0.1	105			0.31	370		6	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B17	**1-Jul-08**	150	8.2	0.02	110	0.33	0.04	45	0.8	105			0.1	425		7.8	
B17	**1-Aug-08**	155	8.1		120	0.36	0.01	46	0.34	120			0.24	440		7	
B17	**1-Sep-08**	170	8.1		120	0.36		54	1.5	140			0.3	465		4.8	
B17	**1-Oct-08**	180	8		135	0.44	0.01	54	1.1	125			0.48	500		5.4	
B17	**1-Nov-08**	160	8.1		130	0.48	0.01	51	0.42	115		1.8	1	385		4.6	
B17	**1-Dec-08**	130	8		105	0.44	0.01	38	0.09	120			1.2	325		4.8	
B11	**1-Jan-08**	120	8	0.02	95	0.52	0.02	37	0.15	100			0.8	310		5.6	
B11	**1-Feb-08**	84	8.2		59	0.51	0.01	26	0.3	60			0.78	175			
B11	**1-Mar-08**	110	8.1		81	0.55	0.01	32	0.26	77			0.4	275		5.6	
B11	**1-Apr-08**	115	7.9		78	0.4	0.01	34	0.2	83			0.49	310		5.8	
B11	**1-May-08**	140	8		96	0.39	0.01	40	0.12	94			0.36	360		6.3	
B11	**1-Jun-08**	145	8		105	0.39	0.01	46	0.11	105			0.33	360		6.6	
B11	**1-Jul-08**	150	8.2		110	0.34	0.01	43	3.8	100			0.14	430		9.2	
B11	**1-Aug-08**	150	8.2		120	0.37	0.01	44	0.6	110			0.19	430		8.6	
B11	**1-Sep-08**	170	8.2		120	0.36		52	1.1	130			0.28	460		6.3	
B11	**1-Oct-08**	180	8.1		135	0.45	0.02	53	0.63	120			0.42	450		6.2	
B11	**1-Nov-08**	160	8		130	0.47	0.01	51	0.4	110			0.96	390		3.2	
B11	**1-Dec-08**	140	8		72	0.47	0.01	43	0.25	145			0.94	190		6.4	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	**1-Jan-09**	105	7.7		140	0.42	0.04	19	0.45	100	2.9	0.38	1.9	87		1.8	
B5	**1-Feb-09**	72	7.6		84	0.26	0.03	15	0.44	76	3.2	0.34	1.6	80		3.4	
B5	**1-Mar-09**	62	7.7		64	0.23	0.04	14	0.16	57	1.7		0.76	83		2.4	
B5	**1-Apr-09**	88	7.6		96	0.26	0.06	13	0.38	99	7.1		3.2	56		0.72	
B5	**1-May-09**	49	7.8		40	0.31	0.01	13	0.06	29		0.47	0.07	82		3.4	
B5	**1-Jun-09**	77	7.8		95	0.22	0.04	13	0.57	76				110		2.5	
B5	**1-Jul-09**	81	7.9		94	0.24	0.13	14	0.45	87	1.9		0.9	76		0.73	
B5	**1-Aug-09**	86	8	0.02	97	0.37	0.04	11	0.3	95	1.1	0.67	1.1	94	52		
B5	**1-Sep-09**	84	7.9	0.02	100	0.47	0.09	15	1	98	2	0.52	1.6	68		3.8	
B5	**1-Oct-09**	100	7.9		125	0.35	0.07	16	0.15	110	82	0.29	1.1	100			
B5	**1-Nov-09**	79	8		93	0.24	0.06	14	0.23	115			0.15	115		3.1	
B5	**1-Dec-09**	78	7.9		94	0.35	0.01	15	0.07	91		0.36	0.21	81		4.5	
B16	**1-Jan-09**	130	7.9		98	0.4	0.03	38	0.31	96			1.4	360		1.8	
B16	**1-Feb-09**	92	7.7		74	0.42	0.03	26	0.81	77	0.62		0.81	220		1.5	
B16	**1-Mar-09**	92	7.6		80	0.36	0.03	22	0.38	70			0.74	180		1.4	
B16	**1-Apr-09**	155	8.3		110	0.39	0.03	49	0.55	105	1	0.48	0.77	400		2.8	
B16	**1-May-09**	150	8.1		110	0.43	0.03	46	0.63	90	1.1	0.78	1.1	430		2.8	
B16	**1-Jun-09**	160	7.7		110	0.36	0.03	50	0.19	96	0.9	1.6	1	450		2.8	
B16	**1-Jul-09**	140	8		98	0.38	0.03	44	0.07	97	0.51	1.5	0.69	410		4.1	
B16	**1-Aug-09**	175	8.1		135	0.45	0.01	55	0.81	120		1.1	1.1	510		3.6	
B16	**1-Sep-09**	140	7.7		110	0.34	0.03	38	0.21	93		0.32	1.8	355		3.3	
B16	**1-Oct-09**	155	8		115	0.38	0.01	47	1.1	100	1.5	0.22	2.2	400		3.6	
B16	**1-Nov-09**	115	8.3		98	0.5	0.05	28	0.19	94	3	0.2	1.3	240		1.6	
B16	**1-Dec-09**	110	8		82	0.36	0.07	30	0.38	86	2.2		1.4	270		2	
B15	**1-Jan-09**	135	8		100	0.42		40	3.4	97			1.4	370		2.8	
B15	**1-Feb-09**	110	7.8		79	0.4	0.02	31	0.93	86	0.92		1	270		2.2	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**1-Mar-09**	97	8		80	0.36	0.02	24	0.27	71			0.75	200		2.6	
B15	**1-Apr-09**	145	8.4		105	0.34		48	0.43	100		0.29	0.59	410		3.8	
B15	**1-May-09**	140	8.3		105	0.4		46	0.5	90		0.5	0.71	410		3.8	
B15	**1-Jun-09**	145	7.7		105	0.36	0.01	44	0.12	100		1.2	0.76	430		3.9	
B15	**1-Jul-09**	140	8.1		98	0.34	0.01	44	0.06	96		1.4	0.57	400		4.6	
B15	**1-Aug-09**	145	8.1		125	0.34		42	0.11	110		0.73	1.1	420		4.4	
B15	**1-Sep-09**	120	7.6		110	0.34	0.01	38	0.16	92		0.36	1.8	350		3.2	
B15	**1-Oct-09**	140	7.7		110	0.38		42	2.2	93	1.9	0.22	2.9	360		2.4	
B15	**1-Nov-09**	115	8.2	0.09	95	0.29	0.06	30	1.3	97	1.8	0.26	1.5	250		1.3	
B15	**1-Dec-09**	110	7.9		80	0.36		30	1.8	81	1.5		1.6	270		1.6	
B6	**1-Jan-09**	62	7.2		20	0.3	0.01	22	1.3	30		0.32		240		5.3	
B6	**1-Feb-09**	60	7.1		22	0.4	0.01	22	1.8	24				250		5.3	
B6	**1-Mar-09**	52	7.4		27	0.42	0.01	17	1.8	28				195		5.6	
B6	**1-Apr-09**	89	8.2		35	0.31	0.01	36	2.2	50				360		5	
B6	**1-May-09**	63	8.2	0.03	30	0.38	0.01	21	1.3	28				260		7.6	
B6	**1-Jun-09**	80	7		44	0.44	0.4	21	7.2	38	7.1			210		2.6	
B6	**1-Jul-09**	92	7.6		40	0.46		34	10	43	3.2			340		6.1	
B6	**1-Aug-09**	98	7.6		41	0.43		37	11	44	0.55	0.31		385		5.9	
B6	**1-Sep-09**	98	7.4		46	0.52		34	10	49	2.6	0.26		325		9	
B6	**1-Oct-09**	135	6.3	5.5	68	2.4	6	42	5.6	56	0.66	0.22	1.5	245		3.6	
B6	**1-Nov-09**	110	4	32	20	1	1.3	38	4.6	26				880		7.6	
B6	**1-Dec-09**	90	5.3	22	20	0.28	1.8	29	9.3	20				700		6.2	
B17	**1-Jan-09**	140	8.3		110	0.4		41	0.76	100			1	360		4	
B17	**1-Feb-09**	100	8.1		82	0.42	0.01	30	0.15	86			1.1	245		1.3	
B17	**1-Mar-09**	105	8.1		87	0.4		28	0.08	80			0.97	245		3	
B17	**1-Apr-09**	135	8.6		100	0.31		42	0.79	99			0.71	380		4.3	
B17	**1-May-09**	140	8.4		110	0.43		45	1.3	92			0.6	410		5.9	
B17	**1-Jun-09**	150	7.8		105	0.33	0.01	44	0.36	96			0.5	420		6	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B17	**1-Jul-09**	140	8.2		105	0.32	0.01	44	0.07	100			0.38	410		6.9	
B17	**1-Aug-09**	150	8.2		120	0.33	0.04	45	0.74	100			0.57	435		6.1	
B17	**1-Sep-09**	155	8		120	0.36	0.02	45	0.16	97			0.82	410		4.1	
B17	**1-Oct-09**	150	8		120	0.4		43	1.4	100	1.8		2.9	360		4	
B17	**1-Nov-09**	125	8.7		100	0.55	0.01	36	0.22	105			1.5	305		2.5	
B17	**1-Dec-09**	110	8.5		86	0.28	0.01	31	0.68	88		0.27	1.4	265		4	
B11	**1-Jan-09**	140	8		110	0.52		42	0.91	110			1	330		7	
B11	**1-Feb-09**	110	8.1		90	0.44		34	0.16	96			1.2	270		3.6	
B11	**1-Mar-09**	100	8.1		89	0.4	0.01	29	0.06	86			1.1	240		3.8	
B11	**1-Apr-09**	125	8.6		100	0.35		39	0.53	105			0.6	340		6.3	
B11	**1-May-09**	135	8.5		110	0.42		40	0.2	89			0.58	390		6.4	
B11	**1-Jun-09**	150	8.1		70	0.3	0.01	28	0.32	58		0.44	0.2	235		8	
B11	**1-Jul-09**	145	8.2		105	0.32	0.01	46	0.09	100			0.36	410		8.1	
B11	**1-Aug-09**	150	8.6		120	0.34		46	0.2	105			0.47	425		8.8	
B11	**1-Sep-09**	150	7.9		120	0.36	0.02	44	0.15	93			0.86	410		4	
B11	**1-Oct-09**	155	8.1		120	0.4	0.01	47	0.52	110			1.1	385		7.4	
B11	**1-Nov-09**	125	8.4		100	0.34	0.01	36	0.76	96			1.6	300		3.4	
B11	**1-Dec-09**	105	8.2		82	0.34	0.01	29	0.18	79			1.3	230		3.2	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	1-Jan-10	56	7.8		48	0.44	0.06	13	0.28	48	1	0.33	0.46	72		1.3	
B5	1-Feb-10								1.4								
B5	1-Mar-10	60	7.8		56	0.24	0.03	19	0.52	58	2.5	0.54	0.67	82		3.7	
B5	1-Apr-10	68	8.1		79	0.24	0.07	13	0.79	74	6.6		2.2	59		2.2	
B5	1-May-10	76	8		88	0.29	0.06	14	0.44	79	7.5		2.8	70		2.7	
B5	1-Jun-10	93	7.6		105	0.32	0.11	16	0.75	97	8		6.5	54		1	
B5	1-Jul-10	95	7.8		105	0.24	0.05	13	0.22	105	6			105			
B5	1-Aug-10	105	7.6	0.02	135	0.46	0.11	13	0.62	96	2		1.1	125		2.3	
B5	1-Sep-10	100	7.7	0.02	130	0.24	0.09	16	0.44	125	1.5	0.34	1.9	97		1.3	
B5	1-Oct-10	105	7.8		130	0.26	0.09	14	0.77	90			0.76	92		2.7	
B5	1-Nov-10	105	8	0.05	51	0.31	0.15	17	0.33	110	2.9	0.44	0.51	100	200	1.3	
B5	1-Dec-10	73	7.8		82	0.28	0.04	18	0.13	71	2.4	0.54	0.89	96		2.5	
B16	1-Jan-10	73	7.6		50	0.31	0.03	20	0.03	44	1.6		0.8	150		1.5	
B16	1-Feb-10						0.03		0.1								
B16	1-Mar-10	59	7.6		40	0.37	0.02	17	0.17	33	0.5		0.35	115		1.7	
B16	1-Apr-10	115	7.8		82	0.34	0.01	40	0.55	86	0.6		0.42	310		2	
B16	1-May-10	95	8		70	0.27	0.01	32	0.08	72		0.43	0.45	250		3	
B16	1-Jun-10	130	8.2		95	0.34	0.02	40	0.26	96		1.2	0.71	345		3.9	
B16	1-Jul-10	120	8.2		98	0.34	0.01	34	0.07	105		0.71	0.36	305		5.4	
B16	1-Aug-10	130	8.1		100	0.27	0.01	41	0.09	145		1	1.3	365		2.3	
B16	1-Sep-10	160	7.7		110	0.43	0.01	47	0.5	140	1.9		2	390		3.7	
B16	1-Oct-10	170	7.8		120	0.52	0.01	48	0.52	160	2.4	0.42	2.4	490		4.6	
B16	1-Nov-10	150	7.5		120	0.4	0.01	40	0.58	140	1.5	0.44	2.5	380		3.4	
B16	1-Dec-10	135	7.9		86	0.51		36	0.31	105	1.9		2.4	360		1.8	
B15	1-Jan-10	79	7.6		54	0.32	0.04	23	1.5	50	1.6		0.88	180		1.7	
B15	1-Feb-10								0.98								

