PART 2: PROBLEM STATEMENT

As mentioned in the previous section the Hex River catchment is situated near the town of Rustenburg within the provincial boundaries if the North West province. Activities within a catchment affect both the physical attributes as well as the chemical constituents of the water body and therefore also affect the biotic integrity of the community (Clean Stream Environmental Services, 2005). Due to the location and the associated industrial development, mining activities and urbanization (formal and informal) taking place within the catchment, the water quality of the Hex River and its tributaries has progressively deteriorated. The National Water Act, 36 of 1998 requires that water quality be managed in an integrated manner at national level in terms of the National Water Resource Strategy, and at regional or catchment level in terms of Catchment Management Strategies. With continual industrial, residential and mining intensification within the North West Province the Hex River catchment can become detrimental to the aquatic environment and unsustainable for specified water users.

The **main aim** of the study is to determine the long-term as well as the current physical, chemical and biological water quality of the Hex River catchment. Existing water quality data are compared to the Target Water Quality Guideline Ranges (TWQGR) as stipulated by the Department of Water Affairs and Forestry to determine the suitability of the water for aquatic ecosystems, domestic use, irrigation and livestock watering. The problematic physical, chemical and biological constituents resulting from industrial, mining, residential as well as agricultural activities within the Hex River catchment will be ascertained. Rehabilitative as well as mitigatory measures to decrease high constituent concentrations will be proposed.

In order to reach the main aim presented above a phased approach had to be followed where the following **objectives** had to be met:

- Undertake an in-depth literature review to accumulate existing information on water quality and water quality management in general as well as for the specific area. Various maps of the study area must be collected. This will aid in the formulation of a methodology to be followed during the study.

- Determine the purpose of water quality monitoring in terms of legislative requirements. Review the Target Water Quality Guideline Ranges as set out by the Department of Water Affairs and

Forestry to acquire the acceptable guideline concentrations for aquatic ecosystems, domestic use, irrigation and livestock watering.

- Undertake a site-assessment to determine the location of the water monitoring localities as well as for orientation purposes.

- Describe the study area with the focus on aspects which are likely to influence the water quality of the Hex River and its associated tributaries, such as land use, geology, vegetation, rainfall and drainage. Identify and demarcate potential point sources of contamination affecting the water quality of the Hex River.

- Determine the land use associated with the study area. Potential water users are those role-players that straddle the Hex River, Klipfontein Spruit, Klipgat Spruit, Dorp Spruit and Paardekraal Spruit, up to the receiving water body, the Bospoort Dam.

- Determine the water use requirements associated with adjacent land uses. This includes description of which water user groups are present in the potential impact area and their water quality requirements including the requirements of the aquatic environment.

- Establish the sampling and analysis methodology followed for the collection and analysis of the physical, chemical and biological water quality of the Hex River and its associated tributaries.

- Collect the most recent as well as historical water quality data (physical, chemical and biological constituents) for the Hex River catchment (Data from July 2002 to June 2006 were obtained from Clean Stream Environmental Services (CSES)).

- Examine the spatial and temporal variation associated with the physical, chemical and biological water quality parameters for a four year period to determine long-term water quality trends and one-year period to determine the current water quality situation.

- Compare monitoring results against the Target Water Quality Guideline Ranges for domestic use, agricultural use as well as the aquatic ecosystem to determine the suitability of the water for identified users.

- Establish the assimilative capacity of the downstream Bospoort Dam acting as the receiving water body.

- Make recommendations towards actions which may facilitate the mitigation of identified problem areas.

In the following section Part 3, water quality, its chemical, physical and biological constituents, and the acceptable concentration ranges for domestic and agricultural use as well as the well-being of the aquatic environment, are discussed. Aspects of legislative measures affecting water quality management are also touched upon.

PART 3: WATER QUALITY AND WATER QUALITY MANAGEMENT

3.1. WATER QUALITY

Various definitions of the term water quality exist. Water quality refers to (DWAF, 2004 p. 16) “all the physical, chemical, biological and ecological attributes of the resource.” According to Jooste (2001) quality refers to: “not only to include the physical and physico-chemical components of water, but also the integrity of biota, the assurance of flow and the habitat structure.” Day (date unknown) defines water quality as the combined physical attributes and chemical constituents of water that contribute to its usefulness for a particular purpose. The chemical, physical and biological properties of water are influenced or controlled by substances, which are either suspended or dissolved in the water and can influence the usefulness of water for a certain purpose (Venter, 2004). According to the National Water Resource Strategy, (DWAF, 2004) different ecosystems and different users can have widely variable water quality requirements. For the purpose of this study water quality should include the determination of the physical, chemical as well as biological aspect of the resource, in order to determine the fitness thereof for use by various water users.

Certain constituents of water represent aggregates of constituents which interact to cause a particular water quality effect such as water pollution (DWAF, 1996a). Water quality is negatively affected by water pollution from both non-point and point sources. Point sources discharge pollutants at specific locations for example through pipes, ditches or sewers into water bodies. Non-point sources cannot be traced to any single site of discharge (Nawn, 2004). The sources of water pollution in the Hex River catchment are both from non-point as well as point pollution sources.

