CHAPTER 3

An investigation into the water quality of the Klip River (Gauteng) and the development of a water quality Guideline Compliance Index (GCI) for rapid water quality classification.

1. INTRODUCTION

A catchment is defined as all the land drained by one river system. The physical, chemical and biological characteristics of any river are determined almost entirely by the nature of its catchment, and activities – anthropogenic and natural- that take place in it (Davies & Day, 1998; Perona *et al*., 1999). A major impact on aquatic ecosystems is often the addition of chemical pollutants into the system. The type of anthropogenic activity in the catchment generally determines the type of pollutant entering the ground and surface waters of the system. Often these pollutants are detrimental for both the biota and the humans reliant on the aquatic resources (Dallas & Day, 1993).

River systems draining highly populated areas, agricultural areas, informal settlements and which receive effluents from waste water treatment works (WWTW's), industries and mines, have been observed to suffer the consequence of these activities all around the world (Koning & Roos, 1999; Perona *et al*., 1999; Jarvie *et al*., 2000; Neal et al. 2000; Ferrier *et al*., 2002). Often the impact is small enough only to have sub-lethal effects on the aquatic biota, resulting in small changes in ecological integrity (Karr *et al*., 1987; Adams *et al*., 1992; Heath, 1999; du Preez 2000). In some cases however, the deterioration was so extreme that it resulted in the eradication of all the biota of the system, becoming a sterile system. These aquatic systems not only suffered a loss of its natural ecological processes, but also became useless to human populations previously reliant on them (Loeb & Spacie, 1994).

The Klip River catchment is characterized by formal and informal settlements, many WWTW's, mining, industrial and agricultural activities, which have been responsible for degradation of the system in the past (Rand Water, 1998; Rand Water, 1999). Apart from its burden by both water quality and quantity changes, this river plays an important role to the communities along its banks, as sources of nourishment, and especially for recreation and spiritual traditions (Chapter 1 and 2). Increased urbanization and the resultant increase in production of effluent of the Klip River catchment may increase the pressure on this already degraded system in the future. It is therefore of cardinal importance to describe the past and current state of the water quality, if future users are to manage, effectively maintain and even improve the integrity of this system.

The knowledge of the state of the water quality of rivers and the changes produced by human activities is the first step towards establishing an efficient water management system (Perona *et al.*, 1999). This chapter deals with the results of the water quality of the Klip River during the study period (1997 to 1999), and also investigates long-term (past 30 years) trends in water quality if the system. It also deals with the development and application of a water quality guideline compliance index (GCI), which was used as a basic system to classify the water quality of the different sites investigated.

2. MATERIALS AND METHODS

3.2.1 <u>Long-term water quality of the Klip River - Rand Water Data Base (1973 to 2001)</u>

Water quality data, as collected and analysed by Rand Water for the Klip River and Suikerbosrand River, was used to assess long-term trends in the water quality of the Klip and Suikerbosrand rivers. Rand Water sampling stations, coinciding with localities sampled during the current study, were used for this purpose. Two Rand Water stations were also used to assess the contribution of major tributaries on the Klip River. These were firstly K5, situated in the Klipspruit just before its confluence with the Klip River directly upstream of locality 4, and secondly R6 in the Rietspruit, just before its confluence with the Klip River directly upstream of locality 6 (Figure 3.1 and Table 3.1).

For each of the Rand Water sampling stations, all historic water quality data available since 1973, was processed by Cleanstream Environmental Services. General statistics (number of records, averages, minimum, maximum, 5th percentile, 50th percentile and 95th percentile) for thirty-one water quality variables were determined. The linear slope of the

data was also determined in an attempt to identify long-term tendencies in each variable at a site. The percentage compliance of each variable to water quality guidelines for the aquatic environment (DWAF, 1996d), domestic use (DWAF1996a), livestock watering (DWAF 1996c) and irrigation use (DWAF, 1996b), was also determined. Variables identified to be of concern were plotted on a map in an attempt to identify spatial trends and probable areas of concern.

Table 3.1: Description of the sampling localities used in the assessment of the water quality of the Klip River catchment.

Locality*	Description
K14 – 1	Most upstream sampling site close to origin of the Klip River.
2	Klip River before entering western boundary of Soweto.
K6 – 3	Klip River before entering Lenasia residential area.
K4 – 4	Klip River downstream of Olifanstvlei WTW.
K21 – 5	Klip River on the Rand Water Zwartkoppies Farm
K25 – 6	Klip River directly downstream of Rietspruit confluence.
K18 – 7	Klip River at Henley-on-Klip weir.
8	Klip River in Rothdene area (Meyerton).
K19 – 9	Klip River just upstream of confluence with Vaal Barrage.
S1 - 10	Suikerbosrand River upstream of the Blesbokspruit confluence.
K5	Klipspruit, before its confluence with the Klip River.
R6	Rietspruit just before its confluence with the Klip River.

*Letter followed by number (eg.K14) refer to Rand Water's sampling station number and number standing alone (eg.1) refer to current study site number.

3.2.2 Site-specific water quality assessments

The following surface water quality variables were measured on site during the study period: pH (325 Microprocessor WTW 100748), water temperature, dissolved oxygen and oxygen saturation (WTW Microprocessor Oxi meter 200212) and conductivity (WTW microprocessor LF 95). One surface water sample was also collected ±10cm beneath the surface and was frozen until macro-water quality variables could be determined by Rand Water. Another two surface water samples were collected ±10cm beneath the surface for metal analysis. One of the samples was filtered through 0.45 µm filter paper to determine the dissolved metal concentrations. Perchloric acid (±2ml) was added to these samples for the fixation of the suspended and dissolved metals. Samples were also taken in sterile bottles for bacteriological analyses. Rand Water's laboratories applied standard methods in the determination of the selected water quality variables.

Statistical analysis of the data was performed by STATCON, a statistical consultation service of the Rand Afrikaans University. In an attempt to determine if there was any statistically significant ($p<0.05$) differences between localities over the study period, an independent sample test was used. The Levene's test was first used to determine equality of variances of the different variables, and then an independent t-test for equality of means was used to determine significant differences ($p<0.05$). The Pearson's correlation coefficient (r) was used to determine if there was any correlation between different variables (Zar, 1974).

3.2.3 Water quality Guideline Compliance Index (GCI)

Physical and chemical water quality is a component of the aquatic environment that largely determines and affects the state of the biological community. Interpretation of the water quality can be complex, as a wide array of variables usually have to be considered. The objective of this new approach was to develop a water quality index that would indicate the ability of the water quality at a site to sustain aquatic biota. Such an index would be valuable to simplify the assessment of the water quality and would supply a method to classify the water quality of the system. The guideline compliance index (GCI) was therefore developed as an index that would indicate the extent of compliance to a specific set of water quality guidelines. Guidelines are usually derived to maintain the fitness of water for specific uses and to protect the health of the aquatic ecosystem (DWAF, 1996d). Due to Rand Water's interest in the Klip River, and therefore this study, emphasis was placed on their raw water guidelines. These guidelines were compiled taking cognisance of the requirements of the three main users of its raw water i.e. the aquatic ecosystem, potable water producers and recreation, always considering the most stringent guideline of the three as the appropriate one. Other guidelines, such as the National guidelines set by the Department of Water Affairs and Forestry (1996a - d) were also considered, especially for variables not included in Rand Water's guidelines. This index should, in the end, assess the ability of the water to sustain aquatic biota in ecosystems. The same approach could be followed to compose an index to determine the compliance of water to criteria for a specific user group, such as irrigation, aquaculture, etc.

Scoring of different water quality variables in the water quality Guideline Compliance Index (GCI) was broadly based on the methodology used in the Index of Biotic Integrity for fish (Karr, 1981). Selected water quality variables were divided into four classes, namely ideal, acceptable, tolerable and unacceptable with a scoring system of 5, 3, 1 or 0. A value of 5 would be given if a variable fell within the ideal range for sustaining aquatic ecosystems. A score of 3 was given to a variable within the range of acceptable levels for sustaining aquatic ecosystems. If a variable fell within the ranges expected to be tolerable for most aquatic biota, a score of 1 was given, and if the variable entered the range expected to be unacceptable for sustaining aquatic ecosystems, a score of 0 was attained.

The natural water quality, and therefore also the criteria/guidelines for protecting rivers, can vary from one river to the next, due to natural regional differences. For the purpose of developing a GCI for the Klip River, emphasis was placed on the guidelines and criteria proposed especially for the Klip River System, although general guidelines were also incorporated for some variables (Table 3.2). It can be expected that the more variables used for the determination of the GCI, the more accurate the assessment would be. The number of variables used in the calculation of the GCI score was therefore indicated as a subscript to the score. The GCI scores could be used to give a general description of the ability of water to sustain aquatic ecosystems, and could furthermore be used to classify rivers, and localities within a river, into different descriptive categories (Table 3.3).

3. RESULTS

3.3.1 Long-term trends in the water quality of the Klip River catchment (1973 – 2001)

<u>K14 – 1</u>

The water quality of locality K14-1, during the period 1973-08-13 to 2001-06-30, indicated that a gradual deterioration in pH, turbidity, alkalinity, sodium (Na), mercury, cyanide,

Table 3.2: The scoring ranges used in the Guideline Compliance Index (GCI).

Variable	Determinant	Unit	SCORE				References
			5	3	1	0	
			Ideal	Acceptable	Tolerable	Unacceptable	
pH			6.5-8.5		5-6.5/8.5-9	<5/>9	1,3,4.
Electrical conductivity		mS/m	<45	45-70	>70-100	>100	1
Dissolved oxygen		mg/l	>9	>5 to 9	4-5	<4	3
Alkalinity		mg/l	⊇20			<20	2
Suspended solids		mg/l	<5	5-15	>15 - 25	>25	3
Ca		mg/l	<150			>150	1
Mg		mg/l	<70			>70	1
Na		mg/l	<50	50-70	>70-100	>100	1,3
NH_3 (Ammonia)		mg/l	<0.25	0.25-5	>5-10	>10	1
Nitrite (NO_2)		mg/l	<20			>20	1,
Nitrate (NO_3)		mg/l	<1	1-3	>3-6	>6	1
Phosphates		mg/l	<0.2	0.2-0.4	>0.4-0.6	>0.6	1,3
Ortho-phosphates		mg/l	<0.3			>0.3	1
SO_4		mg/l	<80	80-200	200-500	>500	1, 3
Cl		mg/l	<50	50-100	100-150	>150	1
F		mg/l	<0.75	0.75-1.5	>1.5-2.54	>2.54	2
C.O.D		mg/l	<20	20-35	>35 - 55	>55	1,3
Cr (Total)		mg/l	<0.05			>0.05	1
Co (Total)		mg/l	<0.25			>0.25	1
Cu(Total)		mg/l	<1			>1	1
Fe(Total)		mg/l	<0.1	0.1-0.5	>0.5-1	>1	1
Mn(Total)		mg/l	<0.1	0.1-0.3	>0.3-0.5	>0.5	1
Pb(Total)		mg/l	<0.08			>0.08	1
Zn(Total)		mg/l	<5			>5	1
Ni(Total)		mg/l	<0.1			>0.1	1
Al(Total)	pH⊆6.5	mg/l	<0.005	0.005-0.01	0.01-0.1	>0.1	2
	PH>6.5	mg/l	<0.01	0.01-0.02	0.02-0.15	>0.15	2
V (Total)		mg/l	<0.5			>0.5	1
Mo(Total)		mg/l	<0.05			>0.05	2
Cd(Total)	<60mg	mg/l	⊆0.15	>0.15<0.3	0.3-3	>3	2
	60-119mg	mg/l	⊆0.25	>0.25<0.5	0.5-6	>6	2
	120-180mg	mg/l	⊆0.35	>0.35,0.7	0.7-10	>10	2
	<180mg	mg/l	⊆0.4	>0.4<0.8	0.8-13	>13	2

[1]Steynberg *et al.* (1996) [2]DWAF (1996d) [3]Rand Water (1998) [4] (Alabaster, 1980).