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**1-Mar-10**	59	7.6		40	0.34	0.04	17	0.43	34	0.58		0.38	115		1.2	
B15	**1-Apr-10**	100	7.8		74	0.32	0.02	30	0.3	66			0.39	260		2.8	
B15	**1-May-10**	100	8	0.02	68	0.3	0.01	30	0.22	68		0.34	0.32	225		1.8	
B15	**1-Jun-10**	120	8.2		94	0.34	0.01	40	0.1	92		0.94	0.51	330		3.4	
B15	**1-Jul-10**	120	8.2		100	0.35	0.01	35	0.55	100		0.55	0.66	320		4.3	
B15	**1-Aug-10**	130	7.9		100	0.31	0.03	39	0.09	105		0.82	1.1	350		2.3	
B15	**1-Sep-10**	160	7.9		110	0.4	0.01	48	0.53	125	0.56	0.3	1.5	390		3	
B15	**1-Oct-10**	160	7.9		120	0.48	0.01	46	0.46	160	0.6		2	430		3.4	
B15	**1-Nov-10**	150	7.6		120	0.52		40	1.7	150	1.6	0.28	2.3	380		2.8	
B15	**1-Dec-10**	110	7.2		78	0.48	0.03	28	3.2	86	1.9	0.11	1.6	275		2.4	
B6	**1-Jan-10**	54	6.9	0.02	24	0.26	0.01	16	1	20				190		4.5	
B6	**1-Feb-10**			4.1			1.3		5.9					435			
B6	**1-Mar-10**	58	7.3	0.03	25	0.36		18	2.2	21				220		4.2	
B6	**1-Apr-10**	90	5.8	14	32	1.8	0.41	37	11	34		1.3		470		8.2	
B6	**1-May-10**	110	4.4	18	42	1.5	0.36	46	13	30		0.46		420		8.2	
B6	**1-Jun-10**	125	4.3	24	30	3.2	0.4	54	15	36		0.63		710		5.4	
B6	**1-Jul-10**	120	4.4	14	32	1.2	0.11	50	14	40		0.24		660		9.2	
B6	**1-Aug-10**	130	4.4	0.32	37	0.74	0.09	57	0.38	43				750		7.1	
B6	**1-Sep-10**	150	4.6	6.6	41	1.2	0.08	68	10	64				460		8.2	
B6	**1-Oct-10**	120	5.7	1.1	32	0.9	0.52	42	10	42	2.6	0.89		570		4	
B6	**1-Nov-10**	98	4.7	14	26	2.4	0.1	38	14	30	0.7	0.34		470		6.7	
B6	**1-Dec-10**	62	6.8	0.08	19	0.53	0.22	17	4	20		0.36		250		3.5	
B17	**1-Jan-10**	85	7.9		55	0.34	0.01	27	0.66	52			0.61	220		3.7	
B17	**1-Feb-10**								0.55								
B17	**1-Mar-10**	65	8		44	0.37	0.01	19	0.03	35			0.47	135		2.6	
B17	**1-Apr-10**	105	7.8		76	0.36		44	2.1	74			0.33	310		7.3	
B17	**1-May-10**	105	8		77	0.27	0.01	36	1.1	66			0.22	290		5.8	
B17	**1-Jun-10**	115	8.2		88	0.32	0.01	36	0.1	92			0.33	295		5.4	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B17	**1-Jul-10**	130	8.5		100	0.36	0.18	40	2.3	150			0.34	370		5.8	
B17	**1-Aug-10**	130	8.1		105	0.31	0.01	40	0.17	105			0.4	350		3.1	
B17	**1-Sep-10**	160	8.1		115	0.4	0.02	48	1.1	135		1.9	0.58	390		3.9	
B17	**1-Oct-10**	77	8.1		130	0.49		48	0.34	170			0.84	430		4.4	
B17	**1-Nov-10**	160	7.9		130	0.44		49	0.18	155			1.1	410		6.2	
B17	**1-Dec-10**	130	8.2		84	0.42		32	0.58	92			0.94	330		3.2	
B11	**1-Jan-10**	80	7.9		54	0.34		24	0.24	45			0.7	190		4	
B11	**1-Feb-10**								0.16								
B11	**1-Mar-10**	65	8.1		43	0.36	0.01	18	0.02	34			0.48	135		3	
B11	**1-Apr-10**	96	8		74	0.32		34	0.44	73			0.52	240		6.2	
B11	**1-May-10**	96	8.1		68	0.31	0.01	34	0.38	71		0.26	0.32	215		5.8	
B11	**1-Jun-10**	110	8.3		87	0.38	0.01	36	0.07	86			0.24	300		7.8	
B11	**1-Jul-10**	125	8.3		81	0.22	0.02	26	0.56	83	3.8		2.6	205		6.5	
B11	**1-Aug-10**	130	8.2		105	0.31	0.01	41	0.28	105			0.25	345		4.3	
B11	**1-Sep-10**	150	8.3		110	0.39		47	0.28	125			0.6	380		6.3	
B11	**1-Oct-10**	170	8.1		130	0.54	0.04	50	0.24	170			0.7	460		6.7	
B11	**1-Nov-10**	165	7.9		130	0.75		48	0.18	160			0.82	410		7	
B11	**1-Dec-10**	130	7.9		82	0.44		34	1.4	97			1	325		5.8	

