

**Development of a generic monitoring protocol for management of
Cryptosporidium and *Giardia* in drinking water**

OMBO 873

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This Dissertation is dedicated to my daughters, Njabulo and Lungelo Sigudu and my son Siphesihle Sigudu

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Abstract

In South Africa, the assessment of the suitability and acceptability of water for drinking purposes is done according to the South African National Standards (SANS) 241 (2006) which requires that *Cryptosporidium* and *Giardia* in drinking water should be less than 1 oocyst/10ℓ and 1 cyst/10ℓ respectively. Although there is a requirement to monitor for these parasitic protozoans, there is lack of uniformity in the monitoring approach. Therefore, the objective of the study was to develop a protocol / methodology that can be applied by drinking water producers to monitor *Cryptosporidium* and *Giardia* to ensure that the risk of exposure to these organisms and the risks of non-compliance to guidelines are reduced. Also, to test the feasibility of the protocol on a small system, the drinking water purification plant at the Vaal River Barrage Reservoir that supplies approximately 350 people with drinking water.

The protocol for monitoring of *Cryptosporidium* and *Giardia* was developed based on monitoring procedures proposed by the US Environmental Protection Agency, the Drinking Water Inspectorate, Australia, New Zealand, and especially on the risk based procedure followed by Northern Ireland with the intention that it will be applicable to all water supply systems irrespective of size and system complexity of the purification works. It is focused on a preventative approach of monitoring *Cryptosporidium* and *Giardia* and it consists of ten steps which are: (i) Assessment of the monitoring requirements, (ii) Description and characterization of the source water types (iii) Abstraction of source water (iv) Assessment of the water purification plant (v) Water quality monitoring (vi) Cryptosporidiosis and Giardiasis outbreak (vii) Risk assessment (viii) Sample collection and Laboratory processing (ix) Data evaluation, interpretation and storage (x) Process evaluation and review.

As stated, the developed protocol was tested at a small purification plants situated at the dam wall of the Vaal River Barrage catchment, Gauteng Province. From this assessment it was evident that steps of the protocol were easy to follow and the possible risks in the water value chain i.e. from source water to the supply of purified drinking water could be identified. Some of the challenges encountered during the application of the protocol include difficulty in obtaining detailed information regarding the activities around the catchment and information on the prevalence of cryptosporidiosis and giardiasis in the local community or in South Africa in general.

From this study, it could be concluded that the source water from the Vaal River Barrage Reservoir was high risk. However, the use of the multi-barrier approach coupled with advanced treatment of UV rendered the water drinking supplied to the local community within the South African Drinking Water Standards for from *Cryptosporidium* and *Giardia* of less than 1 oocyst/10ℓ and 1 cyst/10ℓ. The protocol for the monitoring of *Cryptosporidium* and *Giardia* could contribute to the protection of drinking water consumers by identifying high risk source waters, identifying areas that can be improved in the water treatment system and also protecting the catchment areas from further faecal pollution. With respect to this outcome, the developed protocol could be used by water utilities as part of their Water Safety Plans to optimize monitoring. Furthermore, this methodology has a potential to contribute to the blue drop certification as it should for part of the Water Safety Plans.

Keywords: *Cryptosporidium*, *Giardia*, monitoring, risk score, drinking water

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SYMBOLS AND ABBREVIATIONS

ADWG	Australian Drinking Water Guidelines
AIDS	Acquired Immunodeficiency Syndrome
B-DOM	Barrage Treated Water
B-RAW	Barrage Source Water
CDC	Center for Disease Control
CFU	Colony Forming Units
CRV2	Rietspruit Weir at Loch Vaal
CV17	Vaal River at Vaal River Barrage Outlet
DAPI	4', 6-Diamidino-2-Phenylindole
DIC	Differential Interference Contrast
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
DWI	Drinking Water Inspectorate
DWSNZ	Drinking Water Standards for New Zealand
E. coli	<i>Escherichia coli</i>
EHS	Environment and Health Service
EHU	Environmental Health Unit
ESSF	Earth Sciences for Society Foundation
FSE	Federation for Sustainable Environment
FWR	Foundation for Water Research
GCDWQ	Guidelines for Canadian Drinking Water Quality
HACCP	Hazard Analysis and Critical Control Point
HC	Health Canada
HIV/AIDS	Human Immunodeficiency Virus / Acquired Immunodeficiency Syndrome
IMS	Immuno-Magnetic Separation
ISO 9000	International Organization for Standardization - Quality Management Principles
ISO 14001	International Organization for Standardization -Environmental Management Systems
LIMS	Laboratory Information Management System
LT2 RULE	Long Term 2 Surface Water Treatment Rule
MG	Mail and Guardian
MH	Ministry of Health
NHMRC	National Health and Medical Research Council
NGWS	National Ground Water Strategy
NTU	Nephelometric Turbidity Unit

OHAS 18000	International Organization for Standardization - International Occupational Health and Safety Management System Specification
RW	Rand Water
SANS	South African National Standards
UK	United Kingdom
U.S.A	United States of America
US EPA	United States Environmental Protection Agency
WHO	World Health Organization
WSP	Water Safety Plans
WSR	Water Supply Regulations
µm	Micro metres
<i>C.</i>	<i>Cryptosporidium</i>
<i>G.</i>	<i>Giardia</i>
pH	Potential of hydrogen
min	Minutes
ml	Millilitres
Ct	Contact time
mg	Milligram
%	percentage
°C	Degree Celsius
≥	Greater or equal to
>	Greater than
log	Logarithm
≤	Less or equal to
m	Metre
mj/cm	Millijoules per centimeter

CHAPTER 1: GENERAL INTRODUCTION

1.1 Introduction

Consumption of contaminated drinking water plays a major role in the transmission of pathogens that may lead to gastrointestinal diseases (WHO, 2004). The greatest microbial risks associated with drinking water are linked with ingestion of water that is contaminated with human, animal or bird faeces since faeces, can be a source of pathogenic bacteria, viruses, protozoa and helminthes (WHO, 2004). Although concentrations of pathogenic micro-organisms may be relatively low in drinking water, drinking water reaches almost every member of a population, resulting in the possibility that low concentrations of pathogenic micro-organisms may affect a significant number of consumers (Tenuis, *et al.*, 1997). As a result, control of waterborne diseases such as, cholera, cryptosporidiosis and giardiasis have become an important element of public health policy and an objective of major water utilities (WHO, 2004). Currently, protozoan parasites *Cryptosporidium* and *Giardia* are a major concern for water utilities worldwide, due to their high infectivity and their resistance to chemical disinfection (Angles *et al.*, 2007). These characteristics have led to their present status as critical organisms for the safety of drinking water production process (Tenuis & Havelaar, 2002).

Cryptosporidium and *Giardia* are intracellular protozoan parasites of man, other mammals, birds, reptiles, and fish (WHO, 2006). They enter surface waters such as lakes, ponds and dams as environmentally resistant cysts and oocysts in the faeces of infected people or animals and could be transmitted through water to other human or animal hosts (SANS 241, 2006). The shed cysts and oocysts are immediately infectious and they remain in the environment for weeks or even months without losing their infectivity (LeChevallier & Norton, 1995).

Cryptosporidium causes a disease known as cryptosporidiosis and *Giardia* causes a disease known as giardiasis sometimes referred to as 'beaver fever'. Waterborne outbreaks of cryptosporidiosis have been reported, with the largest cryptosporidiosis outbreak being the Milwaukee (in the United States of America) cryptosporidiosis outbreak which affected an estimated 403 000 individuals (MacKenzie *et al.*, 1994). In these outbreaks the postulated reasons for oocysts and cysts leakage into drinking water systems include source water contamination, water treatment failure, and post treatment contamination (Smith & Rose 1998). Hence it is important to note that to achieve safe drinking water, a holistic approach to water treatment is required. This includes the application of the multi-barrier approach, protection of water sources, the use of appropriate treatment methods, a well maintained distribution system as well as routine monitoring of drinking water (WHO, 2004).

Monitoring of *Cryptosporidium* and *Giardia* is done throughout the world. It has been used for risk assessment purposes, for evaluation of water treatment system reliability and also to assist with waterborne outbreak investigations (Bentacourt & Rose, 2004). However, routine monitoring for *Giardia* and *Cryptosporidium* is not always practical because the available methods are time consuming and have various limitations. These tests require considerable analytical skill and they may not always detect these organisms when present, and cannot reliably identify how many organisms are alive and capable of causing disease (LeChevallier & Norton, 1995).

The monitoring data for *Cryptosporidium* and *Giardia* in drinking water are usually evaluated against drinking water guidelines such as the US Environmental Protection Agency (USEPA) (2006), the World Health Organization (WHO) (2009a), Drinking Water Inspectorate (DWI) (2008) and the Australian Drinking Water Guidelines (ADWG) (2004). In South Africa drinking water quality is evaluated against the South African National Standards (SANS) 241. According to SANS 241 (2006) the operational water quality values for *Cryptosporidium* and *Giardia* in drinking water are less than 1 oocyst/10ℓ and 1 cyst/10ℓ respectively, that is, drinking water is not supposed to have any *Cryptosporidium* and *Giardia*. However, it is important to note that meeting the guidelines is not always a safeguard against transmission of illnesses through the same drinking water, since outbreaks through water that meets guidelines have been reported (WHO, 2006).

1.2 Problem statement

In South Africa, the assessment of the suitability and acceptability of water for drinking purposes done according to the South African National Standards (SANS) 241 (2006) is based on the consideration of its microbial content, physical, organoleptic and chemical properties. Monitoring of the above variables is well developed and the monitoring strategy depends on the variable. However, the problem in South Africa is that, there is a deficiency in the procedures for monitoring of the protozoan parasites *Cryptosporidium* and *Giardia* i.e. monitoring of these protozoan parasites is poorly developed, in most cases it is not performed, and in some instances it is performed only on drinking water. In addition, the sample volumes vary and the frequency of monitoring is not consistent. There is primarily, no uniformly adapted approach for monitoring of *Cryptosporidium* and *Giardia* 'i.e. there is no description of what, where and when to monitor'. Therefore, there is a need for development of a generic protocol that can be applied for the monitoring of *Cryptosporidium* and *Giardia*.

1.3 Objectives of the study

The overall objective of the study is to develop a protocol / methodology that can be applied by drinking water producers to monitor *Cryptosporidium* and *Giardia*. This will ensure that the risk of exposure to these organisms and the risks of non-compliance to guidelines are reduced. The specific research objectives are to:

- To undertake a literature search to establish current approaches to monitoring of *Cryptosporidium* and *Giardia*.
- To use this information to develop a generic protocol for *Cryptosporidium* and *Giardia*.
- To test the feasibility of applying the protocol on a small system, the drinking water purification plant at the Vaal River Barrage wall that supply approximately 350 people with drinking water.

CHAPTER 2:

LITERATURE REVIEW

2.1 Overview of *Cryptosporidium* and *Giardia*

Cryptosporidium and *Giardia* are an important cause of enteric diseases in humans and in many other vertebrates (WHO, 2004). Species within these genera cause human cryptosporidiosis and giardiasis which probably constitute the most common causes of protozoal diarrhea worldwide (Cacciò *et al.*, 2005). The transmission of *Cryptosporidium* and *Giardia* occurs mainly through the faecal-oral route by exposure to contaminated water and food (Rose *et al.*, 2002). The major risk factors for infection include swallowing water while swimming, drinking untreated water and contact with recreational fresh water. As a result, consumption of contaminated water plays a major role in the transmission of these pathogens (WHO, 2004).

The widespread occurrence of *Cryptosporidium* oocysts and *Giardia* cysts in surface water and their resistance to disinfection at the level normally used in the production of drinking water has become a major concern for the water industry (Pezzana *et al.*, 2000). Consequently, outbreaks of cryptosporidiosis have been reported even when the bacterial quality of the water complied with the set of coliform standards (Barrell *et al.*, 2000). As a result, this led to *Cryptosporidium* to be the great public health threat due to the likelihood of infectious oocysts being present in conventionally treated drinking water (Smith *et al.*, 2006; Pezzana *et al.*, 2000).

Cryptosporidiosis outbreaks have most commonly been associated with person to person and waterborne infections (CDC, unknown). It can be life-threatening for individuals with weakened immune systems. These include acquired immunodeficiency syndrome (AIDS) patients, individuals with congenital immunodeficiency, and also patients receiving immunosuppressive drugs e.g., organ/bone marrow transplant and cancer patients. The disease can result in diarrhea lasting days to weeks in susceptible persons (Rendell & Mc Ginty, 2006). In healthy individuals cryptosporidiosis causes watery or mucoid diarrhea with abdominal pains and it is usually self-limiting, with duration of several days and occasionally several weeks (Hunter & Nichols, 2002). Unlike many other protozoans, *Cryptosporidium* is resistant to antimicrobial drugs, i.e. there is no curative therapy for cryptosporidiosis (Clark, 1999). Hence the association of cryptosporidiosis with human immunodeficiency virus / acquired immunodeficiency syndrome (HIV/AIDS) and malnutrition in children means that cryptosporidiosis remains a serious, life-threatening condition that leads to an often fatal, secretory diarrhea largely because of the lack of effective therapy and methods for control (Tzipori & Widmer, 2008).

Giardiasis on the other hand is characterized by abdominal cramps, watery diarrhea and bloating. The symptoms usually appear one to two weeks after ingestion of the cysts. Symptoms may hide for months, they may not appear at all, or they can vanish suddenly and then reappear if symptomatic. These symptoms could disappear in a week without any treatment. Even so, the infected host could still be harboring the cysts, and can unknowingly spreading the disease. In some rare occasions, individuals develop serious symptoms of malabsorption, weight loss, ulcer-like stomach pain (Rockwell, 2002). Giardiasis is not regarded as fatal since there are drugs such as trinitazole and furazolidone available for its treatment (Arnone & Walling, 2006). However, immunodeficient persons, young children, elderly persons, those receiving immunosuppressive treatment, and AIDS patients may have difficulty in clearing the parasites, leading to prolonged diarrhea, which may be life threatening (Tenuis *et al.*, 1997).

2. 2 Taxonomy and Transmission dynamics of *Cryptosporidium* and *Giardia*

The taxonomic and phylogenic relationships of *Cryptosporidium* and *Giardia* remain poorly defined, thus, the understanding of transmission dynamics of these protozoans has been very limited (Applebee *et al.*, 2005). The occurrence surveys of these parasitic protozoans based on oocyst morphology fail to link the contribution of various oocysts to human disease since oocysts of species infectious to humans have similar morphology to oocysts that are not infectious to humans and therefore, cannot be differentiated using standardized microscopy methods. Furthermore, many species that are not infectious to humans are often present in water. As a result, morphology based techniques lead to assumptions that each intact oocyst that is detected is potentially infectious to humans (Smith *et al.*, 2006).

Recent developments on genetic tools as part of taxonomic characterization lead to the ability to observe extensive genetic variation within *Cryptosporidium* and *Giardia* species resulting in a better understanding of the taxonomy and zoonotic potential of these protozoa (Applebee *et al.*, 2005). With the use of these techniques it has been uncovered that not all *Cryptosporidium* and *Giardia* species are infectious to humans and that there are various species of *Cryptosporidium* and *Giardia* in the environment that can infect different hosts (Table 2.1) (Cacciò *et al.*, 2005).

TABLE 2.1: Various species of *Cryptosporidium* and *Giardia* (Cacciò *et al.*, 2005)

<i>Cryptosporidium</i>		<i>Giardia</i>	
Species	Major host	Species	Major host
<i>C. hominis</i>	Humans, monkeys	<i>G. duodenalis</i>	Humans, livestock
<i>C. parvum</i>	Cattle, other ruminants, humans	<i>G. duodenalis (G. enterica)</i>	Humans
<i>C. andersoni</i>	Cattle	<i>G. duodenalis (G. canis)</i>	Dogs
<i>C. muris</i>	Rodents	<i>G. duodenalis (G. bovis)</i>	Cattle, other hoofed livestock
<i>C. suis</i>	Pigs	<i>G. duodenalis (G. cati)</i>	Cats
<i>C. felis</i>	Cats	<i>G. duodenalis (G. simondi)</i>	Rats
<i>C. canis</i>	Dogs	<i>G. agilis</i>	Amphibians
<i>C. wrairi</i>	Guinea pigs	<i>G. muris</i>	Rodents
<i>C. bailey</i>	Poultry	<i>G. microti</i>	Muskrats, voles
<i>C. meleagridis</i>	Turkeys, humans	<i>G. psittaci</i>	Birds
<i>C. galli</i>	Finches, chicken	<i>G. ardeae</i>	Birds
<i>C. serpentis</i>	Reptiles		
<i>C. saurophilum</i>	Lizard		
<i>C. molnari</i>	Fish		

*C. - *Cryptosporidium*; G. – *Giardia*

As a result, currently, it has been accepted that there are fourteen species of *Cryptosporidium* and five species of *Giardia* (Cacciò *et al.*, 2005). Within the fourteen accepted *Cryptosporidium* species, *Cryptosporidium parvum* seems to be the most widely distributed, since it has the broadest host range and it has been found to be most commonly associated with human and livestock infections. Previously similar-sized oocysts recovered from water supplies were also assumed to be infectious to humans. However, recent studies using species-typing tools, differences in geographical and temporal distribution, *Cryptosporidium parvum* and *Cryptosporidium hominis* and *Giardia duodenalis* have been identified to be the parasites infecting humans (Cacciò *et al.*, 2005). Molecular techniques have also revealed that most species of *Giardia* are host adapted, with the exception of *G. duodenalis*, which seems to have a much broader host range and infects many mammalian species. These techniques have, however, revealed that wild mammals harbor host-adapted genotypes that are not considered to be a major public health risk because they have not yet been identified in human infections (Applebee *et al.*, 2005).

2.2.1 Life cycle of *Cryptosporidium* sp.

The protozoan parasite, *Cryptosporidium*, begins its life cycle as sporulated oocysts, which enter the environment through the faeces of the infected host. *Cryptosporidium parvum* oocysts are spherical with a diameter of 4-6 μm . Infection with *Cryptosporidium* oocysts occurs when the oocysts are ingested by a suitable host (Figure 2.1) (CDC, unknown).

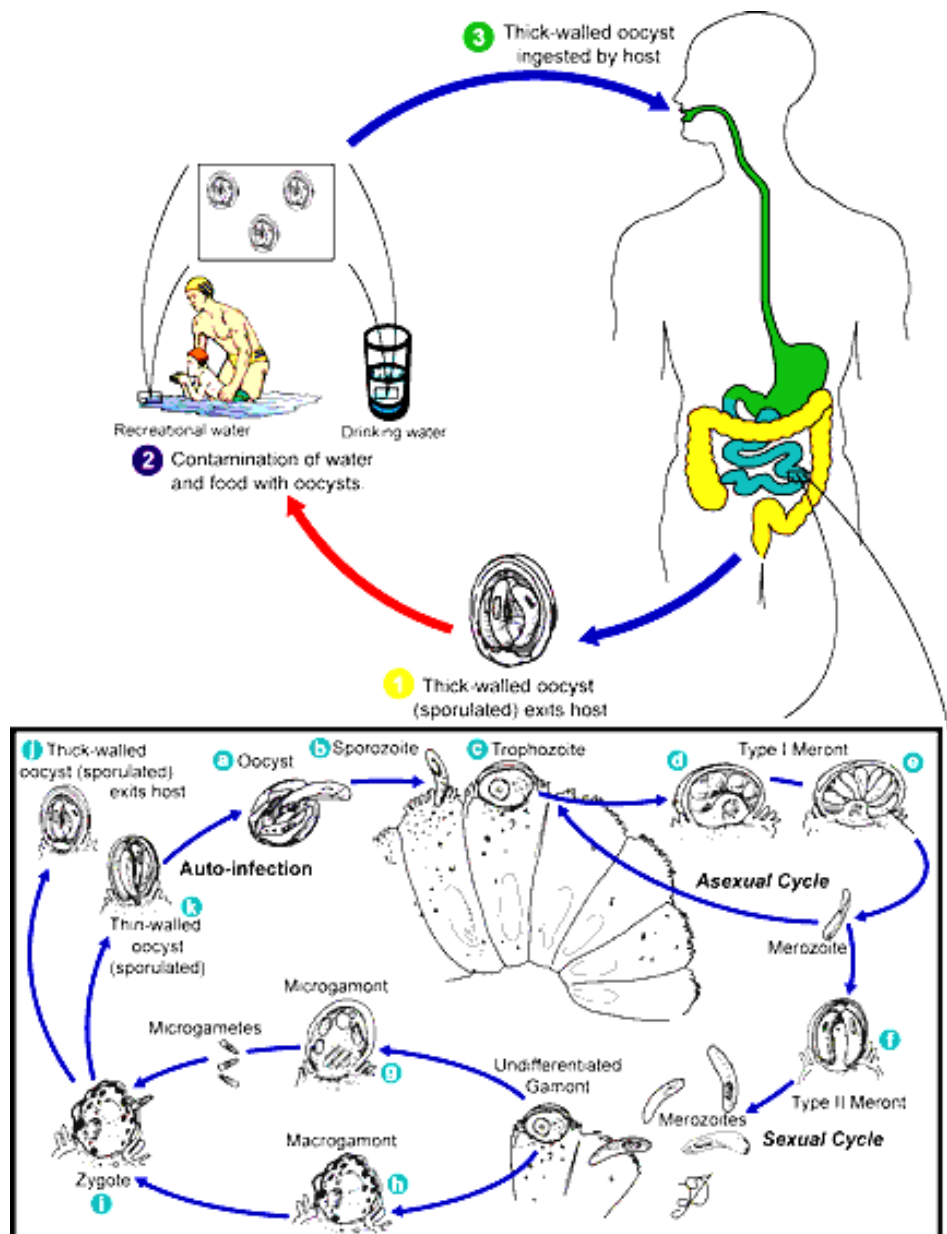


FIGURE 2.1: Life Cycle of *Cryptosporidium parvum* and *Cryptosporidium hominis* (adapted from CDC, unknown)

In the intestines, the oocyst releases sporozoites which invade the epithelial linings of the intestines mainly in the jejunum and ileum (WHO, 2006). The sporozoites transform into several life stages in an asexual (merogony) and a sexual reproduction cycle (gametogony). The oocysts are the result of the sexual reproduction cycle. Thick- and thin-walled oocysts are formed. The thin-walled oocysts may excyst within the same host and start a new life cycle (autoinfection). This may lead to a heavily infected epithelium of the small intestine, resulting in malabsorptive or secretory diarrhoea. The thick-walled oocysts are excreted with the faeces and are environmentally robust (Figure 2.1) (CDC, unknown).

2.2.2 Life cycle of *Giardia*.

As with *Cryptosporidium*, the life cycle of *Giardia* starts as soon as the cyst is accidentally ingested (Figure 2.2) (CDC, unknown)

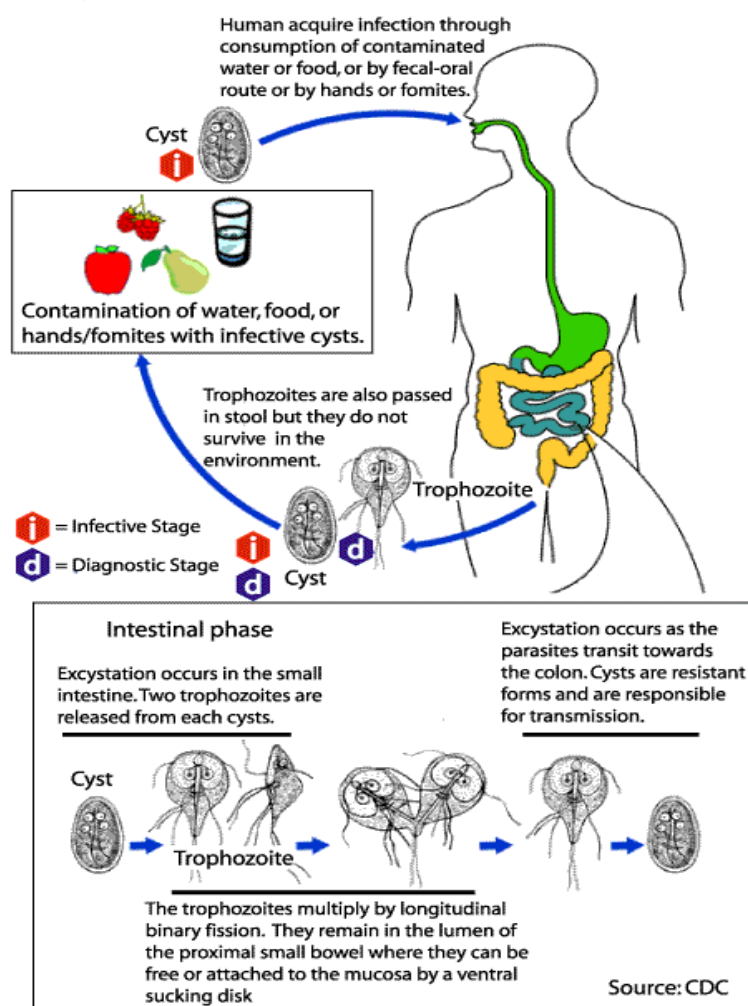


FIGURE 2.2: Lifecycle of *Giardia* (adopted from CDC, unknown)

Once in the stomach, the cyst releases two trophozoites due to stomach acid action and digestive enzymes. The trophozoite is 9 - 15µm long, 5 - 15µm wide, and 2 - 4µm thick. Then the trophozoites multiply by longitudinal binary fusion in the lumen of the small intestine transforming into an egg like structure called a

cyst, which is ultimately passed in the stool. The cysts are 8 - 12µm long by 6 - 9µm in diameter and they can survive for as long as 2 to 3 months in cold water, but they cannot tolerate drying or freezing. Duration of cyst excretion, called shedding, may persist for months. Once outside the body, the cysts can be ingested by another animal and the infection cycle continues (Figure 2.2) (Rockwell, 2002).

2.2.3 Disease outbreak

To date the largest cryptosporidiosis outbreak is the Milwaukee (USA) waterborne cryptosporidiosis outbreak which affected an estimated 403 000 individuals caused by *Cryptosporidium* oocysts that passed through the filtration system (MacKenzie *et al.*, 1994). However, from Table 2.2 it is evident that outbreaks have been recorded throughout the world (Smith *et al.*, 2006). Investigations indicated that inadequacies in the water treatment process or failures within the water distribution system contributed to the passage of oocysts into the water supply. However, some waterborne outbreaks have occurred when no obvious deficiencies in either treatment or distribution were apparent (Butler & Mayfield, 1996).

Studies indicated that prevention of the transmission of protozoan parasites through drinking-water requires a multiple barrier approach: protection of catchments used for drinking water production against contamination with protozoa, plus adequate treatment of water. It has also been shown that varying oocyst removal can be achieved during different treatment stages of conventional treatment (Table 2.3) (WHO, 2004). As a result, these findings emphasize the requirement for a holistic approach during drinking water treatment which includes protection of water sources, application of the multiple barriers, the use of appropriate treatment, a well maintained distribution system as well as routine monitoring of drinking water (WHO, 2004).

TABLE 2.2: Recorded *Cryptosporidium* incidents, species identified and contamination sources (Smith et al., 2006)

Location and year	Contamination source	Number of cases	Species identified
Molecular detection of <i>Cryptosporidium</i> in water concentrates from an outbreak source			
France (2001)	Contamination of public water supply with human sewage	563	<i>C. hominis</i>]
Northern Ireland (2001)	Ingress of wastewater from blocked drain	230	<i>C. hominis</i> , <i>C. parvum</i>
Northern Ireland (2000)	Drinking water		<i>C. parvum</i>
Northern Ireland (2000)	Septic tank contaminated with human sewage	117	<i>C. hominis</i>
England (2000)	Tap water contaminated with animal faeces	58	<i>C. parvum</i>
Ohio, USA (2000)	Swimming pool	700	<i>C. hominis</i> , <i>C. parvum</i>
England (1999)	Surface water (Catchment)	347	<i>C. hominis</i> <i>C. parvum</i> <i>C. meleagridis</i>
England (1999)	Public swimming pool	11	<i>C. hominis</i>
England (1999)	Public swimming pool	16	<i>C. hominis</i> <i>C. parvum</i>
England (1999)	Public swimming pool	11	<i>C. parvum</i>
England (1999)	Public swimming pool	14	<i>C. hominis</i> <i>C. parvum</i> <i>C. hominis</i> <i>C. parvum</i>
Northern Ireland (2000)	Contamination of drinking water with human sewage	12	<i>C. hominis</i> , <i>C. parvum</i>
Ohio, USA (2000)	Accidental human faecal discharge into swimming pool water	102	<i>C. hominis</i> , <i>C. parvum</i>
Molecular detection of <i>Cryptosporidium</i> in water concentrates from a non outbreak source			
Wisconsin, USA (1999–2000)	Waste	12	<i>C. andersoni</i> <i>C. hominis</i> Undescribed species of cervid origin <i>C. muris</i> , <i>C. canis</i> , <i>C. felis</i>
Wisconsin, USA (2000–2001)	Waste	50	<i>C. hominis</i> , <i>C. andersoni</i> , <i>C. cervid</i> <i>C. parvum</i> , <i>muris</i>
Switzerland and Germany (year not stated)	Waste	6	<i>C. hominis</i> , <i>C. parvum</i> , <i>C. muris</i>
New York, USA (1999–2000)	Storm	18	Twelve novel genotypes
Various locations, USA (1999–2000)	Surface	25	<i>C. parvum</i> , <i>C. hominis</i> , <i>C. andersoni</i> , <i>C. baileyi</i>
Massachusetts, USA (2000–2001)	Surface	7	<i>C. parvum</i> <i>C. muris</i> <i>C. baileyi</i>
Switzerland and Germany (year not stated)	Surface	17	<i>C. muris</i> , <i>C. parvum</i> , <i>C. andersoni</i> , <i>C. hominis</i> , <i>C. baileyi</i>
Three novel genotypes Japan (year not stated)	River	2	<i>C. meleagridis</i>) <i>C. parvum</i>
UK (2000–2001)	Mineral	12	<i>C. hominis</i> <i>C. Parvum</i>
Finland (2000)		3	<i>C. parvum</i>
Australia (1999–2000)	Watershed	Not	<i>C. suis</i> Pig genotype II

**C. Cryptosporidium*

TABLE 2.3: Effect of water treatment processes on reductions of bacteria, viruses and protozoa (WHO, 2004)

Treatment process	Pathogen group	Baseline removal	Maximum possible removal
Coagulation/Flocculation/Sedimentation (Conventional clarification)	Bacteria	30%	90% (depending on the coagulant, pH, temperature, Alkalinity, turbidity)
	Viruses	30%	70% same as above
	Protozoa	30%	90% same as above
Filtration (Rapid sand Filtration)	Bacteria	50%	99.5% under optimum ripening, cleaning and refilling in the absence of short circuiting
	Viruses	20%	99.5% same as above
	Protozoa	50%	99.5% same as above
Chlorine disinfection	Bacteria	Ct ₉₉ : 0.088mg min/ℓ at 1-2°C, pH 7; 3.3 mg min/ℓ at 1-2°C, pH 8.5	
	Viruses	Ct ₉₉ : 12mg min/ℓ at 0-5°C, 8 mg min/ℓ at 10°C, both at pH 7-7.5.	
	Protozoa	<i>Giardia</i> Ct ₉₉ : 230mg min/ℓ at 0.5°C, 100mg min/ℓ at 10°C, 41mg min/ℓ at 25°C, All at pH 7-7.5.	
Ozone	Bacteria	Ct ₉₉ : 0.02mg min/ℓ at 5°C, pH 6 - 7;	
	Viruses	Ct ₉₉ : 0.9mg min/ℓ at 1°C, 0.3 mg min/ℓ at 15°C	
	Protozoa	<i>Giardia</i> Ct ₉₉ : 1.9mg min/ℓ at 1°C, 0.63mg min/ℓ at 15°C, pH 6-9	
		<i>Cryptosporidium</i> Ct ₉₉ : 40mg. min/ℓ at 1°C; 44mg min/ℓ at 22°C	
UV. irradiation	Bacteria	99% inactivation: 7mJ/cm	
	Viruses	99% inactivation: 59mJ/cm	
	Protozoa	<i>Giardia</i> 99% inactivation: 5mJ/cm	
		<i>Cryptosporidium</i> 99% inactivation: 10mJ/cm	

2.3. Monitoring of drinking water supply system

Monitoring can be defined as a process of conducting a planned series of observations or measurements of operational and/or the critical limits to assess whether the components of the water supply are operating properly (WHO, 2005). The objective of monitoring is to observe the control measures in a timely manner to prevent the supply of any potentially unsafe water. The process relies on establishing the ‘what’, ‘how’, ‘when’ and ‘who’ principles (WHO, 2005).