Table 3.3: Descriptive categories of the water quality Guideline Compliance Index (GCI).

CATEGORY	Compliance/Condition	General Description of Water Quality	GCI (%)
A	Excellent	Most water quality variables assessed fell within the ideal range for the protection of aquatic ecosystems, and water quality should be adequate to sustain a healthy aquatic ecosystem.	90 – 100
B	Good	The majority of the water quality variables assessed fell within the ideal range for the protection of aquatic ecosystems, and water quality should be more than appropriate to sustain a healthy aquatic ecosystem.	80-89
C	Fair	Most water quality variables assessed fell within the acceptable range for the protection of aquatic ecosystems while some variables may be of concern. It can be expected that the water quality could contribute to a fair amount of the degradation of biotic integrity at these sites.	70-79
D	Poor	The majority of water quality variables assessed fell within the acceptable range for the protection of aquatic ecosystems, although some variables are only tolerable and not ideal to the biota. The prevailing water quality can be seen as poor and could be a limiting factor to biotic integrity.	50-69
E	Very Poor	Most water quality variables assessed are only tolerable, and not ideal for the sustainability of the aquatic ecosystem. The prevailing water quality can be seen as very poor and could be a major limiting factor to biotic integrity.	25-49
F	Critical	Most water quality variables assessed fell within unacceptable ranges for the protection of the aquatic ecosystem. The H_2O quality at this site can be seen as critical and unable to sustain any biota.	0-25

lead (Pb) and chemical oxygen demand (COD) occurred during this period (Appendix 3.1). Variables that had very poor compliance with water quality guidelines over this period included total dissolved solids (TDS), ammonia, aluminium (Al), manganese (Mn), iron (Fe), copper (Cu), cadmium (Cd), chromium (Cr), mercury, cyanide, lead (Pb) and zinc (Zn) (Appendix 3.1).

<u>K6 - 3</u>

At locality K6 – 3, water quality variables, of which the linear slope indicated a deterioration during the period 1973-08-13 to 2001-06-30, included pH, alkalinity, chloride (Cl), fluoride (F), ammonia, ortho-phosphates (PO_4^+), Mn, Pb and COD (Appendix 3.2). Variables with poor compliance to water quality guidelines included TDS, Ca, Mg, sulphates (SO4), ammonia, Al, Mn, Cu, Cd, Cr, mercury, selenium (Se), cyanide, Pb and Zn (Appendix 3.2).

<u>K5 – KS (Klipspruit)</u>

The water quality of locality K5 – KS give an indication of possible variables of concern contributed by the Klipspruit to the Klip River. At this site, linear slopes indicated that pH, F, ammonia, nitrate, nitrite, Mn, Co, mercury, Pb and Ni deteriorated over the period of 1973-08-13 to 2001-06-30. Variables of concern, that complied poorly to water quality guidelines, included turbidity, Ca, SO4, ammonia, Al, Mn, Fe, Cu, Cd, Cr, mercury, cyanide, Pb and Zn (Appendix 3.3).

<u>K4 – 4</u>

At locality K4 – 4, the linear slope of pH, turbidity, F, nitrates and lead indicated deterioration occurring in the period 1973-08-13 to 2001-06-30 (Appendix 3.4). Variables with poor compliance with water quality guidelines included turbidity, Ca, ammonia, Al, Mn, Fe, Cu, Cd, Cr, mercury, cyanide, Pb and Zn (Appendix 3.4).

<u>K21 – 5</u>

Water quality variables with a linear slope indicating deterioration during the period 1973-08-13 to 2001-06-30 at locality K21 – 5 were pH, turbidity, temperature, ammonia, nitrates, Cd, Cr, cyanide and Pb. At this locality, poor compliance to guidelines was observed for turbidity, Ca, ammonia, Al, Mn, Cu, Cd, Cr, mercury, cyanide, Pb and zinc (Appendix 3.5).

R6 – Riet (Rietspruit)

The contribution of the Rietspruit catchment to the Klip River water can be measured by the water quality of locality R6 – Riet, as it is approximately 100m upstream of the confluence with the Klip River. At this locality the linear slopes indicated that pH, turbidity, alkalinity, ammonia, nitrates and nitrites deteriorated during the period 1973-08-13 to 2001-06-30 (Appendix 3.6). Variables with very poor compliance to water quality guidelines at this site included turbidity, TDS, Ca, Mg, Na, SO4, ammonia, Al, Mn, Fe, Cu, Cd, Cr, mercury, Pb and Zn.

K25 – 6

The linear slope of turbidity, temperature, F, nitrate, nitrite, Cd and arsenic indicated that this variable deteriorated during the period 1973-08-13 to 2001-06-30 at locality K25 – 6. Variables with poor compliance to water quality guidelines included turbidity, TDS, Ca, ammonia, Al, Mn, Cu, Cd, Cr, mercury, arsenic, Se, cyanide, Pb and Zn (Appendix 3.7).

K18 – 7

At locality K18 – 7, the linear slope indicated a deterioration in pH, temperature, TDS, ammonia, nitrates and nitrites (Appendix 3.8) during the period 1973-08-13 to 2001-06-30. Variables with poor compliance to water quality guidelines included: turbidity, TDS, Ca, SO_4, ammonia, Al, Mn, Cu, Cd, Cr, mercury, arsenic, Se, cyanide, Pb and Zn (Appendix 3.8).

K19 – 9

This is the most downstream locality in the Klip River and would give an integrative view of the water quality contribution of the Klip River into the Vaal Barrage. At this site, the linear slopes of turbidity, temperature, potassium (K), nitrates, nitrites and COD indicated degradation occurring during the period 1973-08-13 to 2001-06-30 (Appendix 3.9). Poor compliance with water quality guidelines was observed at this site for turbidity, TDS, Ca, Mg, SO_4, ammonia, Al, Mn, Fe, Cu, Cd, Cr, mercury, arsenic, Se, cyanide, Pb and Zn (Appendix 3.9).

S1- 10 (Suikerbosrand River)

Locality S1 – 10 would give an indication of the water quality of the Suikerbosrand River, upstream of the Blesbokspruit confluence, as observed during the period 1973-08-13 to

2001-06-30. The linear slope indicated deterioration of many variables over this period. Deterioration in pH, EC, TDS, alkalinity, hardness, Ca, Mg, Na, K, SO_4, Cl and nitrates was observed (Appendix 3.10). Water quality variables with poor compliance to water quality guidelines at locality S1 – 10 were turbidity, ammonia, Al, Mn, Fe, Cu, Cd, Cr, Hg, As, Se, cyanide, Pb and Zn.

General Compliance with Water Quality Guidelines.

Water quality guidelines for the aquatic environment were generally exceeded at most sites within the Klip River catchment (Appendix 3.1 to 3.9). In this regard, variables of concern included many heavy metals, fluoride and ammonia. Water quality guidelines for domestic use were also often exceeded in the Klip River, with most metals, TDS, turbidity, Ca, Mg, SO_4 generally being the variables of concern. Livestock watering and irrigation guidelines were generally met in the Klip River catchment, with exceptions being pH, TDS, Cd, Mn, Na and arsenic.

At locality S1 –10 in the Suikerbosrand River, aquatic environment guidelines were also generally exceeded, with all metals and ammonia being identified as the variables of greatest concern. Domestic use guidelines at this site were often exceeded for turbidity and most of the metals (except copper). Livestock watering guidelines were generally met with only Cd, and to a lesser extent Pb being identified as possible concerns. Irrigation guidelines were also generally met, with exceptions being manganese, cadmium and arsenic (Appendix 3.10).

Areas of concern for specific variables

Historic data (1973 to 2001) indicated that turbidity was relatively high at site K14-1, low in the middle catchment, and increased gradually from site K21-5 to K19-9 (Appendix 3.11). Alkalinity increased drastically at site K6-3 and stayed relatively constant downstream (Appendix 3.12). Areas of concern regarding total hardness were sites K6-3 and R6-Riet (Appendix 3.13). The average pH at locality K14-1 was acidic but the rest of the Klip River had on average, neutral to alkaline pH levels (Appendix 3.14). At sites K6-3 and R6- Riet very high average levels of electrical conductivity (Appendix 3.15), sulphate (Appendix 3.16), magnesium (Appendix 3.17) and calcium (Appendix 3.18) were observed.

Chloride levels increased significantly between K6-3 and K4-4, with the Klipspruit (K5-KS) contributing to this increase. The Rietspruit (R6-Riet) also contributed to high average chloride levels in the lower Klip River (Appendix 3.19). Chemical Oxygen Demand (COD) increased at locality K4-4 and stayed relatively high throughout the rest of the Klip River (Appendix 3.20). Average ammonia levels were relatively high in the upper reaches of the Klip River from sites K14-1 to K4-4 (Appendix 3.21). Average nitrate levels indicated a gradual downstream increase (Appendix 3.22). In the Klip River, high average nitrite levels were observed at site K4-4 (partly related to influence of Klipspruit - K5-KS) and at K25-6 (partly related to influence from Rietspruit-R6-Riet) (Appendix 3.23).

Average Sodium levels were high from locality K6-3 downstream, with the Rietspruit (R6-Riet) contributing to high levels in the lower section of the Klip River (Appendix 3.24). Average potassium levels were high from locality K5-KS downstream (Appendix 3.25). In the Klip River, the average ortho-phosphate and cadmium levels were visibly higher at locality K4-4 than the rest of the sites (Appendix 3.26 & 3.27). At site K-14-1, average levels of fluoride (Appendix 3.28), aluminium (Appendix 3.29), zinc (Appendix 3.30) and iron (Appendix 3.31) were very high. The Rietspruit (R6-Riet) also had a higher iron level than most other sites investigated. Average chromium levels were visibly higher at sites K14-1 and K21-5 (Appendix 3.32). There is an indication of a source of copper pollution at locality K18-7 (Appendix 3.33). Manganese levels were generally high in the upper reaches of the Klip River, and especially at sites K6-3 and K5-KS (Appendix 3.34). Historic data indicates a problem with lead pollution in the vicinity of site K21-5 (Appendix 3.35). Historic data also indicates that average levels of cyanide (Appendix 3.36), selenium (Appendix 3.37) and arsenic (Appendix 3.38) were high in the lower reaches of the Klip River (Sites K25-6, K18-7 and K19-9). There was an indication of sources of mercury pollution at site K21-5 (Appendix 3.39) and cobalt pollution at site K18-7 (Appendix 3.40). Average nickel levels were generally the highest in the upper Klip River, from sites K14-1 to K4-4 (Appendix 3.41).

3.3.2 Site-specific water quality assessments– Study period (1997 – 1999)

In the Klip River, surface water temperature ranged between 5.8°C during May 1998, to 26°C at locality 7 during February 1999. At locality 10 in the Suikerbosrand River, surface water temperatures ranged between 10.6°C (May 1998) and 26.7°C (February 1998). In general, the highest temperatures in the Klip River were recorded during February 1998 and the lowest during May 1998 (Figure 3.2 and Table 3.4). The uppermost reaches of the Klip River (localities 1 and 2) generally had much lower temperatures than the middle and lower reaches of the Klip River. Water temperatures increased from locality 2 to 3, and again from 3 to 4, after which a decrease was generally observed (Figure 3.2 and Table 3.4).

Surface water pH in the Klip River ranged between 6.4 at locality 1 during August 1997, to 9.0 at locality 5 during November 1997 (Figure 3.3 and Table 3.4). The water at most sites in this system was generally neutral to alkaline, with only localities 1 and 2 having acidic water at times. The pH generally increased gradually from locality 1 to 3, and a reduction in pH was observed between localities 3 and 4, as well as between 5 and 6. At locality 10 (Suikerbosrand River), the pH was neutral to alkaline and ranged between 7.4 (February 1999) to 8.4 (August 1998). The surface water pH values generally fell within the ideal ranges for pH, with values at localities 1, 4 and 5 falling in the acceptable ranges at times (Figure 3.3).