According to Beck (1984, p 294) the management of pollution to water resources requires an implied logic of the known cause and effect relationship which include:

- between the condition of the allowable levels of constituents in a polluting discharge and the effect of these constituents on the attainment of an environmental quality objective, and
- between the stipulation of the composition of an environmental quality objective and its “effects” on the intended “use” of a water body, such as for potable supply or as a habitat for aquatic fauna and flora.

The following section explains the main principals of water quality management in South Africa. Focus is placed on applicable legislative guidelines in order to determine the allowable ranges of constituents and the effect it has on the environment, in this study the Hex River catchment, as well as its effect on the intended use of the resource.

3.2. WATER QUALITY MANAGEMENT

3.2.1. Water quality management in South Africa:

The quality of water used for domestic and other purposes and the protection of water resources, particularly in a water scarce country such as South Africa, are everyone's concern and should be managed according to scientific principles (WRC, 1998). According to DWAF (2000) water quality management is a national competency. The central objective of managing the water resources of South Africa is to ensure that water is used to support equitable and sustainable social and economic transformation and development (DWAF, 2004). Water management requires that the available water is managed properly, is allocated equitably and that the quality of available water is protected. It is essential to ensure that the quality of water resources should not be degraded and that polluted water be purified, especially in South Africa which has scarce water resources (Barnard, 1999).

South Africa's constitution states that every citizen has the right to an environment that does not impact negatively on their health and well-being, and to have the environment protected for the benefit of present and future generations, through reasonable legislative and other measures [Section 24 of the Bill of Rights, Constitution of the Republic of South Africa (Act No. 108 of 1996)]. These legislative measures should prevent pollution and ecological degradation, promote conservation and secure ecologically sustainable development and the use of natural resources while promoting justifiable economic and social development. It can be seen in Part 4 of this minor dissertation that a variety of economic and social developments influence the water quality of the Hex River. In order to propose rehabilitative and management actions to sustainably utilize the water resource of the Hex River catchment the next section (Section 3.2.2, p. 11) focuses on the various legislative measures applicable to water quality. Particular focus is placed on the water quality guidelines stipulated by the Department of Water Affairs and Forestry for domestic use, irrigation, livestock watering and aquatic ecosystems.

3.2.2. Water quality legislation:

Since all life is dependant on water, there are a number of policies and laws, administrated by a variety of departments in all spheres of government, which govern activities dependant on water and affect water resources (DWAF, 2004). Various environmentally related legislation require either directly or indirectly the monitoring of water resources, such as the Environment Conservation Act (Act 73 of 1989), the National Environmental Management Act (Act 107 of 1998), the Minerals Act (Act 50 of 1991) (including Environmental Management Programme Reports (Section 39), Minerals and Petroleum Resources Development Act (Act 28 of 2002). Regulations relating to performance assessments (auditing) of Environmental Management Programme Reports (EMPR's) (Government Notice R801 of 25 June 1999) and Closure requirements (Section 12)), as well as the National Water Act, 1998 (Act 36 of 1998).

The most important legislation for the function of water quality monitoring includes (DWAF, 2000):

3.2.2.1. Constitution of the Republic of South Africa Act No. 108 of 1996:

As mentioned previously Section 24 of the Bill of Rights stipulates that every citizen has the right to sufficient water and that the state must take legislative and other measures to achieve the realization of this right. The constitution enables South Africans to expect that their environment, including water resources, will be protected from unsustainable use (DWAF, 1997).

3.2.2.2. National Environmental Management Act No. 107 of 1998:

According to the DWAF (2004) the management of water resources should be carried out in a manner consistent with the broad environmental policy of government and within the framework of environmental legislation, that is the National Environmental Management Act no. 107 of 1998, as well as those parts of the Environment Conservation Act no. 73 of 1989 that have not yet been repealed by the new legislation (DWAF, 2004). The National Environmental Management Act 107 of 1998 provides umbrella legislation making provision for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment and institutions to promote co-operative governance for co-coordinating environmental functions exercised by organs of the state.

3.2.2.3. National Water Act, Act 36 of 1998:

The National Water Act 36 of 1998 is the legislative measure to ensure the protection of the constitutional right regarding water resources and the aquatic environment. In the South African context, the National Water Act supplies the regulatory background for water resource management (Jooste, 2001). An old management principle states (DWAF, 2004b p. 12); “If you cant’ measure it, you can’t manage it.” This statement is recognized in Chapter 14 of the National Water Act no. 36 of 1998 that requires the monitoring of the quality of water resources in South Africa.

The promulgation of the National water Act, (Act 36 of 1998) lead to a paradigm shift resulting in the natural environment being regarded as an integral part of the water resource itself, as well as one of the competing water users. Hence the biota, the physical and chemical in-stream habitats and the processes which link biota and habitat are all considered being inseparably part of the water resource itself.

Section 26 (1) of the National Water Act, 1998 (Act 36 of 1998) provides for the development of regulations to, amongst others:

- Require that the use of water resources be monitored, measured and recorded;
- Regulate or prohibit any activity in order to protect a water resource or in-stream or riparian habitat; and
- Prescribe the outcome or effect, which must be achieved through management practices for the treatment of waste, or any class of waste before it is discharged into or allowed to enter a water resource

The Water Act (Act 36 of 1998) is, however, not the only instrument for water management in South Africa. The 1994 Water Supply and Sanitation Policy White Paper (now superseded by the Strategic framework for Water Services, 2003), and the Water Services Act no. 108 of 1997, dealing with the provision of potable water and sanitation services, are particularly closely related to the Water Act (DWAF, 2004).