One of the benefits of monitoring is that, it allows the surveillance of water quality and the detection of biological and chemical threats in order to provide early warning in case of unexpected contaminations (Mons *et al.*, 2007). However, drinking water monitoring is frequently carried for compliance purposes, despite the fact that, testing water immediately prior to or within the distribution end point can only highlight potential health problems after the water has been consumed (NHMRC, 2003). As a result, monitoring of both the source water and drinking water quality could be one of the proactive measures that the producers of drinking water can implement to reduce the risk of exposure and infection to drinking water consumers (WHO, 2004).

During monitoring, most drinking water quality guidelines use the presence or absence of the key indicators for assessment of potential public health risk of drinking water, which includes the use of microbial indicators. For more than a hundred years, *Escherichia coli*, thermotolerant faecal coliforms, and total coliforms have been used as bacterial indicators of faecal pollution (NHMRC, 2003). However, reliance on total coliforms for measurement of the microbial safety of a drinking water can result in a false sense of assurance from negative results since some enteric pathogens such as *Cryptosporidium* and *Giardia*, which are resistant to chemical disinfection can occur in the absence of bacterial indicators (ADWG, 2004). As a result monitoring of *Cryptosporidium* and *Giardia* is essential for ensuring the safety of drinking water to the consumers.

2.3.1 *Cryptosporidium* and *Giardia* monitoring

Methods for enumerating *Cryptosporidium* and *Giardia* are becoming more reliable, but they are not yet suitable for routine monitoring of treated water. Furthermore, new methods of assessing the infectiousness of protozoa by using human cell cultures have been developed. However, these new methods are not yet suitable for routine monitoring of *Cryptosporidium* contamination of drinking-water since they cannot identify the species of *Giardia* or *Cryptosporidium*, nor can they determine the viability or infectivity of detected cysts or oocysts (DWSNZ, 2008). Hence the detection and enumeration methods for *Cryptosporidium* in environmental samples still need considerable improvement (Bentacourt & Rose, 2004). As a result of these methodological limitations, monitoring of *Cryptosporidium* and *Giardia* is mainly carried out for risk assessment purposes, for evaluation of water treatment system reliability and also to assist with waterborne outbreak investigations (WHO, 2009a).

2.3.2. The legal framework for *Cryptosporidium* and *Giardia* monitoring in South Africa

Cryptosporidium and *Giardia* monitoring is influenced by, amongst others, by the following acts and guidelines: (i) The Constitution of South Africa (36/1996), (ii) The National Water Act (36/1998), (iii) Water Services Act (108/1997), (iv) South African National Standard 241 (2006), (v) The Drinking Water Quality Framework (DWAF, 2007) and (v) The Drinking Water Quality Guidelines (1996). Some of these pieces of

legislation affect and have had an impact towards monitoring of *Cryptosporidium* and *Giardia*, and these are discussed below

(i) The Constitution (1996): In South Africa, the environment is covered by the Section 24 of the Constitution which clearly states that “Everyone has the right to an environment that is not harmful to their health or well-being, have the environment protected for present and future generations”. Hence in South Africa, access to safe drinking water is essential to health and is a basic human right. In this case safe drinking water is to be defined as water which does not pose a significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages (babies and infants, the immuno-compromised and the elderly) (Hodgson & Manus, 2006). Hence, the presence of *Cryptosporidium* and *Giardia* in drinking water violates the right of an ordinary South African to safe drinking water.

(ii) The National Water Act (36/ 1998): This act provides the policy framework for water resources assessment Chapter 14 of the act places a duty on the Minister, as soon as it is practicable to establish national monitoring systems. The purpose of the systems will be to facilitate the continued and coordinated monitoring of various aspects of water resources by collecting relevant information and data, through established procedures and mechanisms, from a variety of sources including organs of state, water management institutions and water users. Given the serious human health risks associated with surface waters exposed to faecal pollution, there is a need for a national monitoring programme that is focused on microbial water quality (Murray *et al.*, 2004).

(iii) The Water Services Act (108/1997): One of the major goals of the Water Services Authorities and Providers is to ensure access to safe and reliable water services to all the communities. However, notwithstanding the best possible water sources, adequate treatment infrastructure, optimal treatment processes and unexpected incidents can disrupt water supplies. Natural disasters such as floods, and man-made incidents, for example catchment chemical spills and bacteriological contamination can significantly disrupt and impact on the quality of water services thus posing a significant health risk to consumers.

Proper sanitation should thus be supplied, which is not always the case in South Africa since most waste water treatment works in small municipalities in South Africa are not functioning properly (Polasek, 2010). Therefore, if the waste water treatment works are not functioning properly the risk of faecal contamination through discharge of partially treated water increases thereby increasing the risk of exposure to *Cryptosporidium* and *Giardia* through discharge of oocysts into water resources (Murray *et al.*, 2004). This is also substantiated in studies by Dungeni & Momba (2010) where *Cryptosporidium* and *Giardia* were detected in effluents from wastewater treatment works.

Also in the Water Services Act (108/1997), section 5 of Regulation 509 states:

“Should the comparison of the result indicate that the water poses a health risk, the water services institution must inform the Director General of the Department of Water Affairs and Forestry and the Head of the Provincial Department of Health, and it must take steps to inform its customers –

- a) that the quality of the water supplied poses health risk
- b) of the reasons of the health risk
- c) any precautions to be taken by the consumers; and
- d) of the time frame, if any, within which it may be expected that the water of safe quality will be provided.

This regulation emphasizes the requirement for implementation of emergency protocols to minimize the health risks linked to drinking water failures.

(iv) South African National Standards 241 (2006): The Water Services Act (108/1997) requires that water services institution should compare drinking water quality results with prescribed National Drinking Water Standards (SANS) 241 (2006) Drinking Water Specifications, or the South African Water Quality Guidelines published by the Department of Water Affairs (former Department of Water Affairs and Forestry). However SANS 241 does not meet the requirements of the socio-economically developed country like South Africa (Polasek, 2010). The guideline however only protects a certain percentage of people in a country like South Africa where a large population is not receiving treated drinking water or lack sanitation services, thus increasing the risk of infection by protozoan parasites like *Cryptosporidium* and *Giardia*.

According to the South African National Standards (SANS) 241 (2006) the operational water quality values for *Cryptosporidium* and *Giardia* in drinking water are less than 10ocyst/10L and 1cyst/10L respectively. The ideal situation is where drinking water quality satisfies the SANS 241 Class I limits, suitable for lifetime consumptions. When water fails Class I limits, but is within the Class II limits, efforts are required to ensure that water quality is improved to within Class I limits. Importantly, when a health-related water quality constituent does not comply with SANS 241 Class II limits, this is be regarded as a failure and would pose a threat to consumers.

(v) South African Water Quality Guidelines 1996: These guidelines are used by the Department of Water Affairs (DWA) and Forestry as its primary source of information and decision-support to judge the fitness for use of receiving water and for other water quality management purposes. In these guidelines it is required that protozoan parasites in water be less than one oocyst. However, the guidelines are regarded as tentative due to insufficient data to develop comprehensive water quality criteria for protozoan

parasites in water intended for domestic use. The criteria are intended as an indication of safety levels only. The guidelines applicable to *Cryptosporidium* and *Giardia* include the South African Water Quality Guidelines for Domestic Water Use (DWAF, 1996a), the South African Water Quality Guidelines for Recreational Water Use (DWAF, 1996b), and the South African Water Quality Guidelines Agricultural Water Use: Irrigation (DWAF, 1996c).

From the legal perspective it can be concluded that the water utilities in South Africa have a directive to continuously supply consumers with water which meets the SANS requirements, which includes the supply of water containing <1 oocyst /10 l for *Cryptosporidium* and *Giardia* respectively. As a result, monitoring of *Cryptosporidium* and *Giardia* in drinking water is essential, for the fulfillment of the minimum legislated requirements set by the water services authority in order to provide South Africans with safe drinking water. However, waste water treatment works contribute greatly to the presence of *Cryptosporidium* and *Giardia* oocysts in the water resources due to the waste water treatment plants that are not functional, they are however, not involved in the monitoring of the catchments in South Africa.

2.3.3 Overview of *Cryptosporidium* and *Giardia* monitoring in South Africa

2.3.3.1 *Cryptosporidium* and *Giardia* monitoring by Government Institutions

Department of Water Affairs (DWA), has failed in its responsibility as the custodian of water resources in South Africa seeing that, South Africa is currently facing challenges with drinking water quality which is continuously deteriorating to almost undrinkable quality in some smaller municipalities (Polasek, 2010). Many areas lack appropriate sanitation facilities and this has resulted in South Africa's water resources becoming under increasing threat from faecal pollution. The quality of the drinking water is also threatened by increasing urbanization, unplanned and uncontrolled informal settlements, overloading of the sewage systems, ineffective water treatment, and lack of maintenance of the water treatment systems (Figure 2.3).

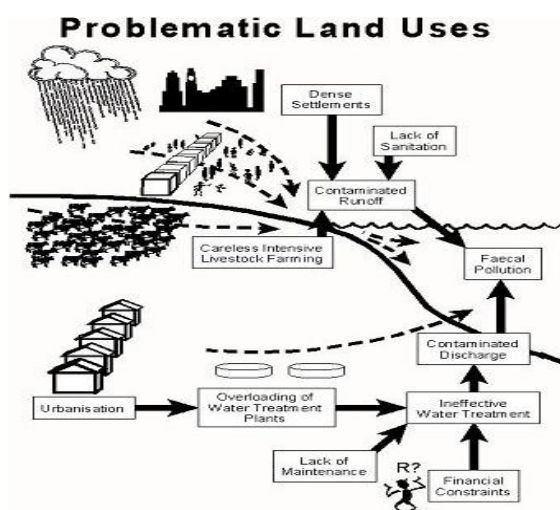


FIGURE 2.3: Land use activities that may lead to pollution of water resources (Murray *et al.*, 2004)

Consequently, in South Africa, water consumers are at increased risk of being exposed to faecal contaminated water which may lead to waterborne diseases (Murray *et al.*, 2004). In an attempt to address microbial pollution resulting from faecal pollution, monitoring programs that are focused on microbial water quality such as the national microbial monitoring programme (Murray *et al.*, 2004) and the Blue Drop Certification Program is currently in place (DWA, 2009). These programmes are well designed and they address monitoring of faecal coliforms in South Africa, however, they do not address monitoring of protozoan parasites such as *Cryptosporidium* and *Giardia*. Instead *Cryptosporidium* and *Giardia* are regarded as water quality hazards and monitoring of these parasitic protozoans only takes place when *Cryptosporidium* and / *Giardia* oocysts are detected in drinking water. As a result these parasitic protozoans are addressed in the drinking water quality framework for South Africa in the incidence management protocol (DWA, 2007) (Table 2.4) which can be regarded as a reactive tool.

Nevertheless, the incident management protocol for drinking water quality requires that the local municipality, DWA and the Department of Health (DoH) be notified when *Cryptosporidium* and *Giardia* cysts are detected in the treated water. Three Alert Levels are allocated to respond to drinking water quality failures and these are alert level I, II and III (Table. 2.4) (DWA, 2007) *Cryptosporidium* and *Giardia* in drinking water are addressed as follows:

- Alert level I – this level is referred to as the drinking water incident. During this level there is no risk of protozoan parasite infection.
- Alert Level II – this is referred to as the drinking water failure. This level poses a potential minor risk to health. Additional monitoring is required to establish the source of the contamination and the risk to public health and if an additional sample result exceeded concentrations specified in alert level II, alert level III is triggered
- Alert Level III – this is the drinking water emergency. During this stage there is potential major risk to health. Activities include major emergencies requiring significant interventions to minimize public health risk such as additional monitoring and establishing the source and the extent of the incident and the risk to public health. Additional monitoring is phased out once the source of the incidence has been identified and rectified and two consecutive results have been within specification.

TABLE 2.4: Incident monitoring protocol (DWAF, 2007)

Classification of Incident	Water Quality Constituent and Concentration	Health implication or risk	Incident management	Required response time	Action
Alert Level I (Drinking Water Quality Incident)	1 <i>E. coli</i> per 100ml 1 Coliphage per 10ml	- Insignificant chance of infection - Very slight risk of viral infection with continuous exposure	Internal	Within 24 hours of result release	- Communicate of range results to relevant municipal staff - Assess associated information and implement corrective action to rectify the incident or resample to confirm the results if required
Alert Level II (Drinking Water Quality Failure)	1 <i>Cryptosporidium</i> / <i>Giardia</i>/10l - Turbidity	- Low risk of protozoan parasite infection - Indirect associated impacts on health due to shielding of bacteria from disinfection	Internal and external	Same day as result release	- Request for additional monitoring as required (both spatially and increased frequency) to establish the source of the contamination and the risk to public health - Assess the treatment efficiency and implement corrective action to optimize the treatment process - Communicate the drinking water failure to the relevant municipal staff, DWAF* and DoH** - If any additional sample results exceeded concentrations specified in alert level II proceed to alert level III
Alert Level III (Drinking Water Quality Emergency)	1 <i>Cryptosporidium</i> / <i>Giardia</i>/10l	- Significant and increasing risk of infectious disease transmission - Significant risk of protozoan parasite infection	Internal and external	Immediately	- Engage emergency management team - Communicate drinking water emergency and health risk to the relevant municipal staff, DWAF and DoH - Continue additional monitoring and extend to the distribution system and point of use to establish the source and the extent of the incident and the risk to public health - Assess the communities at risk and the need for an alternate water supply - Communicate drinking water emergency to the community

					• Implement specialist process assessment and optimization of the drinking water supply system from catchment to consumer • Phase out additional monitoring once the source of the incidence has been identified and rectified and two consecutive results have been within specification • Prepare notifications advising the end of the emergency • Assess required preventative action to reduce the likelihood of the incident recurring • Prepare a report to document and close the incident • Review and update the incident management protocol • Retrain staff on revised Incident management protocol
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DWAF *: Department of Water Affairs and Forestry

DoH **: Department of Health

In addition to the Incident Management Protocol, South Africa has a number of legislations, national standards, and drinking water quality frameworks in place that cover drinking water quality management. The parasitic protozoans *Cryptosporidium* and *Giardia* are indirectly covered in some of the drinking water legislations.

2.3.3.2 Monitoring of *Cryptosporidium* and *Giardia* by Water Utilities in South Africa

It is evident that *Cryptosporidium* and *Giardia* are abundant in the surface waters of South Africa (Kfir *et al.*, 1995; Harding & Genthe 1996; Jarmey-Swan *et al.*, 2001; Adams *et al.*, 2005; Dungeni & Momba 2010). However, not all water utilities in South Africa monitor for these parasitic protozoans although there is clear evidence of the prevalence of the disease caused by these waterborne pathogens (Jarmey-Swan *et al.*, 2001). *Cryptosporidium* monitoring is not a major priority for some major utilities in South Africa. Although Water utilities such as Umgeni Water monitor for *Cryptosporidium* and *Giardia*, these parasitic protozoans are not monitored for on a regular basis and they are only monitored for at selected sampling points (Reddy, 2010). The City of Cape Town only started monitoring for *Cryptosporidium* and *Giardia* in 2010 with monitoring of source water and final water only once a month (Vulindlu, 2011).

Nevertheless, one of the biggest water utilities in South Africa Rand Water, which supplies 13 million people with drinking water monitors for *Cryptosporidium* and *Giardia* oocysts since 1996 initially following a method by Vesey *et al.*, (1993) before converting to monitoring of *Cryptosporidium* and *Giardia* following the current Rand Water Method every alternating week for the raw water as well as for the drinking water (RW, 2010a). Furthermore, Rand Water has developed an incident management protocol to react on the occurrence of *Cryptosporidium* in source and treated water (RW, 2010b). The objective of the protocol is to guide management on what action to be taken when either *Cryptosporidium* oocyst or *Giardia* cyst is detected in the drinking water as well as when high counts of *Cryptosporidium* oocysts and *Giardia* cysts are detected in source water. Generally, two samples are taken during sampling for analysis of these protozoans, with one sample serving as the back-up sample (Figure 2.4). If *Cryptosporidium* oocyst or *Giardia* cyst is detected in drinking water, the backup sample is then analyzed. If the back-up and/or follow up samples are negative, there will be no incident and therefore no further analysis to be done. However, if the back up and the follow up samples are positive, the specific sample is analyzed for five consecutive days and the incident can only be declared closed once those five consecutive results are all negative. The response committee then decides on any other sample points in the distribution/ catchment or purification plants which need to be monitored (RW, 2010b).

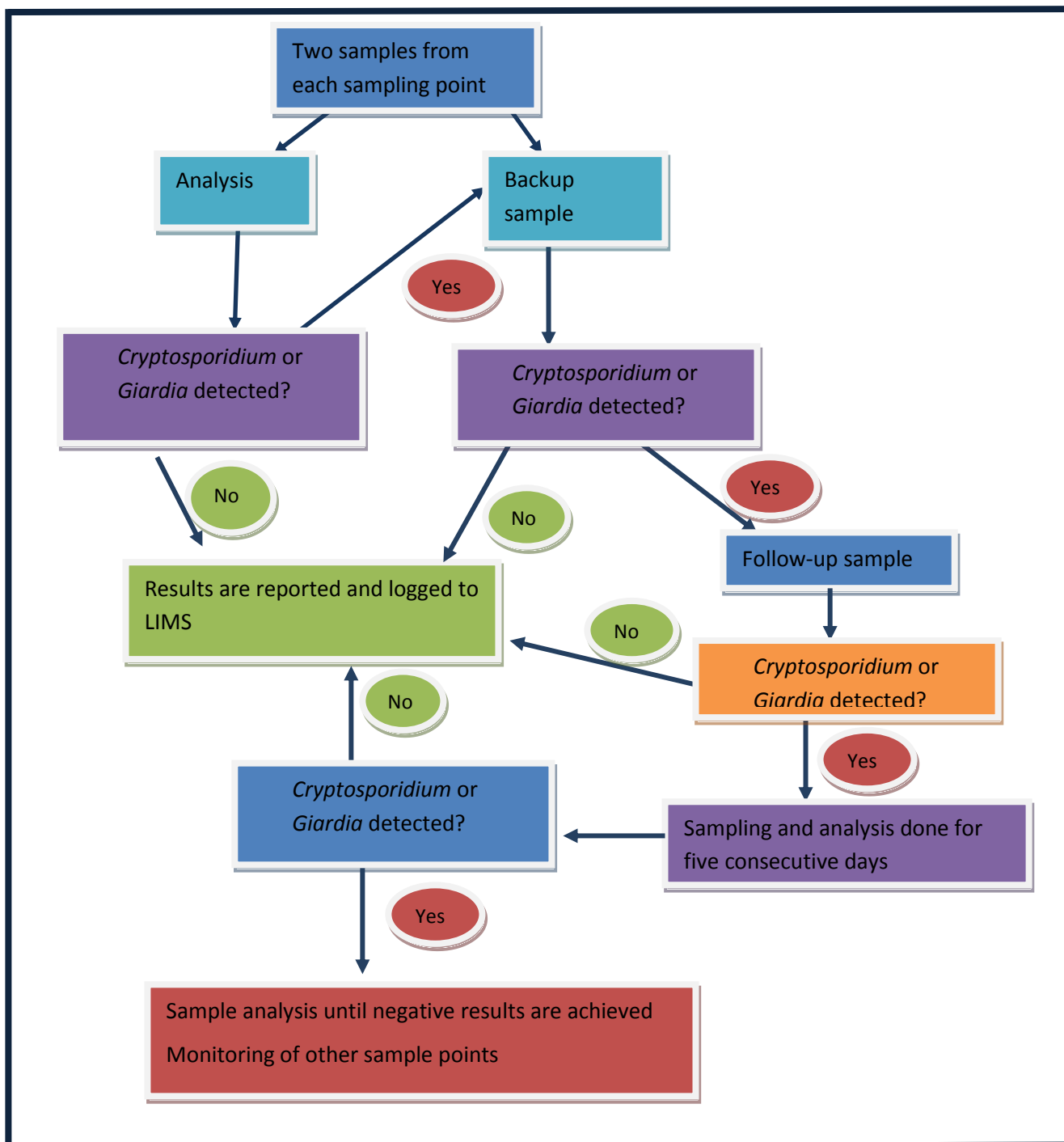


FIGURE 2.4: Steps involved in monitoring of *Cryptosporidium* and *Giardia* at Rand Water

Action is also taken when high counts of *Cryptosporidium* and *Giardia* are detected in source water samples. When high counts (≥ 100) of either *Cryptosporidium* oocysts or *Giardia* cysts are detected in source water, the manager responsible for the maintenance of catchment area is notified so that the affected sample can be re-sampled and analyzed as soon as possible and also to investigate the origin of the sample. Management at the purification works is also notified if high concentrations of *Cryptosporidium* and *Giardia* are detected in source water, for possible optimization of the purification process before the

condition affects the quality of the treated water. Additionally, the specific sampling point may be assessed for the presence of any obvious reasons that may lead to the contamination (RW, 2010b).

There is clear evidence that at Rand Water, *Cryptosporidium* and *Giardia* monitoring is one of the critical functions since there is a monitoring protocol as well as an incident management protocol in place. However, the current protocol is very basic and monitoring of protozoan parasites is reactive and it does not address monitoring of *Cryptosporidium* in source water as well as at the water purification plant. In addition, there is a lack of a clear protocol for monitoring of *Cryptosporidium* and *Giardia* in South Africa. Therefore this study will attempt to address the lack of structured monitoring strategy for parasitic protozoans *Cryptosporidium* and *Giardia*, by developing the framework for monitoring of *Cryptosporidium* and *Giardia*. However, before the framework can be developed, it is important to understand the approach for *Cryptosporidium* and *Giardia* monitoring in other countries with the aim of using some of the information gathered to build up the conceptual monitoring framework for *Cryptosporidium* and *Giardia*.

2.3.4. Monitoring for *Cryptosporidium* and *Giardia* in Australia

The Australian drinking water quality regulations are embedded Drinking Water Guidelines (ADWG) (2004) developed by the National Health and Medical Research Council (NHMRC) in collaboration with the Natural Resource Management Ministerial Council (NRMMC). The objective of these guidelines is to provide a framework for good management of drinking water supplies as well as assurance of safe drinking water to the consumers. As with the Water Safety Plans, the framework for management of drinking water quality in Australia is a risk management approach for management of drinking water quality, based on the hazard analysis and critical control point (HACCP) system which is a systematic approach to the identification of hazards and their prevention, with a particular focus on process control to ensure that preventive measures are operating effectively (ADWG, 2004).

This risk management approach to drinking water supply has been adopted across Australia to increase confidence in the safety of drinking water and reduce reliance on end-point testing. This is based on a comprehensive preventive strategy which focuses on total system management. A key aspect of this approach is the existence of monitoring programs that will verify that the barriers and the system as a whole are working effectively to deliver safe water (ADWG, 2004), thereby, assessing the integrity of the entire water supply system while incorporating strategies to deal with day-to-day management of water quality as well as upsets and failures (NHMRC, 2003).

Recently, it has been highlighted that one of the shortcoming that compromises the effective application of the framework for management of drinking water quality in Australia is that it lacks a quantitative definition of microbial targets. As a result, many utilities have adopted features of international guidelines to overcome these shortcomings. Examples include requirements associated with disinfection and the

operation of filtration plants used to treat surface water supplies included in USEPA regulations (NHMRC, 2010a).

In Australia, it is recognized that *Cryptosporidium* and *Giardia* are likely to be the most important enteric protozoa in water responsible for water-borne transmission for giardiasis and cryptosporidiosis in Australia. Cryptosporidiosis is a notifiable disease in Queensland Australia, and giardiasis is not a notifiable disease, however, data and clusters of cases of giardiasis are gathered on identified outbreaks to ascertain probable sources of infection by water authorities and the general practitioners. Yet there has not yet been any confirmed case of human illness from these parasites involving drinking water in Australia (EHU, 2007). As a result, the Australian drinking Water Guidelines do not recommend routine monitoring for these protozoans, and there are no documented minimum acceptable concentration values for *Cryptosporidium* and *Giardia* in drinking water. The water authorities highlight that currently available methods for *Cryptosporidium* and *Giardia* have significant limitations and acting on the results of such unreliable methods may create unnecessary community concern and costs to water authorities (EHU, 2007). As result, monitoring of these pathogens is classified under investigative research monitoring or in outbreaks in the waterborne diseases (ADWG, 2004).

Recently, the Queensland Health established an expert group consisting of water quality experts in parasitology, microbiology, public health medicine and toxicology, drinking water quality and water treatment whose function is mainly to address the issues associated with *Cryptosporidium* and *Giardia*. This group compiled an interim management and response protocol for *Cryptosporidium* and *Giardia* in drinking water which is triggered by the detection of *Cryptosporidium* at any level (EHU, 2007).

The protocol requires that if *Cryptosporidium* and /or *Giardia* are detected in water, the water utility re-sampling should be carried out on the affected system, the adjacent areas of the system and should search for sources of contamination by assessing the validity of the findings and by performing an audit trial of the water treatment and the supply system and should provide results within 24 hours. Immediate areas downstream of the affected area should be analyzed again. If the problem is identified from the audit there should be another re-sampling. In the absence of any indication of failures or contamination of water treatment, public health action may not be required. However if there is evidence that suggest the presence of *Cryptosporidium* and *Giardia* in drinking water, Queens Health may recommend that a boiled water alert Notice be issued and the Queens Health, acting on the advice of the expert group on water quality which will then determine when the boiled water alert will be withdrawn (EHU, 2007).

2.3.5 *Cryptosporidium* and *Giardia* monitoring in the United States of America (U.S.A)

Monitoring of *Cryptosporidium* in the U.S.A is carried out in accordance with the Long Term 2 Surface Treatment Rule (LT2 rule) published by the Environmental Protection Agency (US EPA) (2006). The purpose of the LT2 rule is to reduce illness linked with the contaminant *Cryptosporidium* and other disease-causing micro-organisms in drinking water and this rule is based on a definition of tolerable risk derived from historical data.

Prior to the LT2 rule, monitoring of *Cryptosporidium* and *Giardia* was done according to the Surface Water Treatment Rule and the Long Term 1 Enhanced Surface Water Treatment Rule (US EPA 2002) which derived log reduction targets from considerations of illness rates, from the source waters survey results and practical achievability. These regulations required that public water systems that use surface water sources and filtration to achieve at least a 2-log removal of *Cryptosporidium*, 3-log removal for *Giardia* and 4-log removal for viruses (NHMRC, 2010a). As a result the LT2 rule was expanded to include testing of source waters for *Cryptosporidium* in order to identify log reduction requirements (USEPA 2006). This was primarily done due to a concern that some surface water sources could contain relatively high concentrations of *Cryptosporidium* and require higher levels of treatment to assure safe drinking water quality than those prescribed in the Long Term 1 Enhanced Surface Water Treatment Rule (NHMRC, 2010a). As a result, the LT2 was developed to control improve the control of microbial pathogens, specifically the protozoan *Cryptosporidium*, in drinking water to address the trade-offs with the disinfection byproducts (US EPA, 2006).

Under the LT2 rule, systems initially conduct source water monitoring for *Cryptosporidium* to determine their treatment requirements. Filtered systems are classified into one of four risk bins based on their monitoring results. The lowest risk bin, carries no additional treatment requirements and higher risk bins must provide 90 to 99.7 percent (1.0 to 2.5-log) additional reduction of *Cryptosporidium* levels. All unfiltered systems must provide at least 99 or 99.9 percent (2 or 3-log) inactivation of *Cryptosporidium*, depending on the results of their monitoring (US EPA, 2003). Exclusion of source water monitoring under the LT2 is allowed if the system can provide a total of at least 3-log *Cryptosporidium* inactivation, equivalent to meeting the treatment requirements for unfiltered systems with a mean *Cryptosporidium* concentration greater than 0.01 oocysts /ℓ (US EPA, 2006).

The concentration of *Cryptosporidium* oocysts in source water samples analyzed during the LT2 rule is used to calculate the mean *Cryptosporidium* concentration for a portable water supplier (PWS) into a treatment requirements referred to as the “bin”. The treatment bin for each portable water supplier is then used to determine whether additional treatment is required or not. The bin classification for filtered water a system and unfiltered water system are provided in Table 2.5 and Table 2.6 below (US EPA, 2006).

TABLE 2.5: The bin classification for filtered water a system (US EPA, 2006)

<i>Cryptosporidium</i> Bin concentration	Bin classification	Conventional filtration treatment including softening	Direct filtration	Slow sand or diatomaceous earth filtration	Alternative filtration technologies
Cryptosporidium<0.075	*1	No additional treatment	No additional treatment	No additional treatment	No additional treatment
0.075 oocysts/ℓ< Cryptosporidium-<1.0 oocysts/ ℓ	**2	1 log treatment	15 log treatment	1 log treatment	***As determined by the state
1.0 oocysts/ ℓ ≤Cryptosporidium - ≤ 3.0 oocysts/ ℓ	**3	2 log treatment	2.5 log treatment	2 log treatment	****As determined by the state
Cryptosporidiumt >3.0 oocysts/ ℓ	**4	2.5 log treatment	3 log treatment	2.5 log treatment	*****As determined by the state

*PWS in Bin 1 - - no additional treatment;** PWS in bins 2 -4 - additional treatment on the other hand additional treatment is needed for: *** total removal /inactivation >4, **** total removal /inactivation > log, *****total removal /inactivation >5.5 log

TABLE 2.6: Bin classification for unfiltered system indicating the inactivation requirements for unfiltered systems (DWSNZ, 2008)

<i>Cryptosporidium</i>	Required <i>Cryptosporidium</i> inactivation
≤0.01	2 log
≥0.01	3 log

The bin classification is calculated by using individual sample concentrations. These concentrations are calculated as follows (DWSNZ, 2008):

Number of oocysts detected/volume analyzed.

For the application of the LT2SWTR treatment systems are divided into large treatment systems and small treatment systems. The large filtered systems include systems that serve at least 10000 people on the other hand the small systems are the systems that serve below 10000 people. Under the LT2ESWTR, it is required that water suppliers monitor their water sources to determine treatment requirements. This monitoring includes an initial two years of monthly sampling for *Cryptosporidium*. Then the source monitoring data is used to categorize the source water *Cryptosporidium* concentration into bin systems.

Large unfiltered portable water systems and wholesalers are required to conduct initial source water monitoring that includes sampling for only *Cryptosporidium* at least once per month for two years (US EPA,

2006). To reduce monitoring costs, small filtered water systems are required to first monitor for *E. coli* which is less expensive to analyze than *Cryptosporidium* and will monitor for *Cryptosporidium* only if their *E. coli* results exceed specified concentration levels.

In addition, the systems that store treated water in open Catchments are required to either cover the Catchment to protect against the contamination of water or treat the Catchment discharge to inactivate 4-log virus, 3-log *Giardia* and 2-log *Cryptosporidium*. These systems are required to review their current level of microbial treatment before making a significant change in their disinfection practice. After the initial bin classification source water monitoring is conducted six years later.