Oxygen saturation levels of the Klip River waters ranged between 50.2 % at locality 3 during February 1998, to 195% at locality 5 during the same month (Table 3.4). In the Suikerbosrand River, oxygen saturation levels ranged between 67% (November 1998) and 152% (November 1997). Dissolved oxygen levels in the Klip River ranged between 3.91 mg/l at locality 3 (February 1998) and 13.41 mg/l at locality 5 (February 1998). At locality 10, dissolved oxygen ranged between 5.2 mg/l (November 1998) and 11.2 mg/l (November 1999). Dissolved oxygen levels in the Klip River generally fell within the acceptable range, with locality 4 lying within the tolerable, and locality 3 within the unacceptable ranges at times (Figure 3.4). Dissolved oxygen levels showed statistically significant decreases ($p<0.05$) from localities 2 to 3, and again from localities 5 to 6 (Table 3.5). Statistically significant increases in dissolved oxygen were observed from localities 4 to 5, and localities 7 to 8 (Table 3.5 and Figure 3.4).

Table 3.4: Physical and Chemical Water quality of the selected sampling localities over the study period (August 1997 to May 1999).

Locality	Survey	Temp (°C)	pH	EC (mS/m)	TDS (mg/l)	Oxygen saturation (%)	Dissolved oxygen (mg/l)	Turbidity (NTU's)	Hardness as $CaCO_3$ (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	SS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Silica mg/l	NH_3 mg/l	Nitrite mg/l	Nitrate mg/l	Ortho phosphates (mg/l)	Total phosphates (mg/l)	SO_4 mg/l	S mg/l	Cl (mg/l)	F (mg/l)	C.O.D. (mg/l)
1	Aug-97	8.3	6.4	43.8	150	97.2	9.42	7.2	64	N/A	33	18	4.6	18	1.8	1.7	0.56	bdl	n/a	bdl	bdl	23	2.2	48	n/a	n/a
	Nov-97	15.2	7.9	26.2	170	122	10.4	1.3	93	74	10	23	8.7	23	bdl	1.1	0.6	bdl	n/a	0.03	bdl	43	N/A	14	0.12	18
	Feb-98	19.1	7.4	55	N/A	97.3	7.42	2	N/A	45	n/a	34	111	75	2.3	8.1	0.27	bdl	0.05	0.2	0.2	220	N/A	bdl	0.13	34
	May-98	6.4	N/A	N/A	N/A	80.1	7.92	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	6.8	7.3	38.7	230	90.9	9.06	0.7	72	60	4	16	7.9	5.1	2.3	0.46	bdl	bdl	0.25	N/A	1.2	110	N/A	11	0.25	19
	Nov-98	13	7.7	35	225	69.6	6.1	1.3	84	64	4	20	8.3	36	1.2	1.4	2	bdl	0.2	bdl	bdl	65	N/A	13	0.13	N/A
	Feb-99	18	7.3	33	N/A	87	6.8	2.8	83	36	n/a	21	7.4	35	2.5	1.1	bdl	0.12	0.27	0.06	N/A	93	N/A	N/A	N/A	N/A
	May-99	10.4	8.1	22	N/A	81.4	7.52	0.86	64	53	9	16	59	17	2.2	N/A	bdl	bdl	0.14	bdl	bdl	28	9.3	N/A	N/A	N/A
	Median	**11.7**	**7.4**	**35**	**197**	**88**	**7.7**	**1.3**	**77**	**56**	**9**	**20**	**8.30**	**23**	**2.2**	**1.3**	**0.2**	**bdl**	**0.2**	**0.02**	**bdl**	**65**	**5.8**	**13**	**0.13**	**19**
2	Aug-97	8.3	8.2	230	2065	88.9	8.51	11	1120	6	26	340	65	63	3.8	0.94	0.97	bdl	N/A	bdl	bdl	144	48	20	N/A	37
	Nov-97	17.2	6.8	188.1	2295	132	10.7	10	1150	19	12	305	95	79	bdl	2.6	0.35	bdl	N/A	0.3	0.3	1200	N/A	24	N/A	29
	Feb-98	20.2	6.8	114.6	N/A	97.4	7.29	60	N/A	16	N/A	170	58	44	1.5	9.9	0.27	bdl	0.93	0.23	0.6	625	N/A	20	0.12	41
	May-98	5.3	N/A	N/A	N/A	81.6	8.53	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	7.4	7.5	120	875	101.6	10.13	1.4	430	145	7	110	38	105	5	1.4	0.05	bdl	1.2	N/A	1.3	100	N/A	33	0.25	23
	Nov-98	14.3	8	109.7	710	98	8.2	1.5	360	360	8	94	30	59	5.2	3.6	0.24	bdl	0.41	bdl	bdl	300	N/A	22	0.22	N/A
	Feb-99	17.3	7.7	55	N/A	107	8.5	1.8	200	55	N/A	73	16	36	2.2	1	bdl	bdl	0.2	bdl	N/A	190	N/A	N/A	N/A	N/A
	May-99	10.4	7.9	54	N/A	85.2	7.27	0.73	210	94	11	52	20	27	3.7	N/A	bdl	bdl	0.36	bdl	bdl	145	49	N/A	N/A	N/A
	Median	**12**	**7.6**	**114**	**1470**	**97**	**8.5**	**1.8**	**395**	**55**	**11**	**110**	**38**	**59**	**3.7**	**2**	**0.2**	bdl	**0.41**	bdl	bdl	**190**	**49**	**22**	**0.2**	**33**
3	Aug-97	12.3	8.3	140	1230	106.1	9.32	4.2	610	74	23	160	50	54	5.9	bdl	0.79	bdl	N/A	bdl	bdl	72	24	20	0.16	33
	Nov-97	19.7	8.2	96.2	715	85	6.6	15	580	170	25	150	49	57	4.5	6	7.1	bdl	N/A	0.8	1.1	465	N/A	31	0.22	51
	Feb-98	19.2	7.3	84.7	470	50.2	3.91	4.5	370	165	39	93	34	42	5	2.4	5.9	0.37	0.71	N/A	bdl	N/A	N/A	28	0.19	24
	May-98	7.8	N/A	N/A	N/A	71.5	7.07	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	10.8	8.4	115	840	93.9	8.64	2.6	490	140	10	120	46	62	6.1	0.12	0	0.08	6.4	N/A	2.3	180	N/A	32	0.19	23
	Nov-98	17.2	7.9	134.7	660	99	7.8	18	365	365	13	91	34	43	3.8	8.6	0.24	0.06	1.2	0.22	0.47	275	N/A	23	0.2	N/A
	Feb-99	20.2	7.4	71	N/A	76	5.8	5	265	170	N/A	64	25	41	6.5	1.8	3.8	bdl	0.35	1.4	N/A	140	N/A	N/A	N/A	N/A
	May-99	12.8	7.7	74	N/A	80.5	7.12	3.5	290	145	13	69	29	39	5.6	N/A	0.55	bdl	2.3	0.13	0.13	200	64	N/A	N/A	N/A
	Median	**15**	**7.9**	**96**	**715**	**82**	**7.1**	**4.5**	**370**	**165**	**18**	**93**	**34**	**43**	**6**	**2.1**	**0.8**	bdl	**1.2**	**0.22**	**0.2**	**190**	**44**	**28**	**0.2**	**28**
4	Aug-97	14.5	8.8	80	605	82.9	7.07	3.8	270	92	25	71	22	54	9.8	4.1	1.6	bdl	N/A	bdl	bdl	25	8.2	41	0.23	39
	Nov-97	19.6	8	59.9	495	83	6.5	2.6	215	115	N/A	54	20	63	22	5.7	0.57	0.16	N/A	0.48	0.48	145	N/A	56	0.26	52
	Feb-98	24.4	7.8	59.4	445	77.2	5.63	4.3	180	N/A	12	46	16	53	12	19	0.33	0.11	3.7	N/A	bdl	N/A	N/A	51	0.2	32
	May-98	12.3	N/A	N/A	N/A	94	8.4	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	13.4	7.4	71	420	80.3	6.97	2.5	160	85	10	40	15	65	16	2.1	0.08	0.25	6.5	N/A	1.6	180	N/A	58	0.29	29
	Nov-98	19.9	8	73.2	460	75	5.2	4.7	180	180	8	47	15	53	13	8.6	0.19	0.09	4.5	0.33	0.66	145	N/A	57	0.28	N/A
	Feb-99	23.2	7.6	68	N/A	71	5	6.2	230	100	N/A	60	20	47	12	1.6	0.15	0.13	2.7	0.57	N/A	160	N/A	N/A	N/A	N/A
	May-99	17.6	7.6	61	N/A	64.9	5.04	3.8	175	85	21	42	17	47	12	N/A	0.24	bdl	3.8	0.66	0.66	115	36	N/A	N/A	N/A
	Median	**18.6**	**7.8**	**68**	**460**	**78**	**6.1**	**3.8**	**180**	**96**	**12**	**47**	**17**	**53**	**12**	**4.9**	**0.2**	**0.1**	**3.8**	**0.48**	bdl	**145**	**22**	**56**	**0.3**	**35.**

Temp – Temperature EC – Electrical conductivity TDS – Total Dissolved Solids SS – Suspended Solids Ca – Calcium Mg – Magnesium Na – Sodium K – Potassium
NH_3 – Ammonia SO_4 – Sulphates S – Sulphur Cl - Chloride F – Fluoride C.O.D – Chemical Oxygen Demand N/A – Not Available
bdl – below detection limit

Table 3.4 (Continue)