3.2.2.4. National Water Resource Strategy:

The National Water Resources Strategy (GN 1160, GG 20491 of 1 October 1999) in terms of Section 5(1) of the National Water Act (Act No. 36 of 1998) was implemented in response to the new direction set by government and as part of a thorough review of existing water law (DWAF, 2004). This provides the framework for the protection, use, development, conservation, management, and control of water resources in South Africa. The National Water Resources Strategy was preceded by the 28 Fundamental Principles and Objectives for a New South African Water Law.

3.2.2.5. Catchment Management Agencies:

With regards to freshwater systems such as a large river fed by smaller tributaries, South Africa can be divided into 19 principle freshwater catchments (Figure 2) (Nawn, 2004). According to Sampson (2001) as quoted in Nawn (2004) the National Water Resource Strategy divides the country into 19 water management areas based of the mentioned freshwater catchments. According to Le Roux (2003) as cited in Nawn (2004) each water management area will be managed by a catchment management agency.

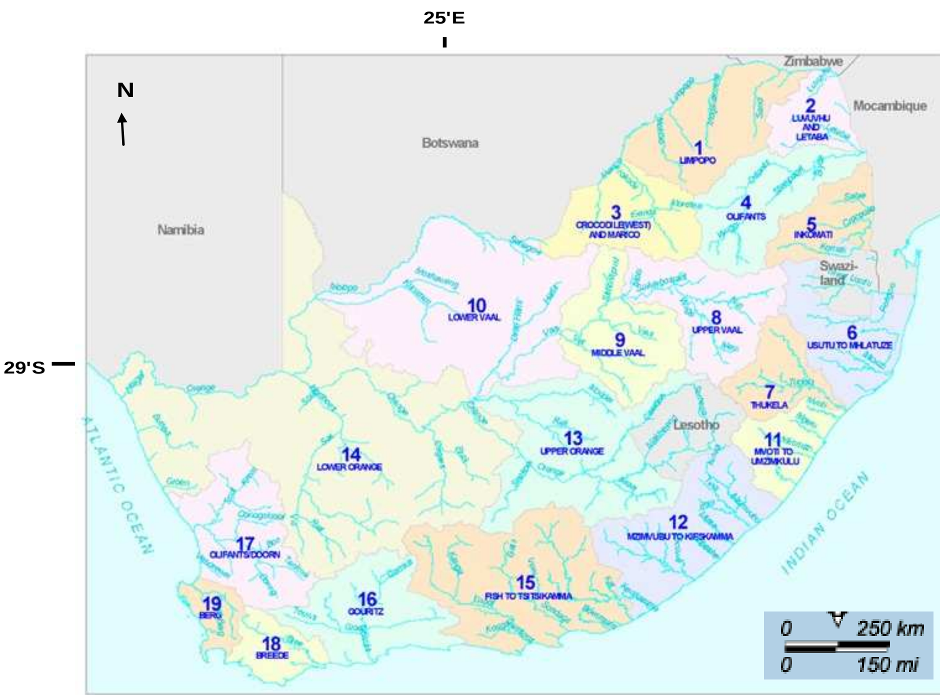

Figure 2: South Africa’s 19 identified water management areas (DWAF, 2002).

A catchment management strategy is the framework for water resource management in a water management area (DWAF, 2004). It is stated in the preamble of Chapter 7 of the National Water Act no 36 of 1998 that the purpose of establishing catchment agencies is to delegate water resource management to regional or catchment level and to involve local communities (Clean Stream

Environmental Services, 2003). The Hex River catchment is situated within the Crocodile (West) and Marico water management area, discussed in more detail in Part 4 of this minor dissertation.

3.2.2.6. The South African Water Quality Guidelines and Target Water Quality Guideline Ranges (TWQGR):

The Department of Water Affairs and Forestry's water quality management (WQM) function consists of (DWAF, 2000 p. 8):

- The Department's directorate Water Quality Management, which provides policy development, capacity building, specialist support, authorization and audit services at a strategic level
- The Department's nine Regional Offices, which provide policy implementation, operation, control and monitoring services at operational level, and
- The Department's institution for Water Quality Studies, which provide a scientific support service.

Water quality objectives as set out by the Directorate Water Quality Management (DWAF, 2001) are specific numeric values for water quality constituents of concern. It is important to distinguish between various terms associated with water quality management according to water quality objectives. A distinction of these terms adapted from Dick (1975); CCREM (1987); Chiaudani & Premazzi (1988) and UNECE (1992) as quoted in WHO/UNEP (1997) are given in Table 1.

Table 1: Definitions related to water quality by means of water quality objectives.