EPA estimates that full compliance with the LT2ESWTR will reduce the incidence of cryptosporidiosis - the gastrointestinal illness caused by ingestion of *Cryptosporidium* - by 89,000 to 1,459,000 cases per year, with an associated reduction of 20 to 314 premature deaths (US EPA, 2003).

2.3.6 *Cryptosporidium* and *Giardia* monitoring in Canada

The drinking water quality guidelines for Canada are contained in the Guidelines for Canadian Drinking Water Quality (GCDWQ) (2006). Regulation of *Cryptosporidium* and *Giardia* is not mandatory in Canada, hence, there is no minimum acceptable concentration of *Cryptosporidium* and/*Giardia* in drinking water. Water utilities are not required to monitor for *Giardia* and *Cryptosporidium* although these protozoan parasites could be responsible for severe and, in some cases, fatal gastro-intestinal illness. Health Canada defends their lack of monitoring using the methodological limitations as the reasons why these protozoan parasites are not included in the guidelines. However, it recommends that if the presence of viable, human-infectious cysts or oocysts is known or suspected in source waters, or if *Giardia* and/ *Cryptosporidium* has been responsible for past waterborne outbreaks in a community, a treatment and distribution regime and a watershed or wellhead protection plan (where feasible) or other measures known to reduce the risk of illness should be implemented (HC, 2009).

Health Canada guidelines for protozoa and enteric viruses refer to the USEPA approach and reference an accepted annual infection risk of <1 in 10,000 people per year. These guidelines recommend that treatment technologies should achieve a minimum 3-log reduction of protozoa or inactivation of cysts and oocysts unless source water quality requires a greater log reduction (GCDWQ, 2008).

Consequently, the drinking water authorities in Canada could be regarded as using the “do nothing” approach for protozoan monitoring which is described as reactive approach, where tools available to drinking water utilities to benchmark current performance or to assess improved performance in achieving

microbial safety add very little value in assessing the absence of enteric viruses and protozoa, for example the measurement of *E.coli* in the drinking water (NHMRC, 2010a).

2.3.7 Monitoring for *Cryptosporidium* and *Giardia* in the United Kingdom (U.K.)

In the UK, direct monitoring of drinking water is embedded in the Drinking Water Regulations 2000/1 (amendment) regulations 2007 (DWI) (2008). Before amendment, of the Drinking Water regulations 2000/1 (DWI, 2003), the water supply systems that are at risk to *Cryptosporidium* were obliged to sample their treated water continuously. Samples of approximately 1000L water were taken over a period of at least 23 hours daily, and it required that an average concentration of *Cryptosporidium* in treated water be less than 1 oocyst per 10ℓ. As a result, the risk supplies were abandoned and the percentage of positive samples in the U.K. declined from 8 to 1% (WHO, 2006).

The regulations were amended following a review, the requirements of the relevant European Directives and the changes in the approach taken by the WHO. In addition the regulations were reviewed in order to consider the possibility of reducing the regulatory administrative burden on the water industry whilst maintaining a tough but fair regulatory regime (Sinclair & Lightbody, 2007). The amendments of the regulations reflect a significant shift towards a preventative risk management approach adopted by WHO which emphasizes identification and management of risks throughout the water supply system, whereas the previous UK regulations promoted a focus on water treatment and treated water.

In the Drinking Water Regulations 2001 (amendment) 2007 it is now required that a comprehensive risk assessment be conducted for each treatment works and connected supply system. This assessment does not cover only *Cryptosporidium* as it did previously; however, it now covers all hazards in the hazardous events using the Water Safety Plan approach (DWI, 2008). In addition to this amendment, the regulation that required continuous monitoring of *Cryptosporidium* on a daily basis has been revoked. Even so, *Cryptosporidium* is monitored for using the required risk assessment in the Drinking Water Regulations 2001 (amendment) 2007 regulations (DWI, 2008).

2.3.8 Monitoring for *Cryptosporidium* and *Giardia* in New Zealand

Cryptosporidium monitoring in New Zealand is enclosed in the Drinking-Water Standards for New Zealand (2008). The New Zealand Drinking-Water Standards (2008) have followed a similar approach as the USEPA's Long Term 2 Surface Treatment rule in requiring the log reductions based on *Cryptosporidium* concentrations with the main objective of providing requirements for drinking-water safety by specifying the maximum amounts of substances or organisms or contaminants that may be present in drinking-water (DWSNZ, 2008).

In New Zealand, protozoans, *Cryptosporidium* and *Giardia* occur in many surface waters and non-secure bore waters. These protozoa are considered priority one determinants in New Zealand due to their public health significance since their presence can lead to rapid and major outbreaks of illness. As a result, *Cryptosporidium* and *Giardia* are required to be monitored in all supplies because they constitute major public health risks with an exception of the secure bore water. Moreover, the maximum acceptable values for total pathogenic protozoa is less than one infectious (oo)cyst / 100 ℓ of sample (DWSNZ, 2008).

Monitoring for *Cryptosporidium* in New Zealand is well documented i.e. it specifies what to monitor, where, whereby a clear description of different sampling locations are outlined including the frequency based on the population served as well as investigations that should be conducted if there is a non conformance. Since *Cryptosporidium* is the most infectious and most difficult protozoan to remove or inactivate, the compliance criteria are constructed based on the principle that, if the treatment process deals successfully with *Cryptosporidium*, they will also deal successfully with other protozoa. In addition, during monitoring, the risk-based criteria that is more stringent for contaminated raw water than for cleaner raw water considering the additive effect of successive different treatment processes on the removal of protozoa where more than one treatment process is used. As a result, *Cryptosporidium* monitoring is carried out to assess treatment performance against operational requirements (DWSNZ, 2008).

New Zealand adopted the log removal efficiency approach for monitoring of *Cryptosporidium* from the US EPA (2006) (DWSNZ, 2008), whereby log credits are allocated according to the treatment requirements, indicating how different treatment processes can remove or inactivate protozoa. This is also referred to as the efficacy of the treatment, and it is measured as percentage removal/ inactivation or is converted to *log removal/inactivation* rates (log credits). Therefore the log credit for a treatment process is related to the percentage of the protozoa the process can remove, by the expression (DWSNZ, 2008):

$$\text{log credit} = \log_{10}[1/\{1-(\text{percentage removal}/100)\}]$$

Monitoring for *Cryptosporidium* is required for all systems serving more than 10,000 people from sources including surface waters, springs and non-secure bore waters. The monitoring program comprises of at least 26 samples collected over a 12 month period and repeated at least every 5 years. Secure bore water are not monitored for *Cryptosporidium* (NHMRC, 2010a), however, source water from surface sources or non-secure bore water requires treatment that qualifies for 2, 3, 4 or 5 protozoa log credits, depending on the protozoa risk arising from the quality of the source water. Compliance with the protozoa criteria is achieved when the treatment process used meets specified performance requirements. Hence, if water treatment fails to meet the required number of log credits or the operational requirements are not met, the supply is non-compliant (DWSNZ, 2008).

For water supplies serving a population up to 10,000 the protozoa log credit requirement is determined using either, the catchment risk category approach or the standard approach (Table 2.7), which is based on perceived risk related to the surface water catchment or groundwater categories.

TABLE 2.7: Log reductions for supplies serving populations of ≤ 10,000 (DWSNZ, 2008)

Catchment type	Required log reduction
Secure bore water	0
Bore water from an unconfined aquifer >30m deep with protection from septic tanks and other waste discharges	2
Bore water from an unconfined aquifer 10-30m deep with protection from septic tanks and other waste discharges	3
Springs and bores 0-10m deep	3-5
Surface water from protected catchments	3
Surface water from catchments with low concentrations of livestock or humans in immediate vicinity or upstream	4
Surface water from catchments with high concentrations of livestock or humans or a waste treatment outfall nearby or upstream	5 log

The log credit requirement for supplies serving a population greater than 10,000 is based on monitoring *Cryptosporidium*. The minimum protozoal log removal requirement depends on the mean *Cryptosporidium* oocyst concentration of the water at the plant inlet for both surface waters and non-secure bore waters (Table 2.8) (DWSNZ, 2008).

TABLE 2.8: Log credit requirements for surface waters, springs, and non-secure bore water 0–10 m deep, based on *Cryptosporidium* monitoring

<i>Cryptosporidium</i> , mean oocysts per 10 ℓs	Log credits
≥10	5
0.75 -9.99	4
<0.75	3

For small water supplies serving a population of less than or equal to 500 people, treatment requirements are based on sanitary surveys and are shown in Table 2.8.

TABLE 2.9: Log reductions for supplies serving populations of ≤ 500 (US EPA, 2003)

Catchment type	Required log reduction	Equivalent % removal
Secure bore water	None	0%
Protected with controlled human access and no livestock operations	2 log reduction	99% removal
Partially protected with no sewage discharges, human habitations and no intensive livestock operations including young and juvenile stock	3 log reduction	99.9% removal
Unprotected catchment	4 log	99.99% removal

According to DWSNZ (2008) the use of log credits in New Zealand will remain practical and a viable alternative for evaluation of protozoans in drinking water until the methodology for numeration of *Cryptosporidium* improves (DWSNZ, 2008).

2.3.9 Monitoring of *Cryptosporidium* and *Giardia* in Northern Ireland

Regulations for water quality in Northern Ireland are embedded in the The Water Supply (Water Quality) Regulations (Northern Ireland) 2007 (WSR, 2007). The regulations make provision for monitoring of water supplies, investigations, of *Cryptosporidium* risk in the water supplies. It requires that *Cryptosporidium* risk assessment be carried out in all the water treatment works on a yearly basis. *Cryptosporidium* is, monitored according to the Guidance for the monitoring of *Cryptosporidium* in treated water supplies in Northern Ireland (EHS, 2002). According to the guide, if it is identified that there is significant risk at the water treatment works the department of regional development will introduce continuous monitoring to reduce the risk of *Cryptosporidium* to lower the risk (EHS, 2002).

The protocol for risk assessment is illustrated in the Table 2.10 (adapted from EHS, 2002). The protocol assesses eleven areas and the specific area is given a score. The protocol covers monitoring all areas of the supply system which include the source water, water treatment and the treated water. After the assessment a final score is assigned which is then for risk classification. The water supply can be classified a low risk, significant risk and high risk (EHS, 2002).

Recently it has been reported that the requirement for risk assessment has been successful resulting in a significant reduction in the number of mains water related outbreaks of cryptosporidiosis. It has been proposed that regulation be amended to extend the requirement for risk assessment at each water treatment works to cover all potential dangers to human health including all other parameters and should also be widened in scope to be in line with the WHO Water Safety pPan framework. It is anticipated that

this will enable Northern Ireland Water to undertake and document a single comprehensive risk assessment for each water supply chain embracing all hazards (PWSR, 2008).

TABLE 2.10: *Cryptosporidium* risk assessment scoring table (EHS, 2002)

<u>CRYPTOSPORIDIUM RISK ASSESSMENT</u>		<u>POSSIBLE SCORE</u>
1. Animals on the source water		
1.1	Cattle/Calves	6
1.2	Sheep/Lamb	6
1.3	Deer	2
1.4	Pigs	2
1.5	High number of birds	2
1.6	Any other farmed animals/birds	1
2.Agricultural Practices on the catchment		
2.1	Slurry spraying, dung spreading or dung or slurry storage	6
3.Possible discharges into the Source water		
3.1	Septic tanks	1
3.2	Sewage water-population served less than 500	2
3.3	Sewage water-population served between 501 – 5000	3
3.4	Sewage water-population served between 5001 – 20 000	4
3.5	Sewage water-population served between 20 001- 50 000	5
3.6	Sewage water-population served greater than 50 001	6
3.7	Storm water outlets	2
3.8	Abattoir/Livestock Market	3
4 Water Source type		
4.1	Boreholes and Deep Wells- vulnerable soil type/topology	3
4.2	Boreholes and Deep Wells- non vulnerable soil type/topology	1
4.3	Secure natural Springs – vulnerable soil type/topology	3
4.4	Secure natural Springs – non vulnerable soil type/topology	1
4.5	Other Shallow Underground source – vulnerable soil type/topology	6
4.6	Other Shallow Underground source – vulnerable soil type/topology	4
4.7	Upland Catchment	4
4.8	Lowland Catchment	6
4.9	Upland river or Burn – Direct abstraction	6
4.10	Lowland River or Burn – Direct abstraction	8
5 River intake management		
5.1	Quality monitors on the intake	-1
5.2	No quality monitors on the intake	3
5.3	Quality monitored alarmed	-2
5.4	Quality monitors cause intake to shut automatically	-4

5.5	Intake shuts manually under poor water conditions	-1
5.6	Intake not shut under poor water conditions	3
6	Water Treatment	
6.1	Simple disinfection only	10
6.2	Microstaining	10
6.3	Simple sand Filtration, (not slow sand filtration) – must have minimum sand depth of 90 cm	8
6.4	Coagulation followed by DAF/sedimentation and Filtration	-10
6.5	Coagulation followed by Rapid gravity or pressure filtration only	-7
6.6	Slow sand filtration, must have minimum depth at least 30 cm	-9
6.6.1	Roughing filters as pretreatment for slow sand filtration	-4
6.6.2	For slow sand filtration - at least 30 cm of sand	-2
6.6.3	For slow sand filtration - at least 30 cm of sand	
6.7	Membrane filtration	-4
6.8	Ozone treatment	-16
6.9	Cartridge / Kalsep filtration	-8
6.10	Filtamat or equivalent	-2
7	Treatment works monitoring	
7.1	Each filter has turbidity meter with a trend/alarm setting	-3
7.2	Each filter has turbidity meter without a trend/alarm setting	0
7.3	One turbidity meter is shared over several filters	2
7.4	No turbidity meter on the filters	6
7.5	Alarmed continuous residual coagulant monitor on works outlet	-2
7.6	Alarmed continuous residual coagulant monitor on works outlet (not alarmed)	0
7.7	No continuous residual coagulant monitor on Works outlet	2
7.8	Routine sampling and analysis of the water quality process carried out at the water treatment works/residual coagulant	-1
7.9	Routine sampling and analysis of the water quality	4
8.	Treatment Works Performance	
8.1	No major quality deviation from normal background levels for filtered or treated water	-4
8.2	Process known to be bypassed	4
8.3	Coliform accidents, considered trivial at water treatment works	
8.4	Coliform accidents, considered non-trivial at water treatment Works	4
8.5	Significant	4
8.6	No significant increase in turbidity before or after filter wash	0
8.7	Signs of significant media loss from filters/severe cracking of filter bed	2
8.8	Filters in good condition	-2
9. Treatment Works Operation		

9.1	Treatment works process control manuals available	-1
9.2	Treatment works process control manuals not available	1
9.3	Action plans for dealing with deviations in quality available	-1
9.4	Action plans for dealing with deviations in quality not available	1
9.5	Record of actions/audit trails available	2
9.6	Record of actions/audit trails not available	1
9.7	Slow start on filters	-2
9.8	No slow start on filters	2
9.9	Filters run to waste or head of works for a period after a backwash	-4
9.10	Water flow through plant changes suddenly	2
9.11	Water flow through plant stable	-2
9.12	Backwash and/or sludge supernatant has to be recycled	2
9.13	Alternative disposal route available for backwash and sludge Supernatant	-2
9.14	Slow-sand filters matured before going into service	-3
9.15	Slow-sand filters not matured before going into service	3
9.16	Plant frequently run above capacity	4
9.17	Turbidity of backwash supernatant monitored when recycled	-2
9.18	Turbidity of backwash supernatant not monitored when recycled	
10. <i>Cryptosporidium</i> monitoring		Possible score
10.1 no <i>Cryptosporidium</i> data available for the raw water		3
10.2	Raw water concentrations all less than 1 oocyst per ℓ - only Applies if treatment score (section 6) is negative. If treatment score is positive, concentration 1 oocyst per 10 ℓs applies	-2
10.3	Raw water concentrations over 1 oocyst per ℓ - only applies if treatment score (section 6) is negative. If treatment score is positive, concentration 1 oocyst per 10 ℓs applies	4
10.4	No <i>cryptosporidium</i> data available for the treated water	4
10.5	Treated water concentrations all less than 1 oocyst/10ℓ	-5
10.6	Treated water concentrations over 1 oocyst/10ℓ	5
10.7	Continuous monitoring of treated water	-5
10.8	Facility for continuous monitoring if required	-1
11. Epidemiology		
11.1	No known cases of cryptosporidiosis in the area served	-1
11.2	No past history of suspected, possible or probable outbreaks	-2

11.3	Past history of suspected outbreak associated with existing supply	15
11.4	Cause of any suspected outbreak or cases has been removed, or Suitable treatment added	0
12. Population Weighting		
12.1	$= 0.4 \times \log_{10} (\text{population served by supply})$ Final Risk Assessment Score = Sum of Sections (1-11) x Population Weighing	

2.4 Conclusions

From the literature review, it is evident that *Cryptosporidium* and *Giardia* are important protozoan parasites since they contribute to the outbreaks of waterborne diseases throughout the world. These protozoans are also resistant to chlorine disinfection rendering them the most difficult pathogens to treat. Different approaches for *Cryptosporidium* and *Giardia* monitoring are used across the world (US EPA, 2006; DWI, 2008; DWSNZ, 2008; EHS, 2002). It was noticeable that there is no standard protocol for monitoring of these protozoan parasites. However, there are three main approaches commonly used for monitoring of these protozoan parasites which are the log-reduction approach, the risk – based assessment and the do nothing approach which was observed in South Africa and Canada respectively (Table 2.11).

TABLE 2 11: *Cryptosporidium* and *Giardia* monitoring approaches followed by different countries

Country	Monitoring approach	Important Aspects of monitoring approaches
<i>Australia</i>	Risk based approach	Approach focuses on the entire water supply system including the possible sources of contamination Surveillance and comprehensive risk assessment are included Presence of interim management and response protocol for <i>Cryptosporidium</i> and <i>Giardia</i>. No documented minimum acceptable concentrations for <i>Cryptosporidium</i> and <i>Giardia</i> in drinking water Presence of interim management and response protocol for <i>Cryptosporidium</i> and <i>Giardia</i> in drinking water
<i>Canada</i>	Do nothing approach	Regulation of <i>Cryptosporidium</i> and / <i>Giardia</i> is not mandatory in Canada
<i>New Zealand</i>	Log reduction approach	Systems are classified into the 'bins' and required log reductions All systems serving more than 10,000 people from sources including surface waters, springs and non-secure bore waters are require to monitor for <i>Cryptosporidium</i> Secure bore water are not monitored for <i>Cryptosporidium</i> The monitoring program comprises of at least 26 samples collected over a 12 month period and repeated at least every 5 years.
<i>Northern Ireland</i>	Risk based approach	Monitoring all areas of the supply system which include the source water, water treatment and the treated water. After the assessment a final score is assigned and risk classified into low, moderate and significant risk. Actions taken in response to different risk categories
<i>United Kingdom</i>	Risk based approach	Emphasizes the identification and management of risks throughout the water supply system. Not only <i>Cryptosporidium</i> is covered but all the hazards and the hazardous using the Water Safety Plans.

South Africa	Do nothing approach	Regulations in place and incident management protocol in place, however not all water utilities monitor for <i>Cryptosporidium</i> and <i>Giardia</i>. There is a lack of a clear monitoring protocol for <i>Cryptosporidium</i> and <i>Giardia</i>.
USA	Log reduction approach (Long Term 2 Surface Treatment Rule)	Systems are classified into the 'bins' and required log reductions. Filtered systems are classified into one of four risk bins based on their monitoring results. The lowest risk bin, carries no additional treatment requirements and higher risk bins must provide 90 to 99.7 percent (1.0 to 2.5-log) additional reduction of <i>Cryptosporidium</i> levels. All unfiltered systems must provide at least 99 or 99.9 percent (2 or 3-log) inactivation of <i>Cryptosporidium</i>, depending on the results of their monitoring Source water monitoring exclusion is if is allowed if the system can provide a total of at least 3-log <i>Cryptosporidium</i> inactivation, equivalent to meeting the treatment requirements for unfiltered systems with a mean <i>Cryptosporidium</i> concentration greater than 0.01 oocysts /ℓ

From the reviewed guidelines, it was noticed that the regulatory agencies in the U.K. and USA approach monitoring water for *Giardia* and *Cryptosporidium* quite differently. The USA monitors for *Cryptosporidium* monitoring using the log reduction approach in which the systems are classified into the 'bins' and required log reductions. A similar approach is observed in the New Zealand guidelines. However, the USEPA and the New Zealand log reduction approach seem to allow omission of monitoring under certain circumstances and also to be subjected to specific areas of the water supply only without looking onto the source of contaminants entering the water sources.

On the other hand, in Australia, UK, and Northern Ireland the risk based approach for monitoring of *Cryptosporidium* is used. This approach focuses on the entire water supply system including the possible sources of contamination and it includes surveillance and comprehensive risk assessment. In this approach, the risk management actions that are most frequently employed for controlling the *Cryptosporidium* and /

Giardia risk to water supply include: monitoring; enhanced catchment protection; optimization of filtration in water treatment and/or the installation of additional water treatment processes (WHO, 2009a).

An approach similar to the one used in Northern Ireland will be followed in this study as the foundation for deriving monitoring protocol for *Cryptosporidium* and *Giardia* which includes source water characteristics, monitoring of the water treatment plant and final water. This will allow the water utilities to identify the sources of the water pollutants as well as other potential risks that may be imposed on the source water the treatment plant as well as the final water.

Furthermore, this approach for monitoring of *Cryptosporidium* and *Giardia* could benefit the water utilities since the water utilities are required to implement the Water Safety Plans (WSP), which is a hazard analysis and critical control point (HACCP) system based approach for drinking water quality management. The objectives of the WSP are to ensure safe drinking water through good water supply practice which includes, prevention of contamination of source waters, water treatment to reduce or remove contamination that could be present to the water quality targets and prevention of re-contamination during storage, distribution and handling of drinking water (WHO, 2005). One of the benefits of the WSP is that it encourages the use of multiple barriers for water treatment, whereby, a failure of one barrier can be compensated for by effective operation of the remaining barriers, minimizing the likelihood that contaminants will pass through the treatment system and harm consumers (WHO, 2004). In general, the focus on the use of multi-barrier monitoring has also increased as most water utilities attempt to adopt complete system risk management which includes identification of key elements which can be monitored to give useful information on potential health risk (NHMRC, 2003)

Included in the Water Safety Plans is need for conducting the sanitary survey which is a collection of information on hazardous events. To assess the hazardous events, the complete system should be described and analyzed for events/conditions that could lead to contamination of water supply actions, including understanding of the characteristics of the drinking water system, understanding what hazards may arise, from which sources, and how these hazards can create risks and which hazards and processes practices may affect drinking water quality (WHO, 2009b). All these hazards could be identified using the protocol that can be more proactive than reactive and that use a more holistic approach towards monitoring of *Cryptosporidium* and *Giardia*. Hence there is a need to develop a generic monitoring framework based on comprehensive preventative approach for management of *Cryptosporidium* and *Giardia*.

CHAPTER 3:

DEVELOPMENT OF A PROTOCOL FOR MONITORING OF *CRYPTOSPORIDIUM* AND *GIARDIA*

3.1 Introduction

The main objective of this chapter is to develop a protocol based on the information from literature reviewed and to present this information in a logical manner that will be easy to follow. The developed protocol will be applicable to all water supply systems regardless of size and system complexity and it will be focused on preventative approach of monitoring *Cryptosporidium* and *Giardia*. The components of the protocol are mainly based on the guidelines for monitoring of *Cryptosporidium* in Northern Ireland (EHS, 2002), US EPA (2006), DWI (2008), ADWG (2004) and DWSNZ, (2008). It is important to note that this framework will be closely linked to the guidance to monitoring of *Cryptosporidium* in Northern Ireland (EHS, 2002) and both approaches are risk based and monitoring is from source to treated water.

3.2 Elements of the protocol

In the current approach, four phases are proposed for the monitoring of *Cryptosporidium* and *Giardia* by Water Utilities namely (Figure 3.1):

- **PHASE I**: Desktop survey of monitoring requirements
- **PHASE II**: Situation analysis of source, water purification plant and epidemiology
- **PHASE III**: Sample collection, analysis and data storage
- **PHASE IV**: Review of the monitoring process

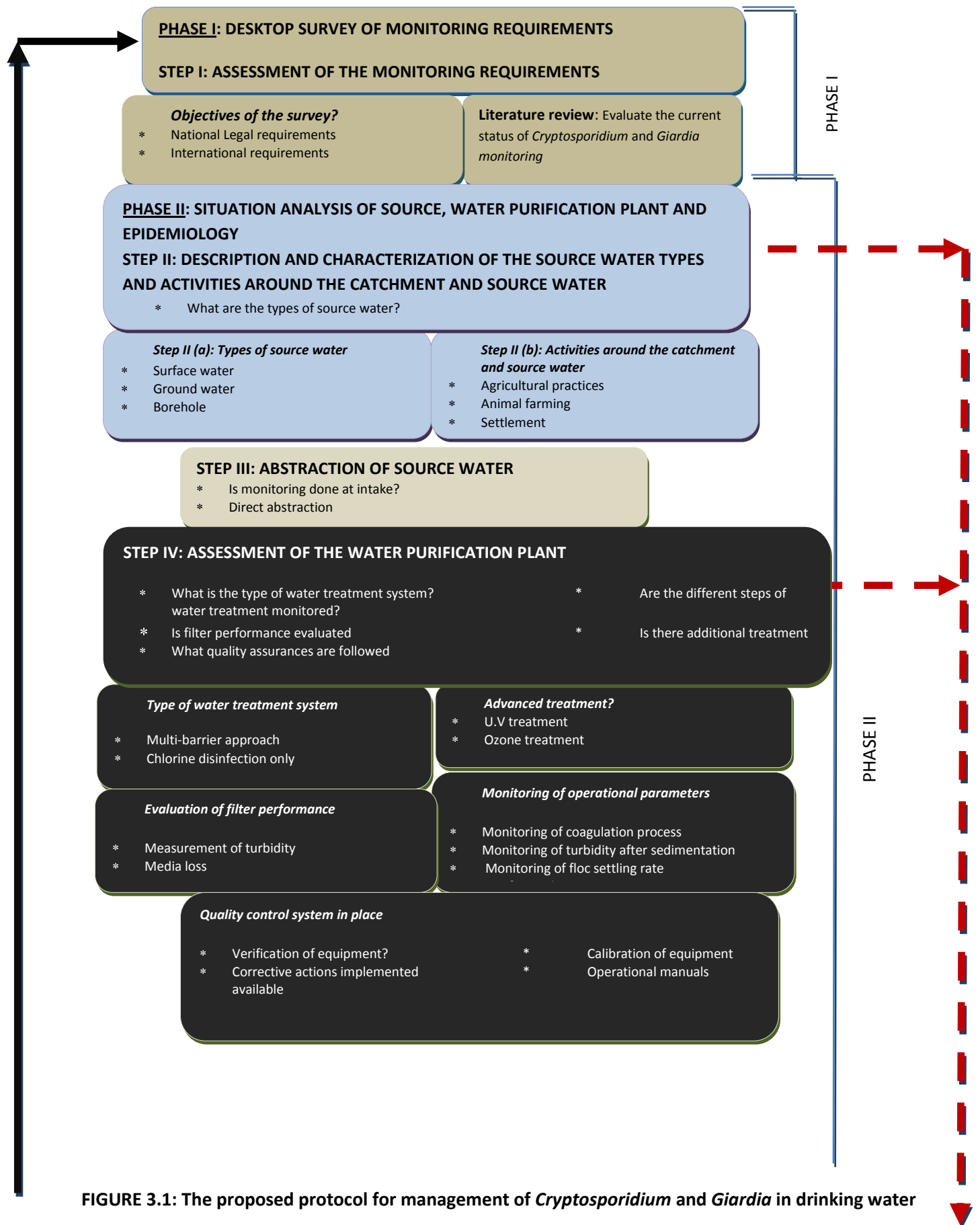


FIGURE 3.1: The proposed protocol for management of *Cryptosporidium* and *Giardia* in drinking water

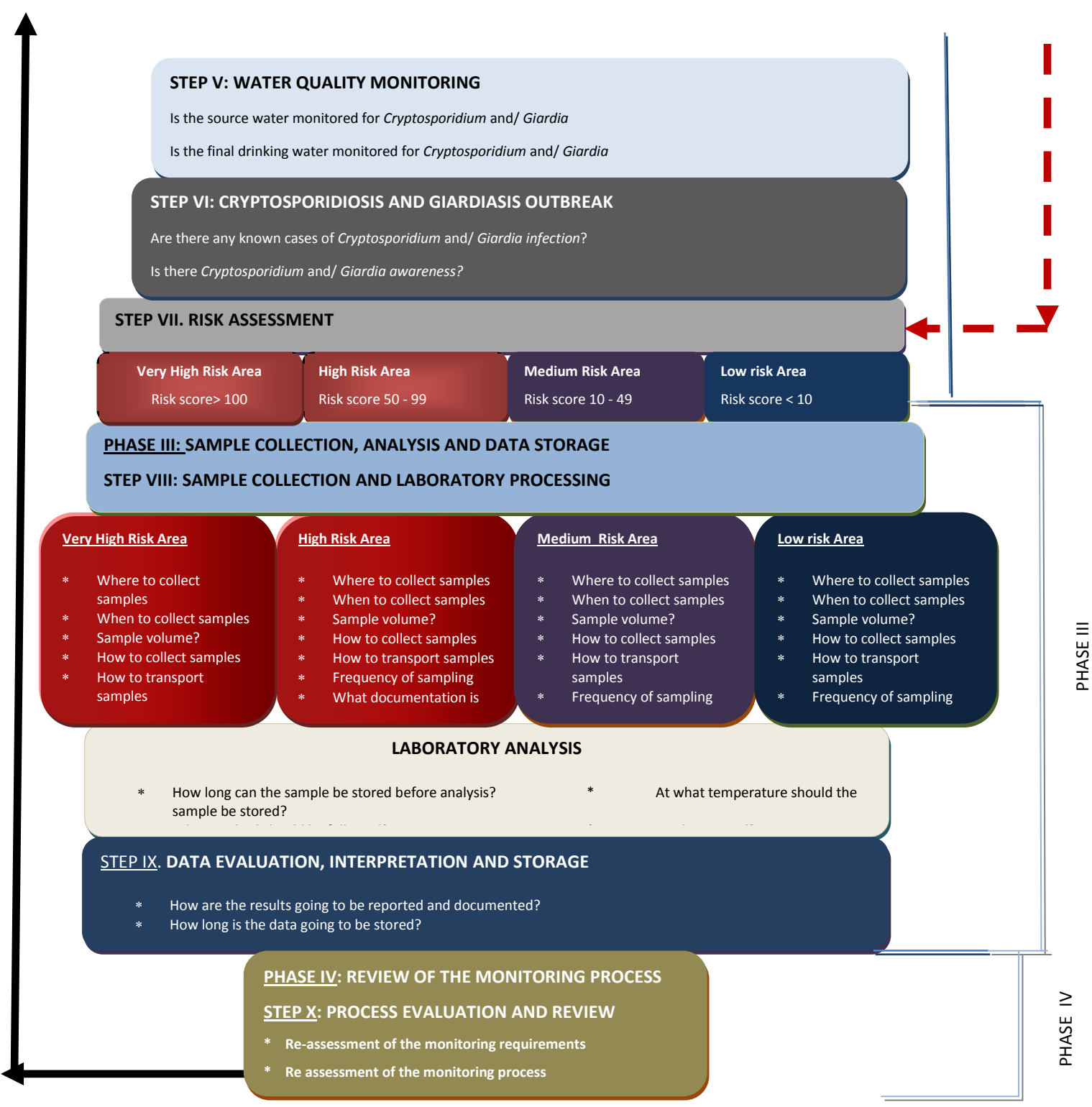


FIGURE 3.1: The proposed protocol for management of *Cryptosporidium* and *Giardia* in drinking water (continued)

3.2.1. Detailed description of the phases and steps of the protocol

Phase I: Desktop survey of monitoring requirements. This phase involves the accessing of *Cryptosporidium* and *Giardia* information from published and non-published sources and forms part of the first step of the protocol. This protocol is based on current information as indicated in the references. However, in future if improvements in technology have been made or when there are changes in the national standards and acts, it is advisable that the water utility revisit the sites.