Locality	Survey	Temp (ºC)	pH	EC (mS/m)	TDS (mg/l)	Oxygen saturation (%)	Dissolved oxygen (mg/l)	Turbidity (NTU's)	Hardness as $CaCO_3$ (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	SS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Silica mg/l	NH_3 mg/l	Nitrite mg/l	Nitrate mg/l	Ortho phosphates (mg/l)	Total phosphates (mg/l)	SO_4 mg/l	S mg/l	Cl (mg/l)	F (mg/l)	C.O.D. (mg/l)
5	Aug-97	13.7	7.8	81	395	108	9.47	6.7	185	105	36	52	13	35	12	7.3	2.8	N/A	N/A	0.56	0.56	14	4.6	51	0.19	32
	Nov-97	19	9	61	495	149	11.9	6.7	205	115	N/A	45	22	66	26	6	0.33	bdl	N/A	0.51	0.51	145	N/A	59	0.24	85
	Feb-98	22.5	7.9	61.1	465	195	13.41	14	185	110	28	46	17	54	15	24	0.29	bdl	3.2	N/A	bdl	N/A	N/A	56	0.2	34
	May-98	11.1	N/A	N/A	N/A	98.1	9.11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	13.5	7.8	71	430	105.1	9.21	8.5	225	100	26	62	17	61	18	1.8	bdl	bdl	6.4	N/A	2	135	N/A	58	0.25	27
	Nov-98	19.2	7.9	73.9	440	100	7.7	15	185	185	28	46	17	55	15	10	0.1	bdl	4.1	0.73	1.1	185	N/A	65	0.23	N/A
	Feb-99	21.4	7.8	65	N/A	110	8.2	20	205	110	N/A	51	19	50	14	1.7	bdl	0.06	3.1	0.81	N/A	135	N/A	N/A	N/A	N/A
	May-99	15.9	7.9	63	N/A	111.8	9.27	12	170	105	33	40	17	52	15	N/A	bdl	bdl	4.1	0.76	0.75	91	31	N/A	N/A	N/A
	Median	**17.4**	**7.9**	**65**	**440**	**109**	**9.24**	**12**	**185**	**110**	**28**	**46**	**17**	**54**	**15**	**6.7**	**0.1**	**bdl**	**4.1**	**0.73**	**bdl**	**135**	**18**	**58**	**0.2**	**33**
6	Aug-97	13.5	7.8	82	685	72.6	6.39	4.6	310	130	26	77	28	71	18	10	N/A	N/A	N/A	N/A	bdl	24	8.1	41	0.26	51
	Nov-97	20.3	8.2	74.3	575	93	7.3	8.1	270	130	N/A	66	26	75	23	7	1.8	0.29	N/A	1	1.4	200	N/A	68	0.27	135
	Feb-98	23.4	7.7	69.4	590	103.7	7.42	16	210	125	43	52	19	63	14	24	1.5	0.29	3.3	N/A	bdl	N/A	N/A	66	0.22	35
	May-98	12.2	N/A	N/A	N/A	100.4	9.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	15.7	7.7	95	630	93.3	7.78	9.8	290	120	40	71	28	82	18	2.3	bdl	0.27	5.8	N/A	0.99	205	N/A	72	N/A	35
	Nov-98	18.8	7.8	100	685	85	6.5	18	300	300	37	75	28	67	13	11	0.16	0.07	3.9	0.54	0.87	185	N/A	72	0.3	N/A
	Feb-99	22.1	7.7	81	550	110	8.3	19	250	110	42	61	24	61	13	1.7	bdl	0.08	3.5	0.87	2.5	195	N/A	N/A	N/A	N/A
	May-99	16.6	7.9	78	550	91.5	7.51	9.2	325	110	30	91	24	64	14	N/A	0.16	0.1	4.42	0.78	1	150	51	71	N/A	N/A
	Median	**17.7**	**7.8**	**81**	**590**	**93.1**	**7.465**	**9.8**	**290**	**125**	**39**	**71**	**26**	**67**	**14**	**8.5**	**0.2**	**0.2**	**3.9**	**0.82**	**0.99**	**190**	**30**	**70**	**0.3**	**43**
7	Aug-97	14.3	7.4	81	715	68.9	6.06	1.7	310	135	58	77	29	72	17	11	N/A	N/A	N/A	N/A	bdl	25	8.2	69	0.27	46
	Nov-97	21.8	8.1	77.3	575	92	7	5.6	285	145	N/A	70	27	80	21	15	1.8	0.38	N/A	1.1	1.3	205	N/A	71	0.28	52
	Feb-98	26	8.3	69	1520	83.1	5.56	28	210	120	7	50	21	62	13	24	0.16	0.05	4.1	N/A	bdl	78	N/A	65	0.27	51
	May-98	10.9	N/A	N/A	N/A	73	6.59	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	15.3	7.7	88	595	78	6.62	8.8	280	120	27	68	27	79	17	2.3	bdl	0.19	6.3	N/A	0.89	205	N/A	70	N/A	32
	Nov-98	19	7.8	91.1	595	91	6.9	31	290	105	98	72	27	67	14	12	0.13	0.08	3.7	0.53	1.2	230	N/A	74	0.3	N/A
	Feb-99	21.7	7.7	77	515	100	7.4	22	235	115	44	57	23	60	13	1.7	bdl	0.11	3.3	0.81	2.9	135	N/A	N/A	N/A	N/A
	May-99	16.4	8	79	545	99.5	8.19	20	230	110	45	54	23	63	14	N/A	0.1	0.06	4.25	0.74	0.74	160	53	69	N/A	N/A
	Median	**17.7**	**7.8**	**79**	**595**	**87.0**	**6.76**	**20**	**280**	**120**	**45**	**68**	**27**	**67**	**14**	**12**	**0.1**	**0.1**	**4.1**	**0.77**	**0.89**	**160**	**31**	**70**	**0.3**	**48.5**
8	Aug-97	16.3	7.4	97	700	78.9	6.48	2.8	325	130	54	79	31	72	17	10	N/A	N/A	N/A	N/A	bdl	26	8.6	70	0.28	45
	Nov-97	20.5	8.3	73.6	615	108	8.4	7.8	270	150	N/A	66	26	79	20	16	1.7	0.57	N/A	0.51	0.51	190	N/A	69	0.27	50
	Feb-98	25.2	8.2	69.6	530	149.5	10.08	20	230	130	142	56	22	61	12	26	0.23	bdl	4.1	N/A	bdl	75	N/A	64	0.25	45
	May-98	10.8	N/A	N/A	N/A	72	6.87	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	13.3	7.9	89	570	92.3	8.24	12	270	120	33	66	26	83	18	2.6	bdl	bdl	5.1	N/A	0.98	190	N/A	73	N/A	31
	Nov-98	18.2	7.8	95.3	635	92	7.3	29	310	105	74	76	29	69	13	12	bdl	0.07	4	0.52	1.4	250	N/A	74	0.3	N/A
	Feb-99	21.7	7.9	75	515	117	8.7	21	230	110	39	55	22	60	13	1.7	bdl	0.1	3.6	0.82	0.83	160	N/A	N/A	N/A	N/A
	May-99	16.4	8.2	79	550	105.6	8.42	19	225	115	42	53	23	64	14	N/A	0.08	bdl	4.14	0.71	0.71	155	52	70	N/A	N/A
	Median	**17.3**	**7.9**	**79**	**570**	**98.9**	**8.32**	**19**	**270**	**120**	**48**	**66**	**26**	**69**	**14**	**11**	**bdl**	**bdl**	**4.1**	**0.61**	**bdl**	**160**	**30**	**70**	**0.3**	**45**

Temp – Temperature EC – Electrical conductivity TDS – Total Dissolved Solids SS – Suspended Solids Ca – Calcium Mg – Magnesium Na – Sodium K – Potassium
NH_3 – Ammonia SO_4 – Sulphates S – Sulphur Cl - Chloride F – Fluoride C.O.D – Chemical Oxygen Demand N/A – Not Available
bdl – below detection limit

Table 3.4 (Continued)

Locality	Survey	Temp (°C)	pH	EC (mS/m)	TDS (mg/l)	Oxygen saturation (%)	Dissolved oxygen (mg/l)	Turbidity (NTU's)	Hardness as $CaCO_3$ (mg/l)	Alkalinity as $CaCO_3$ (mg/l)	SS mg/l	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	Silica mg/l	NH_3 mg/l	Nitrite mg/l	Nitrate mg/l	Ortho phosphates (mg/l)	Total phosphates (mg/l)	SO_4 mg/l	S mg/l	Cl (mg/l)	F (mg/l)	C.O.D. (mg/l)
9	Aug-97	16.7		84.1	580	76	6.34	22	295	N/A	72	74	27	62	15	11	N/A	N/A	N/A	N/A	bdl	23	7.7	62	0.29	50
	Nov-97	21.1	8.1	74.9	570	120	9.2	9.6	280	140		66	28	73	18	16	0.64	0.48	N/A	0.99	1.3	190	N/A	66	0.28	60
	Feb-98	24.3	8.3	77.3	520	99	7.06	21	215	125	172	50	22	59	12	26	0.23	bdl	3.8	N/A	bdl	75	N/A	63	0.25	53
	May-98	11.5	N/A	N/A	N/A	94.3	8.67	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	12.3	7.8	89.0	565	92.3	8.28	15	275	130	40	64	28	77	17	2.4	bdl	bdl	6	N/A	N/A	210	N/A	72	N/A	35
	Nov-98	16.9	7.6	94.4	215	88	7.1	25	300	105	53	75	28	69	13	13	0.06	0.07	3.9	0.55	1.1	235	N/A	77	0.29	N/A
	Feb-99	19	7.9	74	490	115	8.3	21	225	115	40	54	22	59	13	1.8	bdl	0.08	4.3	0.91	2.7	155	N/A	N/A	N/A	N/A
	May-99	16	8	79	560	93.5	7.87	15	235	115	44	54	24	62	14	N/A	0.12	bdl	4.07	0.65	0.65	155	53	73	N/A	N/A
	Median	**16**	**7.9**	**79.0**	**560**	**93.9**	**8.07**	**21**	**275**	**120**	**49**	**64**	**27**	**62**	**14**	**12**	**0.1**	**bdl**	**4.07**	**0.78**	**0.55**	**155**	**30**	**69**	**0.3**	**51**
10	Aug-97	17.3	N/A	32.2	N/A	86	8.49	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	bdl	9.5	N/A	26	0.14	N/A
	Nov-97	25.3	8.1	32.9	240	152	11.2	15	140	115	N/A	25	19	24	4.2	20	0.27	bdl	N/A	bdl	bdl	27	N/A	21	0.16	54
	Feb-98	26.7	7.7	23.5	235	85.9	6.09	28	88	89	130	17	11	13	3.1	N/A	bdl	bdl	bdl	N/A	bdl	N/A	N/A	bdl	0.12	41
	May-98	10.6	N/A	N/A	N/A	87.4	7.86	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Aug-98	14.4	8.4	4.3	245	91.2	7.74	8.7	bdl	170	23	bdl	bdl	bdl	bdl	3.7	bdl	bdl	0.24	N/A	bdl	bdl	N/A	bdl	bdl	2.4
	Nov-98	18.2	8.1	23.2	120	67	5.2	50	79	75	73	15	10	20	4.2	20	0.17	0.03	0.41	0.2	0.6	21	N/A	23	0.18	N/A
	Feb-99	23	7.4	21.7	N/A	72.4	7	51	86	80		18	9.9	16	3.3	3.1	0.21	N/A	0.27	0.26	N/A	19	N/A	N/A	N/A	N/A
	May-99	15.7	8	6.45	159	91.7	7.76	24	120	120	36	23	15	16	2.9		bdl	bdl	0.27	0.07	0.07	15	4	13	N/A	N/A
	Median	**17**	**8.1**	**23.2**	**235**	**86.7**	**7.75**	**26**	**87**	**102**	**55**	**18**	**10**	**16**	**3**	**12**	**0.1**	**bdl**	**0.27**	**0.13**	**bdl**	**17**	**4**	**17**	**0.1**	**41**

Temp – Temperature EC – Electrical conductivity TDS – Total Dissolved Solids SS – Suspended Solids Ca – Calcium Mg – Magnesium Na – Sodium K – Potassium
NH_3 – Ammonia SO_4 – Sulphates S – Sulphur Cl - Chloride F – Fluoride C.O.D – Chemical Oxygen Demand N/A – Not Available
bdl – below detection limit

Table 3.5: Summary of statistically significant ($p<0.05$) changes (increase - ↑ or decrease - ↓) from upstream locality.

VARIABLE	LOCALITY								
	2	3	4	5	6	7	8	9	10
O_2 saturation				↑	↓				
Dissolved O_2		↓		↑	↓		↑		
Turbidity				↑					
Suspended solids				↑					
EC	↑		↓		↑				
TDS	↑				↑				
Hardness as $CaCO_3$	↑		↓		↑				
Calcium	↑		↓		↑				
Magnesium			↓		↑				
Sodium	↑				↑				
Potassium		↑	↑						
Nitrite				↓	↑				
Cl			↑						
Fluoride			↑						

Table 3.6: Pearson's correlation coefficients (>0.5) between various water quality variables observed over the study period (1997 to 1999).

	EC	TDS	Hardness	Ca	Mg	Na	SO_4	MnT	MnD	K	Cl	F	O-PO_4	COD	Turbidity	Silica
EC		0.8	0.9	0.9	0.6	0.6	0.6	0.6								
TDS			0.9													
Hardness				1	0.9		0.7	0.6	0.7							
Ca					0.7				0.7							
Mg							0.6									
Na										0.7	0.6	0.7				
FeD															0.6	
K											0.8	0.7	0.7	0.6		
Cl												0.8				
F													0.7			
O-PO_4														0.6		
SS															0.6	0.6

Chemical oxygen demand (COD) in the Klip River catchment ranged between 18 mg/l at locality 1 (November 1997) and 135 mg/l at locality 6 (November 1997) (Table 3.4). The COD values were generally within the acceptable to tolerable ranges, with locality 5 and 6 having unacceptable COD levels during November 1997. In general there was a gradual downstream increase in COD along the Klip River (Figure 3.5). The COD at locality 10 in the Suikerbosrand River was generally ideal to tolerable, ranging from 2.4 mg/l (August 1998) to 54 mg/l (November 1997). Pearson's correlation coefficients indicated a strong positive correlation between COD and potassium, as well as between silica and Ortho-phosphates (Table 3.6).