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Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B5	**1-Jan-11**	54	6.9		38	0.28	0.01	13	0.12	27		0.5		155		1.8	
B5	**1-Feb-11**	66	7.5		61	0.33	0.03	16	0.38	66	1.3	0.55	0.27	120		2	
B5	**1-Mar-11**	76	7.3		81	0.37	0.02	15	0.08	79	5	0.25	0.84	91		0.96	
B5	**1-Apr-11**	60	7.2		59	0.42	0.01	13	0.21	54	0.85	0.49	0.34	91		1.2	
B5	**1-May-11**	65	7.3	0.21	70	0.3	0.03	16	0.13	56		0.85	0.72	90		2	
B5	**1-Jun-11**	74	7.4		84	0.29	0.07	15	0.18	74	2.6	0.46	0.22	100		3.8	
B5	**1-Jul-11**	81	7.4		87	0.24	0.04	20	0.26	78	6		1.3	46		2.8	
B5	**1-Aug-11**	81	7.3		90	0.17	0.14	18	0.28	74		0.5	0.37	110		0.99	
B5	**1-Sep-11**	80	7.1		84	0.17	0.06	14	0.22	78	3.7		0.44	85		2.3	
B5	**1-Oct-11**	90	7.5		105	0.32	0.03	18	0.34	83	2.5	0.6	0.47	95		2.5	
B5	**1-Nov-11**	92	7.3		98	0.24	0.02	17	0.33	96	1.8		0.38	160		3.2	
B5	**1-Dec-11**	84	7.5		90	0.3	0.02	16	0.1	83		0.42	0.14	130		2.7	
B16	**1-Jan-11**	53	7.2		34	0.26	0.02	14	2.4	28	1.5		0.66	120		2.3	
B16	**1-Feb-11**	74	7.3		60	0.34	0.04	20	0.72	62	3.2		1.1	150		1.9	
B16	**1-Mar-11**	85	7.5		85	0.41	0.01	19	0.68	84	3.1		0.87	140		1.8	
B16	**1-Apr-11**	64	7.3		58	0.38	0.01	16	0.27	52	1.8		0.42	105		3.2	
B16	**1-May-11**	68	7.5		64	0.32	0.01	19	0.08	53		0.39	0.54	100		3	
B16	**1-Jun-11**	76	7.5		84	0.29	0.16	19	0.2	68	1	1.2	0.58	135		2.8	
B16	**1-Jul-11**	84	7.5		89	0.25	0.01	22	0.28	74	3.6	1.3	0.76	140		2.8	
B16	**1-Aug-11**	83	7.5		90	0.2	0.04	22	0.31	67	1.4	0.62	0.54	130		2.4	
B16	**1-Sep-11**	96	7.5		92	0.21	0.02	18	1.2	86	1.6	0.27	1.6	150		3.4	
B16	**1-Oct-11**	100	7.8		120	0.38	0.03	24	0.76	86	2.4	0.72	1.6	170		1.9	
B16	**1-Nov-11**	96	7.5		96	0.3	0.02	18	0.95	82	6.1	0.22	2.2	160		1.3	
B16	**1-Dec-11**	92	7.7		94	0.34	0.02	18	0.32	86	2.4		1.1	140		3	
B15	**1-Nov-10**	150	7.6		120	0.52		40	1.7	150	1.6	0.28	2.3	380		2.8	
B15	**1-Dec-10**	110	7.2		78	0.48	0.03	28	3.2	86	1.9		1.6	275		2.4	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B15	**1-Jan-11**	54	7.1		36	0.27	0.04	14	0.88	29	1.4		0.8	120		2.1	
B15	**1-Feb-11**	74	7.4		60	0.36	0.03	20	2.2	60	3.2		1.4	140		3.6	
B15	**1-Mar-11**	82	7.4		81	0.43	0.02	19	0.66	76	2.7		1.2	125		2.2	
B15	**1-Apr-11**	66	7.3		59	0.38		16	0.2	52	1.6	0.41	0.52	110		0.81	
B15	**1-May-11**	68	7.6		70	0.35	0.02	19	0.08	54		0.44	0.56	115		2.8	
B15	**1-Jun-11**	74	7.6		84	0.3	0.03	20	0.52	65		1.1	0.49	140		3.6	
B15	**1-Jul-11**	80	7.4		84	0.26	0.04	22	0.38	70	1.2	1.6	0.62	120		4.2	
B15	**1-Aug-11**	81	7.5		88	0.24	0.03	22	0.27	50	0.99	0.42	0.87	120		2.2	
B15	**1-Sep-11**	92	7.4		91	0.24	0.02	18	0.72	78	4.8	0.28	2.9	130		3.1	
B15	**1-Oct-11**	100	7.8		105	0.3	0.02	24	1.2	82	2.5		2	76		1.8	
B15	**1-Nov-11**	96	7.5		96	0.32	0.02	18	1.5	84	5	0.21	2.4	150		3.1	
B15	**1-Dec-11**	90	7.7		92	0.33	0.06	18	0.45	80	1.8	1.1	1.6	135		3	
B6	**1-Jan-11**	52	7.3	0.05	46	0.32		18	0.58	34		0.95		185		3.4	
B6	**1-Feb-11**	56	7.4	0.28	50	0.4	0.02	18	0.81	42		0.6		89		6.2	
B6	**1-Mar-11**	46	7.6	0.04	40	0.37	0.01	13	0.12	34				35		6	
B6	**1-Apr-11**	61	6.8		32	0.45				2.2		0.59		225		2.2	
B6	**1-May-11**	58	7.1	0.46	41	0.45	0.06	20	1.7	30		0.2		190		9.2	
B6	**1-Jun-11**	52	7.1	0.09	33	0.36	0.12	17	2	24		0.36		170		8	
B6	**1-Jul-11**	47	7.3	0.02	31	0.31	0.01	18	1.2	22				120		5.4	
B6	**1-Aug-11**	43	7.3	0.05	30	0.28	0.03	16	0.58	14	0.61	0.28	0.17	77		6.1	
B6	**1-Sep-11**	42	7.1	0.04	56	0.3	0.02	12	0.18	22	2.7	1.4	0.33	115		6.7	
B6	**1-Oct-11**	44	7.5		21	0.39	0.01	13	0.16	22				78		5.1	
B6	**1-Nov-11**	42	6.8	0.03	22	0.28	0.06	12	0.08	18				98		5	
B6	**1-Dec-11**	40	7.5	0.02	18	0.3	0.01	10	0.02	20		0.24		70		7	
B17	**1-Jan-11**	66	8		48	0.31		20	0.23	41			0.83	150		4.3	
B17	**1-Feb-11**	76	7.6		59	0.38	0.01	22	1.4	64			1.1	160		5.6	
B17	**1-Mar-11**	83	7.7		73	0.43		22	1.7	70			1.3	135		3	
B17	**1-Apr-11**	71	7.5		61	0.42		19	0.32	55		0.4	0.89	135		5.4	