STEP I: Assessment for monitoring requirements (Figure 3.2). This is a desktop study for monitoring strategies required for *Cryptosporidium* and *Giardia*. During this step, the National Acts and National Standards must be scanned in order to understand the legal requirements for *Cryptosporidium* and *Giardia* drinking water, as well as in source water the moment the assessment is carried out. This will give an insight into current minimum requirements as well as the monitoring requirements for *Cryptosporidium* and *Giardia* in water bodies used for drinking, domestic purposes, agricultural as well as for recreational purposes. In South Africa, National Acts and National Standards such as the South African National Standard (SANS) 241 (2006), National Water Act (NWA) (36/1998), and National Water Services Act (NWSA) (108/1997). SANS 241 (2006) can be obtained from South African Bureau of standards (SABS), the National Water Act (36/1998) and the National Water Services Act (107/1997) can be obtained from the following website: <http://www.lexadin.nl/wlg/legis/nofr/oeur/lxwezaf.htm>.

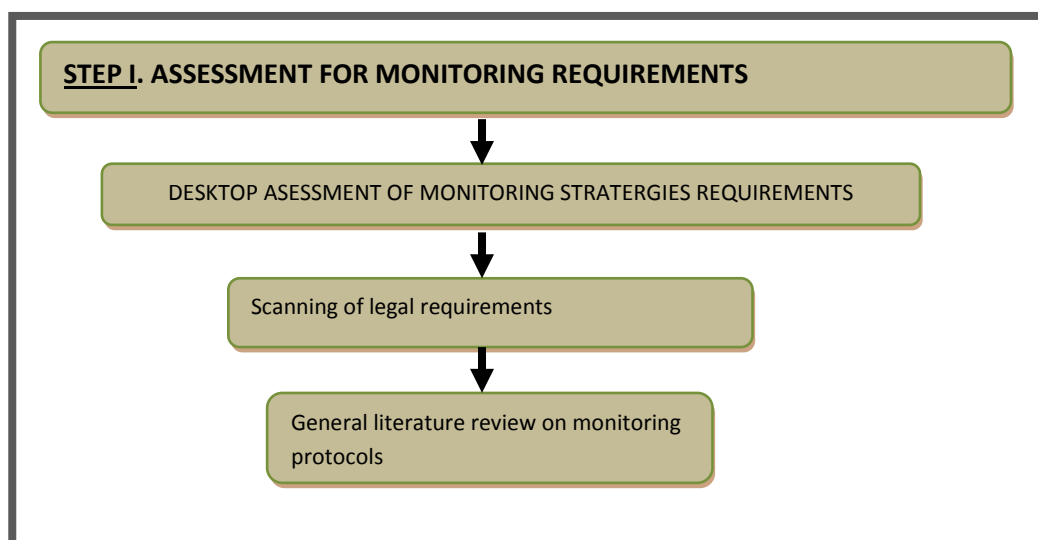


FIGURE 3.2: The activities involved during assessment of the monitoring requirements

The international legal requirements must also be scanned to gain an insight of the proceedings in *Cryptosporidium* and *Giardia* monitoring internationally. The international standards and acts to be scanned will include the U.S. Environmental Protection Agency (USEPA) (2006), Drinking Water Standards New Zealand (DWSNZ) (2008), Australian Drinking Water Quality Guidelines (ADWG) (2004), the Drinking Water Inspectorate (DWI) (2008), the Water Supply (Water Quality) Regulations (Northern Ireland) 2007,

and other relevant international acts and standards applicable during the assessment. Some of these Guidelines and documents can be obtained from the following links: <http://www.dwi.gov.uk> <http://www.epa.gov> <http://www.nhmrc.gov.au> <http://www.moh.govt.nz/water>

Phase II: Situation analysis of source, water purification plant and disease outbreak. This phase includes onsite assessment of the source water, facilities, equipment, operation and maintenance of the entire drinking water system. This is an intensive phase of the survey which includes Step II of the protocol up to Step VII. During this survey the source water as well as the water treatment plant can be evaluated for risk of *Cryptosporidium* and *Giardia*. At the end of this phase the risk of the complete water treatment system can be categorized into either, very high risk, high risk, medium risk or low risk.

STEP II (a): Description and characterization of the source water types (Figure 3.3). Source water should be characterized in order to identifying the possibility of *Cryptosporidium* and *Giardia* contamination. Source water types could be classified into:

- Protected groundwater –groundwater is usually protected against contamination from the surface by soils and covering rock layers (ESSF, 2005). In other cases ground water may be protected by defining source protection zones within which development is limited in order to reduce the chance of spillage of potentially polluting substances (FWR, unknown).
- Unprotected groundwater - is not protected from possible impact from human sewage or livestock faecal material (DWSNZ, 2008).
- Protected surface water catchments – as with ground water protected surface water could have defining source protection zones within which development is limited in order to reduce the chance of spillage of potentially polluting substances (FWR, unknown). Protected surface water usually contains low to moderate numbers of *E.coli*. and it should be considered as being vulnerable to contamination by enteric viruses, protozoa and bacteria (DWSNZ, 2008).
- Unprotected surface water - lacks defined protection zones and can be subject to contamination by enteric viruses, protozoa and bacteria (DWSNZ, 2008).

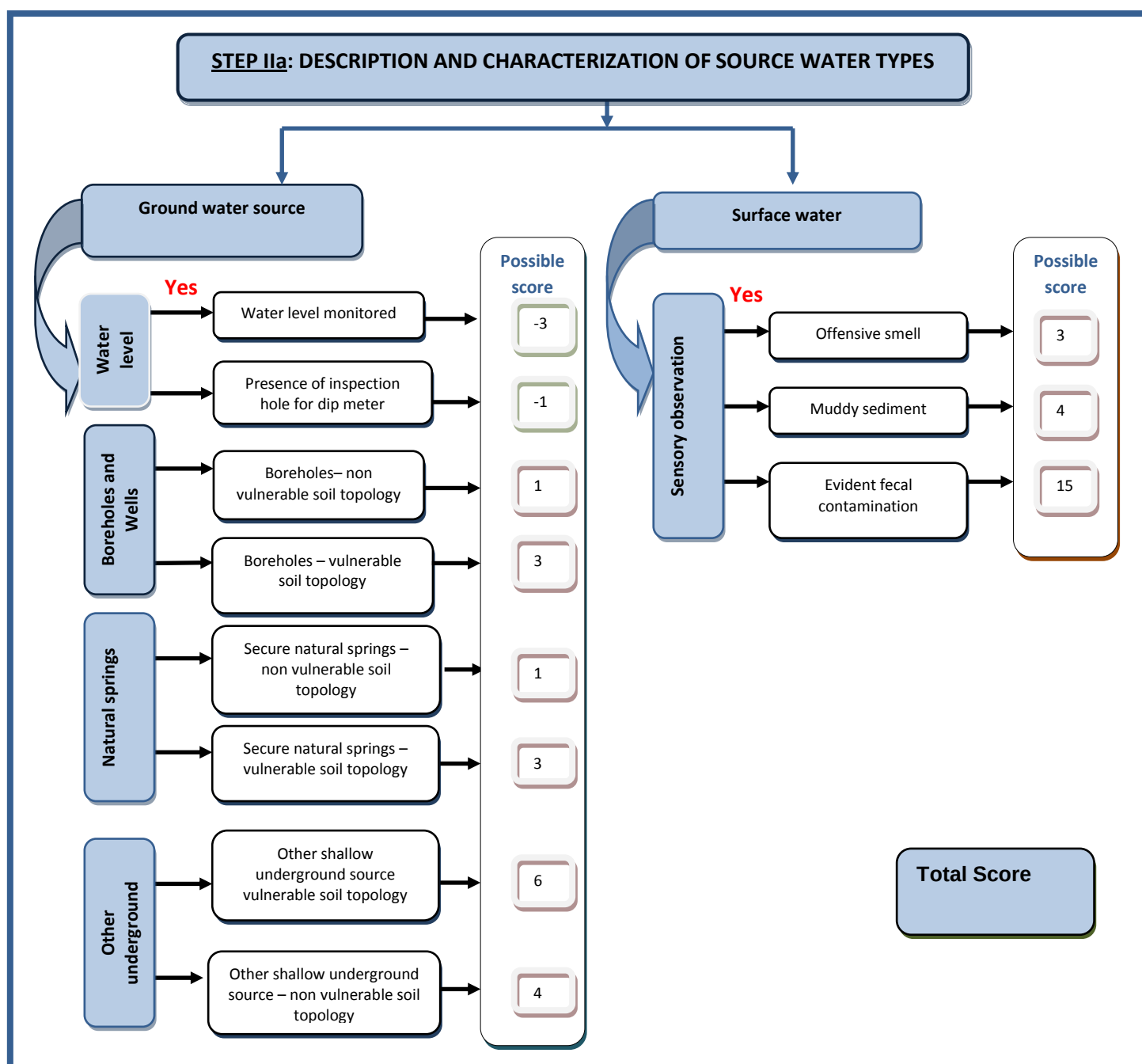


FIGURE 3.3: Description of various activities to assess for when characterizing the source water (adapted from EHS, 2002)

The monitoring requirements for water supplies derived from protected groundwater are different from those derived from unprotected surface water. Protected surface water catchments should contain low-moderate numbers of *E.coli.*, whereas unprotected surface water can be subject to contamination by enteric viruses, protozoa and bacteria and unprotected surface water should be considered as being vulnerable to contamination by enteric viruses, protozoa and bacteria (US EPA, 2006). Since *Cryptosporidium* and *Giardia* are of faecal origin any observations of the source water that could indicate the possibility of faecal contamination become of importance as it may assist in risk classification given that

human sewage and livestock faecal material are the predominant source of human infective *Cryptosporidium* and *Giardia* (DWSNZ, 2008).

STEP II (b): Assessment of the activities around the catchment and the source water (Figure 3.4): The activities around the catchment and source water should be assessed in order to determine the processes that drive and determine the characteristics of the water quality in that specific source water and the catchment (du Preez, 2000; du Preez *et al.*, 2003). The quality of drinking water sources is threatened by land development, runoff from agricultural, commercial and industrial sites, farmed animals, ageing wastewater infrastructure, urbanization as well the type of settlement around the source (Murray *et al.*, 2004). Since certain land use activities may pose a high risk, causing faecal pollution, therefore an initial land-use survey of the catchment should be undertaken to: identify existing and planned developments, potential continuous, intermittent or seasonal pollution patterns and geological features likely to affect water quality and any existing or abandoned waste-disposal sites (ADWG, 2004).

STEP IIb: ASSESSMENT OF THE ACTIVITIES AROUND THE CATCHMENT AND THE SOURCE WATER

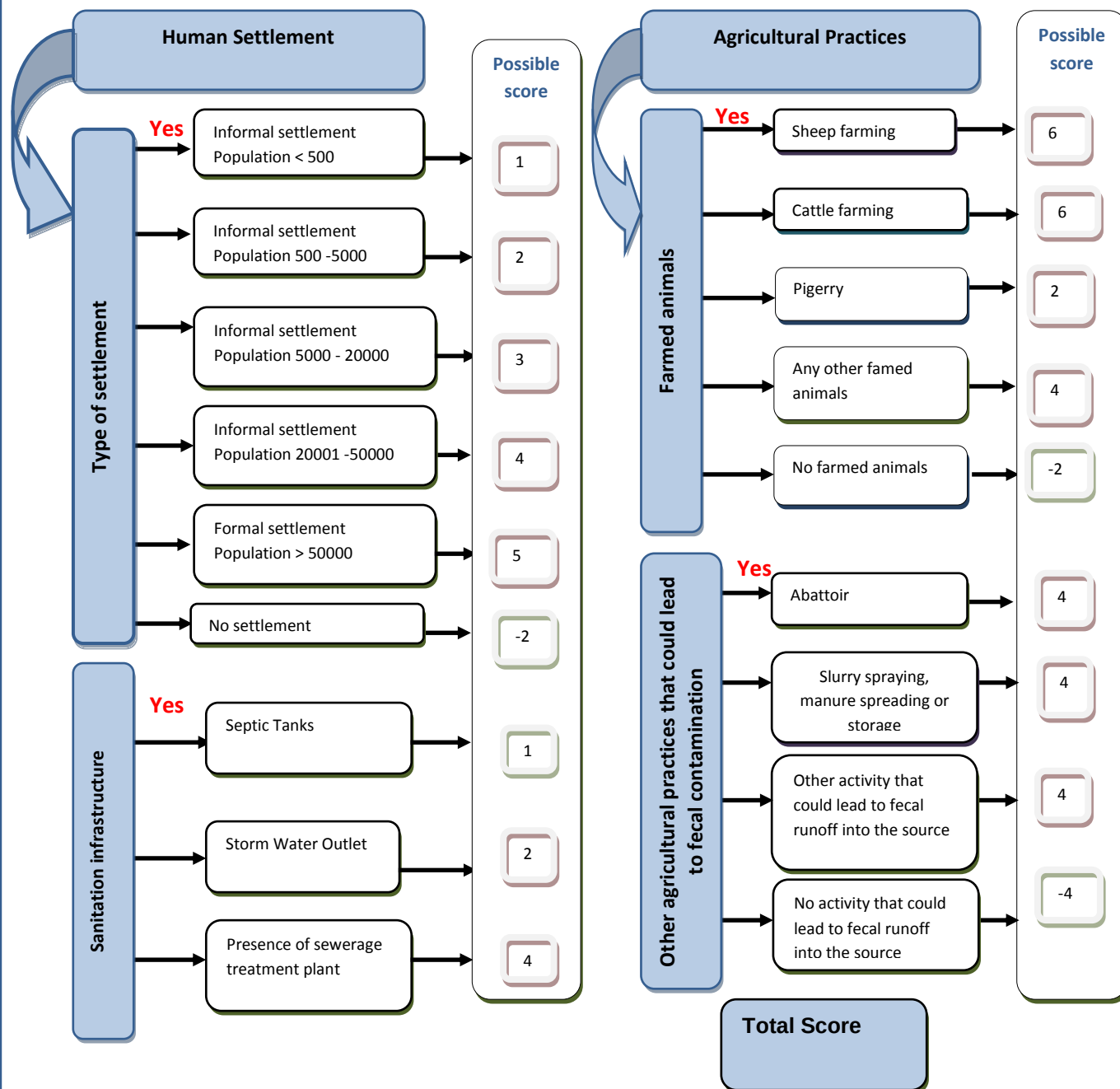


FIGURE 3.4: Assessment of the activities around the catchment and source water (adapted from EHS, 2002)

STEP III: Abstraction of the Source Water (Figure. 3.5) - This step will allow for evaluation of the risk associated with the water quality of water at the abstraction point. The quality of the water at the intake will determine the ability of the treatment plant to effectively treat the water which could pose a health risk.

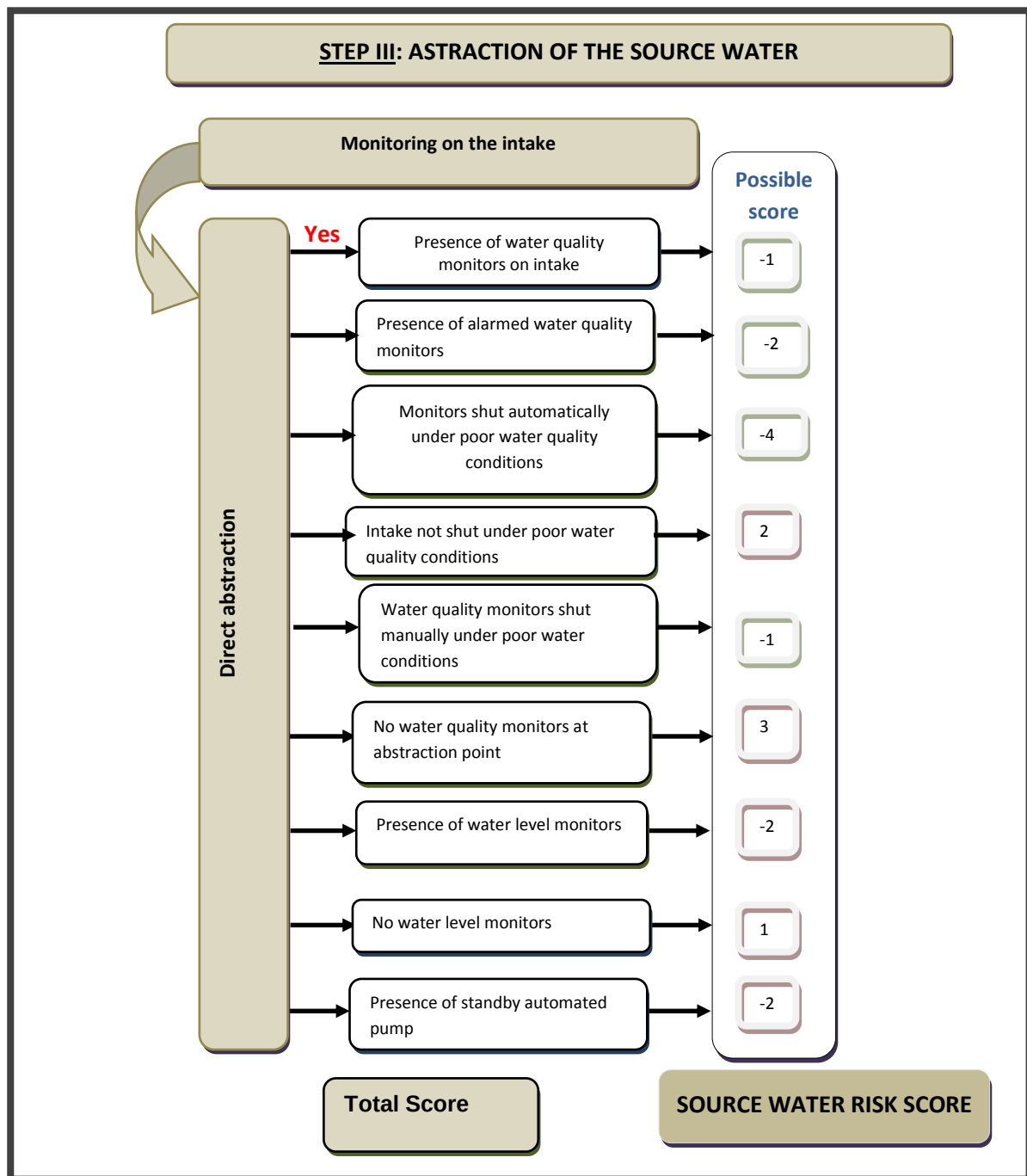


FIGURE 3.5: Monitoring at the abstraction point (adapted from EHS, 2002)

Monitoring at the abstraction point will assist in establishing the levels of source water that can be handled. Monitoring at this point could also identify mechanical failures during abstraction as well as incidences such as power failures which could assist in avoidance of sourcing too little water from the intake to meet the demand (MH, 2001).

STEP IV: Assessment of the water treatment plant (Figure 3.6 - Figure 3.8) – It is critical to monitor the performance of the water treatment plant since it plays a significant role in ensuring that water from the catchment is treated in order for it to be safe for consumers to drink. For the water treatment plant to be completely effective in the removal of *Cryptosporidium*/*Giardia* from the source water the plant should be operating optimally with no interruptions. Monitoring of plant performance will basically include assessing the situations in the plant that could lead to the breakthrough of *Cryptosporidium* and *Giardia* oocysts (ADWG, 2004). The following areas of the water treatment plant that will be evaluated by the protocol include:

(a) The type of water treatment processes (Figure 3.6)

Processes that will be evaluated for water treatment processes will include coagulation/flocculation, sedimentation, carbonation, filtration and disinfection also known as the multi barrier approach. This approach has been reported to be effective for the removal of *Cryptosporidium* and *Giardia* oocysts. The use of disinfection only as well as the use of additional treatment will be evaluated (WHO, 2004).

(b) Operational parameters (Figure 3.6)

Assessment of monitoring in the treatment plant will include monitoring of turbidity after coagulation, monitoring of residual coagulants, monitoring of floc settling rate, inspection of water clarity after sedimentation, as well as evaluation of pH during carbonation.

STEP IV. ASSESSMENT OF THE WATER PURIFICATION PLANT

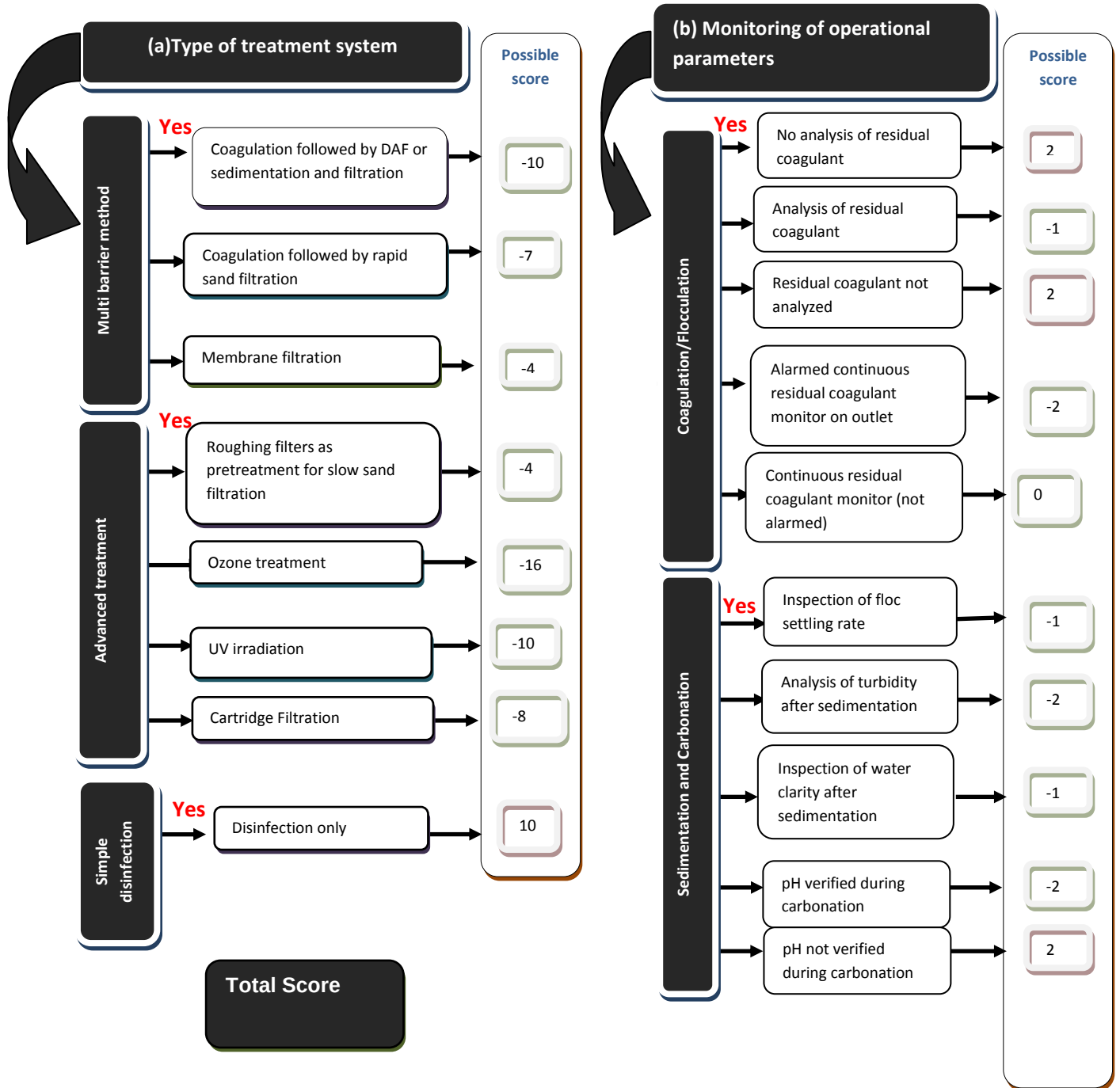


FIGURE 3.6: Assessment of the treatment system and operational parameters of the water purification plant (adapted from EHS, 2002)

(c) Filter performance and turbidity during filtration (Figure 3.7)

When the filtration process is one of the water purification steps it is important to monitor for turbidity from each individual filter to ensure that filtration is effective (ADWG, 2004). It is also important to ensure that there are no disturbances in the flow and the filter nozzles are in a good condition since this could result in poor particle removal (Haarolf, 2008). For effective removal of *Cryptosporidium* oocysts and *Giardia* cysts it is important to maintain the turbidity at less than 0.5 NTU (DWSNZ, 2008).

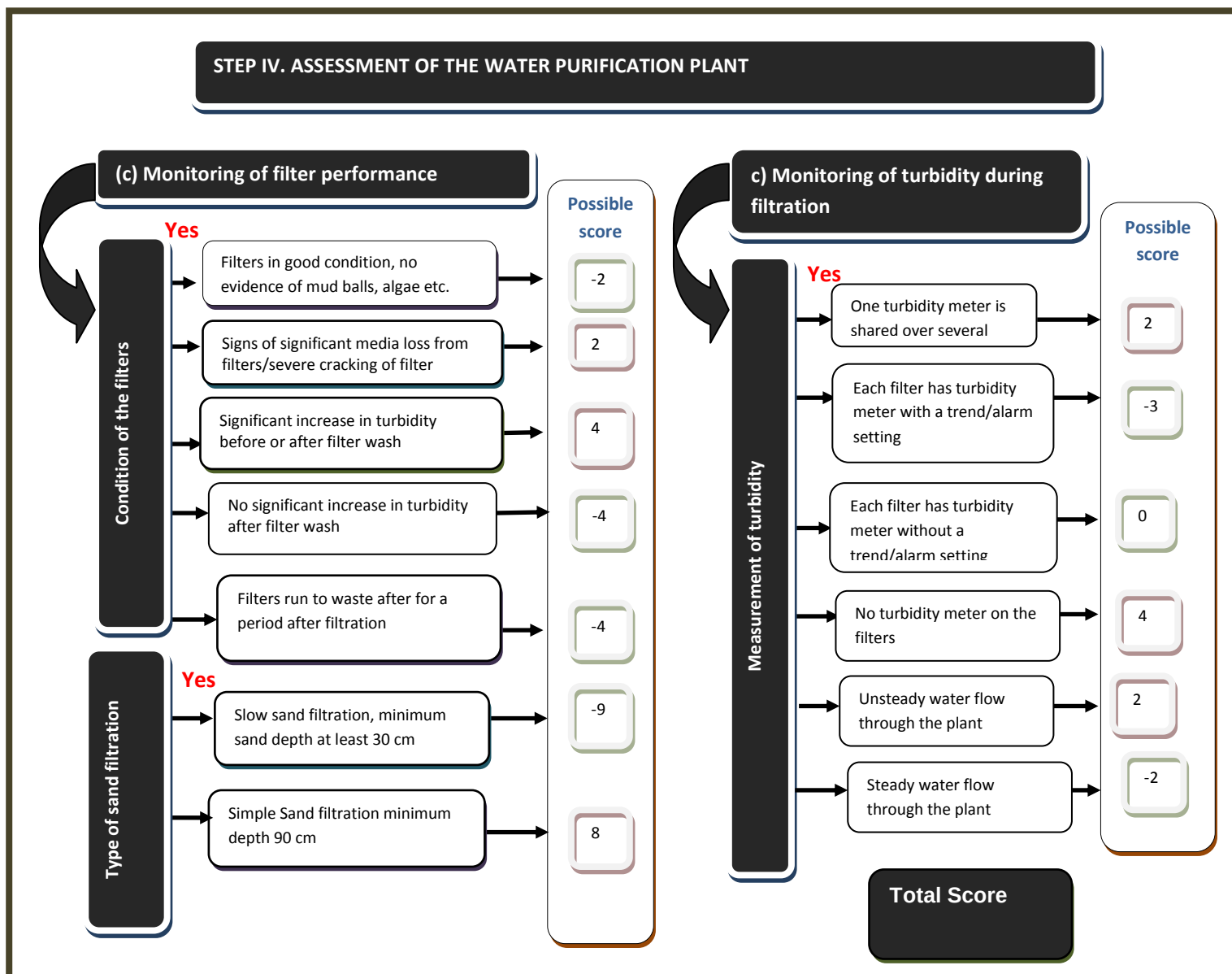


FIGURE 3.7: Assessment of the filter performance and turbidity during filtration (adapted from EHS, 2002)

(d) Quality control (Figure 3.8)

This step will assist in evaluating the presence of the quality control system and the adherence thereto. For the treatment works to operate optimally it is important to ensure that all the deviations to the quality control procedures are attended to. Example of the quality control systems that could be put in place for effective operation of the water purification plant is the ISO 9000, ISO 14001, OHAS 18000.

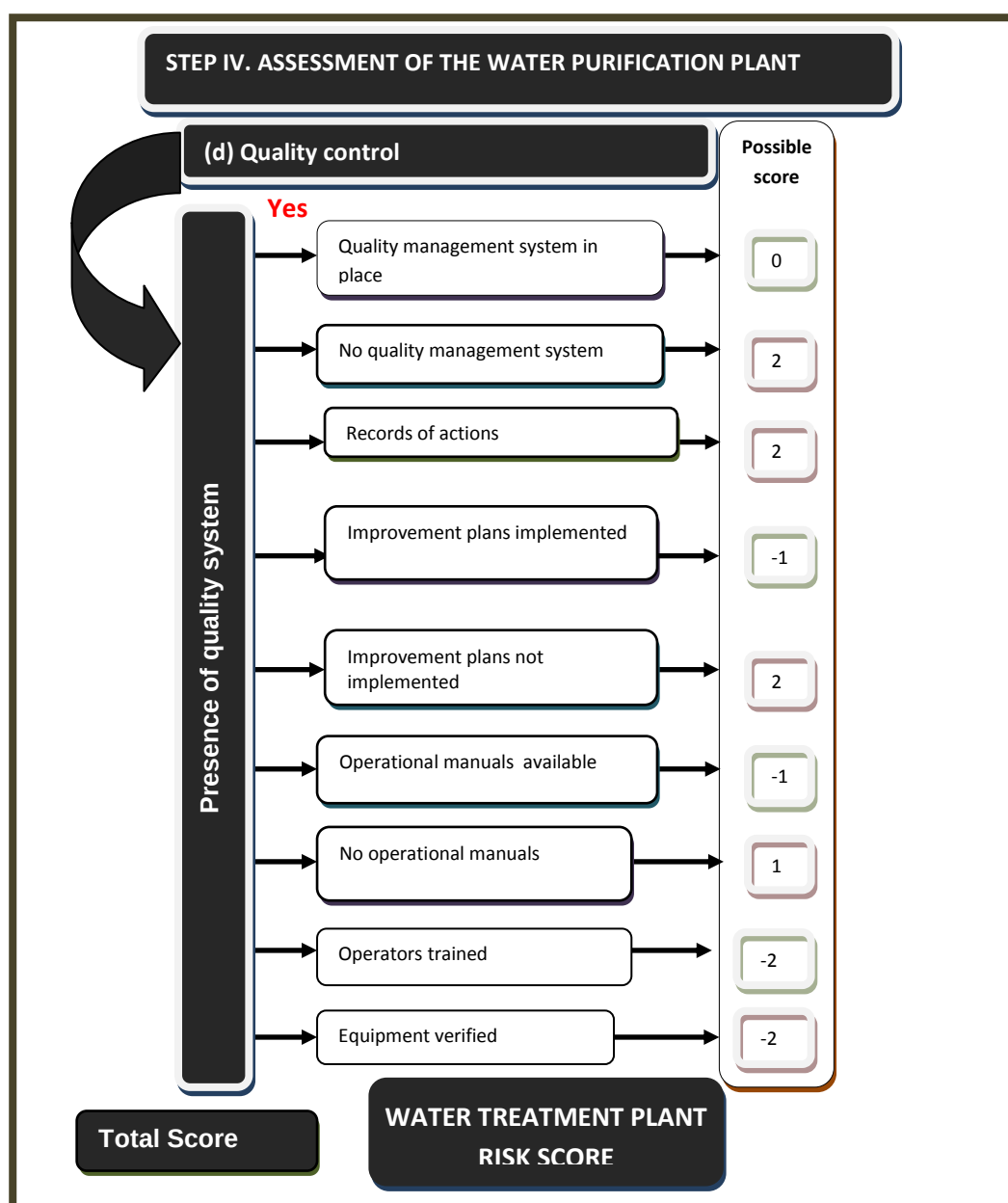


FIGURE 3.8: Steps involved during assessment of the presence of the quality control system (adapted from EHS, 2002)

STEP V. Water Quality Monitoring (Figure 3.9). The purpose of this step is to assess the availability and / or the presence of monitoring data for *Cryptosporidium* and *Giardia*. The availability of data for monitoring of *Cryptosporidium* and *Giardia* in source water will give an indication of the status of the source water in terms of risk. Hence it will assist the water utility in taking the necessary precautionary measures such as selecting the treatment method to be used, and developing an applicable sampling program before using the source water.