Term	Definition
Water quality criterion (synonym: water quality guideline)	Numerical concentration or narrative statement recommended to support and maintain a designated water use
Water quality objective (synonym: water quality goal or target)	A numerical concentration or narrative statement which has been established to support and to protect the designated uses of water at a specific site, river basin or part thereof
Water quality standard	An objective that is recognized in enforceable environmental control laws or regulations of a level of government

The introduction of holistic concepts of water management has led to the recognition that water quality objectives, the setting of emission limits on the concept of best available technology and the use of best available practices are integral instruments in the protection of water pollution (ICWE, 1992; UNCED, 1992; UNECE, 1993 as stated in WHO/UNEP, 1997). Water or resource quality is not only dependant on the physical and chemical characteristics of the water body but on the healthy functioning of the whole ecosystem. It is the healthy functioning of the whole ecosystem which gives a water resource its ability to recover from drought, floods and the impacts of humans. Therefore the most effective approach is to use the receiving water quality objectives as the basis for water environmental quality management (DWAF, 1997). Water quality objectives are use-specific or are targeted to the protection of the most sensitive water use among a number of existing or planned water uses (WHO/UNEP, 1997).

Water Quality Objectives form part of the resource quality objectives of the National Water Act (6 of 1998). The Resource Quality Objectives establishes goals regarding the quality of various water sources. An integral part of the Resource Quality Objectives is to create a balance between protection and the use of water resources. Water quality objectives are developed by scientists and provide basic scientific information about the effects of water pollutants on a specific water use. Water quality objectives are based on variables that characterize the quality of water, some setting a maximum level for the concentration of a substance in water, which will not be harmful when the water is used for a specific purpose. Water quality objectives can further be set to a minimum acceptable concentration to ensure the maintenance of biological functions (WHO/UNEP, 1997).

The application of receiving water quality objectives involves (Barnard, 1999, p.276): "The compilation of water quality guidelines based on the requirements of the recognized water uses... (and the)... formulation of water quality management objectives which recognize the water quality requirements of water users as well as economic, social, political, legal and technological considerations ... (and) ... site-specific effluent standards or other measures to ensure that the water quality management objectives determined for the particular water body will be met..."

Thus water quality management in South Africa is based on the principle of receiving water quality standards. For any water resource, be it dam, river or aquifer, a specific profile of users has developed over time. The standards are developed in such a way that ensures that the effluent disposed of in such a water body remains suitable for the users thereof (Barnard, 1999). In order to apply the above principle, the particulars are required of the different substances that can be found in the water, the extent to which different percentages of these substances can affect the use of the water and the tolerance of users to the substance in the water. For this purpose the Department of Water Affairs and Forestry has developed the South African Water Quality Guidelines (Barnard, 1999).

The South African Water Quality Guidelines (TWQGR) describes the acceptable level of substances or constituents for the different water users. By using the standards the Department of Water Affairs and Forestry strive to maintain the quality of water resources within the country within the No Effect Range (DWAF, 1996). This is the range "... of concentrations or levels at which the presence of ... (a) constituent would have no known or anticipated adverse effect on the fitness of water for a particular use or on the protection of aquatic ecosystems. These ranges were determined by assuming long-term continuous use (life-long exposure) (Barnard, 1999, p.277).

The TWQGR include the following water uses: domestic use, aquatic ecosystems, irrigation, livestock watering, recreational contact and industrial use. For the purpose of this study however only the TWQGR for domestic use, irrigation, livestock watering and the well-being of the aquatic environment will be used. This is because informal settlement along the Hex River can utilize the water for domestic purposes, while agricultural land use also occurs along the Hex River. The aquatic environment of the Hex River has been severely effected in some parts and further economic and social development can lead to disappearance of certain species in section of the Hex River and its associated tributaries.

3.3. WATER QUALITY CONSTITUENTS AFFECTING DOMESTIC USE, IRRIGATION, LIVESTOCK WATERING AND AQUATIC ECOSYSTEMS.

A number of physical, chemical and biological constituents can have an effect on the suitability of a water body for use as domestic, irrigation and livestock watering purposes as well as the aquatic environment. For the purpose of this study only a selected number of physical, chemical and biological constituents as summarized in Table 2, p. 17 will be discussed in Part 6 of the minor dissertation. These constituents were selected as it was decided that they would be indicative of the Hex River water quality profile.

Table 2: Summary of the Target Water Quality Guidelines as stipulated by the Department of Water Affairs and Tourism (1998).

