Occurrence and removal of *Giardia* and *Cryptosporidium* at the Goreangab Reclamation Plant

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Abstract This paper deals with the occurrence of *Giardia* and *Cryptosporidium* in the water sources available for the Goreangab Reclamation Plant (GRP) and the subsequent removal during treatment at the reclamation plant. *Giardia* is detected more often than *Cryptosporidium*. 60% of the time it is detected in the samples from the dam and in 55% of the samples from the maturation pond effluent.

During the investigation, *Giardia* was detected in the final water 5% of the time and *Cryptosporidium* 2% of the time. The maximum *Giardia* cysts detected in a sample was 30, the 99% percentile was 20 and the 97% percentile 10 cysts. A maximum of 20 *Cryptosporidium* oocysts was detected in a sample. The 99% percentile counted 6.2 oocysts and the 97% percentile 0 oocysts.

From the data presented it is clear that the polluted dam water has the same risk level of *Giardia* and *Cryptosporidium* pollution as treated wastewater effluent. This emphasises the fact that the sources should be monitored continuously for these parasites. The sporadic high counts of *Giardia* and *Cryptosporidium* in the raw water sources indicate that a multiple-barrier approach must be followed to ensure the safe operation of even conventional treatment plants using polluted source water.

No correlation could be found between cyst and oocyst removal and other water quality parameters.

The advocating of a final water turbidity of 0.1 NTU and the use of particle counters can only be supported by these findings, as it is possible to achieve a turbidity of less than 0.1 NTU at the sand filter outlet, even in a developing country like Namibia. The challenge lies with the maintenance of equipment and vigilance of the operators.

Keywords Maturation pond, Goreangab Dam, treated sewage effluent, eutrophication, pollution, algae, high pH, DOC removal, *Giardia* cysts, *Cryptosporidium* oocysts

Introduction

This paper deals with the occurrence of *Giardia* and *Cryptosporidium* in the water sources available for the Goreanbag Reclamation Plant (GRP) and the subsequent removal during treatment at the reclamation plant. The primary objective of the study will be to identify those operational variables as well as water quality variables that correlate with the degree of protozoan removal. The study started in January 1996 and results up to August 1999 will be used.

The history, philosophy, experimentation and monitoring of the GRP in Windhoek has been extensively reported on in the past few years (Haarhoff *et al.*, 1996; Haarhoff *et al.*, 1998; König *et al.*, 1998; Menge, 1996; van der Merwe *et al.*, 1996). One of the concerns raised in 1994/95, when various reports on *Giardia* and *Cryptosporidium* were published, was the question of *Giardia* cyst and *Cryptosporidium* oocyst risk in reclaimed water in Windhoek (*Cryptosporidium Capsule*, 1996; Kfir *et al.*, 1995; Rose *et al.*, 1990; Smith, 1992; Vesey *et al.*, 1993). Monitoring for *Giardia* and *Cryptosporidium* in the raw water sources and the final product started in early 1996. Right from the start it was evident, that both parasites were present in both sources supplying the reclamation plant. There are four distinct incidents when cyst/oocyst breakthrough occurred in the plant. This study will also try to identify the cause for these incidents and what was done to rectify the problem.

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Giardia and *Cryptosporidium* samplling and analysis

Sampling and analysis was done according to the conventional method available. 100 litres of sample were filtered through a "Cuno wynd" filter. The samples were sent by courier to a laboratory in Pretoria and subsequently concentrated, purified and stained, using the immunofluorescent dye from "Cellabs" and then microscopically counted. All the samples were analysed by the same laboratory using the same method over the study period (Kfir *et al.*, 1995; Vesey *et al.*, 1993). If one or more cysts or oocysts were present, the result was reported as a positive test. The recovery rate of cysts/oocysts, using the above method, has been determined to be 50% for this particular laboratory. This method cannot distinguish between viable and non-viable cysts/oocysts, however from the slides it was at times evident that cysts/oocysts in the final water were damaged (misformed).

During January 1999 a refrigerated on-line sampling device was installed on the final product water. A 1.5 litre sample passes through the filter every 15 minutes for 7 days. The total volume passing through the filter amounts to approximately 1000 litres. These results are indicated on the time plot on Figure 4. This was done to monitor the overall performance of the plant and to see if spikes did occur, which were not picked up in grab samples. There is enough space in the fridge for additional sample streams. In fact three samples are taken simultaneously. One composite sample of 2 litres over two days for chemical analysis, and another 100 litre sample over 4 to 5 hours for virus testing. This device can be easily expanded to include even more sample streams.