On the other hand, the availability of *Cryptosporidium* and *Giardia* data for treated water could assist the water utility in evaluating whether the treatment process in place is effective or not. Hence this can assist in identifying if there is a need to improve the treatment process or to improve the monitoring processes to

STEP V. Water Quality Monitoring (Figure 3.9). The purpose of this step is to assess the availability and / or the presence of monitoring data for *Cryptosporidium* and *Giardia*. The availability of data for monitoring of *Cryptosporidium* and *Giardia* in source water will give an indication of the status of the source water in terms of risk. Hence it will assist the water utility in taking the necessary precautionary measures such as selecting the treatment method to be used, and developing an applicable sampling program before using the source water.

On the other hand, the availability of *Cryptosporidium* and *Giardia* data for treated water could assist the water utility in evaluating whether the treatment process in place is effective or not. Hence this can assist in identifying if there is a need to improve the treatment process or to improve the monitoring processes to improve the mitigation of *Cryptosporidium* and *Giardia* (ADWG, 2004). In South Africa the requirements of *Cryptosporidium* and *Giardia* are less than 1 oocyst per 10ℓ in countries such as UK, USA and Northern Ireland the minimum acceptable concentration for *Cryptosporidium* and *Giardia* is also less than 1 oocyst per 10ℓ.

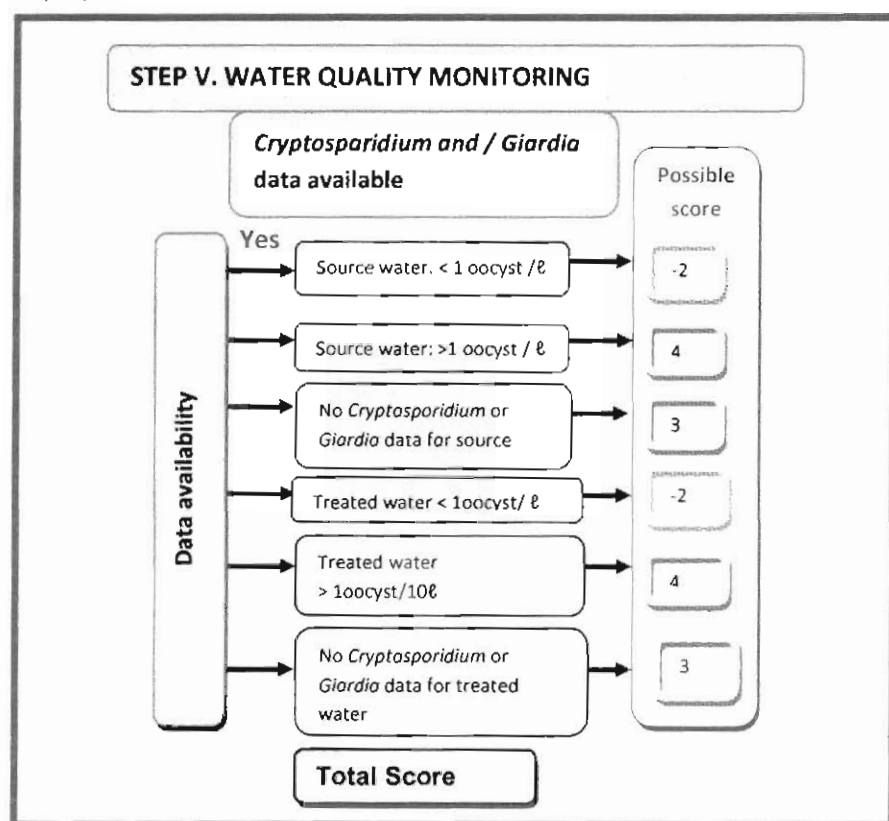


FIGURE: 3.9: Activities involved during water quality monitoring (adapted from EHS, 2002)

improve the mitigation of *Cryptosporidium* and *Giardia* (ADWG, 2004). In South Africa the requirements of *Cryptosporidium* and *Giardia* are less than 1 oocyst per 10ℓ in countries such as UK, USA and Northern Ireland the minimum acceptable concentration for *Cryptosporidium* and *Giardia* is also less than 1 oocyst per 10ℓ.

FIGURE: 3.9: Activities involved during water quality monitoring (adapted from EHS, 2002)

STEP VI: *Cryptosporidiosis* and *Giardiasis* outbreak (Figure 3.10). This step will evaluate if there are any known incidences of *Cryptosporidiosis* and /*Giardiasis* or not, no suspicions of *Cryptosporidiosis* and /*Giardiasis* and also to check awareness of the disease.

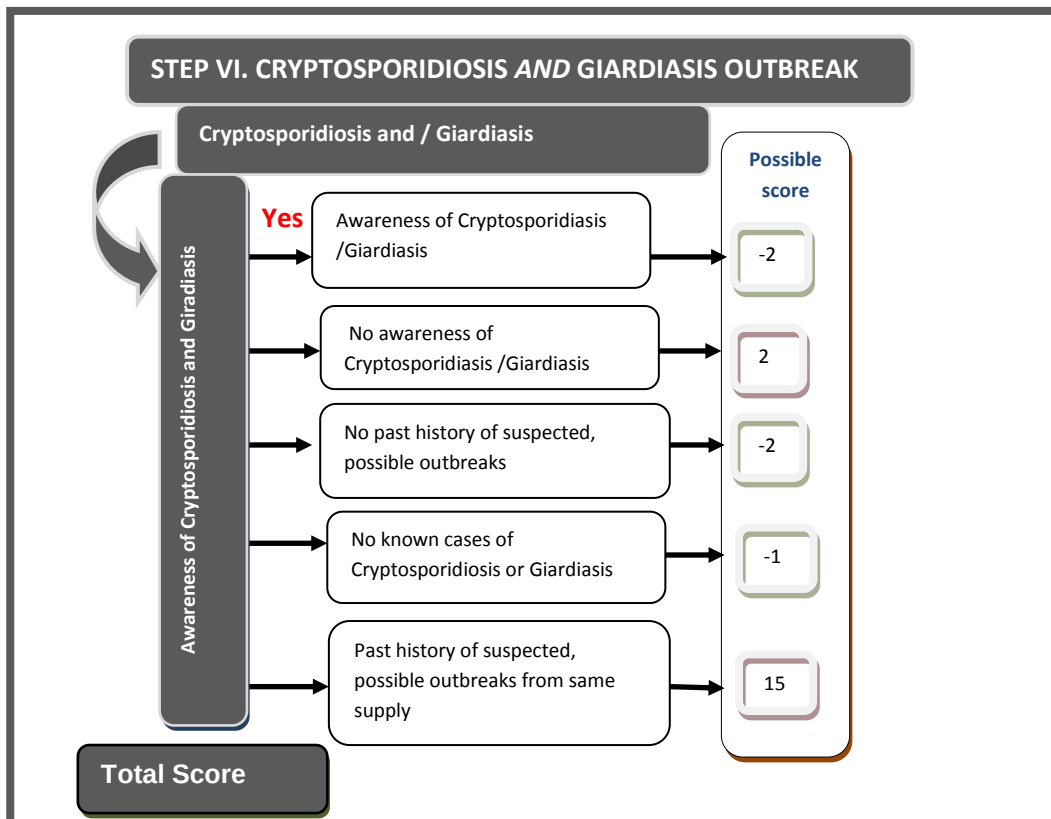


FIGURE 3.10: *Cryptosporidiosis* and *Giardiasis* outbreak (adapted from EHS, 2002)

STEP VII: Risk categorization (Figure 3.11)

In this step all the scores assigned in the previous steps are processed in order to allocate the final risk score and rating.

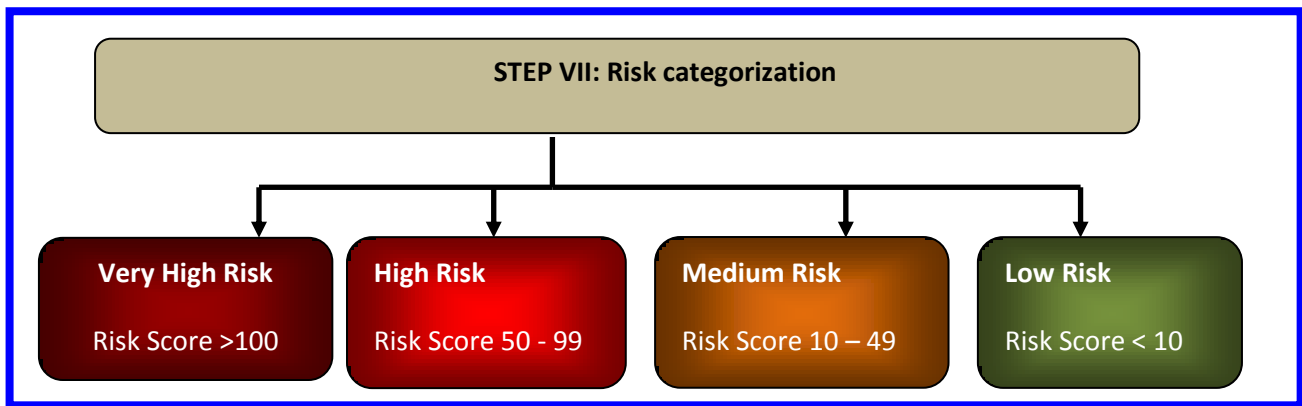


FIGURE 3.11: Characterization of risk using the risk assessment scores

Calculation of the final risk score will be done according to the formula described in the guidelines for monitoring of *Cryptosporidium* in Netherlands (EHS, 2002) which is as follows:

Population Weighting = $0.4 \times \log_{10}$ (population served by supply) Final Risk Assessment Score = sum of total scores x population weighting = ?

Risk will be classified into four categories which are very high risk for the risk score greater than 100, high risk, for the score less than 100 but greater than 50, medium risk for the risk score greater than 10 but less than 50 and low risk for the risk score less than 10 (EHS, 2002). The proposed protocol will allow for assessment of possible risk score from the source water as well as possible risk of *Cryptosporidium* and *Giardia* that could arise from the water treatment plant.

PHASE III: Sampling, analysis and review – This phase of the protocol includes sample collection, analysis, data storage and review. This phase clearly describes what to monitor, where to monitor, when and how to monitor for *Cryptosporidium* and *Giardia*. At the end of this phase it will be possible to quantify the magnitude of *Cryptosporidium* and *Giardia* contamination from the water sources.

STEP VIII: Sampling and laboratory processing (Figure 3.12)

a) Sampling

Sample collection is guided by risk classification since sample frequency, sampling points and the number of samples to be collected is determined by the risk score. The following is recommended for different risk categories:

- (i) **Very high risk areas:** Samples should be collected within 12 hours after risk has been characterized. Sampling must be done at all the critical control points along the water supply chain, i.e. at the source, at abstraction, at the water treatment plant as well as the final treated water. If the source water is from the dam, main tributaries should also be analyzed. The sampling frequency for these areas will be as follows: source water sampling will be done once a week, twice a week at the abstraction point, once at the water purification plant after filtration and three times a week on the final water. This should be adhered to until the risk has been reduced to medium risk. However, if *Cryptosporidium* is detected in the final water despite the risk score, sampling will be done in accordance to the incidence management, described by DWAF (2007) until there are no oocysts detected in the treated water.
- (ii) **High risk areas:** Samples should be collected within 24 hours after risk has been characterized. Sampling must be done at all the critical control points along the water supply chain i.e. at the source, at abstraction, at the water treatment plant as well as the final treated water. If the source water is from the dam, main tributaries should also be analyzed. The sampling frequency for these areas will be once a week until risk has been reduced to medium risk. However, if *Cryptosporidium* is detected in the final water despite the risk score, sampling will be done in accordance to the incidence management, described by DWAF (2007) until there are no oocysts detected in the treated water.

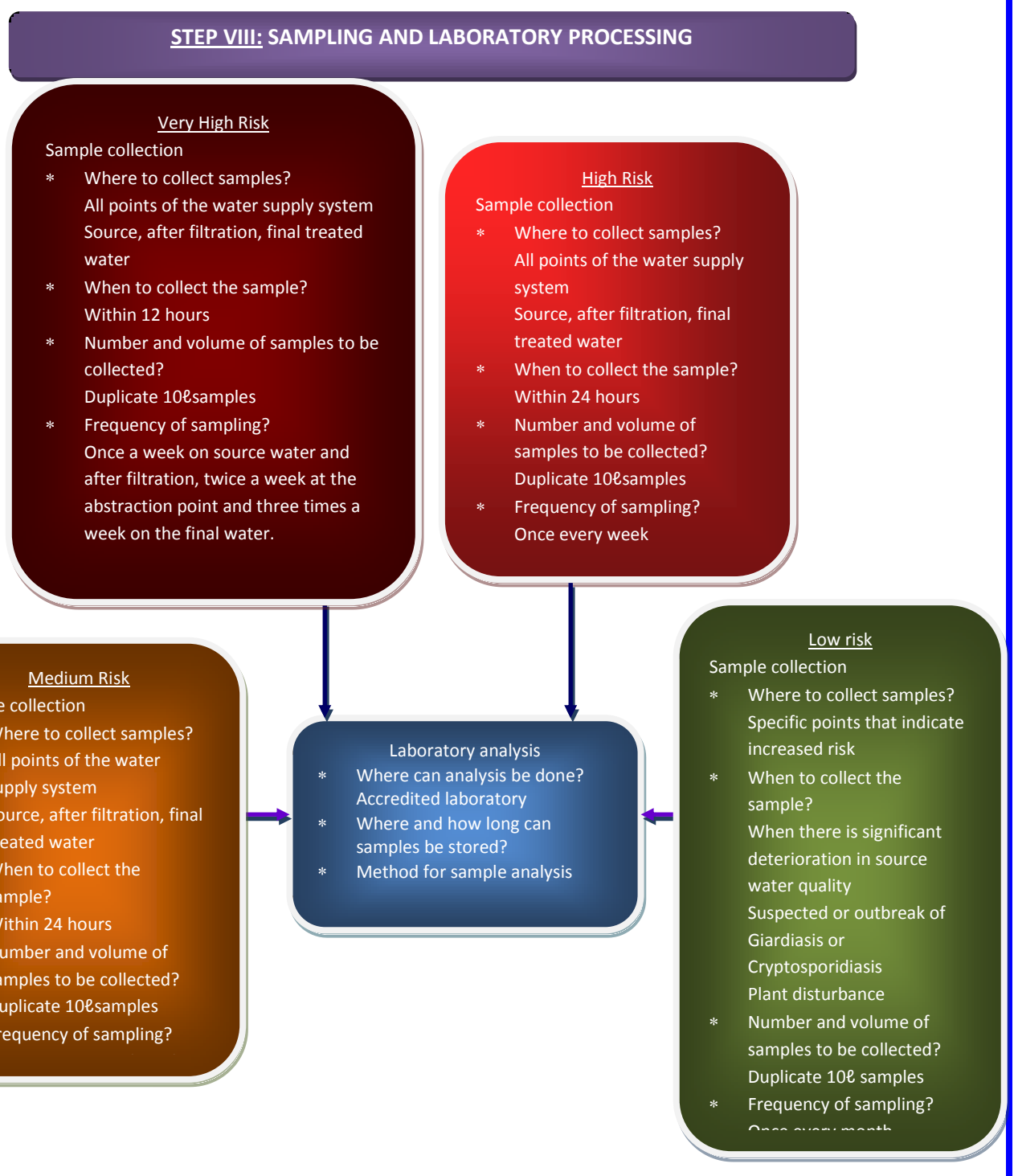


FIGURE 3.12: Activities involved during sampling and laboratory analysis

- (ii) **Medium risk areas:** As with high risk areas, samples should be collected within 24 hours after the risk has been categorized. However samples should be collected at the points of the water treatment system identified as high risk. The sampling frequency for these areas should be once every second week until risk has been reduced to low risk. However in the event where

Cryptosporidium is detected in the final water, sampling must be done in accordance to the incident management protocol, described by DWAF (2007) despite the risk score until no oocysts are detected in the treated water. In addition, during the events such as increased source water contamination and other events that may lead to faecal contamination, the frequency of sampling should be increased to once a week until the effects of the events have subsided (EHS, 2002).

- (iii) **Low risk areas:** Samples will be collected at the points of the water treatment system identified as high risk. The sampling frequency for these areas will be when required. This will be determined by events such as increased source water contamination, during events that may lead to faecal contamination such as sewerage spill as well as during suspected Cryptosporidiosis or Giardiasis (EHS, 2002). However, as with high risk areas and significant risk areas in the incidences where *Cryptosporidium* is detected in the final water, sampling must be done in accordance with the incident management protocol described by DWAF (2007) despite the risk score until there is no oocysts detected in the treated water.

Although the risk determines the sampling point and the sampling frequency it is important that before sampling, the sampling program and the requirements and the protocol are discussed with the laboratory that will be in charge of the analysis. A 10ℓ plastic carboy or container is recommended for sampling. To avoid cross contamination it is recommended that carboys used for collection of source water be dedicated to source water only and those for drinking water be specifically used for collection of drinking water only. For sampling of the surface water it is important to ensure that sediment is not introduced into the sample and this can be achieved by sampling using a 5ℓ beaker until the required volume has been sampled (RW, 2009b).

Correct labeling and detailed documentation of sample location vital for traceability. The information in the table below could be used as a label that should be filled during sample collection. The form will indicate items such as the date, the name of the sampling point if any, location and the volume collected (Table3.1)

TABLE 3.1: Example of the sample collection form that could be used for collection of *Cryptosporidium* and *Giardia* analysis

Date:	Sample name:		
Location:			
Evidence of faecal contamination:			
Yes	☐	No:	☐
Other identified possible risk of faecal contamination:			
Yes	☐	No:	☐
Volume Collected:	☐	Additional comments:	
Collected by:			
Signature:			

b) Laboratory processing

It is important that the selected laboratory should perform internationally accepted methods for the analysis of *Cryptosporidium* and *Giardia*. If possible, analysis should be performed by a laboratory which has been accredited under international standard ISO/IEC 17025 (ISO/IEC 1999). In South Africa, South African National Accreditation System (SANAS) is the body responsible for accreditation of analytical laboratories (Du Preez, 2000). For *Cryptosporidium* and *Giardia* sample analysis, laboratories such as Rand Water (Scientific Services, P.O Box 3526, Vereeniging, 1930, South Africa) and Council for Scientific and Industrial Research (Environmentek, P. O. Box 35 Pretoria, 0001, South Africa) could be approached for analysis. However, this statement is not an endorsement of these laboratories.

c) Analytical methods

At the laboratory samples could be stored for up to 96 hrs at 4°C. The methods required for detection of *Cryptosporidium* oocysts in water are different and more complex than the methods used for the detection of bacteria. There are a number of methods available for analysis of *Cryptosporidium* and *Giardia*. Methods such as sample concentration on flat membrane and cartridge filtration have been widely used and well reviewed. However, due to the methodological challenges associated with *Cryptosporidium* and *Giardia*

analysis, it is recommended that the laboratory performing the analysis must have a documented quality control and quality system in place. It is recommended that well published and well reviewed methods such as the US EPA Method 1623 (US EPA, 2005), Rand Water Method 06 (RW, 2010) and the DWI (2003) be followed for sample processing. The quality control procedures must be carefully followed and adhered in order to render the results credible. The above mentioned methods can be found at the following websites: www.epa.gov/microbes/1623de05.pdf, [http:// www.dwi.gov.uk](http://www.dwi.gov.uk) .

STEP IX: Data Evaluation, interpretation and Storage (Figure 3.13)

The results of the analysis will be reported as oocysts or cysts per 10ℓ. Any incidence of *Cryptosporidium* in treated water at a concentration of one or more oocysts in 10ℓ will be reported as a priority. The procedures described in the Protozoan Incident Management Framework described by RW, (2010b) and DWAF (2007) will be followed. These entail notification of Municipality, Department of Water Affairs and the Department of Health (DWAF, 2007).

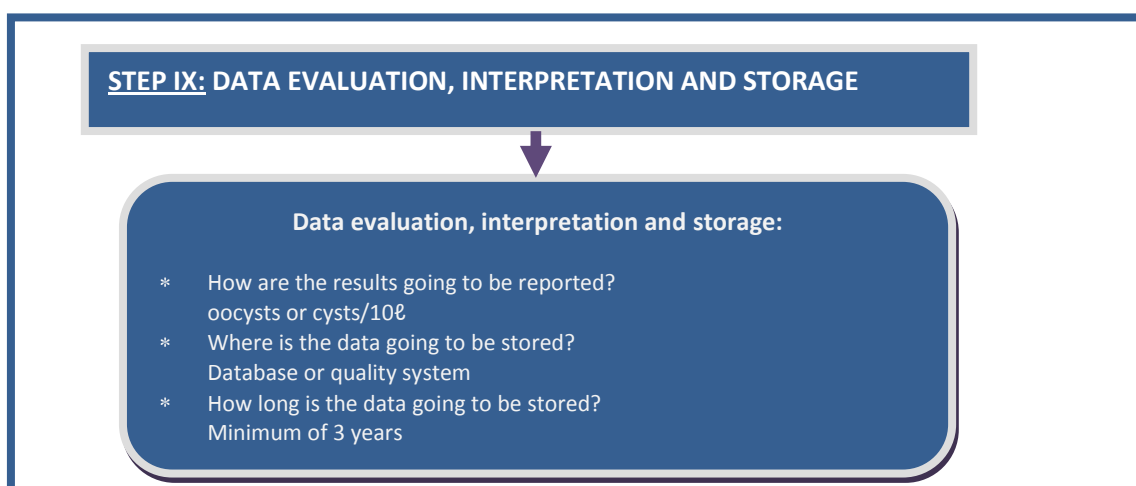


FIGURE 3.13: Data processing and storage

The results should be stored in the database in the presence of software such as laboratory information management system (LIMS). Data reports should be compiled and these should be stored for at least three years

PHASE IV: Monitoring process review – During this phase, the date of the next review will be determined.

STEP X: Process Evaluation and Review (Figure 3.14)

During the review the mitigation measures taken should be considered and these should be noted in the Desktop survey, the review will take place every three years or if there is significant deterioration of the source water quality, if there is a suspected Cryptosporidiosis or Giardiasis outbreak or in the event of plant

disturbance which could possibly result in the leakage of *Cryptosporidium* and *Giardia* oocysts into the treated water (EHS, 2002). However, in case of very high risk areas the frequency of monitoring could be increased and the mitigation measures be imposed until the results are satisfactory. Desktop survey should be re-assessed in order to ensure that there are no major changes in the regulations.

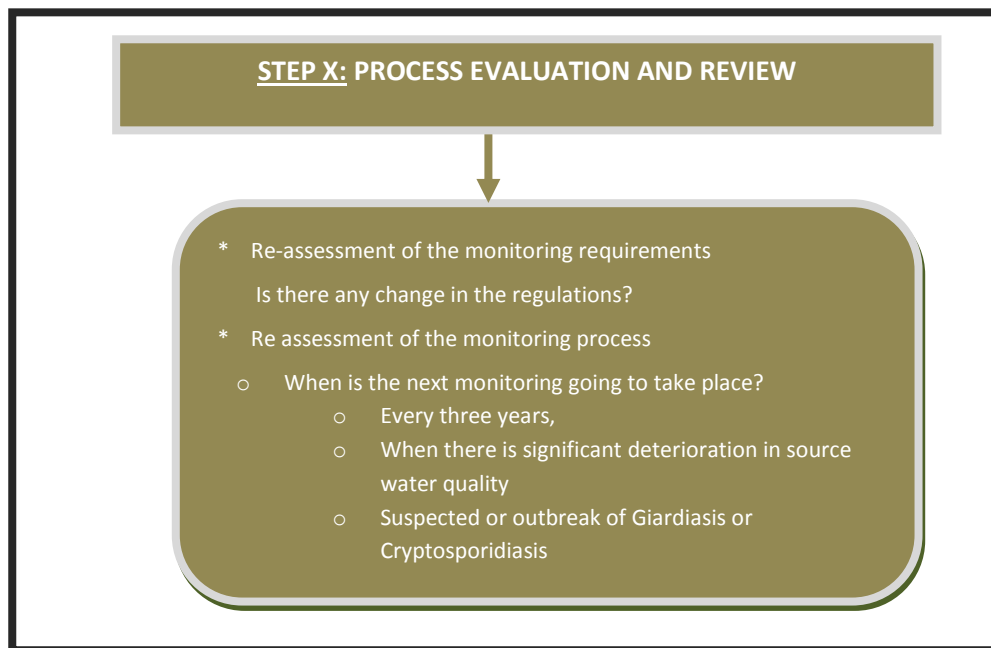


FIGURE 3.14: Process evaluation and review

3.3. Conclusions

A generic monitoring protocol for management of *Cryptosporidium* and *Giardia* in drinking water has been developed. Monitoring of *Cryptosporium* and *Giardia* should be well planned to ensure that the objectives of the assessment are achieved. Monitoring procedures described in this chapter must be followed, although in some cases certain activities are not applicable to the specific area of investigation. At the end of the assessment the water utilities will be able to identify very high risk areas, high risk areas, medium risk areas, as well as low risk areas and this will enable them to draw up mitigation plans for very high risk areas and high risk areas as well as plans to avoid contamination of the low risk areas. However, before the protocol is applied, the feasibility of applying the protocol will be tested on a small system, the drinking water purification plant.

CHAPTER 4

EVALUATION OF PROTOCOL ON VAAL RIVER BARRAGE SYSTEM

4.1 Introduction

The Vaal River Barrage catchment (Barrage) was built downstream of the Vaal Dam in 1923. It is situated in the lower Vaal River in Gauteng. It covers an area of approximately 64 kilometers with an estimated storage capacity of 63 million liters, the surface area of 168,35 square kilometers and has an average depth of 4, 5 meters (RW, unknown). It was the main source water for Rand Water, but, due to deterioration of water quality in the catchment, most (97%) of the source water is now abstracted from the Vaal Dam. However, the source water from the Vaal River Barrage catchment is currently used as an emergency water source for Rand Water and for agricultural, industrial, as well as for domestic purposes in Gauteng and the lower Vaal River (van Wyk, 2000; du Preez, 2000). The Barrage has become a major recreational place for the local communities, surrounding towns and cities where, activities such as camping, canoeing, boating, picnicking, bird watching, water-skiing and fishing are performed (van Wyk, 2000). These activities are illustrated in Figure 4.1.



FIGURE 4.1: Recreational activities, towns along the Vaal River Barrage catchment, and tributaries feeding into the Vaal River Barrage catchment (Loch Vaal, 2010)

However, there is a concern about the water quality at the Barrage due to the quality of water from the rivers feeding into the catchment. These rivers include, Suikerbosrant, Klip, and Rietspruit Rivers which flow from industrial and heavily populated areas such as Johannesburg, Vereeniging and Sasolburg (Rand Water, unknown). Pollution of these rivers result from urban run-off, run-off from informal settlements, industrial

discharges, discharge of partially treated effluent from the waste water treatment works, and overloading of the wastewater treatment works (Osche, 2007). It has reached levels where it may have an impact on the water quality at the Vaal River Barrage catchment, and it could pose a risk to domestic, recreational water and agricultural users at the catchment (du Preez, 2000; du Preez *et al.*, 2003), since the use of faecal contaminated water for drinking, recreation, or irrigation may cause serious health risk (Murray *et al.*, 2004).

Given that drinking and swallowing faecal contaminated water may lead to infection with protozoan parasites *Cryptosporidium* and *Giardia*, which can result in Cryptosporidiosis and Giardiasis respectively (WHO, 2004), Rand Water has a duty to ensure that the water supplied to their consumers is free from these parasitic protozoan. To achieve this Rand water has to implement the Water Safety Plans (WSP) of which monitoring of variables such as *Cryptosporidium* and *Giardia* form an important component of the WSP. Furthermore, Rand water has a duty to protect its source water by minimizing deterioration of the quality of in the source water, in order to supply safe drinking water (van Wyk, 2000). Therefore, it is important that the water supply system is monitored from source to tap.