Site	Date	EC	pH	AL	Cl	F	Fe	Mg	Mn	Na	NH_4	NO_3	PO_4	SO_4	COD	DO	SS
B17	**1-May-11**	76	7.8		66	0.38		24	0.07	54			0.59	140		3.5	
B17	**1-Jun-11**	81	7.7		78	0.32	0.02	24	0.15	62			0.49	170		3.4	
B17	**1-Jul-11**	90	7.8		94	0.3	0.01	26	1.2	74			0.35	180		3	
B17	**1-Aug-11**	94	7.7		98	0.3		28	0.25	55	6.6		0.15	205		3.6	
B17	**1-Sep-11**	98	7.5		98	0.28	0.01	22	0.31	79			0.5	155		5.7	
B17	**1-Oct-11**	105	8		110	0.3		26	0.29	83			1	200		1.8	
B17	**1-Nov-11**	110	7.7		110	0.7	0.01	23	0.5	92		0.24	1.3	150		1.6	
B17	**1-Dec-11**	105	7.9		100	0.38	0.01	24	0.18	86			1.5	170		4	
B11	**1-Jan-11**	56	7.3		36	0.34	0.01	14	0.9	30			0.62	120		4	
B11	**1-Feb-11**	78	7.7		58	0.47	0.02	23	0.29	62			0.8	170		5.6	
B11	**1-Mar-11**	84	7.7	0.1	70	0.45	0.01	23	0.2	69			0.86	145		5.4	
B11	**1-Apr-11**	74	7.6		62	0.43		20	0.15	56			0.77	150		3.1	
B11	**1-May-11**	76	7.7		65	0.37		22	0.06	52			0.56	140		4.6	
B11	**1-Jun-11**	80	7.9		80	0.34	0.01	24	0.14	62			0.44	180		6	
B11	**1-Jul-11**	88	7.9		91	0.3	0.01	24	0.08	66			0.29	175		5.2	
B11	**1-Aug-11**	96	7.7		97	0.31	0.02	28	0.26	67			0.24	210		3.4	
B11	**1-Sep-11**	99	7.6		98	0.28	0.03	24	0.2	80	0.96		1.2	160		3.2	
B11	**1-Oct-11**	110	8.2		110	0.6	0.01	28	0.18	84			0.76	150		4.6	
B11	**1-Nov-11**	110	7.9		115	0.38		26	0.22	76			0.88	180		8	
B11	**1-Dec-11**	110	7.9		110	0.44	0.06	26	0.21	100		1.1	1	180		2.8	

Appendix 3: Mean seasonal and inter-annual results in tabular format

Monthly Average Sulphate (mg/L) from 2000 to 2010												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
B6	210	197	174	289	275	351	273	284	241	249	332	242
B5	94	102	105	102	124	104	130	129	127	134	122	121
B16	467	377	341	558	558	554	596	608	649	614	566	448
B15	476	372	366	561	593	565	531	599	582	572	522	446
B17	426	351	314	477	523	521	584	588	589	602	528	481
B11	507	411	326	452	574	542	508	605	593	609	563	495
Minimum and maximum values per site highlighted in yellow												

Monthly Average Sulphate (mg/L) in 2011												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
B6	185	89	35	225	190	170	120	77	115	78	98	70
B5	155	120	91	91	90	100	46	110	85	95	160	130
B16	120	150	140	105	100	135	140	130	150	170	160	140
B15	120	140	125	110	115	140	120	120	130	76	265	205
B17	150	160	135	135	140	170	180	205	155	200	150	170
B11	120	170	145	150	140	180	175	210	160	150	180	180
Minimum and maximum values per site highlighted in yellow												

Inter-annual Average Sulphate (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	393	268	231	232	326	237	81	72	321	366	487	121
B5	104	122	134	125	142	108	109	122	121	86	87	106
B16	627	652	659	657	609	508	446	416	363	352	315	137
B15	616	577	640	652	564	525	427	417	363	345	289	153
B17	512	537	598	638	574	520	447	439	360	354	321	163
B11	551	573	617	739	582	510	457	439	345	330	291	163
Minimum and maximum values per site highlighted in yellow												