Turbidity of the Klip River water ranged between 0.7 NTU's at locality 1 (August 1998) and 60 NTU's at locality 2 (February 1998). Turbidity showed statistically significant increases ($p<0.05$) from locality 4 to 5 (Table 3.5). Median turbidity levels also indicated an increase between localities 6 and 7. There was generally a gradual downstream increase in turbidity visible in the Klip River (Figure 3.6). In the Suikerbosrand River, the turbidity at locality 10 ranged between 8.7 NTU's (August 1998) and 51 NTU's (February 1999), with a median level of 24 NTU's, which was higher than median turbidity of the sites in the Klip River (Figure 3.6). Pearson's correlation coefficients indicated a strong positive correlation between turbidity and suspended solids (Table 3.6)

In The Klip River, suspended solids measured between 4 mg/l at locality 1 and 172 mg/l at locality 9. Similar to turbidity, there was a statistically significant ($p<0.05$) increase in suspended solids between localities 4 and 5 (Table 3.55). The suspended solids generally decreased from locality 3 to 4. In general, there was also a slight, but gradual downstream increase in suspended solid loads in the Klip River (Figure 3.7). Suspended solid levels at locality 10 (Suikerbosrand River) were similar to the scenario observed for turbidity, generally higher than that of the Klip River. At locality 10 the suspended solids load levels ranged between 23 mg/l (August 1998) and 130 mg/l (February 1998) with a median value of 36 mg/l (Table 3.4). Pearson's correlation coefficients indicated a strong positive correlation between suspended solids and turbidity, as well as between suspended solids and silica (Table 3.6).

Electrical conductivity (EC) levels in the Klip River ranged between 26.2 mS/m at locality 1 (November 1997) and 230 mS/m at locality 2 (August 1997) (Table 3.4). There was a

statistically significant ($p<0.05$) increase in EC levels from locality 1 to 2, and again from localities 5 to 6 (Table 3.5). Electrical conductivity levels showed a statistically significant decrease between localities 3 and 4 (Table 3.5). In The Klip River, only EC levels at locality 1 fell within the ideal range. Most recorded values at the other sites fell within the acceptable and tolerable levels. Localities 2 and 3 were identified as areas of special concern, where values often fell within the unacceptable range (Figure 3.8). Electrical conductivity levels at locality 10 (Suikerbosrand River) were always within the ideal range, ranging between 6.45 mS/m (May 1999) to 32.9 mS/m (November 1997). Pearson's correlation coefficients indicated a strong positive correlation between EC and TSD, hardness, Ca, Mg, Na, SO4 and total Mn (Table 3.6).

As can be expected, total dissolved solids (TDS) indicated similar trends to EC. In the Klip River, the lowest TDS levels were again observed at locality 1 (150 mg/l), and the highest TDS levels at locality 2 (2 295 mg/l) (Table 3.4). TDS levels also showed a statistically significant increase between localities 1 and 2, and again between localities 5 and 6 (Table 3.5). There was a profound decrease in TDS from locality 2 to 4 (Figure 3.9). The TDS at locality 10 was always very low, ranging between 159 mg/l (May 1999) and 245 mg/l (August 1998). Both EC and TDS levels stayed relatively constant from locality 6 downstream to locality 9. Pearson's correlation coefficients indicated a strong positive correlation between TSD, EC and water hardness (Table 3.6)

Sulphate (SO_4) levels in the Klip River ranged between 14 mg/l (locality 5) and 1200 mg/l (locality 2). At locality 10, sulphate levels were low with a maximum level of 27 mg/l detected during November 1997 (Figure 3.10). Pearson's correlation coefficients indicated a strong positive correlation between sulphate and EC, hardness and Mg (Table 3.6).

Water hardness in the form of $CaCO_3$ ranged between 64 mg/l at locality 1 and 1150 mg/l at locality 2 in the Klip River (Table 3.4). Similar to the scenarios observed for EC, there were statistically significant ($p<0.05$) increases in hardness between localities 1 and 2, as well as between localities 5 to 6 and again a statistically significant decrease between locality 3 and 4. Water hardness in the form of $CaCO_3$ in the Suikerbosrand River was generally very low at locality 10, reaching a maximum level of 140 mg/l (Figure 3.11). Pearson's correlation coefficients indicated a strong positive correlation between water hardness and Ca, Mg, SO4, total and dissolved Mn (Table 3.6).

Levels of calcium (Ca) in the Klip River ranged between 16 mg/l (locality 1) and 340 mg/l (locality 2) (Figure 3.12 & Table 3.4). Calcium concentrations had similar trends to EC and water hardness, with statistically significant increases occurring between localities 1 and 2, and 5 and 6, and statistically significant decreases between localities 3 and 4 (Table 3.5). The calcium levels in the Klip River were generally within the acceptable range, with only localities 2 and 3 having values within the tolerable ranges. The calcium levels detected at locality 10 (Suikerbosrand River) were always very low and within the acceptable range, with a maximum value of 25 mg/l recorded during November 1997 (Table 3.4). Pearson's correlation coefficients indicated a strong positive correlation between calcium and EC, TDS, water hardness, Mg and dissolved Mn (Table 3.6).

Total alkalinity (as $CaCO_3$) in the water of the Klip River, ranged between 6 mg/l at locality 2 and 365 mg/l at locality 3 (Table 3.4). The total alkalinity at localities 2 to 6 was very much higher during November 1999 (Figure 3.13). The standard deviation of total alkalinity was very high at localities 2 and 3. Most values for total hardness fell within the ideal range, while only locality 2 had unacceptable total alkalinity levels at times (Figure 3.13). Total alkalinity at locality 10 also fell within the ideal range, measuring between 75 mg/l (November 1998) and 170 mg/l (August 1998).

Levels of magnesium (Mg) in the Klip River ranged between 4.6 mg/l and 111 mg/l, both recorded at locality 1 (Table 3.4). Magnesium levels generally increased from locality 1 to 2, afterwhich it decreased towards locality 4 (Figure 3.14). There was a statistically significant decrease in Mg from locality 3 to 4, and a statistically significant increase in Mg from locality 5 to 6 (Table 3.5). Magnesium levels in the Klip River were mostly within the acceptable ranges, with only localities 1 and 2 having unacceptable concentrations at times. At locality 10, the Mg levels were low with a maximum level of 19 mg/l detected (Table 3.4). Pearson's correlation coefficients indicated that Mg had a strong positive correlation with EC, hardness, Ca and sulphate (Table 3.6).

Sodium concentrations in the water of the Klip River ranged between 17 mg/l at locality 1 and 105 mg/l at locality 2 (Table 3.4). Statistically significant increases in Na concentrations occurred from localities 1 to 2, and from localities 5 to 6. Most values detected in the Klip River fell within the ideal and acceptable levels. Levels detected at localities 1, 2, 6, 7, 8 and 9 fell, at times, into the tolerable range and during August 1998

at locality 2, in the unacceptable range (Figure 3.15). Sodium levels at locality 10 were always within the ideal range, with a maximum level of 24 mg/l recorded during November 1998 (Table 3.4). Pearson's correlation coefficients indicated that Na had a strong positive correlation with EC, K, Cl and F (Table 3.6).

Detectable potassium (K) levels in the Klip River ranged between 1.2 mg/l at locality 1 and 26 mg/l at locality 5 (Table 3.4). The highest levels of potassium in the Klip River were recorded during November 1997 and August 1998 (Figure 3.16). Potassium levels showed a statistically significant increase from localities 2 to 3 and especially from 3 to 4 (Figure 3.16 and Table 3.5). In the Suikerbosrand River, locality 10 had very low potassium levels, with a maximum of 4.2 mg/l detected during November 1997 and 1998. Pearson's correlation coefficients indicated that K had a strong positive correlation with Na, Cl, F, ortho phosphates and COD (Table 3.6).

Detectable chloride (Cl) levels in the Klip River ranged between 11 mg/l at locality 1 and 77 mg/l at locality 9 (Table 3.4). A gradual downstream increase in Cl was observed in the Klip River, with a statistically significant increase taking place from locality 3 to 4 (Figure 3.17 & Table 3.5). Chloride levels at localities 1 to 4 generally fell within the ideal range and at localities 4 to 9 within the tolerable range (Figure 3.17). At locality 10 in the Suikerbosrand River, chloride levels were always within the ideal range, with a maximum level of 26 mg/l recorded during August 1997. Pearson's correlation coefficients indicated that Cl had a strong positive correlation with Na, K and F (Table 3.6).

In the water of the Klip River, fluoride (F) levels ranged between 0.12 mg/l (localities 1 and 2) and 0.28 mg/l (locality 8) (Figure 3.18). There was a statistically significant increase in F levels from localities 3 to 4 (Table 3.5). The concentrations of fluoride detected in the Klip River were, however, low and always fell within the ideal range. At locality 10, a maximum fluoride level of 0.18 mg/l was detected during November 1998 (Table 3.4). Pearson's correlation coefficients indicated that fluoride had a strong positive correlation with Na, K, Cl and ortho-phosphates (Table 3.6).

Ammonia (NH_3) levels in the Klip River ranged between below detection limit and 7.1 mg/l (Table 3.4). There was a profound increase in ammonia levels from locality 2 to 3. Most sites in the Klip River had median ammonia levels within the ideal range, with only

locality 3 falling within the acceptable range. Ammonia levels at locality 3 were at times very high, falling within the tolerable level (Figure 3.19). At locality 10 ammonia levels were always within the ideal range, with a maximum concentration of 0.27 recorded during November 1997 (Figure 3.19).

In the Klip River, nitrate levels ranged between 0.05 mg/l (locality 1) and 6.5 mg/l (locality 4) (Table 3.4). Nitrate levels increased slightly from locality 2 to 3, and a very sharp increase in nitrates occurred from locality 3 to 4 (Figure 3.20). Median nitrate levels determined for locality 1 and 2 fell within the optimal range, and at locality 3, within the acceptable range. A profound deterioration between localities 3 and 4 gave the result of the rest of the Klip River localities (4 to 9) having median nitrate levels within the tolerable range (Figure 3.20). The highest nitrate levels were detected during August 1998, when concentrations exceeded the unacceptable levels at localities 3, 4, 5, 7 and 9 (Figure 3.20). Nitrate levels at locality 10 were always within the ideal range, with a maximum level of 0.27 mg/l recorded at this site (Table 3.4).

Detectable nitrite levels in the Klip River ranged between 0.05 mg/l (locality 7) and 0.57 mg/l (locality 9) (Table 3.4). Nitrite levels showed a statistically significant decrease from locality 4 to 5, and increased again significantly from locality 5 to 6 (Table 3.5). Nitrite levels at locality 10 were very low, with a maximum value of 0.3 mg/l detected.

Detectable ortho-phosphate levels in the Klip River ranged between 0.03 mg/l (locality 1) and 1.4 mg/l (locality 3). There was a gradual, consistent increase in ortho-phosphates from locality 2 to 6 (Figure 3.21). Median ortho-phosphate levels determined for localities 1 to 3 fell within the ideal range, while median levels for the rest of the Klip River sites were within the tolerable range (Figure 3.21). The ortho-phosphate levels of locality 10 were always within the idea range, with a maximum level of 0.26 mg/l recorded during February 1999. Pearson’s correlation coefficients indicated that ortho-phosphates had a strong positive correlation with K, F and COD (Table 3.6).