As indicated in Chapter 3, a generic monitoring protocol for *Cryptosporidium* and *Giardia* in treated water was developed (Figure 4.2), which will contribute to the WSP. In this section of the dissertation, the developed protocol is tested at the Rand Water Barrage water purification plant that supplies drinking water to the local community. As a result, the main objectives of this Chapter are:

- To apply and evaluate the monitoring protocol proposed in Chapter 3 at the Vaal River Barrage catchment
- To evaluate the present risk category of the source water and the treated water from the Vaal River Barrage catchment

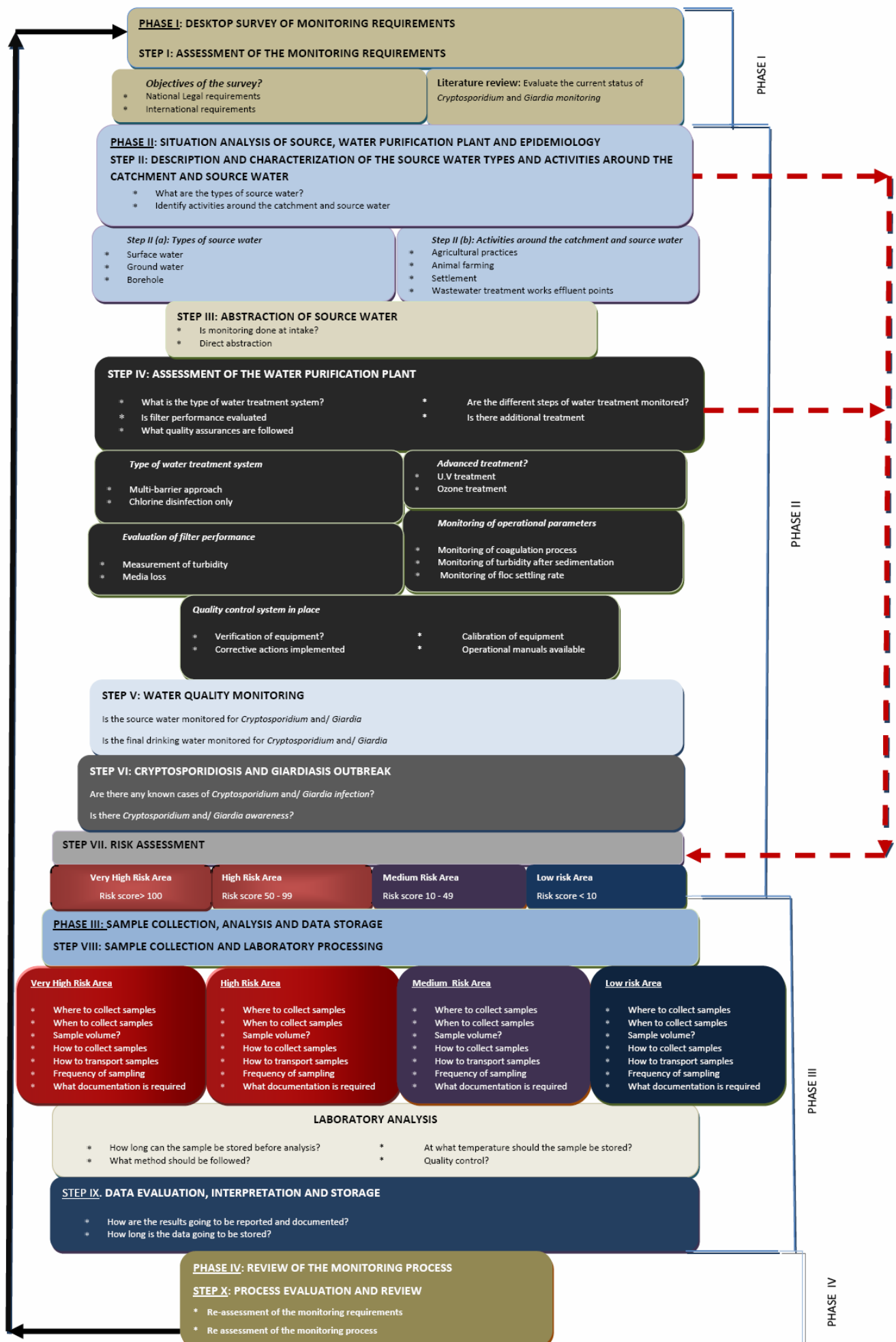


Figure 4.2: The developed protocol for monitoring of *Cryptosporidium* and *Giardia*

4.2 Monitoring of *Cryptosporidium* and *Giardia* at the Vaal River Barrage catchment using the developed protocol

4.2.1 Phase I: Desktop survey of monitoring requirements - Accessing of *Cryptosporidium* and *Giardia* information from published and non-published sources.

4.2.1.1 Step I: Desktop survey of monitoring requirements

The objective of the survey is to assist management of Rand Water in achieving the South African legal requirements of less than 1 oocyst/10ℓ and 1 cyst/10ℓ *Cryptosporidium* oocysts and *Giardia* cysts respectively in drinking water.

With all the specified regulations, it was noticeable from the literature that three main approaches for monitoring of these protozoan parasites have been identified. These are the log-reduction approach, applied in the United States (US EPA, 2006) and New Zealand (DWSNZ, 2008), the risk – based assessment followed in the United Kingdom (DWI, 2008) and Northern Ireland (EHS, 2002) and the nothing approach was observed in South Africa and Canada (GCDWQ, 2004) respectively.

Although the do nothing approach was observed in South Africa, the drinking water quality in South Africa is evaluated against the South African National Standards (SANS) 241 (2006) which requires that *Cryptosporidium* and *Giardia* in drinking water should be less than 1 oocyst/10ℓ and 1 cyst/10ℓ respectively. In addition, from the literature, it could be deduced that *Cryptosporidium* and *Giardia* are abundant in the surface waters of South Africa (Kfir *et al.*, 1995; Harding & Genthe 1996; Jarmey-Swan *et al.*, 2001; Adams *et al.*, 2005; Dungeni & Momba 2010). However, not all water utilities in South Africa monitor for these parasitic protozoans (Jarmey-Swan *et al.*, 2001) and there is no standard protocol for monitoring of these protozoan parasites.

Lack of monitoring of *Cryptosporidium* and *Giardia* was also noticed in Canada and Australia. In Canada, regulation of *Cryptosporidium* and *Giardia* is not mandatory, hence, there is no minimum acceptable concentration of *Cryptosporidium* and *Giardia* in drinking water. Water utilities are not required to monitor for these protozoan parasites. However, Health Canada guidelines for protozoa and enteric viruses reference an accepted annual infection risk of less than 1 in 10,000 people per year (GCDWQ, 2004). Similarly, in Australia, monitoring of *Cryptosporidium* and *Giardia* is not compulsory and there are no minimum acceptable values for *Cryptosporidium* and *Giardia*. These parasitic protozoans are only monitored under investigative research monitoring or in outbreaks in the waterborne diseases (ADWG, 2004).

In contrast, monitoring of *Cryptosporidium* is mandatory in the United States of America as it is required that all water utilities using surface water for production of drinking water monitor for *Cryptosporidium*. *Cryptosporidium* is monitored according to the Long Term 2 Surface Water Treatment Rule (LT2 rule). The rule requires that all unfiltered systems must provide at least 99 or 99.9 percent (2 or 3-log) inactivation of *Cryptosporidium*, depending on the results of their monitoring (US EPA, 2003). Exclusion of source water monitoring under the LT2 rule is allowed if the system can provide a total of at least 3-log *Cryptosporidium* inactivation, equivalent to meeting the treatment requirements for unfiltered systems with a mean *Cryptosporidium* concentration not greater than 0.01 oocysts / ℓ (US EPA, 2006). A similar trend is followed in New Zealand in requiring the log reductions based on *Cryptosporidium* concentrations the maximum acceptable values for total pathogenic protozoa is less than one infectious oocyst / 100ℓ of sample (DWSNZ, 2008). In the United Kingdom (U.K.) it is required that that a comprehensive risk assessment be conducted for each treatment works and connected supply system. This assessment covers all hazards in the hazardous events whereby *Cryptosporidium* is considered to be one of the hazards (DWI, 2008).

4.2.2 Phase II: Situation analysis of source, water purification plant and disease outbreak - This is an intensive phase which includes onsite assessment of the entire drinking water system i.e. the source water, water treatment facilities, operation and maintenance and the treated water.

4.2.2.1 Step II: Description and characterization of the source water types and activities around the catchment and source water

4.2.2.1a Step II (a): Description and characterization of the source water types (Figure 4.3)

The description and characterization of the source water was done following the steps in Figure 4.3. The survey took place in November 2010 at the Vaal River Barrage catchment. It was carried out at the catchment around the source water, at the abstraction point, at the water purification plant as well as on the treated water. Colour was assigned to the scores, red colour was assigned to the scores above one and green colour was assigned to scores zero and below zero. At the end of survey, the source water and the water treatment plant was categorized into either, low, medium, high or very high risk and the entire water supply system could also be categorized.

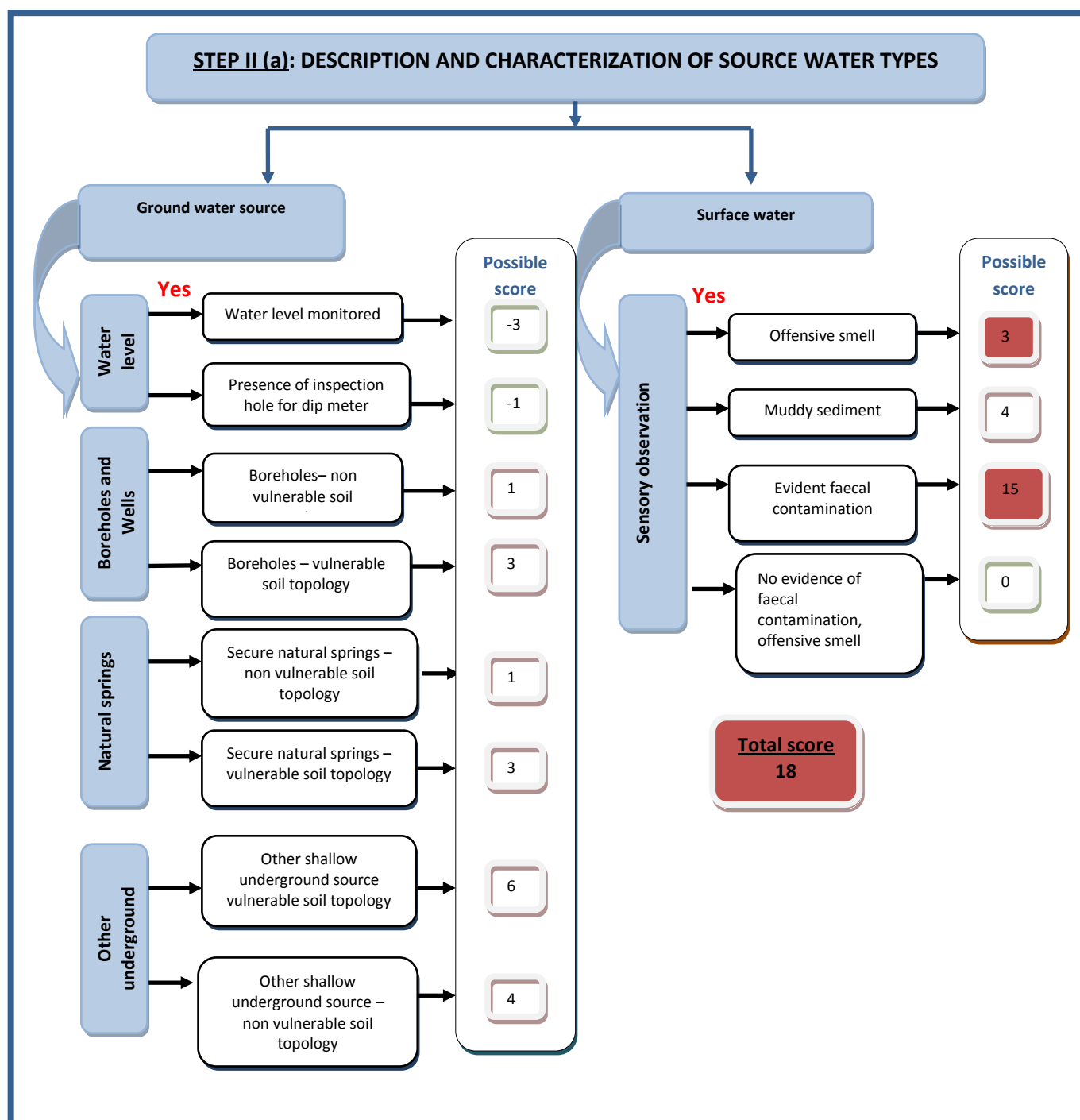


FIGURE 4.3: Description and characterization of source water types

At the Vaal River Barrage catchment, unprotected surface water is used as source water. From the literature, is indicated that unprotected surface water could have possible impact from human sewage or livestock faecal material (DWSNZ, 2008). Hence it is anticipated that the source water could have a significant amount of micro-organisms from faecal origin.

A visual assessment was done, and from that assessment, there was no evidence of faecal pollution, muddy sediment as well as no offensive smell at the Vaal River Barrage abstraction point. However, other areas of the catchment are impacted by dumping of untreated water resulting in offensive smells. Industries that have been identified around the catchment area include abattoirs, at least four wastewater treatment plants, and informal settlements (van Baalen, 2003). These can result in effluent discharge, discharge of partially treated waste water, urban runoff, and storm water drainage into the Vaal River Barrage (Groenewald, 2000), resulting in unsightly, offensive smelling faecal contaminated source water. Recently, a similar incident of discharge of unsightly, offensive smelling effluent was reported at the Klip River catchment, where it was alleged that the effluent from the Groenpunt Prison piggery was directly discharged into the river without any treatment resulting in unsightly, offensive smelling water (FSE, 2009).

4.2.2.1b Step II (b): Assessment of the activities around the catchment and the source water (Figure 4.4)

The activities around the catchment and the source water were assessed (following the steps in Figure 4.4) in order to determine the processes that influence the water quality at the Vaal River Barrage catchment. Rivers that feed into the Vaal River Barrage catchment include Suikerbosrand River, Klip River, and Rietspruit (Figure 4.1) (RW, unknown). These rivers result in drainage of pollutants into the catchments as a result of urban run-off, run-off from informal settlement, industrial discharges, discharge of partially treated effluent from the waste water treatment works as well as from overloading of the waste water treatment works. Therefore, the inputs into the Vaal River Barrage catchment incorporate the activities around these rivers and the activities include irrigation, sewage treatment plant, mining and urban development (DWAF, 2004).

Visual assessment on land use and activities around this catchment was done and it was observed that, land use in this area includes livestock farming, dry land farming, mining, industrial activities and urban development (Figure 4.5). This was substantiated by studies by Osche (2007) and similar land use patterns were reported by van Baalen, 2003.

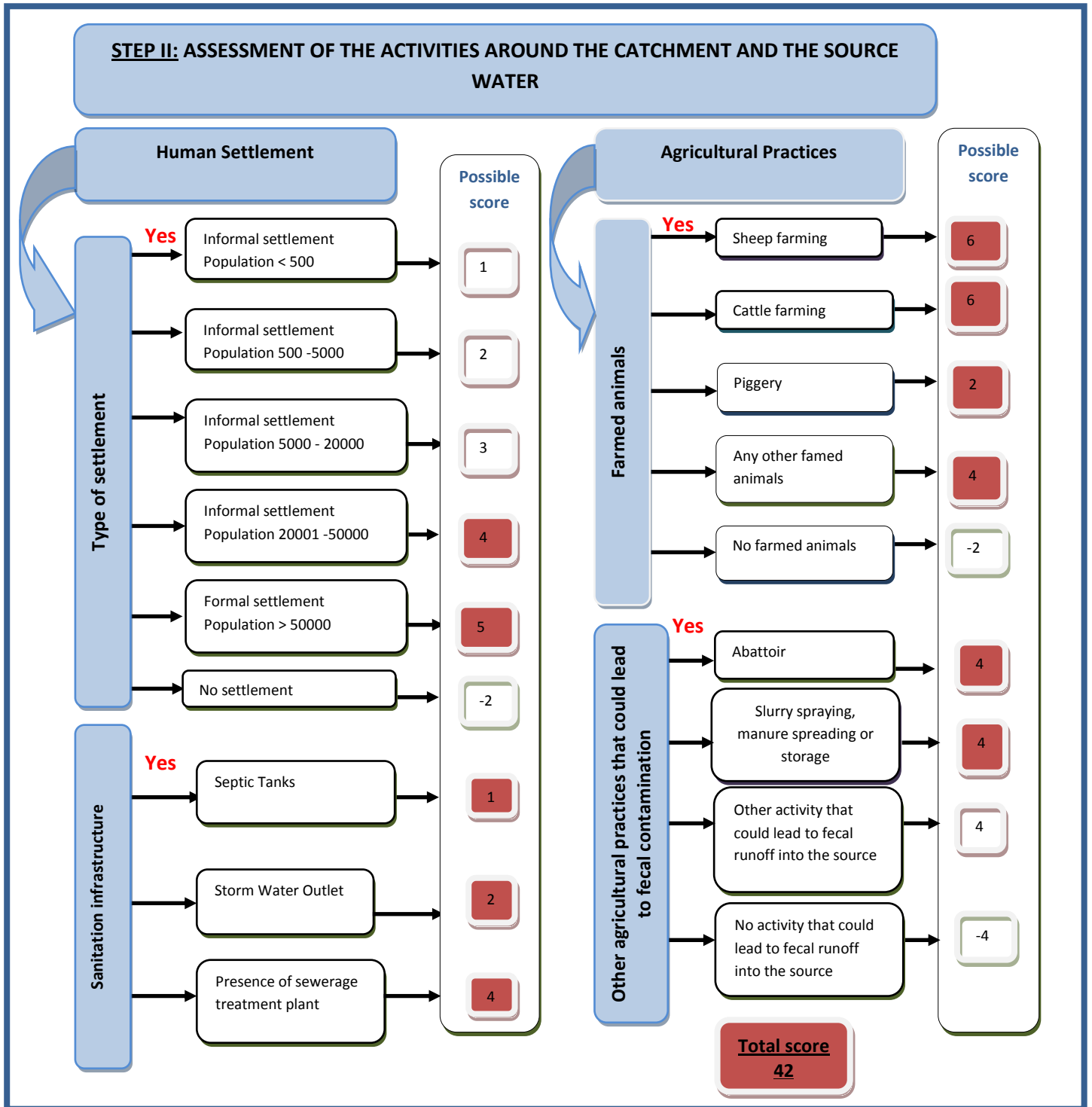


FIGURE 4.4: Assessment of the activities around the catchment and source water

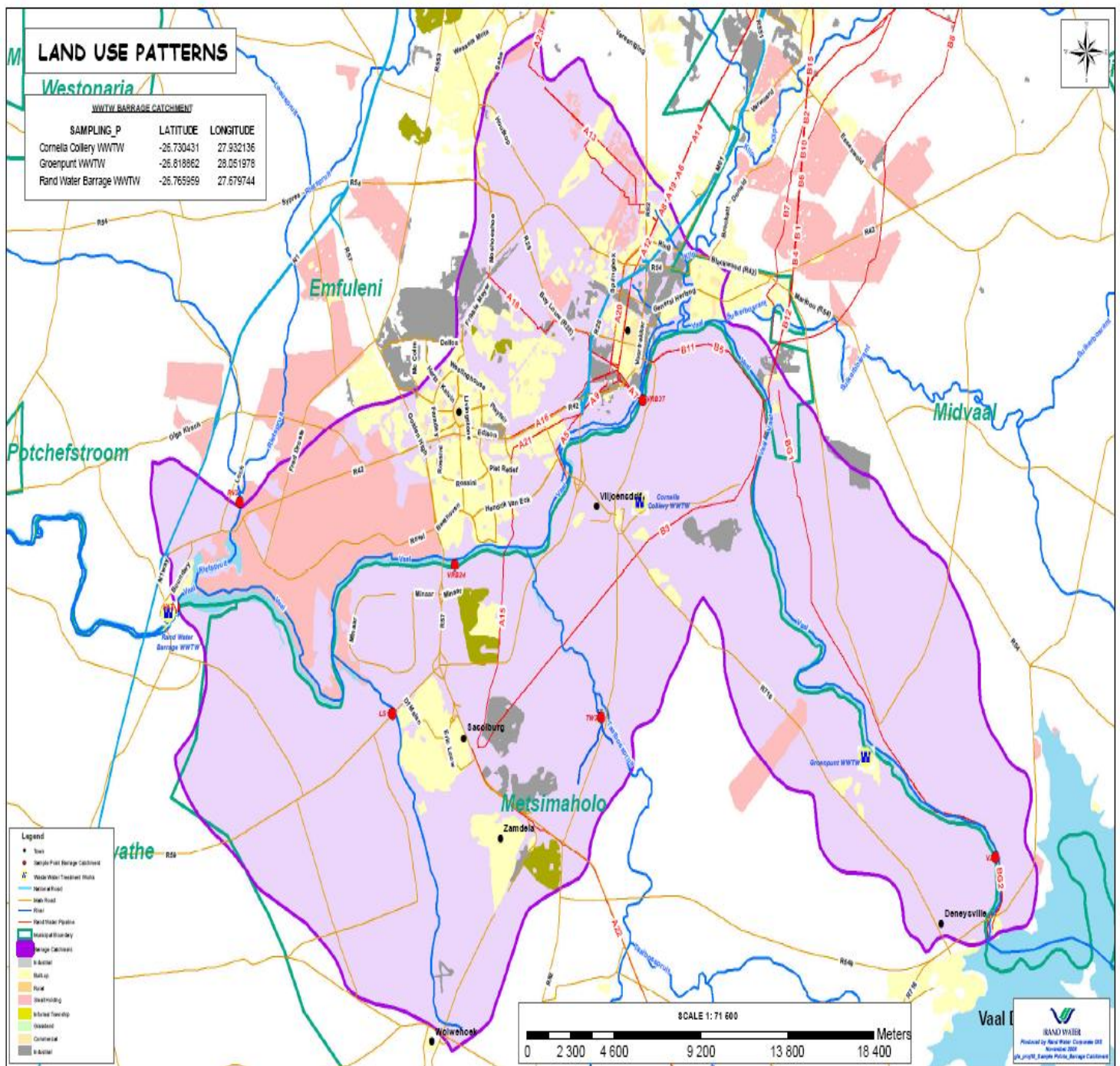


FIGURE 4.5: Land use pattern along the Vaal River Barrage catchment

The increase in urban population, informal settlements, waste water treatment plants and industrial complex along the Vaal River Barrage catchment may have an impact on the rivers draining into the Vaal River Barrage catchment. Along the Rietspruit catchment, a third of the catchment area is covered by the informal settlements, urban areas, waste water treatment plants, industry and mining (van Baalen, 2003). Some of the formal and the informal settlements around the catchments of the rivers feeding into the Vaal barrage do not have proper sanitation facilities. In 1996, the number of inhabitants around the Rietspruit catchment is not less than 816 215 and the population (van Baalen, 2003), to date the settlements are still growing.

Several events that could lead to increased faecal pollution on the Vaal River catchment have been reported. These include pumping of raw water into the Vaal River Barrage (FSE, 2009) and frequent, overloading of the sewage works as a result of heavy rains, which results in spillage of the effluent into the Vaal River Barrage Catchment (MG, 2006). These events could pose a serious health risk since untreated sewage samples were found to contain an average of 1000 - 445000 *Cryptosporidium* oocysts /10ℓ and 1000 -51 3330 *Giardia* cysts/10ℓ (Robertson *et al.*, 2006).

The septic tanks and the storm water outlets are also present around the source water, increasing the risk of discharging faecal contaminated water into the source water. Studies have also indicated that discharge of partially treated wastewater may result in high concentration of faecal micro-organisms of concern such as *E. coli*, *Klebsiella* and parasitic protozoans such as *Cryptosporidium* and *Giardia* in the source water (Pitt, 2007). This is confirmed in by Dungeni & Momba (2010) where up to 400 *Cryptosporidium* oocysts/10ℓ and up to 1750 *Giardia* cysts/10ℓ were detected in the effluents of wastewater treatment plants in Gauteng.

In Rand Water, monitoring of the source water have also revealed that some of the rivers such as Rietspruit, Klip River, feeding into the Vaal River Barrage contain high concentrations of faecal coliforms which are bacteria from faecal origin. Concentrations of up to 260000 cfu/100ml of faecal coliforms were detected at Rietspruit Weir at Loch Vaal (C-RV2) which is Rand Water sampling point located at Rietspruit (Figure 4.6).

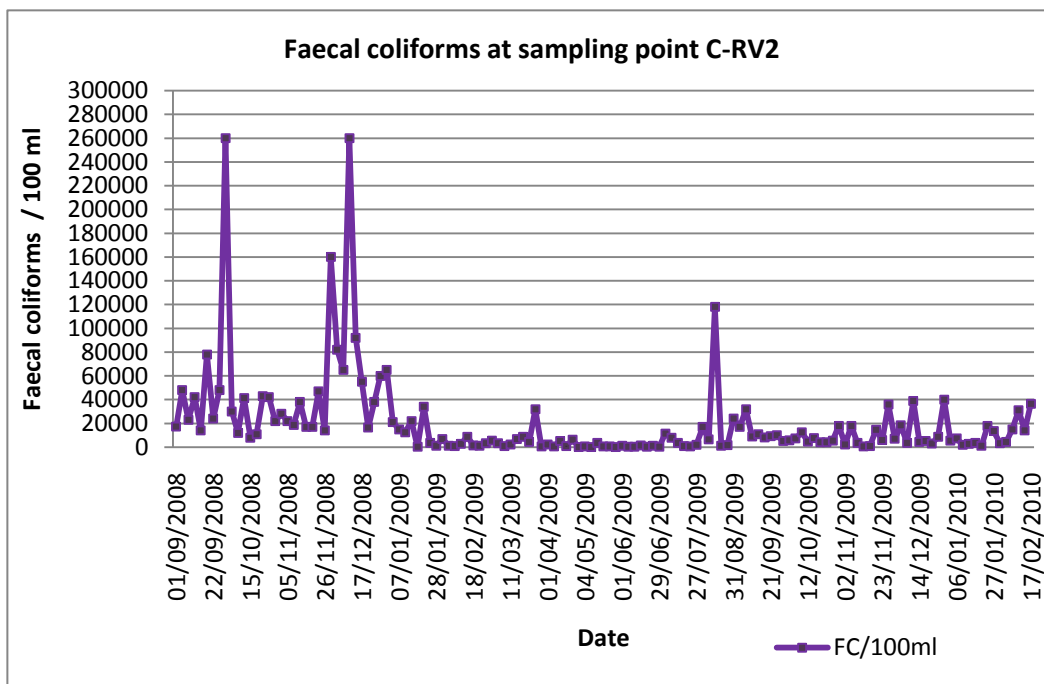


FIGURE 4.6: Faecal coliforms isolated from Rietspruit Weir at Loch Vaal (C-RV2) for the period September 2008 – February 2010

Faecal coliforms were also isolated from other tributaries feeding into the Vaal River Barrage catchment, such as the sampling point at the Klip River (C-K19) where up to 160000 cfu/ 100ml faecal coliforms were isolated Figure (4.7).

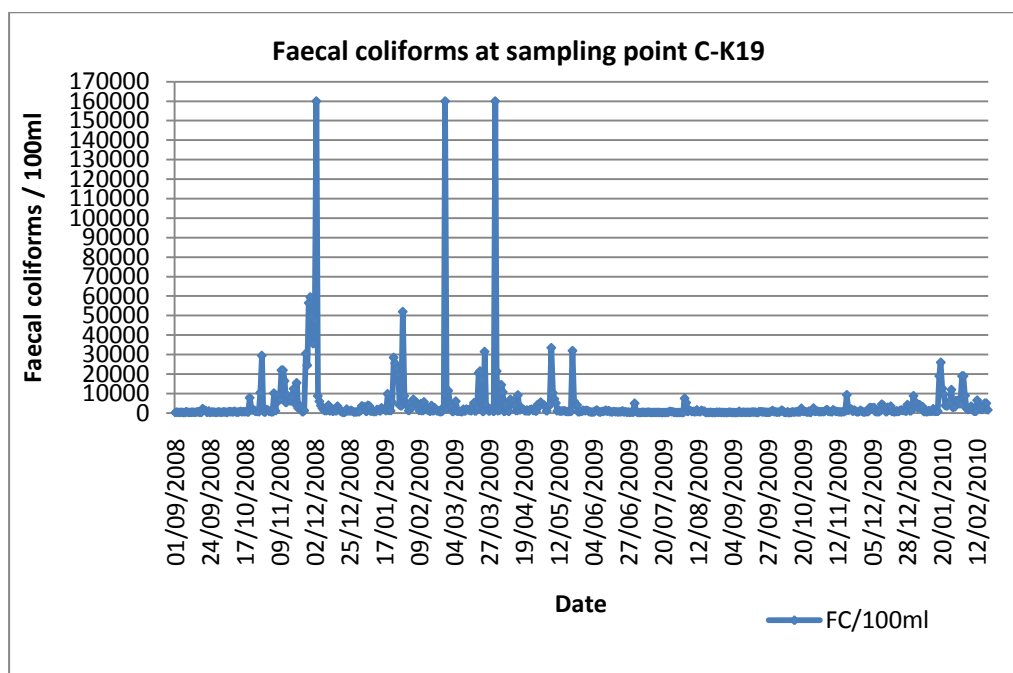


FIGURE 4.7: Faecal coliforms isolated from Klip River (C-K19) for the period September 2008 – February 2010

From the sampling point at the Suikerbosrand (C-S2) where up to 10000 cfu / 100ml faecal coliforms were isolated (Figure 4.8). At the Barrage sampling point (B-Raw) up to 1000 cfu / 100ml were isolated (Figure 4.9)

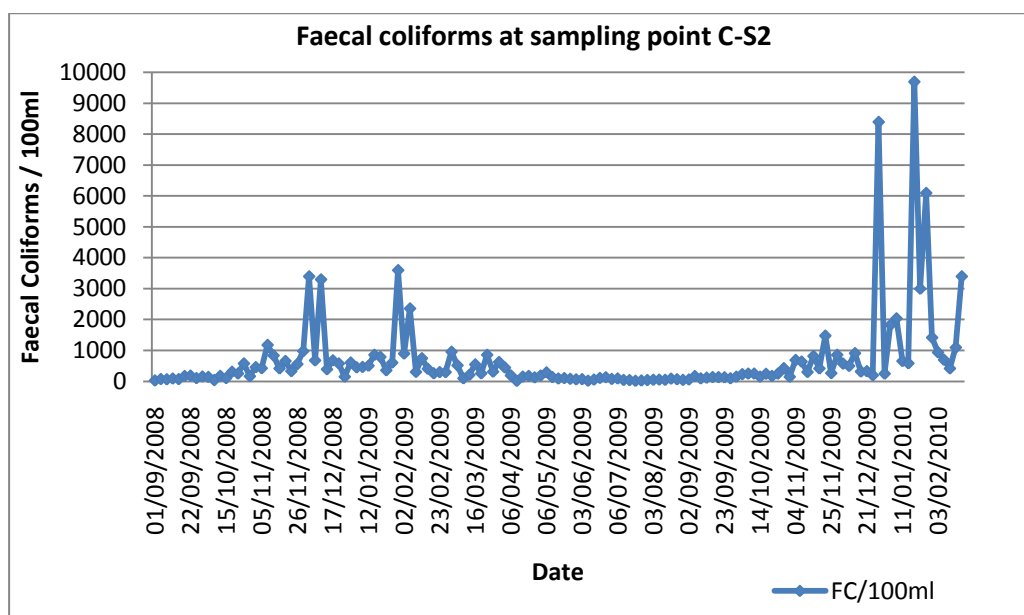


FIGURE 4.8: Faecal coliforms isolated from Suikerbosrand (C-S2) for the period September 2008 – February 2010

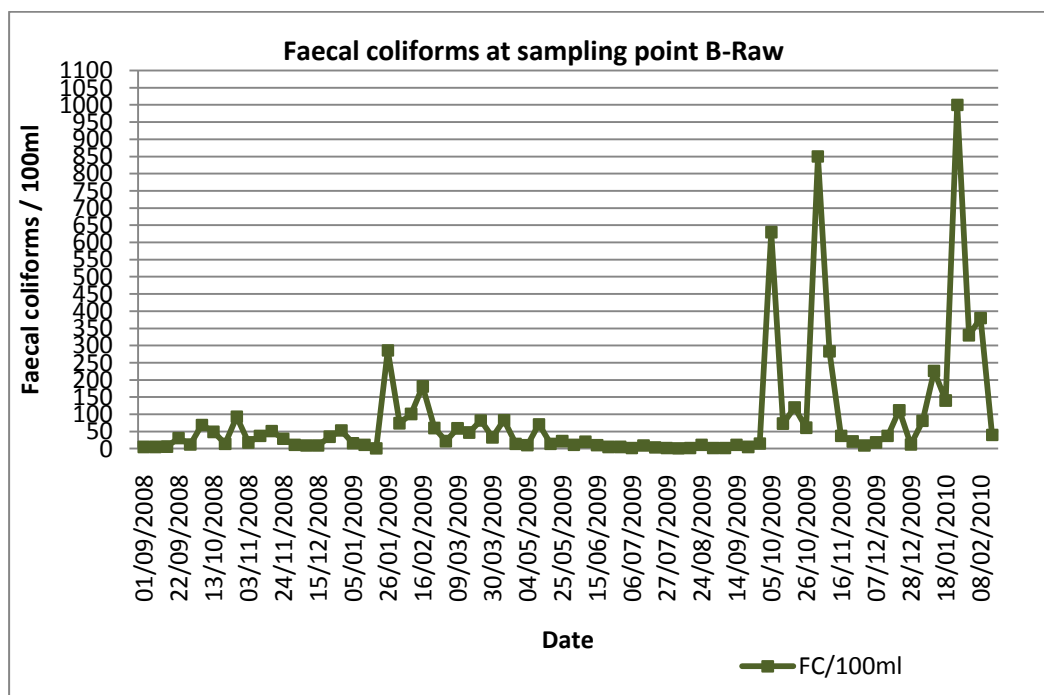


FIGURE 4.9: Faecal coliforms isolated from source water at Barrage abstraction point (B-Raw) for the period September 2008 – February 2010

The presence of sheep farming, cattle farming and piggery could be observed at the households along the catchment. Since it has been reported that presence of even small farmed animals along the catchment or source water could pose a risk since infected lambs, and goats kids and calves have been reported to shed a significant number of cysts and oocysts between the age of 5 to 25 days (Sari *et al.*, 2009) therefore these animals can be regarded as posing a risk of *Cryptosporidium* oocysts and *Giardia* cyts shedding. Additionally, the piggeries could be identified along the catchment (at Groenpunt Prison) which discharge

into upper Vaal Dam. Intense animal farming (Karen Beef) could also be observed along the catchment which also has an abattoir draining into the Suikerbosrand River. The risk score of the source water was calculated using a formula in section 4.2.2.6 of this document.