Monthly Average Sodium (mg/L) from 2000 to 2010												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	48	46	36	48	54	58	56	65	70	53	51	40
B5	107	108	97	96	121	119	134	146	156	149	138	120
B16	123	119	115	132	134	134	130	156	164	157	142	117
B15	123	114	114	128	131	137	133	158	158	153	134	120
B17	124	114	105	106	126	135	135	149	159	148	145	128
B11	131	116	109	121	134	137	128	160	172	173	151	135
Minimum and maximum values per site highlighted in yellow												

Monthly Average Sodium (mg/L) in 2011												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	34	42	34	2	30	24	22	14	22	22	18	20
B5	27	66	79	54	56	74	78	74	78	83	96	83
B16	28	62	84	52	53	68	74	67	86	86	82	86
B15	29	60	76	52	54	65	70	50	78	82	117	83
B17	41	64	70	55	54	62	74	55	79	83	92	86
B11	30	62	69	56	52	62	66	67	80	84	76	100
Minimum and maximum values per site highlighted in yellow												

Inter-annual Average Sodium (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	89	53	65	59	69	47	31	39	41	36	36	24
B5	121	159	155	122	144	125	121	113	86	86	87	71
B16	143	173	170	164	145	124	118	116	101	94	102	69
B15	144	171	165	159	140	123	118	117	101	93	89	73
B17	132	137	157	158	144	129	128	122	103	95	102	68
B11	134	168	175	173	145	134	129	126	103	94	95	67
Minimum and maximum values per site highlighted in yellow												

Monthly Average Chloride (mg/L) from 2000 to 2010												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	40	35	34	48	53	62	58	65	61	56	52	38
B5	118	128	102	125	130	124	143	157	155	167	130	124
B16	120	113	107	122	134	130	150	148	173	150	148	121
B15	119	115	108	119	130	131	146	154	157	146	144	125
B17	121	114	103	114	132	130	148	157	177	159	153	138
B11	133	122	103	119	134	131	150	159	167	166	159	147
Minimum and maximum values per site highlighted in yellow												

Monthly Average Chloride (mg/L) in 2011												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	46	50	40	32	41	33	31	30	56	21	22	18
B5	38	61	81	59	70	84	87	90	84	105	98	90
B16	34	60	85	58	64	84	89	90	92	120	96	94
B15	36	60	81	59	70	84	84	88	91	105	108	85
B17	48	59	73	61	66	78	94	98	98	110	110	100
B11	36	58	70	62	65	80	91	97	98	110	115	110
Minimum and maximum values per site highlighted in yellow												

Inter-annual Average Chloride (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	65	59	76	57	61	44	32	37	38	34	32	35
B5	135	163	169	133	164	132	126	120	94	94	92	79
B16	142	156	168	153	153	129	124	126	99	102	88	81
B15	132	153	164	149	148	130	125	126	100	99	84	82
B17	139	151	164	154	151	137	133	138	101	104	91	83
B11	129	158	169	175	162	138	136	142	100	101	88	83
Minimum and maximum values per site highlighted in yellow												

Monthly Average Magnesium (mg/L) from 2000 to 2010												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	20	17	16	22	22	28	25	28	27	24	25	19
B5	16	19	15	17	18	17	20	18	18	18	18	17
B16	48	46	43	54	60	58	57	64	60	67	61	47
B15	49	49	44	49	58	60	58	58	61	63	57	49
B17	47	45	40	43	57	59	60	58	60	64	61	51
B11	53	46	40	44	58	60	60	58	65	69	66	57
Minimum and maximum values per site highlighted in yellow												

Monthly Average Magnesium (mg/L) in 2011												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	18	18	13	UDL	20	17	18	16	12	13	12	10
B5	13	16	15	13	16	15	20	18	14	18	17	16
B16	14	20	19	16	19	19	22	22	18	24	18	18
B15	14	20	19	16	19	20	22	22	18	24	29	23
B17	20	22	22	19	24	24	26	28	22	26	23	24
B11	14	23	23	20	22	24	24	28	24	28	26	26
Minimum and maximum values per site highlighted in yellow												

Inter-annual Average Magnesium (mg/L)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	31	21	23	20	24	19	14	14	30	29	43	16
B5	19	18	21	18	20	15	16	17	15	14	15	16
B16	61	60	72	70	62	54	48	48	41	39	36	19
B15	63	60	68	66	58	55	48	47	42	38	34	21
B17	54	51	66	66	60	57	51	49	42	40	38	23
B11	53	57	71	75	64	58	52	51	42	38	36	24
Minimum and maximum values per site highlighted in yellow												

Monthly Average Electrical Conductivity (mS/m) from 2000 to 2010												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	79	66	60	75	79	90	85	90	88	82	87	70
B5	97	103	89	102	103	102	113	120	121	123	108	104
B16	158	149	145	171	186	183	187	197	205	208	189	164
B15	163	153	145	164	181	186	190	198	197	195	183	172
B17	160	144	134	156	174	182	192	194	202	198	191	171
B11	169	155	141	155	179	185	189	200	206	210	195	180
Minimum and maximum values per site highlighted in yellow												

Monthly Average Electrical Conductivity (mS/m) in 2011												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	52	56	46	61	58	52	47	43	42	44	42	40
B5	54	66	76	60	65	74	81	81	80	90	92	84
B16	53	74	85	64	68	76	84	83	96	100	96	92
B15	54	74	82	66	68	74	80	81	92	100	123	100
B17	66	76	83	71	76	81	90	94	98	105	110	105
B11	56	78	84	74	76	80	88	96	99	110	110	110
Minimum and maximum values per site highlighted in yellow												

Inter-annual Average Electrical Conductivity (mS/m)												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	110	84	84	70	95	72	49	52	81	86	106	49
B5	107	127	127	108	125	106	100	100	86	80	85	75
B16	186	211	216	214	197	170	161	159	137	135	122	81
B15	183	214	210	210	192	172	161	155	139	129	114	87
B17	168	189	202	212	198	177	166	167	138	133	115	88
B11	177	217	208	223	193	175	168	169	139	133	120	88
Minimum and maximum values per site highlighted in yellow												

Monthly Average pH from 2000 to 2010												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	7.0	7.2	7.5	7.3	7.2	7.1	7.1	7.4	7.3	7.2	6.7	7.1
B5	7.8	7.8	7.9	7.8	7.8	8.0	8.0	8.0	8.1	7.7	7.9	7.9
B16	7.9	8.0	7.9	8.0	8.1	8.0	8.1	8.1	8.0	8.0	8.0	7.9
B15	8.0	8.0	7.9	8.0	8.0	8.0	8.0	8.1	8.0	7.7	8.0	8.0
B17	8.1	8.1	8.0	8.1	8.1	8.1	8.2	8.2	8.2	8.1	8.2	8.1
B11	8.1	8.2	8.1	8.2	8.2	8.1	8.2	8.3	8.2	8.2	8.2	8.1
Minimum and maximum values per site highlighted in yellow												

Monthly Average pH in 2011												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B6	7.3	7.4	7.6	6.8	7.1	7.1	7.3	7.3	7.1	7.5	6.8	7.5
B5	6.9	7.5	7.3	7.2	7.3	7.4	7.4	7.3	7.1	7.5	7.3	7.5
B16	7.2	7.3	7.5	7.3	7.5	7.5	7.5	7.5	7.5	7.8	7.5	7.7
B15	7.1	7.4	7.4	7.3	7.6	7.6	7.4	7.5	7.4	7.8	7.6	7.5
B17	8.0	7.6	7.7	7.5	7.8	7.7	7.8	7.7	7.5	8.0	7.7	7.9
B11	7.3	7.7	7.7	7.6	7.7	7.9	7.9	7.7	7.6	8.2	7.9	7.9
Minimum and maximum values per site highlighted in yellow												