Table 1 shows a statistical summary of *Giardia* cysts and *Cryptosporidium* oocysts detected in the two water sources to the treatment plant during the period of study from January 1996 to August 1999.

Table 1 statistics of *Giardia* and *Cryptosporidium* in Goreangab Dam and Maturation Pond effluent (analysis conducted over the period January 1996–December 1999)

	Gorengab Dam		Maturation pond effluent	
	Giardia	*Cryptosporidium*	*Giardia*	*Cryptosporidium*
Total samples analyses	55	55	80	80
50% percentile	50	0	25	0
70% percentile	117	0	72	30
95% percentile	300	200	137	307
Max count in all samples	500	600	250	1000
% of samples positive	60%	16%	56%	35%

Water sources supplying the grp

The two sources were sampled from January 1996 to August 1999. Over the period of 190 weeks 55 Dam samples and 80 Maturation Pond (MP) effluent samples were analysed for *Giardia* and *Cryptosporidium* (taking into consideration that the plant was down for maintenance and that both sources were used alternatively or simultaneously, depending on their quantity). Other quality parameters are analysed twice per week on each sample point. Figure 1 and 2 summarise these results.

Goreangab Dam

The Goreangad Dam is a small impoundment, with the Windhoek City and its settlements located in its catchment area. Since 1990 the quality of this source has deteriorated to the extent that the organic content is equal or at times exceeds that of the treated wastewater effluent.

Maturation Pond effluent from Gammams Water Care Works

The City of Windhoek's domestic sewage is treated at the Gammams Water Care Works

(GWCW) by conventional primary treatment, nutrient removal activated sludge and eight maturation ponds with a retention time of three to four days. The number of bacteria counts is significantly reduced in these maturation ponds.

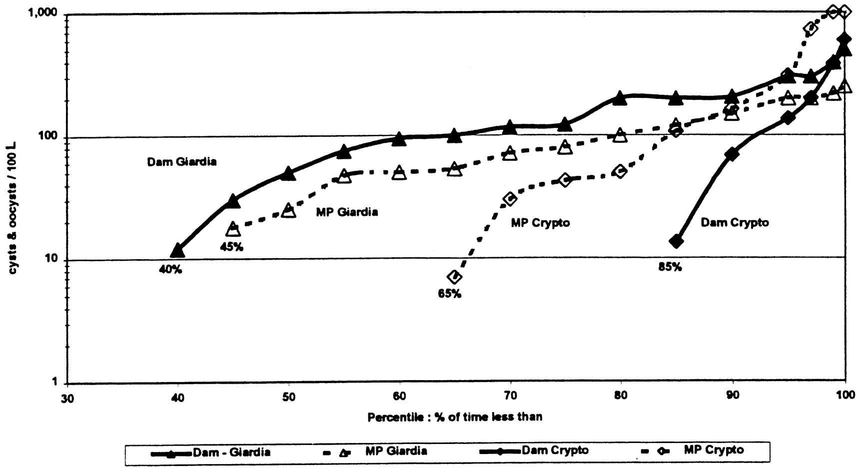

Figure 1 Goreangab Dam and Maturation Pond effluent – *Giardia* and *Cryptosporidium*