Detectable total phosphate levels in the Klip River ranged between 0.13 mg/l (locality 3) and 2.9 mg/l (locality 7). Median total phosphates indicated increases between localities 2 and 4 as well as from locality 5 to 6 (Figure 3.22). Median total phosphate levels determined for localities 1 and 2 fell within the ideal water quality range. Locality 3 had a

median total phosphate level in the acceptable range, while the median total phosphate level at localities 4 and 5 fell within the tolerable range. Median total phosphate levels of localities 6 to 9 were unacceptably high (Figure 3.22). All of the localities in the Klip River had, at times, unacceptably high total phosphate levels (Figure 3.22). The total phosphate levels of locality 10 were generally below detection limits, although a value of 0.6 mg/l was recorded during November 1998.

Total and dissolved cadmium, chromium, cobalt, copper, lead, boron, vanadium and molybdenum were generally below detection limits at all the sites investigated (Table 3.7). The only metals to occur during the study period (1997 – 1999), in significant levels in the waters of the Klip River, were Fe, Mn, Zn and Al. Total iron (Fe) ranged between 0.1 mg/l (locality 1) and 1.0 mg/l (locality 4) in the Klip River (Table 3.7). Total Fe levels in the Klip River generally increased from locality 1 to 3, then decreased towards locality 4, afterwhich a slight and consistent increase occurred towards locality 8 (Figure 3.23). Median total Fe levels for localities 1 to 6 fell within the acceptable range, while localities 7 to 9 were within the tolerable range. The total Fe levels at locality 10 were generally much higher than those of the Klip River, ranging between 0.31 mg/l to 1.7 mg/l (Table 3.7). The median total Fe levels for this site also fell within the tolerable range, although the unacceptable level was exceeded at times.

Median total manganese levels in the water of the Klip River increased from an ideal level at locality 1 (<0.0001mg/l), to a tolerable level at locality 2 (0.43 mg/l) and then to an unacceptable level at locality 3 (0.86mg/l). Thereafter, a significant decrease occurred, in which the median total manganese in the middle and lower Klip River ranged between the acceptable and tolerable ranges (Table 4.7 and Figure 3.24). Median total zinc levels decreased gradually from locality 1 (0.13mg/l) to locality 3 (<0.0001mg/l). Again there was an increase in zinc levels at locality 5 (0.1mg/l), afterwhich it stayed relatively constant throughout the rest of the river (Figure 3.25). Dissolved aluminium indicated a spatial trend similar to zinc, decreasing from locality 1 (0.11mg/l) to 3 (< 0.0001mg/l). Median aluminium levels increased at locality 6 (0.11mg/l), probably due to the influence of the Rietspruit, and stayed relatively constant downstream (Figure 3.26).

Table 3.7: Metal levels (in mg/l) detected in the surface water of the sampling sites over the study period (August 1997 to May 1998).

LOCALITY	SURVEY	TOTAL												DISSOLVED												
		Cr	Co	Cu	Fe	Mn	Pb	Zn	Ni	Al	B	V	Mo	Cd	Cr	Co	Cu	Fe	Mn	Pb	Zn	Ni	Al	B	V	Mo
1	Aug-97	bdl	bdl	bdl	3	bdl	bdl	0.13	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.12	bdl	bdl	bdl
	Nov-97	bdl	bdl	bdl	0.17	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.15	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.1	0.4	bdl	0.14	bdl	bdl	bdl	0.17	bdl	bdl	bdl	bdl	bdl	0.39	0.35	bdl	0.14	bdl	0.44	bdl	0.1	bdl
	Aug-98	bdl	bdl	bdl	0.11	bdl	bdl	0.16	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.12	bdl	0.2	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.24	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.18	bdl	bdl	bdl	bdl	0.24	bdl	bdl	bdl
	Feb-99	bdl	bdl	bdl	0.48	0.26	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.24	0.26	bdl	bdl	bdl	0.11	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	bdl	bdl	bdl	0.18	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.17	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.2**	**bdl**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.2**	**bdl**	**bdl**	**bdl**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**
2	Aug-97	bdl	0.25	bdl	0.23	5	bdl	0.4	0.82	1	bdl	bdl	bdl	bdl	bdl	0.26	0	1.3	5	0.11	0.28	0.84	0.36	bdl	bdl	bdl
	Nov-97	bdl	bdl	bdl	0.82	0.66	bdl	0.11	0.12	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.26	1.1	bdl	0.19	0.19	bdl	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.32	0.54	bdl	0.11	0.11	bdl	bdl	0.14	bdl	bdl	bdl	bdl	bdl	0.4	0.62	0.16	0.11	0.21	0.1	bdl	0.2	bdl
	Aug-98	bdl	bdl	bdl	0.33	0.43	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.44	0.39	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.23	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.17	bdl	bdl	0.13	bdl	0.29	bdl	bdl	bdl
	Feb-99	bdl	bdl	bdl	0.23	bdl	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.21	bdl	bdl	bdl	bdl	0.12	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	bdl	bdl	bdl	0.29	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.2**	**0.4**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.2**	**bdl**	**bdl**	**0.1**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**
3	Aug-97	bdl	bdl	bdl	0.59	0.17	0.1	0.13	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.15	0.11	0.13	bdl	bdl	bdl	bdl	bdl	bdl
	Nov-97	bdl	bdl	bdl	0.19	1.2	0	0.17	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.19	2.5	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.34	1.6	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.32	1.8	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Aug-98	bdl	bdl	bdl	0.29	0.34	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.21	0.36	0.38	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.46	0.86	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.35	0.77	bdl	bdl	bdl	0.46	bdl	bdl	bdl
	Feb-99	bdl	bdl	bdl	0.89	2.3	bdl	bdl	bdl	bdl	bdl	bdl	0.11	bdl	bdl	bdl	bdl	0.79	2.3	bdl	0.1	0	0.1	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	0.19	0.66	bdl	0.44	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.68	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.3**	**0.9**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.2**	**0.8**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**
4	Aug-97	bdl	bdl	bdl	0.96	0.17	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.24	0.11	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Nov-97	bdl	bdl	bdl	0.11	0	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.26	0.2	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.48	0.25	bdl	0.24	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.19	0.2	bdl	bdl	bdl	0.13	bdl	bdl	bdl
	Aug-98	bdl	bdl	bdl	0.21	0.12	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.27	0.12	0.13	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.23	1.2	bdl	bdl	0.12	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.25	1.2	bdl	bdl	0.11	0.33	bdl	bdl	bdl
	Feb-99	bdl	bdl	bdl	1	0.95	bdl	bdl	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.61	0.94	bdl	bdl	bdl	0.12	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	0.18	0.29	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.25	bdl	0.25	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.2**	**0.3**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.2**	**0.3**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**

Detection limit for Cd, Cr and Fe was 0.05 µg/l.
Detection limit for Co, Cu, Mn, Pb, Zn, Ni, Al, B, V and Mo was 0.10 µg/l

bdl –Below Detection Limit

Table 3.7 (Continue)

Locality	Survey	TOTAL												DISSOLVED												
		Cr	Co	Cu	Fe	Mn	Pb	Zn	Ni	Al	B	V	Mo	Cd	Cr	Co	Cu	Fe	Mn	Pb	Zn	Ni	Al	B	V	Mo
5	Aug-97	bdl	bdl	bdl	0.43	0.32	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.11	bdl	0.14	bdl	bdl	bdl	bdl	bdl
	Nov-97	bdl	bdl	bdl	0.19	1.4	bdl	0.16	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.26	0.11	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.37	0.39	bdl	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.15	0.16	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Aug-98	bdl	bdl	bdl	0.37	0.22	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.15	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.51	0.5	bdl	0.11	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.29	0.3	bdl	0.11	bdl	0.86	bdl	bdl	bdl
	Feb-99	0.1	bdl	bdl	0.59	0.46	bdl	0.1	bdl	bdl	bdl	bdl	bdl	bdl	0.1	bdl	bdl	0.44	0.39	bdl	0.18	0.1	0.14	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	0.29	0.28	bdl	0.21	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.24	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.4**	**0.4**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.2**	**0.1**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**
6	Aug-97	bdl	bdl	bdl	0.36	0.66	0.1	0	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.15	0.6	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Nov-97	bdl	bdl	bdl	0.28	0.2	bdl	0.13	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.22	0.4	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.42	0.34	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.16	0.17	bdl	0.12	bdl	0.15	bdl	bdl	bdl
	Aug-98	bdl	bdl	bdl	0.62	0.31	bdl	0.15	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.16	0.19	bdl	0	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.66	0.46	bdl	0	bdl	1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.36	0.38	bdl	0.19	bdl	0.29	bdl	bdl	bdl
	Feb-99	bdl	bdl	bdl	0.57	0.43	bdl	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.16	0.14	bdl	0.18	bdl	0.11	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	0.25	0.23	bdl	0.22	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.15	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.4**	**0.3**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.2**	**0.2**	**bdl**	**0.1**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**
7	Aug-97	bdl	bdl	bdl	0.14	0.55	bdl	0	bdl	bdl	bdl	bdl	bdl	bdl	0.1	bdl	bdl	0.42	0.55	bdl	0.17	bdl	0.23	bdl	bdl	0.34
	Nov-97	bdl	bdl	bdl	0.12	0.16	bdl	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.22	0.5	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.76	0.61	bdl	0.37	bdl	bdl	bdl	bdl	bdl	bdl	0.1	bdl	bdl	0.36	0.35	bdl	0.12	bdl	0.12	bdl	bdl	0.11
	Aug-98	bdl	bdl	bdl	0.54	0.27	bdl	0.11	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.15	0.14	0.23	bdl	0.1	bdl	0	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.73	0.58	bdl	bdl	bdl	1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.45	0.53	bdl	bdl	bdl	0.24	0.27	bdl	bdl
	Feb-99	bdl	bdl	bdl	0.52	0.5	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0	0.33	bdl	bdl	bdl	0.13	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	0.19	0.25	bdl	0.14	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.18	0.23	bdl	0.18	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.5**	**0.5**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.2**	**0.4**	**bdl**	**0.1**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**
8	Aug-97	bdl	bdl	bdl	0.89	0.75	bdl	0.19	bdl	1	bdl	bdl	0.22	bdl	bdl	bdl	bdl	0.32	0.6	bdl	0.14	bdl	0.14	bdl	bdl	0.16
	Nov-97	bdl	bdl	bdl	0.27	0.24	bdl	0.11	bdl	1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.35	0.47	bdl	bdl	bdl	0.18	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.52	0.33	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.1	bdl	bdl	0.58	0.19	bdl	0.11	bdl	0.2	bdl	bdl	bdl
	Aug-98	bdl	bdl	bdl	0.64	0.34	bdl	0.14	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.29	0.2	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.76	0.51	bdl	bdl	bdl	1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.38	0.43	bdl	0.18	0.11	0.49	0.22	bdl	bdl
	Feb-99	bdl	bdl	bdl	0.58	0.36	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.16	bdl	0.13	bdl	bdl	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	0.15	0.2	bdl	0.22	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.14	bdl	0.14	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.6**	**0.3**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.3**	**0.2**	**bdl**	**0.1**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**

Detection limit for Cd, Cr and Fe was 0.05 µg/l. bdl –Below Detection Limit

Detection limit for Co, Cu, Mn, Pb, Zn, Ni, Al, B, V and Mo was 0.10 µg/l

Table 3.7 (Continue)