4.2.2.2 Step III: Abstraction of the Source Water (Figure. 4.10)

This step will allow for evaluation of the risk associated with the water quality of water at the abstraction point. During the assessment it was observed that, the abstraction point at the Vaal Barrage catchment lacked water quality monitors, water level monitors as well as the additional standby pump, increasing the risk of overloading of the water treatment system with water of poor quality. The results of the assessment are indicated in Figure 4.10.

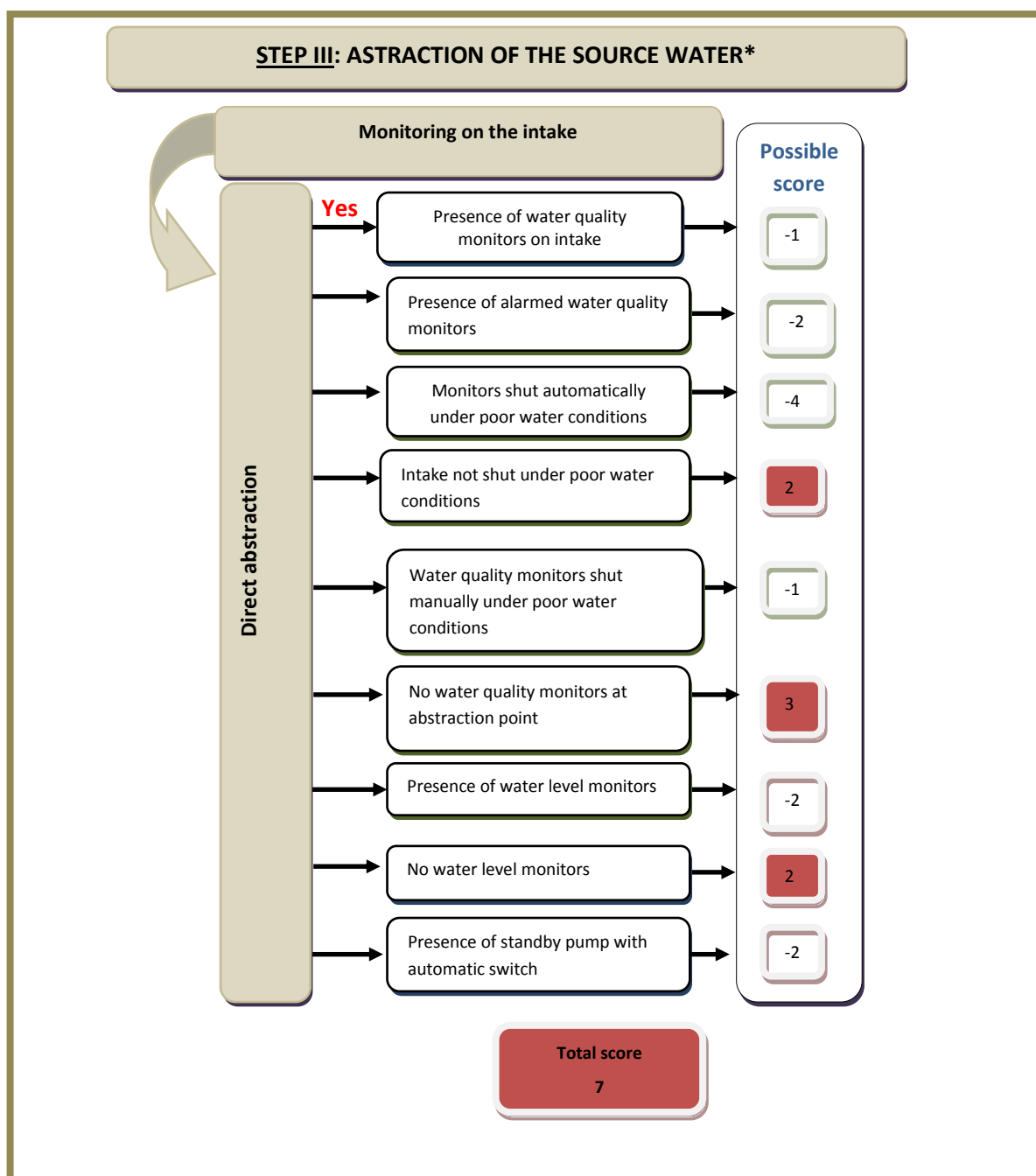


FIGURE 4.10: Monitoring at the abstraction point

4.2.2.3 Step IV: Assessment of the water treatment plant (Figure 4.11, 4.13 and 4.14)

The type of the water treatment processes, operational parameters, filter performance and turbidity during filtration, quality control were assessed. It was observed that, at the Vaal River Barrage catchment a multi-barrier water treatment system is used (Figure 4.1).

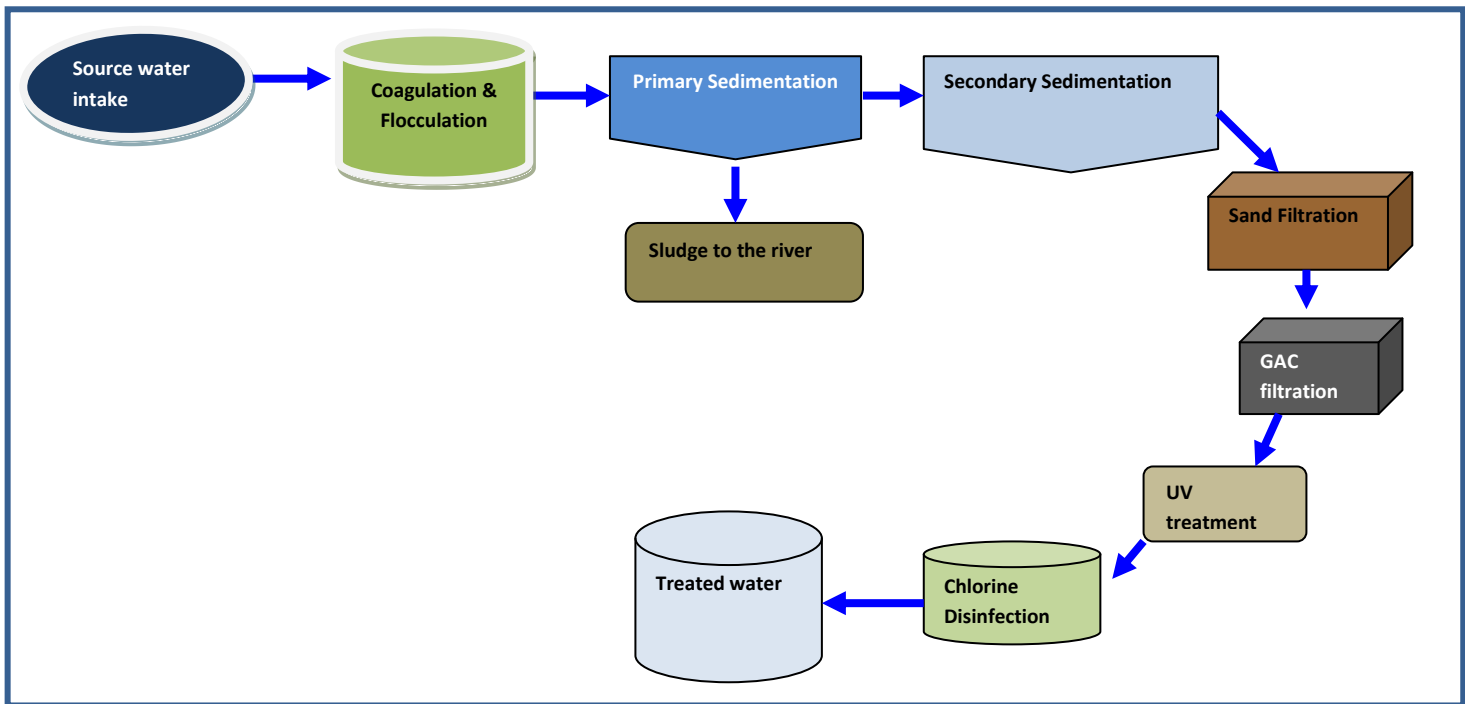


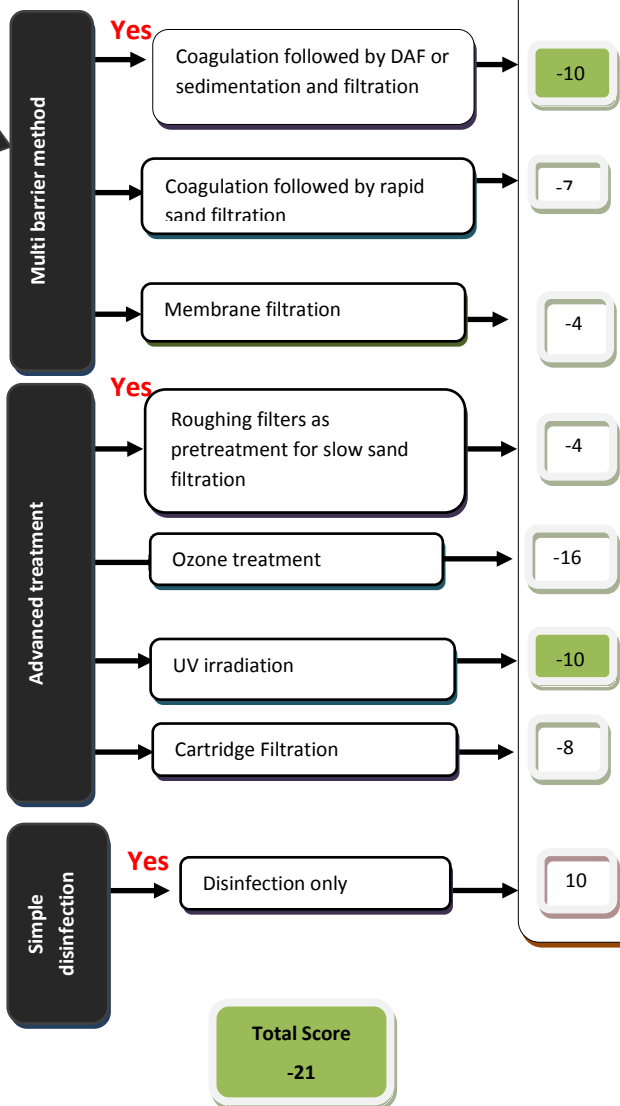
FIGURE 4.11: Schematic representation of the Vaal barrage water treatment plant (Adapted from RW, 2009a)

The Vaal River Barrage treatment plant uses coagulation/flocculation, sedimentation, carbonation and chlorination to treat source water. Rand Water has adopted the multi-barrier approach to achieve the water quality target in accordance with the SANS 241 (2006). Multi-barrier approach is widely accepted for managing water quality and recommends the provision of water quality protection mechanisms at multiple points from the catchment to the tap (WHO, 2009).

In addition the UV plant has been installed which has been reported to achieve up to 99% protozoan removal (WHO, 2004). Water flows through the UV plant where the light intensity is maintained above 80% should it fall below this level there is an audible alarm. The water is tested on a grab sample basis. Quality should meet SANS CLASS 1 Drinking water standard. An alert is submitted to management. Should deterioration in quality of the UV output be noted by the operator, UV light tubes are replaced (RW, 2009a). Chlorination step follows UV treatment. Assessment of the water treatment plant is illustrated in Figure 4.12.

STEP IV. ASSESSMENT OF THE WATER PURIFICATION PLANT

(a) Type of treatment system



(b) Monitoring of operational parameters

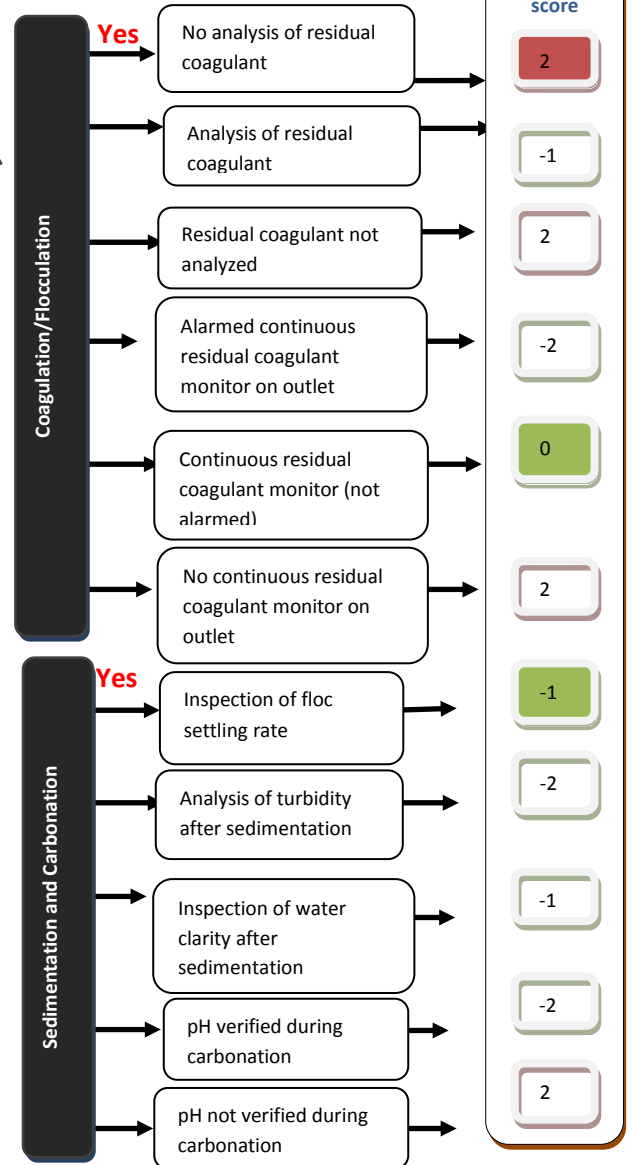


FIGURE 4.12: Assessment of the treatment system and operational parameters of the water purification plant

While assessing the operational parameters, it was observed that residual coagulant was not monitored, but, other operational parameters such as floc settling rate, sedimentation and carbonation were closely monitored. The filters were in good condition as there was no evidence of mud balls and algae (Figure 4.14). No observed increase in the turbidity of the treated water complied 99% of the evaluated period since it was less than 0.5 NTU most of the time. This can also be observed in Figure 4.13.

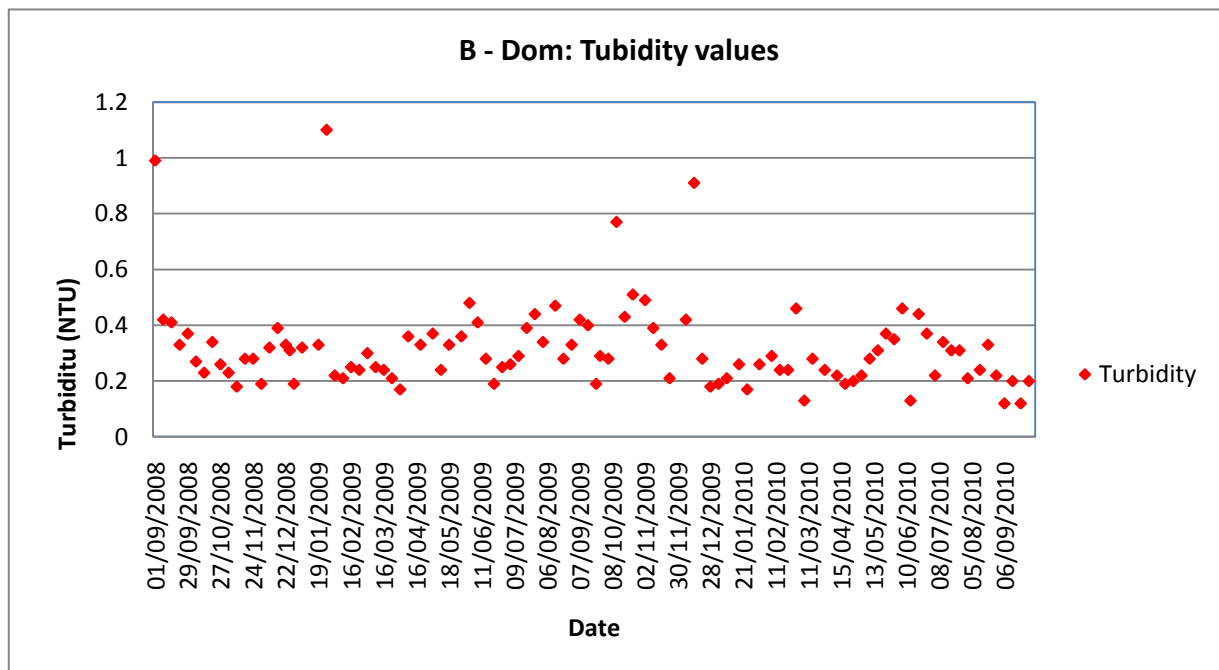


FIGURE 4.13: Turbidity values for the treated water at the Vaal River Barrage catchment

STEP IV. ASSESSMENT OF THE WATER PURIFICATION PLANT

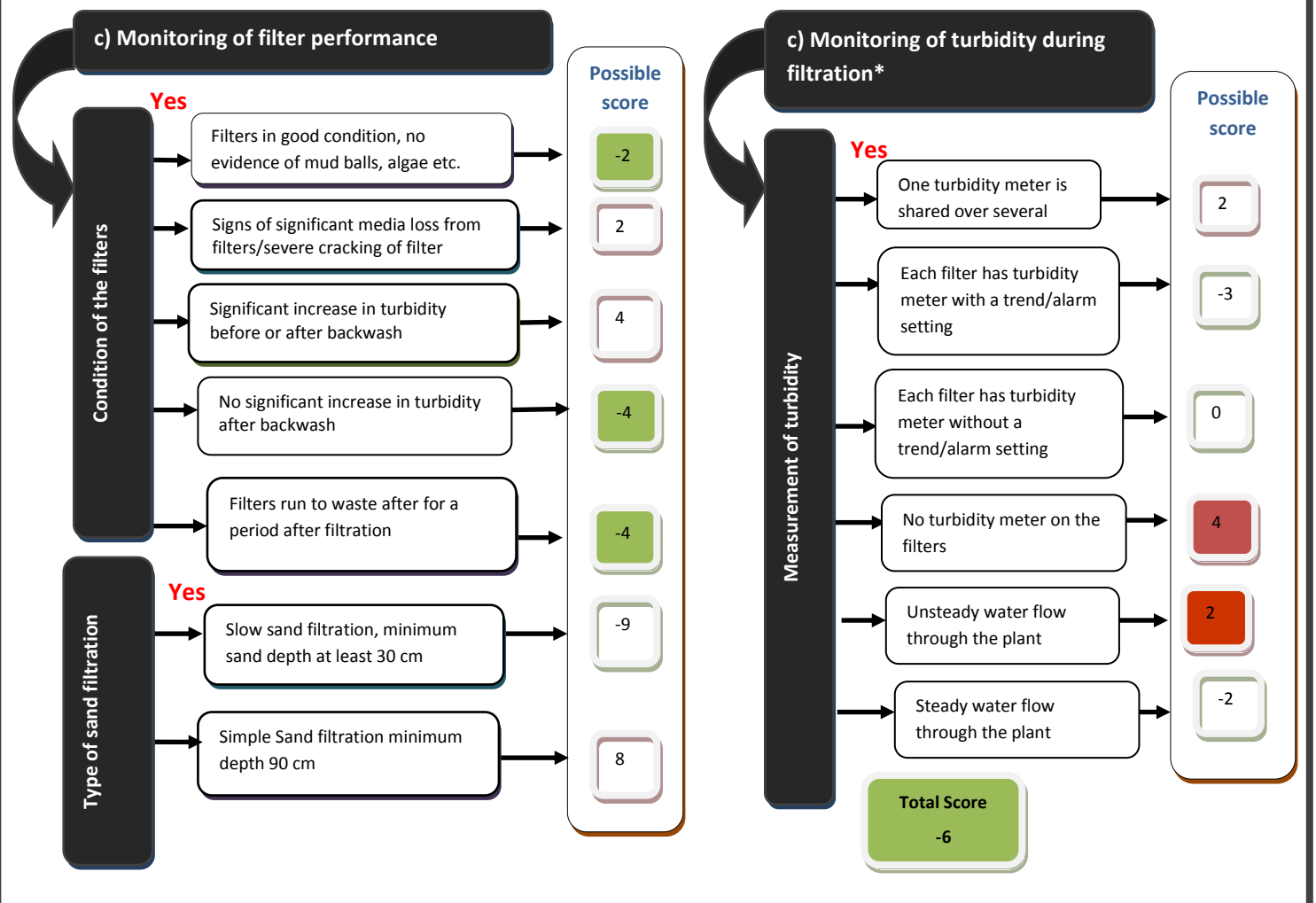


FIGURE 4.14: Assessment of the filter performance and turbidity during filtration

The availability of the quality control system was also assessed and it was found that the quality system is in place (Rand Water is ISO 9000 accredited) hence the operational manuals are available, equipment is verified, operators have been trained and deviations to quality are corrected by implementing the corrective actions (Figure 4.15).

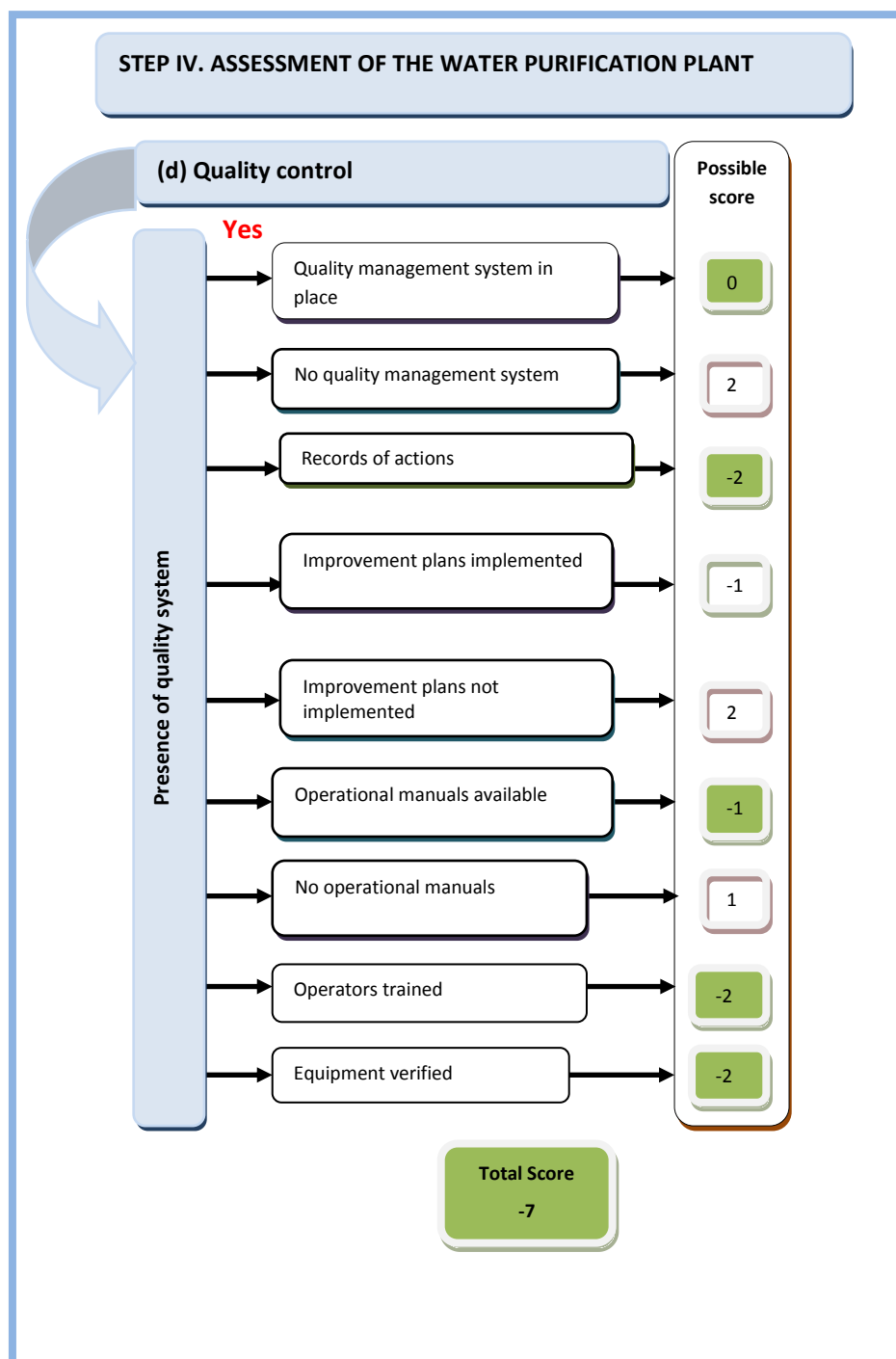


FIGURE 4.15: Steps involved during assessment of the presence of the quality control system

4.2.2.4 Step V: Water quality monitoring

Water quality monitoring at the Vaal River Barrage was assessed following Figure 4.16. It was found that both source and treated water quality are monitored for *Cryptosporidium* and *Giardia*. Source water is monitored every second week whereas treated water is monitored every week. To evaluate the concentration of *Cryptosporidium* and *Giardia* oocysts in both source and treated water, assessment of the water quality monitoring was then carried out according to the activities in Figure 4.16

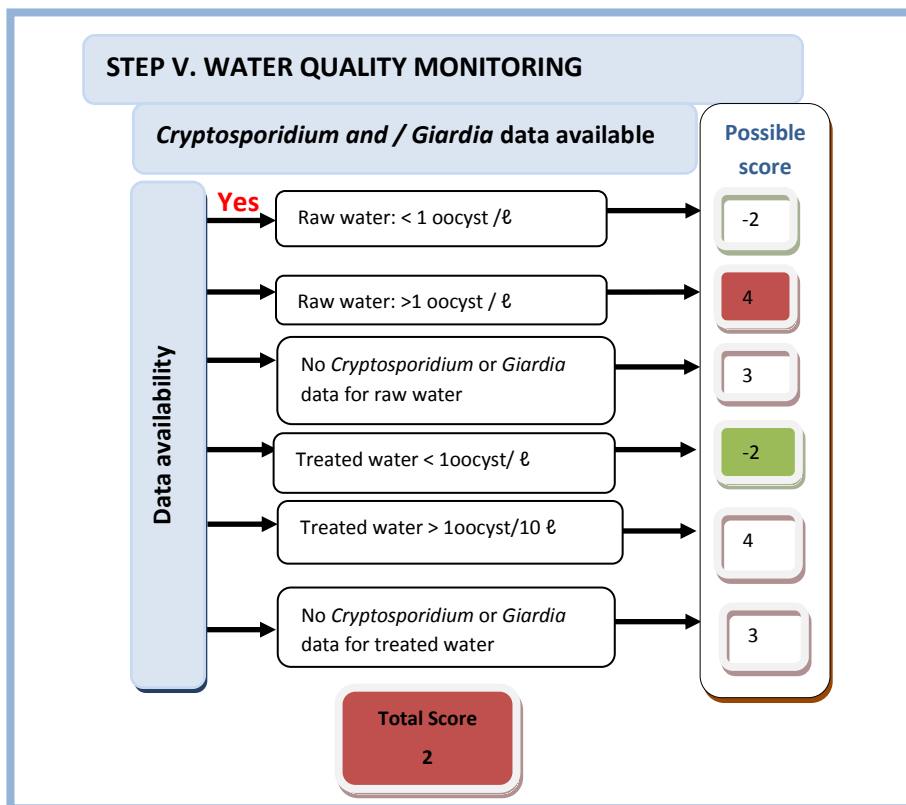


FIGURE 4.16: Activities involved during water quality monitoring

For the purpose of this study, *Cryptosporidium* and *Giardia* data collected from September 2008 up to April 2010 from the following sampling points was used (Figure 4.17):

- CRV2 -Rietspruit Weir at Loch Vaal
- CV17- Vaal River at Vaal River Barrage Outlet
- B-Raw: Barrage source water
- B-Dom: Barrage treated water

From the data, it can be observed that source water at the Vaal River Barrage catchment contains *Cryptosporidium* and *Giardia* cysts. A significant number of *Cryptosporidium* oocysts and *Giardia* cysts were detected at Rietspruit Weir at Loch Vaal (C-RV2). At this sampling point, *Cryptosporidium* oocysts concentrations can be as high as 950 oocysts per 10ℓ and *Giardia* cysts can be as high as 500 cysts/ 10ℓ (Figure 4.18). A significant increase in *Cryptosporidium* concentrations was observed during the period February 2010 and June 2010. This could most likely be as a result of wastewater discharges into the Rietspruit.