VARIABLE	AQUATIC ECOSYSTEMS	IRRIGATION	LIVESTOCK WATERING	DOMESTIC (class 0 = ideal)	DOMESTIC tolerated (class 1 = good)	DOMESTIC (class 2 = marginal)	DOMESTIC (class 3 = poor)	DOMESTIC (class 4 = unacceptable)	Unfit for any TWQGR
Physical water quality constituents									
pH	5 % or 0.5 of a pH unit variation	6.5 - 8.4	-	6.0 - 9.0	5 - 9.5	4 - 4.5 / 10 - 10.5	3.5 - 4 / 10/5 - 11	<3 / >11	**<3 / >11**
T.D.S mg/l	< 15 % variation	< 260	1000 diary 1000 pigs 1000 poultry 2000 cattle 3000 sheep	0 - 450	450 - 1000	1000 - 2400	2400 - 3400	>3400	**> 3000**
EC mS/m	-	< 40	500	0 - 70	70 - 150	150 - 370	370 - 520	>520	**>520**
Turbidity (NTU)		-	-	< 0.1	0.1 - 1	1 - 20	20 - 50	> 50	**> 50**
Chemical water quality constituents									
Cl mg/l	400 max	0 - 100	0 - 1500 non-rum. 0 - 3000 ruminants.	0 - 100 1000 max	100 - 200 (<1000)	200 - 600	600 - 1200	>1200	**> 3000**
SO_4 mg/l	-	200 max	0 - 1000	0 - 200	200 - 400	400 - 600	600 - 1000	>1000	**> 1000**
NO_3 mg/l as N - CS	-	-	-	<6	6 - 10	10 - 20	20 - 40	>40	**>40**
Ammonia mg/l	< 0.007 free NH3	-	-	0 - 1.0 2 max total NH3	1.0 - 2.0	> 2 - 10	> 10	>10	**>10**
PO_4 mg/l	< 0.005 inorganic	-	-	< 2	-	-	-	-	**> 10**
Fe mg/l	-	0 - 5.0	1 - 10	0 - 0.5	0.5 - 1.0	1.0 - 5.0	5.0 - 10.0	>10.0	**>10**
Mn mg/l	< 0.18	0 - 0.02	0 - 10	0 - 0.1	0.1 - 0.4	0.4 - 4.0	4.0 - 10	>10	**>10**
Al mg/l	<0.005	1 - 5.0	0 - 5	0 - 0.15	0.15 - 0.5	>0.5	> 0.5	-	**>5**
F mg/l	< 0.75	0 - 2	0 - 2	<0.7	0.7 - 1.0	1.0 - 1.5	1.5 - 3.5	>3.5	**>3.5**
Hardness (CaCO3) mg/l	-	-	-	0 - 200	200 - 300	300 - 600 (very hard)	> 600 (extremely hard)	-	**> 1000**
Biological water quality constituents									
Total coliforms counts / 100 ml	-	-	-	0	0 - 10	10 - 100	100 - 1000	>1000	**>1000**
Faecal coliforms counts / 100 ml		-	0 - 200	0	0 - 1	1 - 10	10 - 100	>100	**>100**
E Coli (coliphages) counts / 100 ml	-	< 1	-	0 - 1	0 - 1	1 - 10	10 - 100	>100	**>100**
				-		**High**		**Elevated**	

To determine the physical, chemical and biological water quality of the Hex River the following constituents were analyzed.

- pH
- Total dissolved solids (mg/l)
- Electrical conductivity (mS/m)
- Hardness (mg/l)
- Chloride (mg/l)
- Sulphate (mg/l)
- Fluoride (mg/l)
- Iron (mg/l)

- Manganese (mg/l)
- Aluminum (mg/l)
- Ortho-phosphate (mg/l)
- Nitrate (mg/l)
- Ammonium (mg/l)
- Turbidity (mg/l)
- Total coliforms counts
- Faecal coliform counts
- E. Coli

3.2.1. Physical Water Quality:

Physical water quality refers to water quality properties such as temperature, electrical conductivity, pH and oxygen content that may be determined by physical methods. The physical water quality parameters are summarized in Table 3, p. 18. The physical quality affects the aesthetic as well as chemical quality of the water. For the purpose of this study pH, electrical conductivity, total dissolved solids as well as turbidity will be discussed and a brief discussion of each are given in section 3.2.1.1 to 3.2.1.3.

Table 3: Physical water quality attributes

Physical quality	
Parameter	**Relevance**
pH	Affects the corrosivity and taste of water
Electrical conductivity/ Total dissolved solids	Serves as a general indicator of change in water quality and affects the taste "freshness" of the water. Indicates the salinity and quantity of dissolved substances.
Turbidity	Indicates the cloudiness of the water and affects the risk of infectious disease transmission.
Temperature	Affects equilibrium reactions and oxygen solubility

3.2.1.1 pH

pH is a logarithmic expression of the hydrogen ion concentrations and reflects the degree of acidity (pH less than 7) or alkalinity (pH greater than 7) of the water (DWAF, 1996a). The pH of pure water at a temperature of 24 C is 7.0 i.e. the number of H^+ and OH^- ions are equal. When the concentrations of hydrogen ions $[H^+]$ increases, pH decreases and the solution becomes more acidic. Conversely, as $[H^+]$ ions decreases, pH increases and the solution becomes more basic (DWAF, 1996b).

The TWQGR for pH values for domestic use, irrigation and aquatic ecosystems are indicated in Table 2, p. 17. As depicted in Table 2, p 17 no specified guideline can be set for aquatic ecosystems as well as livestock watering. The TWQGR for aquatic ecosystems indicate that the pH value should not be allowed to vary from the range of background pH values for a specific site and time of day by more than 0.5 of a pH unit.

3.2.1.2. Electrical Conductivity (EC) and Total Dissolved Solids:

Materials dissolved in water are measured as total dissolved solids (TDS), conductivity or as salinity. Total dissolved solids are a measure of the quantity of all compounds dissolved in water. Electrical conductivity is a measure of the ability of water to conduct an electrical current. Total dissolved solids are directly proportional to electrical conductivity (DWAF, 1996b). For the purpose of this study total dissolved solid concentrations recorded were used to indicate the salinity of the Hex River.