Locality	Survey	TOTAL												DISSOLVED												
		Cr	Co	Cu	Fe	Mn	Pb	Zn	Ni	Al	B	V	Mo	Cd	Cr	Co	Cu	Fe	Mn	Pb	Zn	Ni	Al	B	V	Mo
9	Aug-97	bdl	bdl	bdl	0.19	0.52	bdl	0.15	bdl	bdl	bdl	bdl	0.1	bdl	bdl	bdl	bdl	0.52	0.59	bdl	0.25	bdl	0.26	bdl	bdl	0.14
	Nov-97	bdl	bdl	bdl	0.44	0.27	bdl	0.11	bdl	bdl	bdl	bdl	0	bdl	bdl	bdl	bdl	0.26	0.41	bdl	bdl	bdl	0.15	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.65	0.32	bdl	0.12	bdl	bdl	bdl	bdl	0.15	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Aug-98	bdl	bdl	bdl	0.64	0.29	bdl	0.15	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.35	0.21	bdl	0.1	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	0.68	0.47	bdl	0.21	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.2	0.3	bdl	bdl	bdl	0.35	0.2	bdl	bdl
	Feb-99	0.1	bdl	bdl	0.57	0.37	0.1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.11	0.12	bdl	0.27	bdl	0.11	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	0.16	0.2	bdl	0.18	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.6**	**0.3**	**bdl**	**0.2**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.2**	**0.3**	**bdl**	**0.1**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**
10	Aug-97	bdl	0.17	bdl	0.64	0.12	bdl	bdl	bdl	bdl	bdl	bdl	0.4	bdl	bdl	0.17	bdl	0.51	0.12	bdl	0.36	bdl	0.22	bdl	bdl	0.39
	Nov-97	bdl	bdl	bdl	0.31	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.63	0.11	bdl	bdl	bdl	0.29	bdl	bdl	bdl
	Feb-98	bdl	bdl	bdl	0.86	0.18	bdl	0.13	bdl	1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	1.2	0.21	bdl	0.17	bdl	0.57	bdl	bdl	bdl
	Aug-98	bdl	bdl	bdl	0.37	bdl	bdl	0.14	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	0.23	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Nov-98	bdl	bdl	bdl	1.7	0.27	bdl	bdl	bdl	1	bdl	bdl	bdl	bdl	bdl	bdl	bdl	1.5	0.14	bdl	bdl	bdl	bdl	0.62	bdl	bdl
	Feb-99	bdl	bdl	bdl	1.3	bdl	bdl	0.15	bdl	bdl	bdl	bdl	bdl	bdl	0.1	bdl	bdl	2.4	0.28	bdl	bdl	bdl	0.63	bdl	bdl	bdl
	May-99	bdl	bdl	bdl	0.6	bdl	bdl	0.23	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl	bdl
	Median	**bdl**	**bdl**	**bdl**	**0.6**	**bdl**	**bdl**	**0.1**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**bdl**	**0.6**	**0.1**	**bdl**	**bdl**	**bdl**	**0.2**	**bdl**	**bdl**	**bdl**

Detection limit for Cd, Cr and Fe was 0.05 µg/l.
Detection limit for Co, Cu, Mn, Pb, Zn, Ni, Al, B, V and Mo was 0.10 µg/l

bdl –Below Detection Limit

Median faecal coliforms (fc's) were generally low in the upper catchment, but increased from locality 2 (160 fc's/100ml) to locality 3 (2700 fc's/100ml). They decreased again toward locality 5 (640 fc's/100ml), but increased significantly towards locality 6 (9700 fc's/100ml). The faecal coliforms then stayed relatively high in the rest of the Klip River, downstream of locality 6 (Figure 3.27). Median faecal coliforms were very low at locality 10 (11 fc's/100ml).

3.3.3 Water quality Guideline Compliance Index (GCI)

The Water quality Guideline Compliance Index (GCI) indicated a downstream deterioration in water quality along the Klip River (Figure 3.28). GCI scores calculated for locality 1 ranged between 96.8% (category A-Excellent) and 76.3% (C-Fair), with a median value for the study period of 91.9%, lying within category A (Excellent) (Table 3.8). There was a profound decrease in water quality, based on the GCI, from locality 1 to 2. The GCI scores at locality 2 indicated a significant improvement in water quality occurring over the study period (1997 to 1999). Values improved from category D (Poor) in August 1997, to A (Excellent) in May 1999 (Figure 3.28). The median GCI score calculated for locality 2 (79.3%) fell within category C (Fair).

Median GCI scores indicated a slight, but gradual deterioration in water quality from locality 2 to 5. The median GCI scores for localities 3, 4 and 5 indicated fair water quality at these sites. An obvious deterioration in water quality took place between locality 5 (Fair) and 6 (Poor) (Figure 3.28). The GCI scores in the rest of the Klip River stayed relatively constant, with median values from locality 6 to 9 lying within the poor water quality category (Figure 3.28). The water quality of locality 10 (Suikerbosrand River) ranged between category C (Fair) and A (Excellent). The median GCI score at locality 2 were high in category B, indicating on average, a very good water quality at this site (Table 3.8 & Figure 3.28).

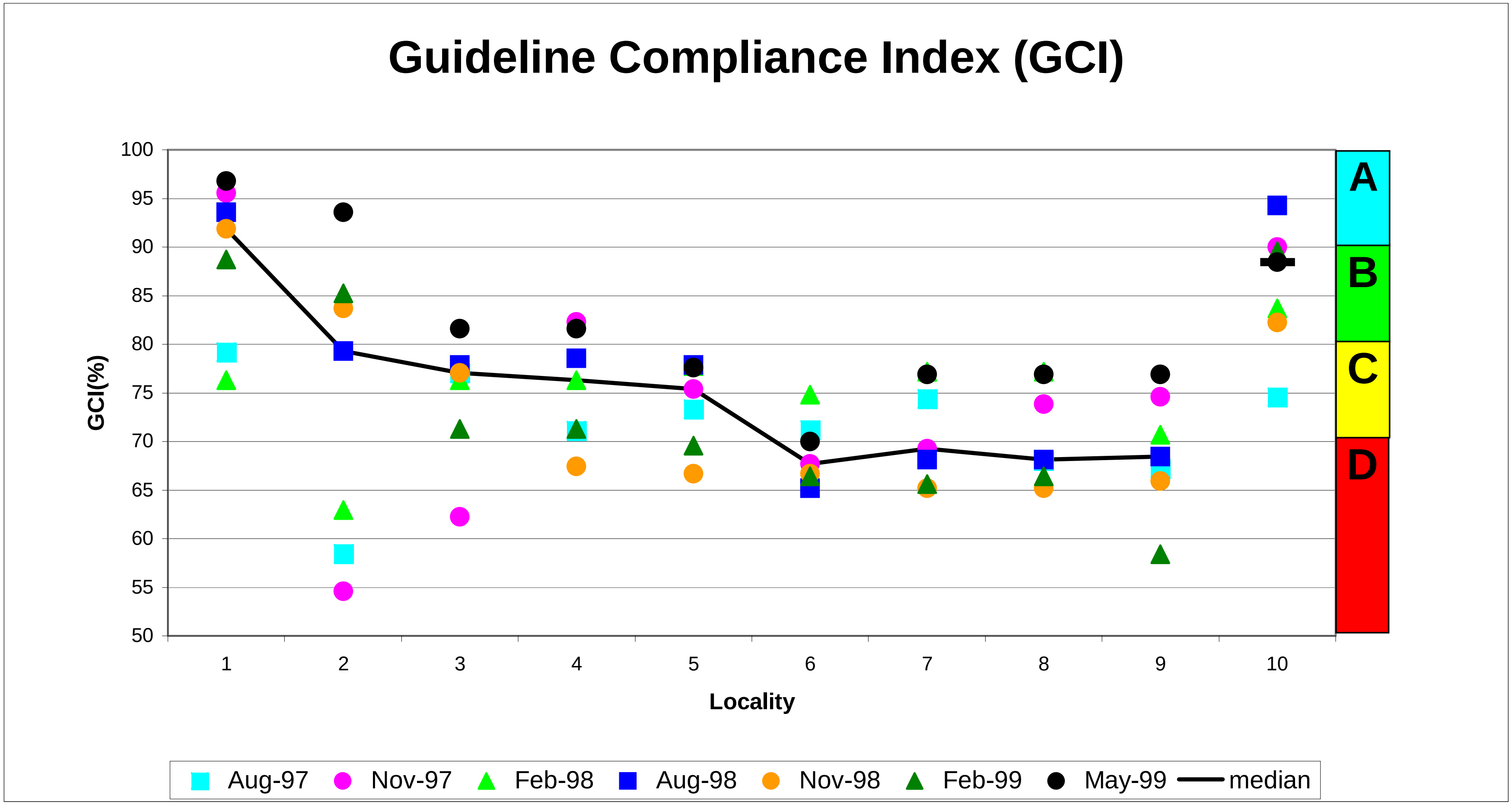

Figure 3.28: Results of the water quality Guideline Compliance Index and the relative classification of the water quality of each site investigated.

Table 3.8: Water quality Guideline Compliance Index (GCI) scores calculated for each survey.

SURVEY	LOCALITY									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Aug-97	79.20	58.46	77.04	71.11	73.33	71.20	74.40	68.00	67.20	74.55
Nov-97	95.56	54.62	62.22	82.31	75.38	67.69	69.23	73.85	74.62	90.00
Feb-98	76.30	62.96	76.30	76.30	77.78	74.81	77.14	77.14	70.71	83.70
Aug-98	93.57	79.29	77.86	78.57	77.86	65.19	68.15	68.15	68.46	94.29
Nov-98	91.85	83.70	77.04	67.41	66.67	66.67	65.19	65.19	65.93	82.22
Feb-99	88.70	85.22	71.30	71.30	69.57	66.40	65.60	66.40	58.40	89.57
May-99	96.80	93.60	81.60	81.60	77.60	70.00	76.92	76.92	76.92	88.46
MEDIAN	**91.9**	**79.3**	**77.0**	**76.3**	**75.4**	**67.7**	**69.2**	**68.2**	**68.5**	**88.5**
Category	**A**	**C**	**C**	**C**	**C**	**D**	**D**	**D**	**D**	**B**

4. DISCUSSION

The physical and chemical constituents of natural freshwaters are regionally influenced by climate, geomorphology, geology and soils, as well as by the aquatic and terrestrial biota living in a particular area (Davies & Day, 1998). Water chemistry is affected by the underlying geology of the catchment, because rocks of different kinds vary in chemical composition. Various components of the aquatic biota can also affect water chemistry. Rivers draining highly populated areas, industrial and mining complexes are known to bear the consequenses of human activities (Dallas & Day, 1993; Davies & Day, 1998). Some anthropogenic impacts are directly visible, such as solid waste disposal, but deterioration of water quality is often only observed by intensive and costly analyses. The water quality is, however, a crucial component for the existence and health of the biota, and the entire ecological integrity of a river system. The absence or state of the biotic communities in the river is often a good and reliable reflection of the water quality of the system (Karr & Chu, 1997, Barbour *et al.*, 1999).

Due to the highly developed catchment drained by the Klip River, temporal and spatial changes in water quality are inevitable. Drastic spatial changes and high levels of some pollutants prevailing in areas for long periods characterize the river water quality. In the most upper reaches (locality 1), the water quality was generally excellent. This site lies within five kilometers of the source of the river, and the human impacts are minimal. The quality of the river can be expected to degrade downstream as it accumulates more and more impact of the catchment (Perona *et al.* 1999). Although within 200 metres from a residential area, the human activities did not significantly alter the water quality of locality 1. The only water quality variables that reached unacceptable levels at locality 1 during the study period (1997 to 1999) were suspended solids, magnesium and phosphates. Long-term water quality assessments indicated high average levels of turbidity, ammonia, fluoride, iron, chromium, aluminium, nickel and zinc prevailing at this site over the past 30 years. Water quality deterioration in this section of the Klip River can most probably be attributed to the effect of storm-water runoff after rains. Storm water originating from residential areas often contains high levels of pollutants, washed from roads and paved surfaces. Gold mining impacts and industrial effluents may also have contributed to water quality deterioration in this part of the river at times.