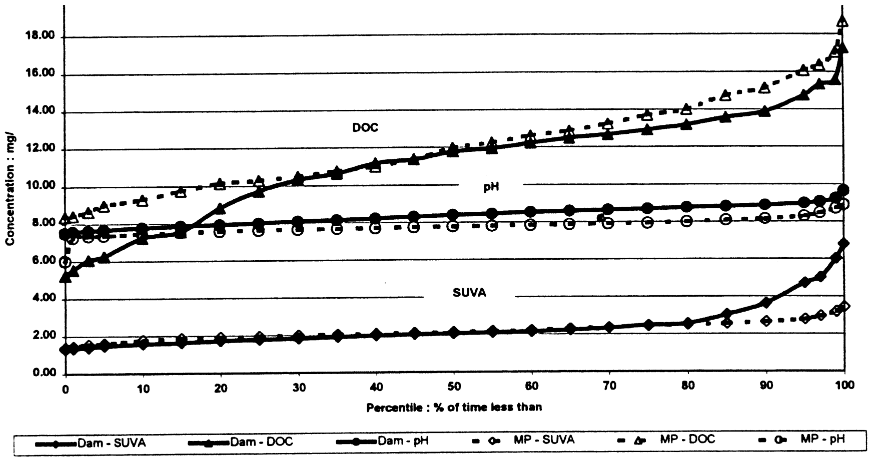

Figure 2 Goreangab Dam and Maturation Pond effluent – SUVA, DOC and pH

Discussion

Giardia is detected more often than *Cryptosporidium*. 60% of the time it is detected in the samples from the dam and in 55% of the samples from the maturation pond effluent. *Cryptosporidium* is more prevailing in the MP effluent, i.e. 35% of the time. Only 15% of the dam water samples contained *Cryptosporidium*. The DOC profiles for the dam and MP effluent are very similar, ranging from 7.5 to 18.7 mg/l. The pH of the dam is higher than the pH of the MP effluent. 75% of the time the pH of the dam is above 8, and for 5% above 9. The pH of the MP effluent is only 20% above 8, with a maximum of 8.9. The Specific Ultraviolet Absorbance (SUVA) for the dam water is the same as that of the MP effluent. 15% of the time the SUVA value is higher than that of the MP effluent, with a maximum value of 6.7. The maximum SUVA value for MP effluent is 3.4. There is no particular seasonal pattern in the occurrence of the parasites in both sources.

Treatment: Goreangab Reclamation Plant (GRP)

Both sources follow the same treatment processes. Ferric chloride is dosed as primary coagulant at a concentration ranging from 30–50 mg/l, the average dosage being 35 mg/l. The water is then flocculated and separated with dissolved air flotation (DAF) and sand filtration. Then follows granular activated carbon (GAC) adsorption with 30 minutes empty bed contact time (EBCT), break-point chlorination with 60 minutes contact time, secondary chlorination with additional 60 minutes contact time and stabilisation.

The plant consists of two legs, see Figure 3. Goreangab Dam (Dam) water is mostly treated in Leg 1 and Maturation Pond effluent (MP effluent) in Leg 2. Sometimes both sources are blended and the mixture is treated either in one leg or in both legs.

To increase the capacity of the plant from 4.2 Ml/day to 8.6 Ml/day during the drought in 1996, two additional sandfilters were commissioned. The existing granular activated carbon contact columns could not handle the increased flow. To overcome this problem the two new filters were built with a sand bed of 50 mm and a layer of 1200mm deep granular activated carbon on top, to ensure a empty bed contact time of 30 minutes. To extend the life of the GAC columns, a 500 mm deep layer of GAC was added to the existing four sandfilters, which had a sand bed depth of 800 mm.

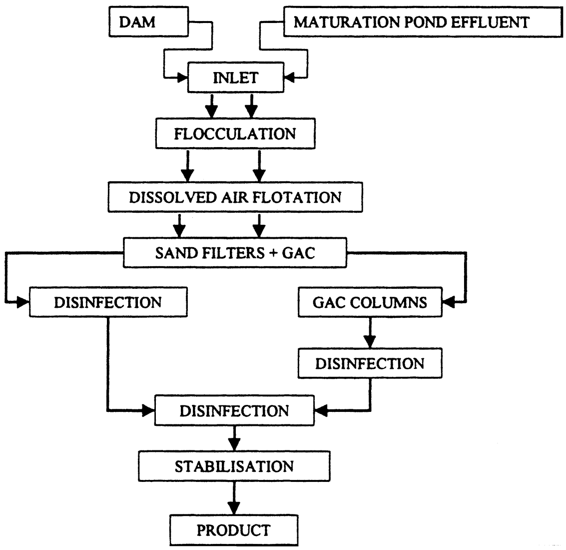

Figure 3 GRP flow diagram

Plant performance

The product or final water of the GRP was sampled every week for cysts and oocysts. A total number of 122 samples were analysed during the study period. The results are summarised in Figure 4. During the investigation, *Giardia* was detected in the final water 5% of the time and *Cryptosporidium* 2% of the time. The maximum *Giardi*a cysts detected in a sample was 30, the 99% percentile was 20 and the 99% percentile counted 6.2 oocysts and the 97% percentile 0 oocysts.

Some special samples with volumes of up to 12 900 litre were sampled during a period when *Giardia* and *Cryptosporidium* was suspected. One sample contained 1800 cysts per 6 3000 litre (= 29 cysts/100 litre). As part of the monitoring strategy sampling was increased during periods of suspected breakthrough (positive samples).