Inter-annual Average pH												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
B6	5.8	7.2	7.6	7.3	7.6	7.4	7.7	7.9	7.2	6.9	5.3	7.2
B5	7.8	8.0	8.1	8.0	7.9	7.8	7.7	7.9	7.6	7.8	7.8	7.3
B16	8.0	8.2	8.1	8.1	8.2	8.0	7.8	7.9	7.9	8.0	7.9	7.5
B15	7.7	8.1	8.1	8.0	8.2	8.0	7.9	8.0	7.9	8.0	7.9	7.5
B17	8.0	8.1	8.2	8.1	8.2	8.2	8.1	8.1	8.0	8.2	8.1	7.7
B11	8.0	8.3	8.3	8.1	8.2	8.2	8.1	8.1	8.1	8.2	8.1	7.8
Minimum and maximum values per site highlighted in yellow												

Appendix 4: Guidelines for operation of the Montreux Record

GUIDELINES FOR OPERATION OF THE MONTREUX RECORD
28/10/1996 (Adopted by the Conference of the Contracting Parties in Resolution VI.1, Brisbane, 1996, accompanying the Guidelines for Operation of the Montreux Record)

3.3. The following procedure should be observed when considering the removal of a listed site from the Montreux Record:

3.3.1 The Bureau is requested to remove a listed site from the Montreux Record by the Contracting Party in whose territory the site is included. The Bureau may also receive information from other sources, suggesting that there is no longer a risk of change in the ecological character of the listed site.

3 3.2 The Bureau will submit the concise questionnaire (see "**Montreux Record - Questionnaire**") to the Contracting Party and forward the completed questionnaire to the Scientific and Technical Review Panel (STRP) for advice in line with the "Working Definitions and Guidelines for Describing and Maintaining the Ecological Character of Listed Sites".

3.3.3 Any requests from the STRP for further information, together with the STRP's technical comments or advice, will be forwarded by the Bureau to the Contracting Party. The Bureau may also request information from other sources.

3.3.4 At the invitation of the Contracting Party, the Bureau may organize a site visit, ideally by the relevant Bureau staff member, the regional member of the STRP, and other appropriate experts.

3.3.5 A wetland will be removed from the Montreux Record based on the request of the Contracting Party and after consideration of advice and/or comment from the STRP. The final decision will be made by the Contracting Party.

3.3.6 The Bureau will, unless the Contracting Party concerned objects, provide information on the decision made by the Contracting Party to other interested bodies.

[This resolution was accompanied by the "**Montreux Record - Questionnaire**", included here as a separate document.]

The Convention on Wetlands: (Ramsar, Iran, 1971)

Montreux Record - Questionnaire

(As adopted by the Conference of the Contracting Parties in Resolution VI.1)

Section One

Information for assessing possible inclusion of a listed site in the Montreux Record

Essential items

(based on the Blesbokspruit Information Sheet updated on 21 August 1998, South African Wetlands Conservation Programme, 1999 http://www.ngo.grida.no/soesa/nsoer/resource/wetland/blesbokspruit_ris.htm (Accessed 20 March 2012)

- **Name of site**

  The Blesbokspruit (designated 02/10/86, Gauteng, 1,858 ha, Montreux Record 06/05/96)

- **Ramsar Criteria for listing the site as internationally important**

  "1c: Wetland is a particularly good representative example of a wetland which plays a substantial hydrological, biological or ecological role in the natural functioning of a major river basin;
  2a: It supports an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plant or animal, or an appreciable number of individuals of any one or more of these species;
  3b: It regularly supports substantial numbers of individuals from particular groups of waterfowl, indicative of wetland values, productivity or diversity"

  Nature of the change in ecological character/potential for adverse change

  "The site has been listed on the Montreax Record due to upstream and adjacent activities, which threaten the ecological nature of the site. Due to the linearity of the system and the fact that the site is located downstream of potentially harmful industries, mines and sewage works these threats are difficult to control. The lack of an integrated catchment management plan also contributes to the difficulties experienced with the site. It has been proposed that the Department of Water Affairs and Forestry in conjunction with a Catchment Management Agency will develop such a plan."

- **Reason(s) for adverse change, or potential adverse change, in ecological character**

  "The site has been listed on the Montreax Record due to upstream and adjacent activities, which threaten the ecological nature of the site. Due to the linearity of the system and the fact that the site is located downstream of potentially harmful industries, mines and sewage works these threats are difficult to control. The lack of an integrated catchment management plan also contributes to the difficulties experienced with the site. It has been proposed that the Department of Water Affairs and Forestry in conjunction with a Catchment Management Agency will develop such a plan."

- **Additional items which may be included**

- **Date Information Sheet on Ramsar Wetlands submitted**

  21 August 1998

- **Date and source of Information Sheet updates (e.g. National Reports, national wetland inventory, specific survey)**

  21 August 1998 by Candice Haskins under the South African Wetlands Conservation Programme

- **Benefits and values derived from the site**

*“**Hydrological values:** Water from the Blesbokspruit ultimately flows into the Vaal River Barrage where it is distributed to people in the province for drinking and other domestic purposes. Maintaining good quality water in the Blesbokspruit is therefore important. Although the wetland does have a natural purification capacity it is not regarded as the primary purifier of effluents entering the catchment as effluents are required to be treated to Department of Water Affairs standards. Since this ideal is not always realized, the Blesbokspruit wetland undoubtedly assists with purification. Extensive reedbeds (estimated at greater than 90% of the total wetland area) possibly assist with uptake of nutrients, toxins and heavy metals.Flow of water may be slowed by these reedbeds - flood control? The residence time of water in the system is cause for concern for some adjacent residents whose properties occasionally experience flooding.The reedbeds have a well-developed root structure that traps sediments. Reedbeds occur as rooted structures and floating "islands". The relative proportions of these two colony types/growth forms is not known. The relative contributions of these to purification, nutrient uptake and sediment trapping is not known.*

***Ecological features:** the Blesbokspruit wetland predominately provides dense (Typha sp. and Phragmites sp.) reed habitat. These reedbeds exist mainly as large and small single species colonies with some mixed species clumps. Open water habitat is limited to small deep-water pools. Shallow water habitat suitable for wading birds is rare.Inundated sedges and grassland (marshy habitat) is a small component, which exists mainly during the summer rainfall periods. These portions occur as a narrow band on the outer edge of the wetland.Natural plant communities adjacent to the Blesbokspruit are described as Highveld Grassland. These communities are however currently limited due to urbanization and surrounding land use practices (mining, agriculture etc). Adjacent lands are utilized for agricultural purposes e.g. maize and other vegetable crops.Trees are not a natural feature in the landscape. The exotic South American water fern (Azolla filiculoides) has been introduced into this country and occurs in many wetlands, including the Blesbokspruit. Transfer of this species between wetlands probably occurs when portions of the plant, seeds or spores become attached to waterfowl. This plant occurs mainly in slow moving or stagnant portions of the wetland.*

***Noteworthy flora:** the Blesbokspruit is situated in the Cymbopogon-Themeda veld (Acocks veld type no 48). This veld type merges with the Bankenveld and is a spare, tufted sourveld. The aquatic habitat consists mostly of Phragmites australis, bulrushes Typha latifolia and sedges which cover 90% of the water surface. These wetlands cover an area approximately 85% of the Marievale Bird Sanctuary. The remaining 15% is a grassland which is broadly classified as Bankenveld.A wide variety of flowering plants occur. A few of the more spectacular are the Orange River lily Crinum bulbispermum, plough breaker Erythrina zeyheri and Aloe ecklonis.*