TDS (mg/l) = EC (mS/m at 25 degrees Celsius) x 6.5

According to Dallas & Day (2004) as cited in Nawn (2004) salinity refers to the saltiness of water. Virtually all natural waters contain varying concentrations of TDS and therefore the TDS of natural waters often depend on the characteristics of the geological formations that the water was, or is, in contact with. TDS are likely to accumulate in water as water moves downstream because salts are continuously being added through natural and manmade processes, while very little are removed by precipitation or natural processes (DWAF, 1996d). The properties of the TDS are governed by the characteristics of the constituent inorganic salts dissolved in the water. As such, TDS is also closely related to other water quality constituents such as the total hardness and the corrosion and scaling potential of water (DWAF, 1996a).

From Table 2, p. 17 it is evident that the TWQGR for total dissolved solids applicable to aquatic ecosystems does not have a specific value but the variation of total dissolved solid concentrations should be prevented. TDS concentrations should not be changed by more than 15% from the background concentration.

3.2.1.3. Turbidity

TWQGR for turbidity ranges only exists for domestic use, and no guideline values are applicable to irrigation, livestock watering and aquatic ecosystems. Turbidity is a measure of the light-scattering ability of water and is indicative of the concentration of suspended matter in water. Turbidity in water is caused by the presence of suspended matter which usually consists of a mixture of inorganic matter, such as clay and soil particles, and organic matter. The turbidity of raw water can range from less than one nephelometric turbidity unit (NTU) in very clear water, to over 1 000 NTU in turbid, muddy water (DWAF, 1996a). Turbidity has no health effect but influences the microbial water quality of a water body.

3.2.2. Chemical Quality:

The chemical quality of water refers to the nature and concentrations of dissolved substances such as organic or inorganic compounds, including metals, in the water body. The chemical composition of natural water is derived from many different sources of solutes such as gases and aerosols from the atmosphere, weathering and erosion of rocks and soil, precipitation reactions under ground and cultural effects resulting from human activities (Hern, 1989 in Venter, 2004). The chemical attributes of water is summarized in Table 4, p. 20 and the relevance of each are indicated.

Many chemicals in water are essential for the biotic community and may form an integral part of the nutritional requirements. However, elevated levels may be limiting for some of the downstream users. The chemical constituents indicative of the water quality of the Hex River and discussed in this study include chloride, sulphate, nitrate, ammonium, ortho-phosphate, manganese, aluminium, iron, fluoride and hardness.

Table 4: Chemical water quality attributes

Chemical quality	
Parameter	**Relevance**
Alkalinity	Indicative of intrinsic buffering capacity against acidification
Major anions	Influence the salinity levels
Hardness	Affects the scaling and foaming quality of the water
Major cations	Elevated levels could affect the taste of water
Heavy metals	Toxic at low concentrations

3.2.2.1. Chloride

Chloride is the anion of the element chlorine. Chlorine does not occur in nature, but is found only as chloride. Chloride is a common constituent in water, is highly soluble, and once in solution tends to accumulate. Chloride inputs to surface waters can arise from irrigation return flows, sewage effluent discharges and various industrial processes (DWAF, 1996a). Chloride is of concern in water supplies because elevated concentrations impart an unpalatable taste to water and accelerate the corrosion rate of metals. Chloride and sodium ions impact on water quality both by fallout from polluted air and by deicing salt used on highways (Strahler & Strahler, 1996).

3.2.2.2. Sulphate

The TWQGR for sulphate are summarized in Table 2, p. 17 for domestic use, livestock watering as well as irrigation. No TWQGR for sulphate for aquatic ecosystems exists. Sulphate is a common constituent of water and arises from the dissolution of mineral sulphates in soil and rock, particularly calcium sulphate (gypsum) and other partially soluble sulphate minerals (DWAF, 1996a). The release of sulphates leads to increased suspended solids and total dissolved solids and thus to salinisation (MMSD, 2001). The formation of sulphate-rich solution leads to the increasing solubility of arsenic, cobalt, iron, magnesium, nickel and uranium (Brink *et al*, 1990 in MMSD, 2001). Sulfate ions enter runoff both by fallout from polluted urban air and as sewage effluent Strahler & Strahler, 1996).

3.2.2.3. Nitrate

The only water use for which TWQGR for nitrate concentrations are specified is domestic use (Table 2, p. 17). Nitrate is the end product of the oxidation of ammonia or nitrite. Nitrate in drinking water is primarily a health concern in that it can be readily converted in the gastrointestinal tract to nitrite as a result of bacterial reduction. A significant source of nitrates in natural water results from the oxidation of vegetable and animal debris and of animal and human excrement. Treated sewage wastes also contain elevated concentrations of nitrate (DWAF, 1996a). According to Strahler and Strahler (1996) important sources of nitrate ions are fertilizers and sewage effluent. Excessive concentration of nitrate in freshwater supplies is highly toxic and their removal is difficult and expensive.