The available Rand Water Guidelines (RWG) are also used in-house as guidelines for

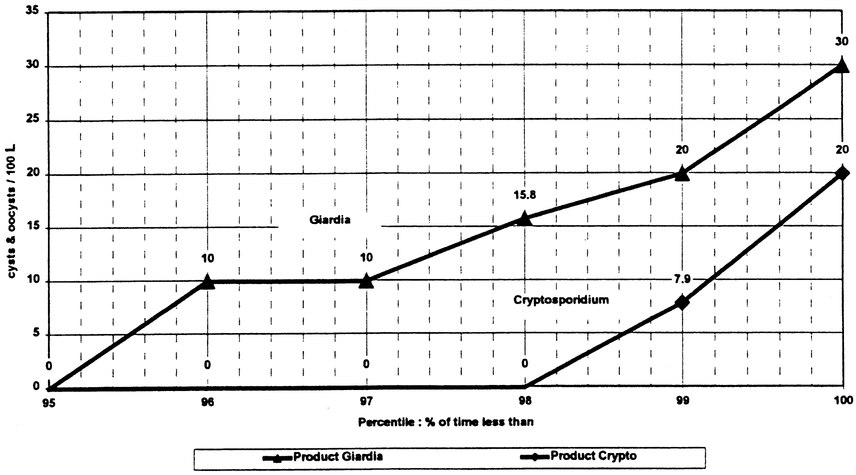

Figure 4 Final product water of Goreangab Reclaimation Plant *Giardia* and *Cryptosporidium*

Table 2 Rand Water Guidelines and plant performance figures (if calculated over total period)

	Units	95th percentile limit	97th percentile limit	99th percentile limit
Rand Water Guideline for *Giardia*	Org/2l	0	2	5
GRP performance	Org/2l	0	0.2	2
Rand Water Guidelines for *Cryptosporidium*	Org/2l	0	0	1
GRP performance	Org/2l	0	0	0.2

Note: Numbers in the table include viable and non-viable cysts and oocysts

final water quality regarding *Giardia* and *Cryptosporidium*. These guidelines and actual plant performance are shown in Table 2.

From the table it is clear that plant performance was within limits. However it should be noted, if calculated over shorter production periods, plant failure occurred in the second incident as a result of filter breakthrough. This should also be viewed against the background that if the final water from the GRP is blended with other sources (borehole water and purified surface water) at a 1:3 ratio it would decrease the risk considerably.

Giardia and / or Cryptosporidium breakthrough

Four distinct incidents of *Giardia* cyst and *Cryptosporidium* oocyst breakthrough happened during the period of investigation. These are indicated in Figure 5.

Incident 1 (02/96–03/96): During this single incident 100 *Giardia* cysts and 400 *Cryptosporidium* oocysts were detected in a 100 litre sample taken after the GAC columns. The oocysts were reported to be damaged cells. After this step follows breakpoint chlorination and a final chlorination point. Free chlorine residual levels are kept between 2–3 mg/l with a minimum contact time of 60 minutes (Ct product = 120–180 mg.min/l).

Incident 2 (07/97–11/97): During this period *Giardia* was detected on 9 occasions in the final product water, cyst counts ranging between 5 and 30 per 100 litre sample. On two occasions *Cryptosporidium* was detected, counting 10 and 20 oocysts. In two samples taken after the GAC columns 20 and 125 *Giardia* cysts were counted.

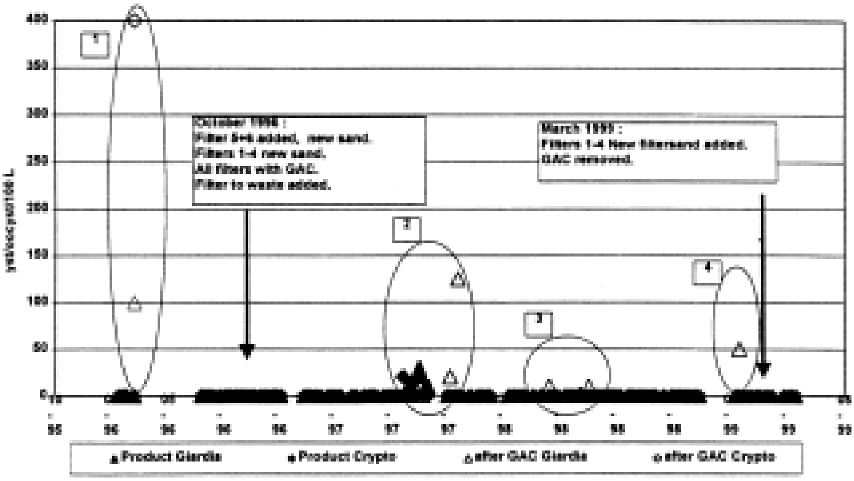

Figure 5 *Giardia* and *Cryptosporidium* in final product water, breakthrough through sand filters indicated

Incident 3 (03/98–06/98): During this period one sample of the final product water tested positive for *Giardia* (2 cysts), and two samples taken after the GAC columns, contained 10 cysts on both occasions.