***Noteworthy fauna:** the Blesbokspruit supports significant numbers of waterfowl, including up to 4000 yellow-billed duck, Anas erythrorhyncha and 1000 spur-winged goose Plectropterus gambensis in the dry season, when levels are maintained artificially at a high level. The high-productivity water provides food for greater flamingo Phoenicopterus ruber, and lesser flamingo Phoeniconaias minor, which are South African Red Data Book Species. Other notable birds* *include avocet Recurvirostra avosetta, purple heron Ardea purpe rata, spoonbill Platalea alba, glossy ibis Plegadis falcinellus and yellow-billed stork Mycteria ibis. African marsh harrier Circus ranivorus, which has been displaced from much of the veld, maintains a strong population here. There are at least three heron roosts with a total of over 3500 birds.Increasing urbanization and industrialization in the central Gauteng reduce the number of sites available to the local fauna and flora. The Blesbokspruit supports a variety of fish, amphibians, reptiles, crustaceans and rodents. Spotted-necked otters Lutra maculicollis, water mongoose Atilax palidinosus and many larger birds depend on these animals for their food.The reedbuck Redunca arundinum regarded as uncommon in South Africa, has also been recorded here. See attached list for other fauna recorded.Avifauna count data is available from biannual CWAC (Coordinated Waterfowl Counts) reports, while species lists are submitted by reserve visitors to BIRP (Birds In Reserves Programme) - both programmes are run by the Avian Demography Unit at the University of Cape Town.*

Social and cultural values: *before mining started in the area in the early 1930's the Blesbokspruit flowed unrestricted through a broad, grassy valley. A single bridge, built in 1899-1900 linked the town of Springs to the farm Vlakfontein. By the mid-1940's, mines in the area were in full production. Residential areas had been established for mine employees and thousands of trees and shrubs planted. Several roads built on embankments crossing the spruit had dammed up large areas of shallow open water which provided habitat for beds of Phragmites and Typha.In the past, hunting was popular along the spruit. The mining companies owning land along the spruit afforded some protection to the wildlife of the area. Both on Marievale and Daggafontein annual duck shoots were held. In 1963 Marievale prohibited shooting on their property.Approximately 1000ha of the designated site falls in a proclaimed provincial nature reserve (Marievale Bird Sanctuary). The reserve is mainly valued for its bird watching facilities. Short walking trails are also available on the reserve."*

- **<u>Extent to which values and benefits derived from the site have decreased or changed</u>**

"Mining - mainly gold mines. Dewatering of mine shafts contributes large quantities of poor quality water to the Blesbokspruit. Fish kills have occurred due to the presence of a red iron precipitate in the discharged water. Settling ponds and a pilot desalination plant have/are been introduced to reduce the pollution to the wetland. An open-cast coal mine and clay extraction facility has been proposed for a site adjacent to the designated site (approximately opposite the Grootvlei Mine, but on the other bank).

Sewage treatment works - several sewage treatment works are located along the Blesbokspruit and treated sewage is discharged into the Blesbokspruit. These discharges have contributed to the eutrophic status of the wetland. Continued urban growth in the catchment has necessitated the upgrading of existing, and creation of new, sewage treatment works. The impact of sewage discharges on the Blesbokspruit is likely to increase (unless more efficient treatment technologies are introduced).

Both mining and sewage works contribute more water to the system than would be expected in pristine conditions. These quantities of water are likely to increase in the future due to urban expansion in the catchment."

"Urban expansion in the catchment will increase runoff and demand for land adjacent to the site."

"Lack of funds to treat discharged mine water from gold mine shafts adjacent to the site means that the quality of water discharged into the Blesbokspruit could conceivably deteriorate."

- **Monitoring programme in place at the site, if any (technique(s), objectives, and nature of data and information gathered)**

  "Gauteng Nature Conservation undertook a one-year pilot project to test the feasibility of utilizing registered herbicides for the control of Typha and Phragmites reeds. Control of reeds was deemed necessary to create a variety of bird habitats. The test addressed the economic and ecological aspects of this management technique.

  A variety of Environmental Impact Assessments have been prompted by development proposals adjacent to, and upstream of, the designated site. These studies generally addressed various ecological and environmental issues, which contributes to the knowledge of the Blesbokspruit system.

  The Avian Demography Unit at the University of Cape Town is running a countrywide project called BIRP (Birds in Reserve Project). Bird watchers fill in a species list for nature reserves and then forward them to Cape Town for analysis. Marievale Nature Reserve is listed on the project. An information request service is available through Cape Town - a fee is charged for information retrieval and printing of reports.

  An interested member of the public undertakes a bird survey approximately once a month along the entire Blesbokspruit system - this information is available to interested parties."

- **Assessment procedures in place, if any (how is the information obtained from the monitoring programme used)**

  "Gauteng Nature Conservation undertook a one-year pilot project to test the feasibility of utilizing registered herbicides for the control of Typha and Phragmites reeds. Control of reeds was deemed necessary to create a variety of bird habitats. The test addressed the economic and ecological aspects of this management technique.

  A variety of Environmental Impact Assessments have been prompted by development proposals adjacent to, and upstream of, the designated site. These studies generally addressed various ecological and environmental issues, which contributes to the knowledge of the Blesbokspruit system.

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  An interested member of the public undertakes a bird survey approximately once a month along the entire Blesbokspruit system - this information is available to interested parties."

- **<u>Ameliorative and restoration measures in place or planned (if any) so far</u>**

  "Proposed measures: A management plan for the Ramsar site is to be developed by external consultants in consultation with all landowners and affected parties. If approved, provincial government will fund the study. Part of the study will address the lack of clarity around the boundaries of the Ramsar site.Management activities within the Ramsar site will have to be funded and implemented by all stakeholders."

  "The Blesbokspruit Ramsar site has suffered a lack of committed management for many years. This has undoubtedly contributed to its precarious status. An Interim Blesbokspruit Management Committee was formed to discuss objectives for the site. A management plan has yet to be developed and implemented.

  Gauteng Nature Conservation has undertaken management of the provincial nature reserve, Marievale, located in the southern portion of the designated site. A staff member has been allocated to the reserve and a variety of infrastructure developments have added to the services offered and appeal of the reserve (e.g. upgrading of roads, wheel chair access to bird hides and toilet facilities, bird hides upgraded or repaired, new hides built, thatched shaded picnic facilities supplied). Scientific input on the creation or promotion of bird habitat has been given - this was believed to be important as reedbeds dominate the wetland and continue to encroach on other marginal habitats.

  Fire is a serious potential hazard on the provincial reserve. Accidental or deliberate fires frequently burn uncontrollably in the vast reedbeds. This poses a significant threat to visitors and reserve or private properties. Creating firebreaks in grassland adjacent to the reedbeds is difficult as fire can easily enter the reeds. During 1997, managers of Marievale used herbicides to create fire safety zones in high risk areas - i.e. along the southern (50m wide), eastern and western boundaries (100m each)."