3.2.2.4. Ammonia

Ammonia may be present in the free, un-ionized form (NH_3) or in the ionized form as the ammonium ion (NH_{4+}). Ammonia is a common pollutant and is one of the nutrients contributing to eutrophication (DWAF, 1996b). Ammonia id the initial product of the decay of the nitrogenous organic wastes, and its presence frequently indicates the presence of such wastes (Manahan, 2000). Surface waters which are not contaminated with organic wastes, generally have a low ammonia nitrogen concentration, typically less than 0.2 mg/l. Concentrations exceeding 10 mg/l are found in raw untreated sewage; ammonia concentrations tend to be elevated in waters where organic decomposition under anaerobic conditions takes place. Ammonia is found in runoff from agricultural lands, where ammonium salts have been used for fertilizers. The TWQGR for ammonia are based on the free ammonia nitrogen concentration. This is the sum of the NH_3 and NH_4 nitrogen concentrations, and is given in units of mg/l (DWAF, 1996b). The TWQGR for free ammonium for aquatic ecosystem is less than 0.007 mg/l and for domestic use less than 1 mg/l.

3.2.2.5. Ortho-phosphate

Phosphorus, according to DWAF (1996b), occurs in numerous organic and inorganic forms and may be present in waters as dissolved and particulate species. Orthophosphates, polyphosphates, metaphosphates, pyrophosphates and organically phosphates are found in natural waters. Of these orthophosphate species H_2PO_4 and HPO_4^{-2} are the only forms of soluble inorganic phosphorus directly utilizable by aquatic biota (DWAF, 1996b). Phosphate ions are contributed in part by fertilizers and by detergents in sewage effluent (Strahler and Strahler, 1996). The TWQGR for orthophosphate for aquatic ecosystems are less than 0.005 mg/l and for domestic use less than 2 mg/l (Table 2). Occasional increases in inorganic phosphorus concentrations above the TWQGR are less important than continuously high concentrations (Nawn, 2004).

3.2.2.6. Manganese

Manganese is the eighth most abundant metal in nature (Stednick, 1991 as cited in Bridgett, 2003). Manganese is a grey-white brittle metal and is found in water in several oxidation states (DWAF, 1996d). In aquatic ecosystems, manganese does not occur naturally as a metal but is found in various salts and minerals, frequently in association with iron compounds. Various industries use manganese, its alloys and manganese compounds in their processes, or in their products. Acid mine drainage also releases a large amount of the manganese. Iron and steel foundries release manganese into the atmosphere, where it is then redistributed through atmospheric deposition (DWAF, 1996b). The TWQGR for manganese as applicable to domestic use, irrigation, livestock watering as well as the well being of the aquatic environment are indicated in Table 2, p. 17.

3.2.2.7. Aluminium

Although aluminium is the third most abundant element in the Earth's crust, it rarely occurs in solution in natural water in concentrations greater than a few tenths or hundredths of a milligram per litre (Hem, 1989 as cited in Bridgett, 2003). The exception is water with low pH values. Under acidic ($pH < 6.0$) or alkaline ($pH > 8.0$) conditions, or in the presence of complexing ligands, elevated concentrations may be mobilised to the aquatic environment (DWAF, 1996b). Aluminium occurs in water in two main phases, either as suspended aluminium minerals or as dissolved aluminium species (DWAF, 1996a).

3.2.2.8. Iron

Iron is the fourth most abundant element and constitutes five percent of the earth's crust (DWAF, 1996a). According to Tolgyessy (1993) as cited in Bridgett (2003), the forms of occurrence of dissolved and non-dissolved iron depend on pH and the presence of complex-forming inorganic and organic substances. Iron is naturally released into the environment from weathering of sulphide ores and igneous, sedimentary and metamorphic rock (Hem, 1989 in Bridgett, 2003). In water, iron can be present as dissolved ferric iron, Fe(III), as ferrous iron, Fe(II) or as suspended iron hydroxides (DWAF, 1996a). The TWQGR for iron concentrations regarding irrigation, livestock watering as well as domestic use are stipulated in Table 2, p. 17.

3.2.2.9. Fluoride

Fluoride is a halogen gas which is highly reactive with a variety of substances. Fluoride reacts rapidly with calcium and phosphate ions to form insoluble complexes, which tends to settle out of the water column. Fluoride is a relatively stable anion which is difficult to remove from water to the required concentration range (DWAF, 1996a). Table 2 indicates the specified TWQGR for fluoride for the aquatic ecosystem, irrigation, livestock watering and domestic use.

3.2.2.10. Hardness

Calcium ions, along with magenesium and sometimes iron ions, accounts for water hardness (Manahan, 2000). Temporary hardness is due to the presence of bicarbonates of calcium and magnesium and can be removed by boiling, whereas permanent hardness is attributed to other salts such as sulphate and chloride salts, which cannot be removed by boiling (DWAF, 1996a). No TWQGR for hardness concentrations exists for aquatic ecosystems, irrigation and livestock watering. The TWQGR of hardness concentrations for domestic use is 0 mg/l to 200 mg/l.

3.2.2. Microbiological Quality:

The microbiological quality of the water refers to the presence of organisms that cannot be individually seen by the naked eye, such as protozoa, bacteria and viruses. Many of these microbes are associated with the transmission of infectious water-borne diseases such as gastro-enteritis and cholera. It is difficult to detect some of these organisms and it is therefore common practice to use microbial indicators as an indicator of recent faecal pollution and the potential risk of infectious diseases from the water. Faecal and total coliform bacteria as indicated in Table 5, p. 25 are commonly used as indicator organisms to determine the microbiological status and safety of water. Total coliforms, faecal coliform as well as E.coli counts will be discussed briefly for the Hex River as contamination poses a risk to human health.