Incident 4 (02/99): During this occasion one sample taken after the GAC columns contained 50 *Giardia* cysts per 100 litre.

In summary: During the total period of investigation (from January 1996 to August 1999) 10 samples of the final product water tested positive, with *Giardia* cyst counts ranging between 5 and 30. Two of the samples were positive for *Cryptosporidium* containing 10 and 20 oocysts respectively.

Figure 6 sums up the log values of *Giardia* and *Cryptosporidium* in the raw water sources and the log removal in the GRP. The log values for *Giardia* range from 1.18 to 2.7

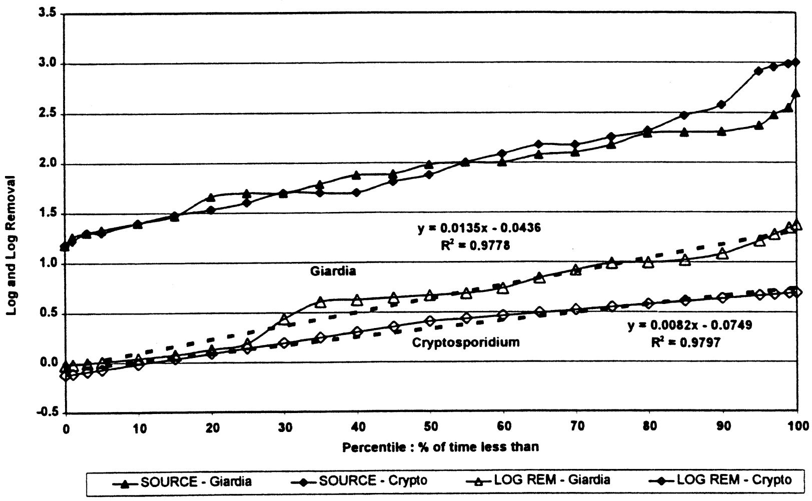

Figure 6 GRP – *Giardia* and *Cryptosporidium*: log and log removal

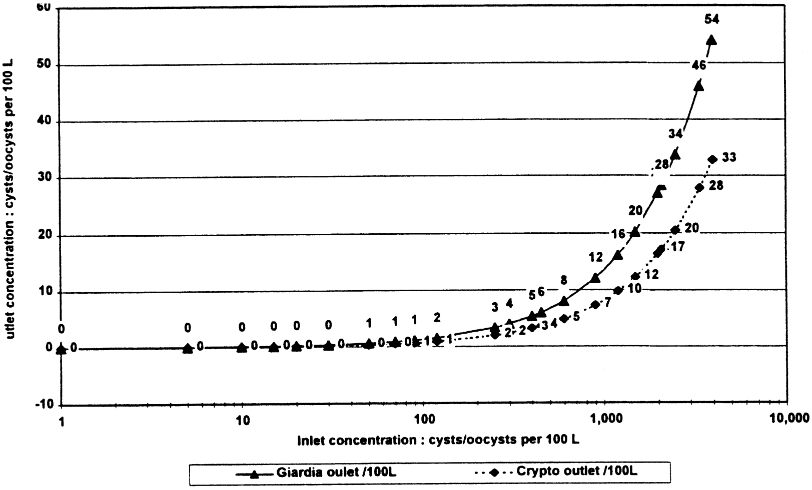

Figure 7 Expected *Giardia* cysts and *Cryptosporidium* oocysts in 100 litre treated water sample

log and for *Cryptosporidium* from 1.3 to 3.0 log. The log removal for *Giardia* ranges from –0.47 to 1.6 log and for *Cryptosporidium* from 0 to 0.4 log. Figure 7 is an attempt to show the amount of cysts and oocytes that can be expected in the final product water, calculated according to the removal rates achieved with the GRP. However, the results shown indicate poor correlation with removal efficiencies stated in the literature.