Surface water temperatures were generally the lowest at locality 1 (median = 11.7°C), increasing gradually downstream. Under natural conditions the thermal characteristics of an aquatic ecosystem are reliant on the hydrological, climatic and structural features of its catchment (Heath, 1987). The natural variation in temperatures can, however, be negatively influenced by anthropogenic activities such as releases from dams, reservoirs, power stations, as well as the clearing of natural vegetation (Dallas & Day, 1993). The large numbers of exotic Black Wattle trees (*Acacia mearnsii*) growing on the banks in the area of locality 1 shaded most of the river and could therefore have contributed to the low water temperatures. Water temperatures generally increased significantly from locality 2 (median = 12°C) to locality 3 (median = 15°C). The Klip River opened up and flowed through wetland areas in this section, allowing the water to be exposed to sunlight and thus to be warmed. The increase in water temperature between locality 3 (median = 15°C) and 4 (median = 18.6°C) could also be attributed to the impact of water from wastewater treatment works (WWTW). The water from these works is generally warm due to the exposure to sunlight in the final stages of treatment. The Klip River can be classified as a cool water system, with mean summer temperatures ranging between 17°C in the upper reaches and 26°C in the lower reaches. Fish species diversity is generally lower in cold and cool water rivers than warmer, tropical rivers. The Klip River, with its cool waters, had an expected diversity of only 11 fish species, which is low when compared to, for instance the warm water Mpumalanga lowveld rivers with up to 35 fish species (Pienaar, 1978). Similar scenarios have also been observed with species diversity ratios in other aquatic systems around the world (Paller, 1994; Kleynhans, 1999).

The significant deterioration in water quality from locality 1 to 2 is an aspect of major concern. Electrical conductivity (EC), total dissolved solids (TDS), hardness (as $CaCO_3$), calcium (Ca) and sodium (Na) showed a statistically significant increase ($p<0.05$) in this section of the river. These variables furthermore had strong positive correlation with each other, indicating that they may, in general, be associated with the same source of pollution. Electrical conductivity, total alkalinity, magnesium, sodium, sulphate and total manganese furthermore exceeded guidelines and reached unacceptable levels at this site. The variables of concern identified at locality 2 are often associated with water quality deterioration due to mining and industrial activities (Dallas & Day, 1993; Adendorf, 1997; Kotze, 1997). It is therefore envisaged that this deterioration can primarily be attributed to the impact of gold mining activities in this stretch of the Klip River. Total dissolved solids (TDS) concentrations are a measure of all the salts in water and are usually directly proportional to the electrical conductivity (EC) of the water (DWAF, 1996d). These variables can affect the metabolism of fish, decrease aquatic species diversity, and change community structure and ecological processes. It has also been observed in the decreasing growth rate and life expectancy, and in influencing osmotic balance in fish (Kotze, 1997). Median EC levels detected in the Klip River were generally higher than the average value of 35mS/m for typically unpolluted rivers (Koning & Roos, 1999).

With the unacceptably high concentrations of many water quality variables detected at locality 2, it can thus be expected that the water quality in this section would generally be unable to sustain even the most tolerant of biota. This was observed during biological sampling with very few macro-invertebrates, and only one fish species observed at this site (Chapter 5 and 6). The poor water quality in this section of the river furthermore act as a chemical barrier, preventing fish from recolonising the upper reaches of the river. This might explain the absence of fish from locality 1, where the water quality was excellent and the habitat fair, being able to sustain a viable fish population, but no fish were present. The improvement of the water quality at locality 2, based on guideline compliance index (GCI) scores, over the study period is however, a hopeful sign and can be attributed to reduced mining activities and improved management in the area.

Water quality generally deteriorated further towards locality 3, where the water quality can in general, only be classified as fair. Most variables assessed deteriorated between localities 2 and 3, and dissolved oxygen and potassium levels showed a statistically significant deterioration ($p<0.05$) between these two sites. Variables that exceeded guidelines and reached unacceptable levels at locality 3 included dissolved oxygen, suspended solids, EC, magnesium, phosphates, nitrate and total manganese. Long-term trends indicated that most of these variables have been problematic in this area for many years. The water quality deterioration in this section of the Klip River is a result of the continuation of the mining impacts, being even further degraded by pollution from informal and formal settlements. The impact of informal settlements on the water quality was reflected by nutrient enrichment with increased levels of nitrates, ortho-phosphates and ammonia often associated with this source of pollution (Dallas & Day, 1993; Koning & Roos, 1999; Perona *et al*., 1999; Ferrier *et al*., 2001). Phosphate was the only water quality variable to exceed the unacceptable range at all sites within the Klip River, being of great concern at locality 3, 6 and 7. High concentrations of phosphorus are likely to occur in waters that receive sewage as well as leaching or runoff from cultivated lands, again indicating the negative impact of informal settlements, WWTW and agriculture on the water quality of the Klip River. Ortho-phosphates are the only form of soluble phosphorus which is immediately available to aquatic biota and which can be transformed into an available form by naturally occurring processes (DWAF, 1996d). The increase in ortho-phosphates in the Klip River results in changes in the trophic status of the river water, and causes increased growth of algae (DWAF, 1996d). This, in turn, has a negative impact on the habitat quality of the river, embedding substrates and limiting niches for aquatic biota (Chapter 4).

Based on the GCI, the general water quality deteriorated slightly between locality 3 and 4. A statistically significant deterioration occurred for potassium, chloride and fluoride, while there were obvious increases in temperature, sodium, ortho-phosphates, nitrates and nitrites. These changes in water quality can most probably be attributed to the impact of the WWTW effluents, discharging in this section and specifically upstream of locality 4 (Olifantsvlei WWTW) as well as the influence of the Klipspruit water. Ammonia and chloride both have their anthropogenic sources in WWTW effluents discharged from urban areas (Jarvie *et al*., 2000). Effluents from WWTW's are often responsible for degradation of water quality, and thus the biological communities downstream of their effluent discharge (Quibell & Hohls, 1997). High levels of chloride, phosphates, ammonia and TDS in WWTW effluents have been identified as probable causes for biotic degradation downstream of WWTW's (Quibell & Hohls, 1997; Ferrier *et al.*, 2001). Sodium, potassium, chloride, sulfate and ortho-phosphates have also been associated with sewage impact on the Ouse River, United Kingdom (Neal *et al.*, 2000). Chloride is widely used in sewage and potable water treatments and also occurs in various industrial effluents (Coetzee, 1996; DWAF, 1996d). Chloride increases the TDS of natural waters and chlorine dissolves in water to form hydrochloric acid, free forms of chlorine or combined available chlorine or chloramines (DWAF, 1996d). This has various chronic and acute effects on fish, including avoidance behaviour, changes in blood chemistry, decreased growth rate, loss of equilibrium and death. It can also cause damage to gill epithelia and change the behaviour, reproduction and spawning cycles of fish (Kotze, 1997).

The influence of water from the Klipspruit is another source probably contributing to the water quality deterioration between localities 3 and 4. Potassium, nitrites, nitrates, ammonia and chloride have been problematic in this section of the Klip River over the period of 1973 - 2001, with evidence of high levels originating from the Klipspruit. Ortho-phosphates and chromium were also identified as being a variable of great concern in this section of the Klip River over this period, but with no major contribution originating from the Klipspruit. It is therefore evident that the sources presently responsible for deterioration of these water quality variables have had a long-term impact on this section of the Klip River. Water quality variables that indicated a significant spatial improvement in this section of the river included EC, hardness, Ca and Mg. It therefore seems that the mining impact in the upstream reaches of the river is only stabilized in this section of the river. The improvement of these variables can probably also be related to dilution as a result of the contribution of WWTW effluent to this section of the river.

Most water quality variables stayed relatively constant between localities 4 and 5, with the GCI indicating a general, slight downstream deterioration. It therefore seems that the vast wetland in this section of the Klip River does not improve the quality of the water significantly, as is generally expected from wetland systems (Davies & Day, 1998; RWSS, 1998). Historic data indicated that the only variables that were improved by this stretch of river were ammonia, nitrites and ortho-phosphates. Agricultural activities increase in this section of the Klip River, with vegetable and maize production, as well as livestock farming being the main form of land use in the lower section of the Klip River. The impact of these activities was clearly reflected by the significant increases in suspended solids and turbidity from locality 4 to 5, and by the deterioration of these variables further downstream. Decomposing reed beds and WWTW's could also have contributed to the increased turbidity and suspended solids observed in the Klip River. Hydrological and geomorphological processes determine the natural turbidity levels of rivers (Wotton, 1994) but human-induced impacts result in changes in natural regimes. Over-grazing, non-contour ploughing, removal of riparian vegetation and forestry operations accelerate erosion and increase turbidity levels (DWAF., 1996b). Expected impacts by increased turbidity and suspended solids on aquatic systems include reduced visibility, changes in community structure, impairment of gill functioning, reduced growth, reduced spawning success, egg development and increased susceptibility to disease (Berkman & Rabeni, 1987; Kotze, 1997; Ferrier *et al*., 2001). The turbidity in the Klip River was generally lower than the Suikerbosrand River, which has a much higher level of agricultural activity in its catchment. Turbidity levels detected during the current study was also much lower than those detected in the Modder River (Orange-Vaal System) which had turbidity levels ranging between 10 and 900 NTU's (Koning & Roos, 1999).

The water quality of the Klip River deteriorated significantly between locality 5 and 6. This deterioration can be primarily attributed to the cumulative effect of activities on the Klip River between these two sites, together with the impact of the water from the Rietspruit. The Rietspruit drains a highly developed area and is characterized by urbanized sections, informal housing settlements, agricultural holdings and diverse industrial and mining developments (Rand Water, 1999). Statistically significant deteriorations were observed between localities 5 and 6 for dissolved oxygen, EC, TDS, Hardness, Ca, Mg, Na and nitrite. These variables indicate that especially mining and industrial activities in the Rietspruit catchment contribute to poor water quality. Increased levels of faecal coliforms in this section of the Klip River indicate informal settlements and dysfunctional WWTW's contribute further to the poor water quality of the Klip River. Historic data indicates that high levels of Fe, Na, Mg, Ca, EC, TDS, SO4, nitrites and chloride in the lower section of the Klip River, over the period of 1973 to 2001, could be attributed to the impact of the Rietspruit.

Water quality variables remained relatively stable in the lower section (localities 6 to 9) of the Klip River, and can generally be classified as poor. The only water quality variable that deteriorated prominently in this section was turbidity, which could primarily be ascribed to the impact of agricultural activities in the area, together with WWTW's effluents. Bank erosion in the lower section of the river was increased due to the unnaturally high flows, originating mainly from WWTW's (Chapter 4). Nitrate levels were also relatively high in the lower section of the Klip River. Nitrates are essentially associated with agriculture and the release of mineralized organic nitrogen (Neal *et al*., 2000) and often also due to WWTW's effluents. It is therefore envisaged that the agricultural activities, together with WWTW's in the lower section of the Klip River may contribute to these high nitrate levels.

In most river systems there are clear temporal trends, with levels of most water quality variables decreasing with increased flows, due to a dilution effect (Perona *et al*., 1999; Neal *et al*., 2000; Ferrier *et al*., 2001). In the Klip River, there were generally no specific temporal trends for most water quality variables. This could be attributed to the lack of natural flow variations in this river system (Chapter 4). The natural flow cycles have been totally modified, especially by return water from various WWTW discharging in the Klip River. This results in uniform overall flows throughout most of the year, with little variation in pollutant input and dilution.

5. CONCLUSION

It was evident from this study that the water quality of the Klip River is highly degraded, and has deviated from its natural state due to the extensive anthropogenic activities in its catchment. The GCI indicated that the water quality of the river was excellent in the upper reaches, but that it deteriorated drastically downstream. Urban runoff, gold mining and industrial activities, as well as formal and informal settlement runoff affected mainly the water quality of the upper Klip River. In the middle reaches of the system, water quality degradation could be attributed to the influence of the Klipspruit water, wastewater treatment works (WWTW) effluents. Agricultural activities together with WWTW effluents were identified as the major causes for the further degradation of the water quality in the lower section of the Klip River. The water quality guideline compliance index (GCI) was identified to be of great value to classify the general water quality of a river site. This index considers an array of variables and therefore gives an overall view of the water quality at a site, thereby simplifying the interpretation of the water quality/chemical integrity of a site. It is recommended that this index be applied to monitor changes in water quality of the Klip River, and also be modified for application to other river systems.

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