Table 5: Microbiological water quality attributes

Microbiological quality	
Parameter	**Relevance**
Faecal Coliforms	Indicates recent faecal pollution and the potential risk of contracting infectious disease
Total Coliforms	Indicates the general hygienic quality of the water

3.2.3.1. Total Coliforms

Total coliform bacteria are frequently used to assess the general hygienic quality of water and to evaluate the efficiency of drinking water treatment and the integrity of the distribution system. They should not be detectable in treated water supplies. If found, they suggest inadequate treatment, post-treatment contamination and/or aftergrowth or an excessive concentration of nutrients. In some instances they may indicate the presence of pathogens responsible for the transmission of infectious diseases (DWAF, 1996a). The TWQGR for Total Coliforms for domestic use are stipulated in Table 2, p17.

3.2.3.2. Faecal Coliforms and *Escherichia coli* (E. Coli)

Faecal coliforms, and more specifically *Escherichia coli (E.coli)*, are the most commonly used bacterial indicators of faecal pollution. Faecal coliforms and E.coli are used to evaluate the quality of wastewater effluents, river water, sea water at bathing beaches, raw water for drinking water supply, treated drinking water, water used for irrigation and aquaculture and recreational waters. The presence of *Escherichia coli* is used to confirm the presence of faecal pollution by warm-blooded animals (often interpreted as human faecal pollution). Some organisms detected as faecal coliforms may not be of human faecal origin but are almost definitely from warm-blooded animals (DWAF, 1996a). It is pointed out that no counts of faecal coliforms and E. Coli should be present in drinking water. The TWQGR for Faecal Coliforms as well as E. Coli is stipulated in Table 2, p 17.

It is essential to assess the microbial water quality of the Hex River as informal settlements in the area may utilize the water resource for domestic use. Sources of microbial contaminants include sewage related impacts from the informal settlement as well as the subsistence farming in the vicinity of the Hex River as well as effluent from the Rustenburg Waste Water Treatment Works.

3.2.4. Factors influencing Water Quality:

Pollution of surface water occurs when too much of an undesirable or harmful substance is discharged into the water, so that the natural assimilative capacity of the resource is exceeded and the water is rendered unfit for subsequent uses. Pollution of groundwater occurs when harmful substances in excess of the natural assimilative capacity of the soil overlying the aquifer system, infiltrates into the ground and comes into direct contact with the underground water. Water quality management is thus essential to a strategy for water resource management (DWAF, 2004).

The factors influencing water quality can either be natural or as a result of human activity. The main natural influence on water quality is the geology of the formations over which water flows or through which it percolates. Water quality is further influenced by vegetation, the slope of the land as well as the flow rate. Impacts from human activity on water quality are more complex. Diffuse pollution results from various land use activities; most significantly agricultural practices and human settlements as well as the precipitation of pollutants from the air. Point sources of pollution typically are where urban, industrial and mining effluent is discharged to streams other and receiving waters (DWAF, 2004). The main activities according to the National Water Resource Strategy (DWAF, 2004) impacting on water quality are mining (acidity and increased metals content); urban development (salinity, nutrients, microbiological); industries (chemical, toxins), and agriculture (sediment, nutrients agro-chemicals, salinity through irrigation return flows). Mermut & Eswaran (2001) states that the agricultural application of sewage sludge is a common practice for both practical and economic reasons. The presence of metals in these residues can affect plants, ground and surface waters and human health through the food chain.

Strahler & Strahler, (1996) states that a variety of water pollutants exist. Some industrial plants dispose of toxic metals and organic compounds by discharging them directly into streams and lakes. Many communities still discharge untreated or partly treated sewage wastes into surface waters. In urban and suburban areas, pollutant matter entering streams and lakes include deicing salt and lawn conditioners (lime and fertilizers), which can also contaminate groundwater. While in agricultural regions sources of pollutants include fertilizers and the body waste of livestock. Mining and the processing of mineral deposits are major sources of water pollution. In addition the chemical pollution there is thermal pollution from discharge of heated water from electric power-generating plants. Further a contamination with radioactive substances from nuclear power and processing plants exists. Toxic metals along with pesticides and a host of other industrial chemicals are introduced into streams and lakes in quantities that are locally damaging or lethal to plant and animal life, Sewage introduces live bacteria and viruses that pose a threat to human life (Strahler & Strahler, 1996). Urbanization, according to Goudie (2000) affects flood runoff as it produces impermeable surfaces and the construction of sewage and storm drains accelerate runoff. Human activities further impact on the quantity and quality of materials carried in rivers. Inputs of dissolved salts (sodium, chloride and sulphate) by human activities created the overall global augmentation of river solute loads of about 12 percent.

In order to ascertain the water quality of the Hex River and its primary tributaries, it is necessary to describe the actual study area. The following section, Part 4 of this minor-dissertation focus on the location of the Hex River and its tributaries as well as the physical and anthropogenic factors influencing the water quality of the study area. A discussion on the various land and water users is also included.