- **<u>List of attachments provided by the Contracting Party (if applicable);</u>**
- **<u>List of attachments provided by the Ramsar Bureau (if applicable).</u>**

Section Two

Information for assessing possible removal of a listed site from the Montreux Record

- **<u>Success of ameliorative, restoration or maintenance measures (describe if different from those covered in Section One of this questionnaire)</u>**

  The long term inter annual trends over the eleven years covered in this study support the hypothesis that the surface water quality in the Blesbokspruit wetland has been improving, primarily because a range of water quality management interventions have taken place subsequent to the Grootvlei Mine 'incident' in 1996. From 2001, with the installation of more effective water treatment plants by Grootvlei Mine, the salt load downstream of the mine discharge point had been decreasing until 2010—when that mine ceased pumping operations. From 2000 to 2010, a progressive decline in the salt levels correlated with lesser conductivity values as well as a neutral to alkaline pH levels (7.6 8.3) throughout the sites along the Blesbokspruit wetland. The improvement in the surface water quality of the Blesbokspruit wetland is ultimately linked to the closure of the Grootvlei mine (lastly owned by Aurora Empowerment Systems) in December 2010. It can be concluded that this mine was the main culprit through the discharge of its high in salts underground mine waters. However, the concentrations of Na and Cl showed a different story, with similar higher concentrations of these two elements recorded in the water entering the Blesbokspruit wetland at site B5 and exiting at site B11. This means that the majority of the Na and Cl loading did not originate from the underground mine water pumping operations at Grootvlei Mine, but came from other sources (e.g. paper and pulp industry, sewage plant) using Cl and Na in their processes prior to the discharge of waste water into the stream.

  The year 2011—during which there was no pumping of mine water from Grootvlei Mine and after Sappi Enstra had decommissioned its pulp plant—was marked by a consistent decrease in all the salts; EC dropped in parallel with the reduced salt load. pH values for the sites along the Blesbokspruit wetland were uniform over the ten years 2000 to 2010, with values within the band pH = 7.6 to 8.2. However, in 2011, a distinct drop of ~0.5 pH units occurred—i.e. indicating a slight trend towards acidification, in coincidence with the cessation of underground pumping and the closure of the pulp plant. This consistent improvement in the Blesbokspruit water quality challenges previous views that surface water quality would deteriorate after discontinuation of underground pumping. However, the decanting of underground water may occur in future since it is reported that the water table is rising rapidly in this water compartment. The signature of high Na and Cl in the inlet water also challenges the view that high salinity of Blesbokspruit water was primarily caused by the mine discharges—inflow of saline surface water from upstream industries has also been shown to be a major contributor to the pollution load.

- **<u>Proposed monitoring and assessment procedures (describe if different from those in Section One of this questionnaire)</u>**

  Surface water monitoring is performed by members of the Blesbokspruit Forum, which includes Rand Water Board. Rand Water collects routine and non routine samples, depending on the requirements of the day. For external testing (for instance: for customers with specific job requirements), Rand Water performs non routine testing, whereas, as part of their normal monitoring programme for drinking, sewage and catchment water, Rand Water collects samples on a routine basis following established procedures. The sampling procedures for drinking, sewage and catchment water are each different.

  Qualified technicians perform water sampling fieldwork and laboratory analyses. The technicians undergo two to six months training and evaluation until proven competent. Certified competency of the technicians, both in the field and at the laboratories, is an essential condition for the overall accreditation of Rand Water's sampling and analytical laboratory, and for the credibility of results provided to third parties.

- **Extent to which the ecological character, benefits and values of the site have been restored or maintained (provide details)**

  Since the pumping of underground water stopped in 2010 (when Grootvlei mine met financial troubles—the mine was still under liquidation in 2011 2012), the pollution load from this source has reduced. Drastic drops in SO4, Mg and associated EC levels after 2010 confirm this. Nevertheless, Na and Cl concentrations proven to originate from other effluents (i.e. pulp plant and sewage plant), have, in part, negated conclusions drawn by previous investigations which used to link all Na and Cl to just the underground mine water pumping operations. After 2010, with the closure of the pulp plant at Sappi Enstra, Na and Cl showed a further slight drop in levels across the samples taken from the water entering the Blesbokspruit wetland to the exit point at B11.

  With the continuous decrease of the salt load over the years and the discontinuation of discharge by Grootvlei Mine and Sappi Enstra in 2011, surface water quality in the Blesbokspruit wetland can be expected to gradually reach desirable conditions for—mainly—the aquatic biota, including the return of abundant waterfowl (through which the wetland first gained its international accreditation). If desirable water conditions are to continue in the Blesbokspruit wetland, it is necessary to control the different sources of water pollutants and eliminate conflict with agricultural and aquatic ecosystem water requirements (i.e. in terms of salts and inherent EC). Effective management of the Blesbokspruit wetland and better water treatment technologies/desalination plants (by industries or users of the Blesbokspruit water) remain essential to the good health of this important water source.

- **Rationale for removing the site from the Montreux Record (refer to Guidelines for operation of the Montreux Record, together with Section One of this questionnaire)**

  On the grounds of the progressive inter annual decline in all the salts and combined EC, as well as with pH values being above neutral, it is now possible to consider making application to the Ramsar Committee requesting the delisting of Blesbokspruit wetland from the Montreux Record. However, possible future threats of surface decanting, from underground works because of rising water levels in the absence of underground pumping operations or from derelict mines (Table 6), could still pose an ecological hazard with socioeconomic repercussions (Table 6). The need for a viable and holistic management plan still exists—a plan that will embrace underground mine water pumping requirements with environmental conservation.

- **List of further attachments (if applicable).**

For further information, please contact:

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Tel: +41 22 999 0170, Fax +41 22 999 0169
E-mail: ramsar@ramsar.org
Web: http://ramsar.org

Appendix 5: Minutes of the meeting with Rand Water Board

<table>
<tr><td colspan="3">Minor-dissertation Consultation Minutes of Ambani AE
“Long-term assessment of the surface water quality in the Blesbokspruit Ramsar wetland site”</td></tr>
<tr><td colspan="2">Purpose of the meeting</td><td>Understand Rand Water Board (RWB) monitoring campaign and the validity of the surface water quality data as provided</td></tr>
<tr><td colspan="2">Attendees</td><td>Marc De Fontaine (MF) (Water Quality Specialist and Manager at RWB)
Ambani Annie-Estelle (AEA) (MSc Student at University of Johannesburg)</td></tr>
<tr><td colspan="2">Date, Time & Place</td><td>20120605 10:030-11:00, Rand Water Board, Glenvista Head Office</td></tr>
<tr><td colspan="2">Agenda item</td><td></td></tr>
<tr><td>1</td><td colspan="2">Data validity:
• It will be better if Rand Water Board could provide validated data not averaged values to students for academic research</td></tr>
<tr><td>2</td><td colspan="2">Metadata:
• It will be useful for students to understand of metadata on sampling sites - providing information on how and why specific water monitoring sites were chosen in terms of the planning of the sampling network</td></tr>
<tr><td>3</td><td colspan="2">Sampling network:
• To find out if the current sampling network still answer Rand Water's initial goal and objectives/criteria</td></tr>
<tr><td>4</td><td colspan="2">Availability of historic data:
• To find out if Rand Water has record of surface water quality data close to the year 1996, as a key point for this water system with the Grootvlei Mine ‘incident’ and listing of the whole Blesbokspruit Ramsar site onto the Montreux Record</td></tr>
<tr><td>5</td><td colspan="2">Academic involvement in RWB research:
• To get students involved in various projects such as the assessment of the current sampling network or to work in collaboration with the University of Johannesburg Departments (Geography, Environmental Management, Chemistry, Botany or Zoology) for further research and development</td></tr>
<tr><td colspan="3">The meeting ended at 11:00 am and MF promised to send surface water quality data (from 2000 – 2011) to AEA in the next coming days</td></tr>
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