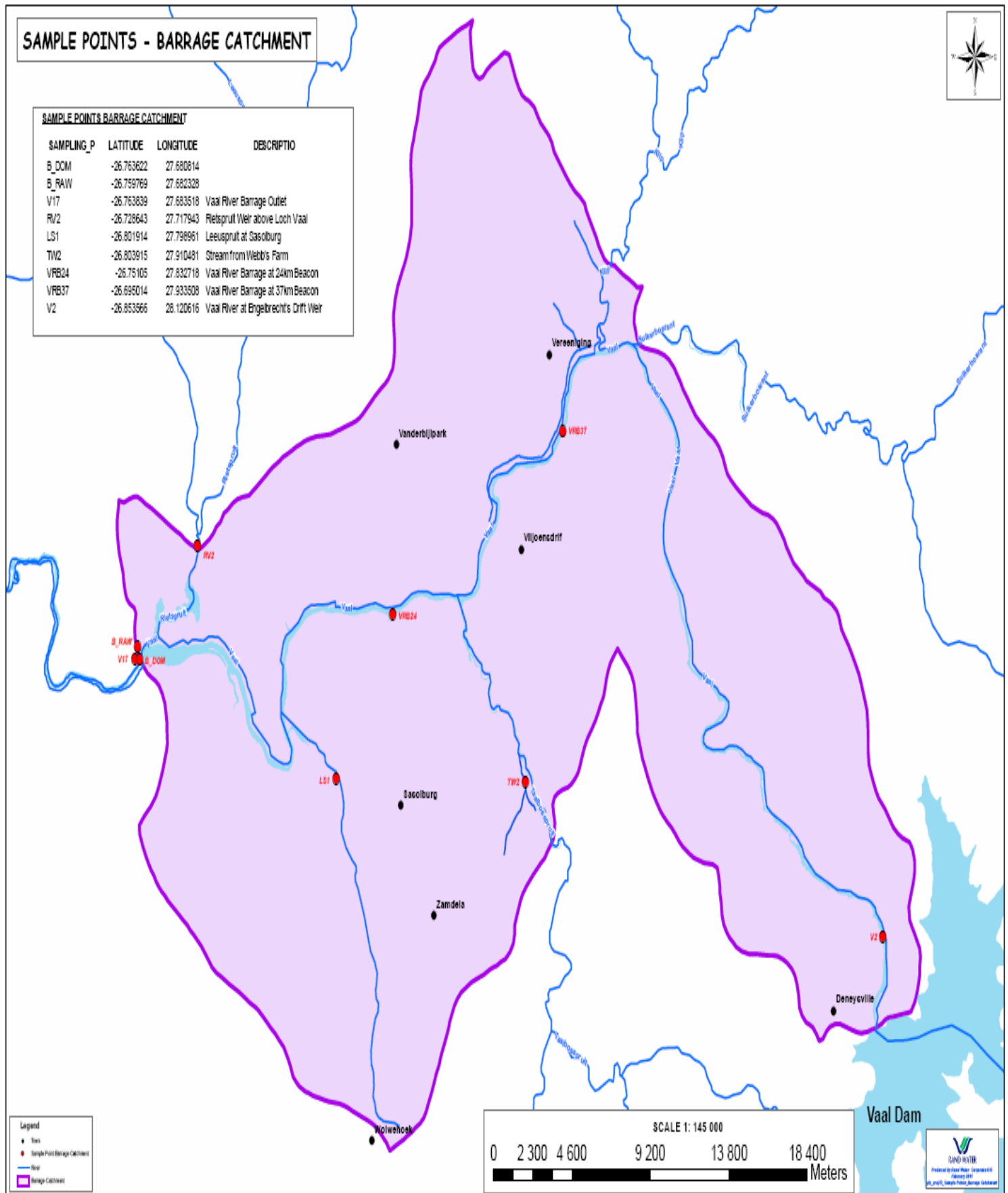


FIGURE 4.17: Location of the sampling points used for the study (RW, 2007)

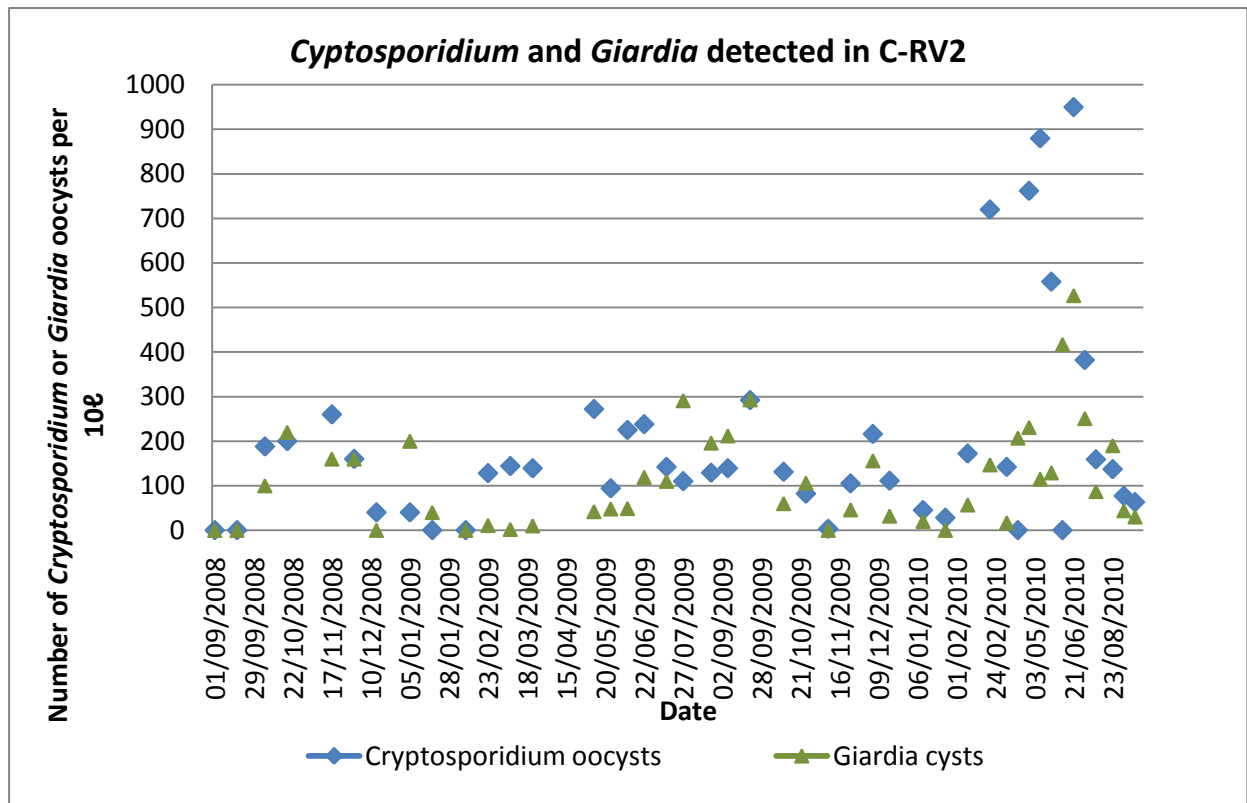


FIGURE 4.18: *Cryptosporidium* and *Giardia* oocysts detected in Rietspruit Weir at Loch Vaal (C-RV2) for the period September 2008 – August 2010

Cryptosporidium cysts were also detected at Vaal River at Vaal River Barrage Outlet (C-V17 (Figure 4.18) as well as at the Barrage source water (B-Raw) (Figure 4.19). *Cryptosporidium* oocysts as high as 22 oocysts/10ℓ were detected at the Vaal River Barrage outlet, and *Cryptosporidium* oocysts concentrations as high as 15 oocysts/10ℓ were detected at the Vaal River Barrage source water.

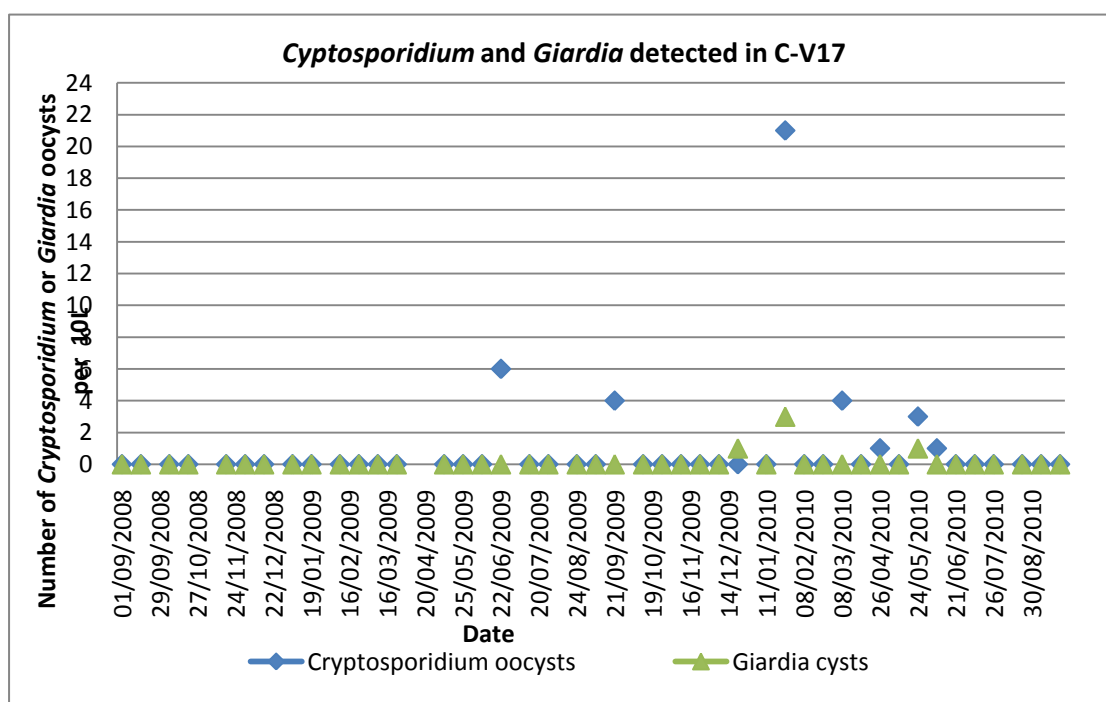


Figure 4.19: *Cryptosporidium* and *Giardia* oocysts detected Vaal River at Vaal River Barrage outlet (C-V17) for the period September 2008 – August 2010

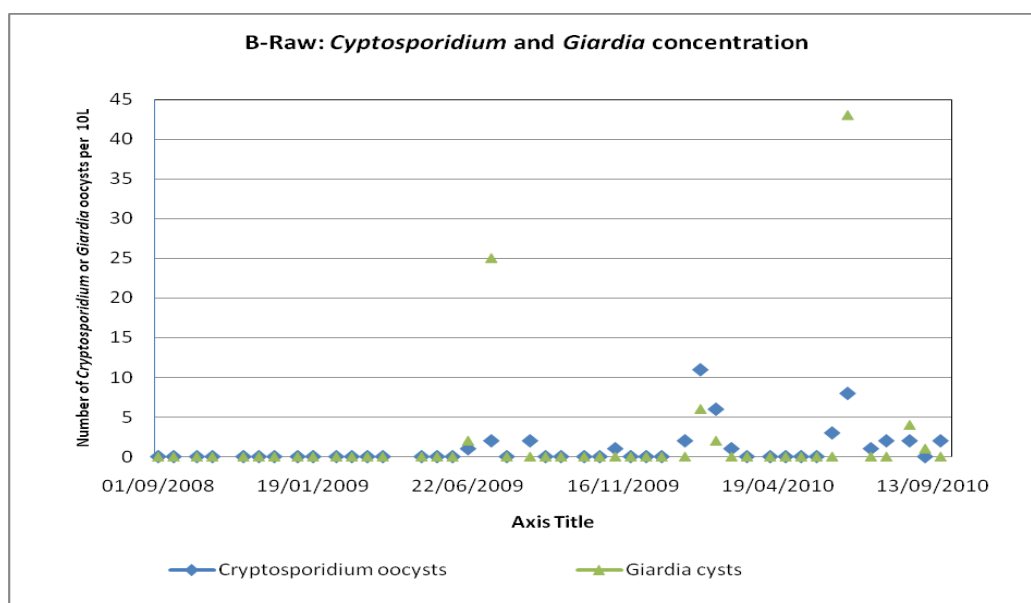


Figure 4.20: *Cryptosporidium* and *Giardia* oocysts detected at Barrage source water (B-raw) for the period September 2008 – September 2010

Although it is evident that source water contained *Cryptosporidium* and *Giardia* cysts, only one *Cryptosporidium* cyst was detected in the treated water and no *Giardia* cysts were detected in the treated water for the period September 2008 – September 2010 (Figure 4.21). This could be attributed to the

treatment system at the barrage which is the multi barrier system as well as the advanced treatment system of the UV plant installed at the Vaal River Barrage catchment.

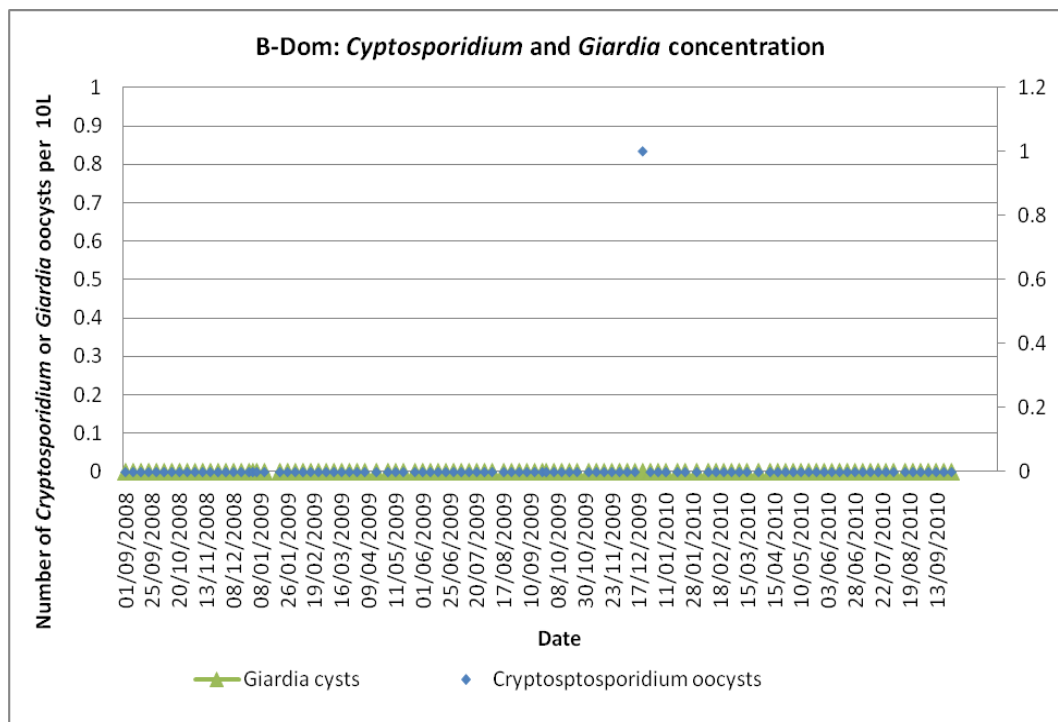


FIGURE 4.21: *Cryptosporidium* and *Giardia* oocysts detected in the Barrage treated water (B-Dom) for the period September 2008 – September 2010

4.2.2.5 Step VI: *Cryptosporidiosis* and *Giardiasis* outbreak

In this step awareness of *Cryptosporidium* was valuated (Figure 4.22), as well as the history of cryptosporidiosis and giardiasis from the same supply. It was found that there was lack of *Cryptosporidium* and / *Giardia* awareness among the community. Therefore, no cryptosporidiosis and giardiasis have been reported at the Vaal River Barrage. In general there is lack of cryptosporidiosis and giardiasis epidemiological data in South Africa.

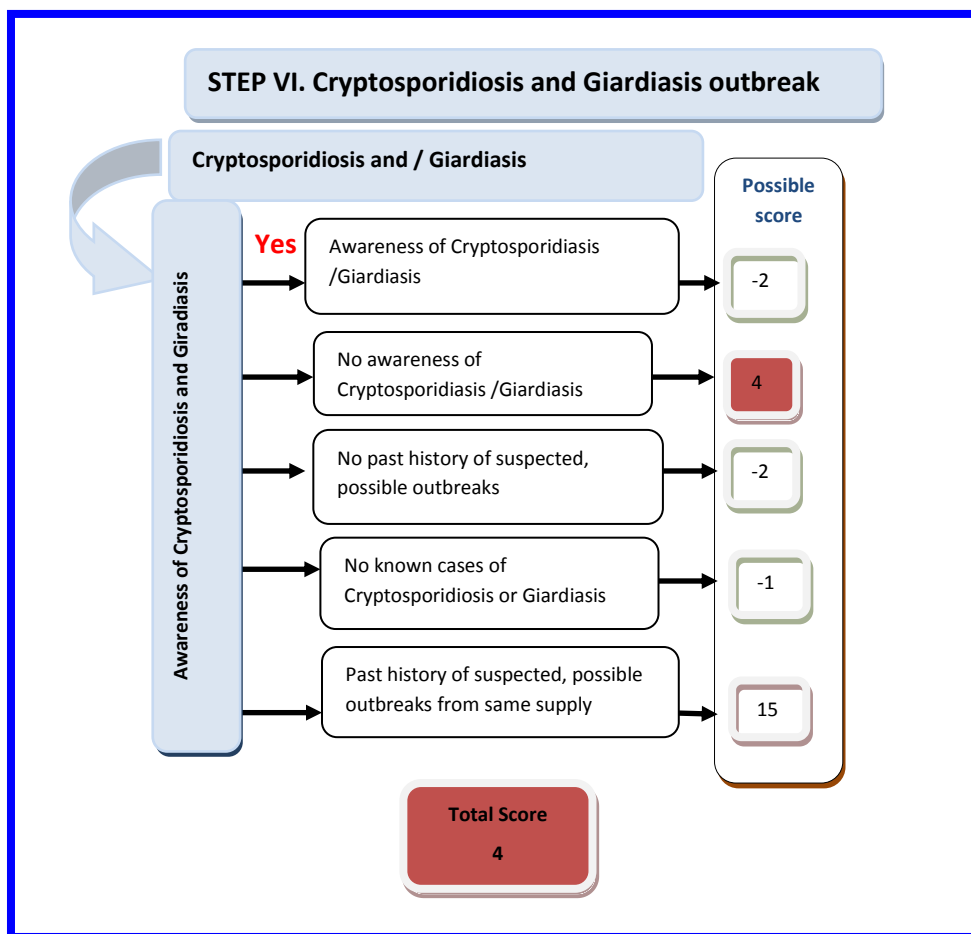


FIGURE 4.22: *Cryptosporidiosis* and *Giardiasis* outbreak

4.2.2.6. Step VII: Risk categorization

Calculation of the final risk score will be done according to the following equation described by EHS, (2002):

$$\text{Population Weighting} = 0.4 \times \log_{10} (\text{population served})$$

$$\text{Final risk assessment score} = \text{sum of total score} \times \text{population weighting}$$

The risk score of the source water was calculated as follows:

Based on 2001 census figures, the population in the Vaal Triangle is 816 215 (Van Baleen 2003)

For this assessment: Population impacting the source water = 816 215

$$\text{Therefore, population weighting} = 0.4 \log_{10} (816\,215) = 2.36$$

Final risk score for source water: =sum of total score (source water) x population weighting

$$= (18 + 42) \times 2.36$$

$$= 60 \times 2.36$$

$$= \mathbf{142}$$

Risk score for the Vaal River Barrage catchment source water is **142**, which implies that the Vaal River Barrage catchment can be regarded as a very high risk area for *Cryptosporidium* and *Giardia*. This is based on the four risk categories described in the previous Chapter and EHS (2002) which are very high risk for the risk score greater than 100, high risk, for the risk score less than 100 but greater than 50, medium risk for the risk score greater than 10 but less than 50 and low risk for the risk score less than 10.

The risk score for the treated water was calculated as follows:

For this assessment: Population served by source = 350

$$\text{Therefore, population weighting} = 0.4 \log_{10} (350) = 1.02$$

Final risk score for treated water: =sum of total score (treated water) x population weighting

$$= [7 + (-21) + (-8) + (-7) + 2 + 4] \times 1.02$$

$$= -23 \times 1.02$$

$$= \mathbf{-23.46}$$

Risk score for the Vaal River Barrage catchment treated water is **-23.46**, which implies that the Vaal River Barrage catchment treated water can be regarded as low risk with regards to *Cryptosporidium* and *Giardia* since -23.46 is less than 10 (Figure 3.11). This could be attributed to the multi-barrier water treatment system as well as the UV irradiation plant operational at the Vaal River Barrage. It has been reported that up to 99.9% *Cryptosporidium* and *Giardia* oocysts removal can be achieved with the use of multi-barrier

treatment process. In addition UV irradiation has been reported to be quite effective for *Cryptosporidium* and *Giardia* removal where up to 99.9% *Cryptosporidium* and *Giardia* oocysts can be achieved with the use of UV irradiation (WHO, 2004).

4.2.3. Phase III Sampling, analysis and data storage – This phase of the protocol includes sample collection, analysis, data storage and review. At the end of this phase it will be possible to quantify the magnitude of *Cryptosporidium* and *Giardia* contamination from the water sources.

4.2.3.1 Step VIII: Sampling and laboratory processing

Sample collection was done according to RW (2009b). The analyses were conducted at Rand Water Scientific Services Laboratory which has been accredited under International Standard ISO/IEC 17025 (ISO/IEC, 1999).

A 10ℓ volume of water was collected in a carboy in the field for source water or tap at treated water a sampling point according to RW (2009b) and transported to the laboratory. The sample was filtered in the laboratory through the Envirocheck cartridge and the oocysts, cysts, and extraneous materials were retained on the filter. These were removed by elution with an aqueous buffered salt and detergent solution. The eluent was centrifuged to pellet the oocysts and cysts, and the supernatant was aspirated. The oocysts and cysts were magnetized by attachment of magnetic beads conjugated to anti-*Cryptosporidium* and anti-*Giardia* antibodies. The magnetized oocysts and cysts were separated from the extraneous materials using a magnet, and the extraneous materials were discarded. The magnetic bead complex was then detached from the oocysts and cysts. The oocysts and cysts were stained on well slides with fluorescently labeled monoclonal antibodies and 4', 6-diamidino-2-phenylindole (DAPI). The stained sample was examined using fluorescence and differential interference contrast (DIC) microscopy. The oocysts were also examined using the DAPI filter. Quality was assured through reproducible calibration and testing of the filtration, immunomagnetic separation (IMS), staining, and microscopy systems (RW, 2010a). Qualitative data analysis was performed by scanning each slide well for objects that meet the size, shape, and fluorescence characteristics of *Cryptosporidium* oocysts or *Giardia* cysts. Potential oocysts or cysts were confirmed through DAPI staining characteristics and DIC microscopy - Quantitative analysis was performed by counting the total number of objects on the slide confirmed as oocysts or cysts.

4.2.3.2 Step IX: Data Evaluation, interpretation and Storage

The results of the analysis were reported as oocysts or cysts per 10ℓ. The results were stored in the database, Laboratory Information Management System (LIMS) and these are stored for at least three years (RW, 2010a).

4.2.4 Phase IV: Monitoring process review- This is the phase that will determine when the next review will take place.

4.2.4.1 Step X: Process Evaluation and Review

From the evaluation, the Vaal River Barrage catchment is a very high risk *Cryptosporidium* and *Giardia* area. Samples should be collected at the points of the water treatment system identified as very high risk. The sampling frequency for these areas should be once a week at the source water and after filtration, twice a week at the abstraction point and three times a week on the final water until risk has been reduced to medium risk. However, if *Cryptosporidium* oocysts and / *Giardia* cysts are found in drinking water samples, the sampling frequency will be adapted to meet the needs of the protozoan Incident Management Framework described by RW, (2010b) and DWAF (2007). This involves increasing the sampling frequency, notification of Municipality, Department of Water Affairs and the Department of Health (DWAF, 2007). In cases where there is an expansion in the water supply or the capacity of the water treatment plant is exceeded and if there are any operational changes in the plant, the entire water supply system will be evaluated for risk using this developed protocol.

During the review the mitigation measures taken should be considered and these should be noted in the desktop survey. The review will take place every three years or if there is significant deterioration of the raw water quality, if there is suspected cryptosporidiosis or giardiasis outbreak or in the event of plant disturbance which could possibly result in the leakage of *Cryptosporidium* and / *Giardia* oocysts into the treated water (EHS, 2002). However, in case of high risk areas the frequency of monitoring could be increased and the mitigation measures be imposed until the results are satisfactory.

4.3 Conclusions

A generic monitoring protocol for management of *Cryptosporidium* and *Giardia* in drinking water has been tested at the Vaal River Barrage water treatment plant. The *Cryptosporidium* and *Giardia* risk status of the Vaal River Barrage drinking water system is now known and therefore plans to avoid future contamination in this area can be prepared. In addition, data from this assessment confirms the effectiveness of the use of multi-barrier approach in combination with the advanced treatment (UV irradiation) for the removal of *Cryptosporidium* and *Giardia* cysts.

From the information gained from the study, it can be concluded that the Vaal River Barrage catchment is a very high risk area for *Cryptosporidium* and *Giardia* and it could also be observed that the Vaal Barrage water purification plant is effective for the removal of *Cryptosporidium* and *Giardia*. The use of the developed protocol at the Vaal River Barrage catchment was found to be simple and easy to apply. It can be

concluded that the protocol will be of significance in monitoring of *Cryptosporidium* and *Giardia* in the drinking water value chain, described by Ncube (2009). However, the challenges identified during the application of the protocol include difficulty in obtaining detailed information on the catchment and the difficulty in obtaining information on the epidemiological survey data of *Cryptosporidium* and *Giardia*.

CHAPTER 5:

GENERAL DISCUSSION

5.1 General Discussion

Microbial contamination of surface water has become a major concern throughout the world. Of particular interest is the contamination of water bodies by parasitic protozoans. From the literature it is evident that ingestion of oocysts or cysts from *Cryptosporidium* and *Giardia* may lead to diseases known as cryptosporidiosis and giardiasis respectively. As a result the protozoan parasites *Cryptosporidium* and *Giardia* are a major concern for water utilities worldwide (Angles *et al.*, 2007).

To protect the consumers from contaminated drinking water, countries have developed drinking water quality standards. In South Africa, the minimum requirement of *Cryptosporidium* in drinking water is less than 1 oocyst/10ℓ and that of *Giardia* is less than 1 cyst /10ℓ. To ensure compliance with the guidelines there must be a monitoring strategy in place. The presence of *Cryptosporidium* and *Giardia* oocysts in South African surface waters have been reported in various studies (Dungeni and Momba, 2010; Jemey-Swan *et al.*, 2001), yet, there is lack of standard monitoring procedure for *Cryptosporidium* and *Giardia*.

Routine monitoring of *Cryptosporidium* and *Giardia* is not always practical because of various limitations encountered with the detection methods in source water (DWSNZ, 2008). As a result, different monitoring strategies that will rely minimally on the current methods will play a significant role in monitoring of the parasitic protozoa. The monitoring approaches for protozoan parasites *Cryptosporidium* and *Giardia* include the log-reduction approach, the risk – based assessment and the do nothing approach. In South Africa monitoring of these protozoan parasites is poorly developed, there is a lack of a clear protocol for monitoring of *Cryptosporidium* and *Giardia*. Consequently, in this study, a protocol for monitoring for *Cryptosporidium* and *Giardia* is developed. The developed protocol is based on guidelines such as Drinking Water Inspectorate (DWI) (2008) and the Australian Drinking Water Guidelines (ADWG) (2004), but it based mainly on the guidance of monitoring of *Cryptosporidium* and *Giardia* in Northern Ireland (EHS, 2002). The practical application of the developed protocol is based on catchment information by identifying the activities that may lead to faecal run-off into the source water, the type of water treatment processes, water quality monitoring as well as the sample analysis procedures. Hence the developed protocol includes four phases which are:

- **PHASE I: Desktop survey of monitoring requirements** - This phase involves the accessing of *Cryptosporidium* and *Giardia* information from published sources and non-published sources. includes the following steps:
 - **Step I:** Assessment of the monitoring requirements
- **PHASE II: Situation analysis of source, water purification plant and disease outbreak** - This is an intensive phase which includes onsite assessment of the entire drinking water system i.e. the source water, water treatment facilities, operation and maintenance and the treated water.
 - **Step II:** Description and characterization of the source water types
 - **Step III:** Abstraction of source water
 - **Step IV:** Assessment of the water purification plant
 - **Step V:** Water quality monitoring
 - **Step VI:** Cryptosporidiosis and giardiasis outbreak
 - **Step VII:** Risk assessment
- **PHASE III: Sampling, analysis and review** - This phase of the protocol includes sample collection, analysis, and data storage
 - **Step VIII:** Sample collection and laboratory processing
 - **Step IX:** Data evaluation, interpretation and storage
- **PHASE IV: Monitoring process review** - This phase determines the events in which the monitoring process will be repeated
 - **Step X:** Process evaluation and review

Each of these steps are discussed in the protocol (Chapter 3) and were tested by applying on a small water treatment plant (Chapter 4). The approach of providing a stepwise protocol with detailed guidance on how to apply has proven to provide guidance to project managers, catchment managers and governmental authorities towards the assessment analysis and communication of the risk status of the drinking water supply systems.

However, few challenges were identified during the application of the protocol which includes difficulty in obtaining detailed information on the catchment and the difficulty in obtaining information on the prevalence of *cryptosporidiosis* and *giardiasis* in the local community. However, despite these challenges the developed protocol is still a viable tool for monitoring of *Cryptosporidium* and *Giardia*.

CHAPTER 6:

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The primary objective of the study was to develop a protocol / methodology that can be applied by drinking water producers to monitor *Cryptosporidium* and *Giardia*. The protocol was developed and applied at the Vaal River Barrage catchment and it was found that it is easy to follow and by applying the protocol the risk areas and the possible risks in the water supply system can be identified. The approach of developing a protocol and testing it under operational conditions appeared to be effective and should be followed in future studies. The only constraint is that the study was tested on one water treatment plant. From the study, it could be concluded that the source water from the Vaal River Barrage catchment was very high risk. However, the use of the multi-barrier approach coupled with advanced treatment of UV rendered the water free from *Cryptosporidium* and *Giardia*. Therefore, the population receiving treated water from the Barrage purification plant is not at risk of *Cryptosporidium* and *Giardia*.

The developed protocol could contribute to protection of drinking water consumers by identify high risk source waters, to identify areas that can be improved in the water treatment system and also to protect the catchment areas from further faecal pollution. Furthermore, it can be used by the catchment management agencies as one of the tools that will assist them in identifying the potential risk that could have an impact on to the catchments.

Water utilities can also benefit with the use of the protocol since the developed protocol can assist managers to evaluate their source water catchments and establish the *Cryptosporidium* and *Giardia* risk status of the water source. Improvement strategies for example negotiations with the local and national government to improve catchment management strategies can thus be emitted. The water utility can decide to reduce the risk of *Cryptosporidium* and *Giardia* contamination by implementation of the advanced treatment processes or to upgrade their treatment processes to UV or ozone treatment. In addition the protocol can be used by water utilities as part of their Water Safety Plans to optimize monitoring. The developed protocol would thus be beneficial to governmental agencies as well as water utilities tasked to ensure the production of safe drinking water to consumers.

6.2 Recommendations

Based on the availability literature and testing of the protocol the following are recommended:

- **Testing of the robustness of the protocol**
 - The protocol should be tested at small and large water treatment plants using different source water. Since *Cryptosporidium* and *Giardia* monitoring is of National importance, the Water Research Commission can be requested to fund such a project.
- **Adoption of the protocol by water utilities**
 - The developed protocol should be adapted by and applied by water utilities all across South Africa. The aim of the study was to address the lack of a uniform approach towards monitoring of the parasitic protozoan's *Cryptosporidium* and *Giardia* in South Africa. Adapting the protocol can address the lack of consistency in terms of what, where and when to monitor during *Cryptosporidium* and *Giardia* monitoring. In response, this will enable the water utilities to be vigilant of the activities in and around their catchment areas that could increase the risk of *Cryptosporidium* and *Giardia* impact on their water sources. In addition, it will enable the water utilities to be able to improve and upgrade their water purification plants to the water purification plants that could effectively treat source water containing *Cryptosporidium* and *Giardia*. This could also facilitate compliance to the SANS 241 requirements of less than 1 oocyst /10ℓ and that of *Giardia* is less than 1 cyst /10ℓ.
- **Implementation of the protocol by the Department of Water Affairs**
 - The blue drop certification requires that, the water utilities should implement the Water Safety Plans. Within the water safety plans, there is a requirement for risk assessment of the catchment, treatment works and reticulation (DWAF, 2010). The developed protocol could play a significant role in monitoring for *Cryptosporidium* and *Giardia* since it entails risk assessment of the entire water supply system from source to tap. Therefore it is proposed that the protocol should form part of the Water Safety Plans and be adopted in South Africa by the Department of Water Affairs, which is the custodian of water resources in South Africa and be managed in collaboration with the Department of Health (DoH).
- **Dissemination of the protocol**
 - It is recommended that the developed protocol be publicized, through publishing in appropriate scientific journals. The protocol should also be presented at conferences such as the Water Institute of South Africa (WISA), Municipality Conference and various scientific forums.

- Dissemination of the protocol could also be done by development of manuals or brochures that can be supplied to possible users for example, government agencies and water utilities.
- The protocol can be developed into an interactive software that can be used in conjunction with the brochures. This could also assist in further simplifying the implementation process. The manuals could be used by catchment managers, plant operators as well as the analysts.

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