Steps taken after the breakthrough of *Giardia* cysts and *Cryptosporidium* oocysts

A thorough literature study was conducted and several experts consulted. Further *Giardia* and *Cryptosporidium* tests were conducted on all treatment steps to determine the extent of the problem and when and how the cysts and oocysts did get through the filters. Tests clearly indicated both cysts and oocysts at the filter inlet as well as during the filter ripening period after filter backwash when higher turbidities were read. This cyst and especially oocyst counts were in some cases higher in the filter outlet than in the filter inlet. These findings in early 1996 prompted a re-evaluation of the filter design, and a filter-to-waste feature was added to the design of filters 5 and 6. It was also decided to add the filter-to-waste feature as upgrade for filters 1 to 4. This feature resulted in the waste of filtered water for 20 minutes after start-up.

From July 1997 to November 1997 (incident 2) *Giardia* cysts and *Cryptosporidium* cysts were detected in the final water of the GRP. Many samples were taken after the sandfilters. Most of them tested negative. On one particular occasion *Giardia* was detected in the sandfilter outlet at three different filters. This time a report was filed and submitted to management with the advice to stop the treatment plant and change the filter medium, as it was suspected and subsequently confirmed that the activated carbon filter sand were mixing during filter backwashing. Due to technical reasons the way the filter control system was constructed and the mode in which the filters were operated, it was not possible to use the automatic filter control device. Operators had to manually operate the level control. During a plant inspection in November 1997, it was noticed that instructions to control the level control smoothly were not followed, and the control valves were opened too fast, resulting in filter shearing during adjustment. This brought us to the conclusion to add an on-line continuous sampling device to continuously monitor the final product water of the treatment plant, to be able to establish if cyst and oocyst breakthrough occurred continuously or if it was only sporadic. Due to unforeseen circumstances this device could only be installed in January 1999. To date no cysts or oocysts have been detected with this composite sample from the GRP final product water. However at another sample site, from another source, *Giardia* cysts have been detected in very high numbers, which would not have been able to be detected with a 100 litre grab sample. These special composite on-line refrigerated samples will be placed on every critical point in the distribution system, to continuously monitor the quality of all supply sources.

At the end of 1998 the turbidity measurements of the final product water were rising due to high levels of iron in the raw water from the dam. Turbidity was low after the sand filters, but after breakpoint chlorination, the iron was oxidised and started to precipitate. A report was submitted to management, advising to stop the treatment plant, change the filter sand of filters 1 to 4 and to clean all the sumps. The use of caustic soda was also advised, as the dosing of lime caused a rise in turbidity of the final water. Operation of the plant was stopped for two months to replace the filter sand and do the necessary maintenance.

Of particular interest is the fact that it was noticed that sporadic high chlorophyll concentrations (spikes) were recorded after the sand filters. There is no pattern or relation with *Giardia* and *Cryptosporidium* breakthrough, but it points to the fact that the filter level control is done manually. As was pointed out by other authors, this can cause cyst and oocyst breakthrough, especially when filters are close to the end of a filter run. Turbidity spikes at the sandfilter outlets during periods of breakthrough also indicate possible operational failure in the sense that treatment was not optimal.

No correlation could be found between cyst and oocyst removal and other water quality parameters.

Conclusion

From the data presented it is clear that the polluted dam water has the same risk level of *Giardia* and *Cryptosporidium* pollution as treated wastewater effluent. This emphasises the fact that the sources should be monitored continuously for these parasites. The sporadic high counts of *Giardia* and *Cryptosporidium* in the raw water sources indicate that a multiple-barrier approach must be followed to ensure the safe operation of even conventional treatment plants using polluted source water.

Optimised treatment unit performance is crucial. This includes good maintenance of the plant, good operational practice and vigilance of the operating staff. On-line monitoring of the plant is a must to monitor good operational practice and continuously optimise the treatment unit performance. Regular monitoring for various water quality parameters by a qualified laboratory (not only by the operators) is necessary to guarantee the production of pathogen free potable water.

The advocating of a final water turbidity of 0.1 NTU and the use of particle counters can only be supported by these findings, as it is possible to achieve a turbidity of less than 0.1 NTU at the sane filter outlet, even in a developing country like Namibia. The challenge lies with the maintenance of equipment and vigilance of the operators.

From the findings in 1996 it was decided to add a membrane filtration step in addition to ozonation in the new Goreangab Reclamation Plant as a further safety barrier against *Giardia* and *Cryptosporidium*. On-line monitoring and continuous sampling at various treatment steps, will also form an integral part of the new GRP.

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