Cryptosporidium & Giardia Removal in Small Water Treatment Systems

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Abstract
In projects conducted at small community scale and pilot water treatment facilities, the removal of *Cryptosporidium* and *Giardia* has been monitored to measure the effects of treatment system components on overall performance. Data have been generated using widely accepted methods always including rigorous controls for recovery efficiency to express results in terms of concentration. Sampling has been designed to permit forming mass balances for both organisms. Measured concentrations and removal performance has been compared to predictions using a simple spread-sheet model and actual treatment system design and operating data. Results from a variety of treatment system types show that small systems can perform at levels comparable to those previously published for large systems. Specific performance at individual treatment facilities is sensitive to operating conditions and in particular, the consistency of operating conditions.

Keywords
Small water treatment systems, treatment performance, *Cryptosporidium*, *Giardia*, concentrations

INTRODUCTION

Control of *Giardia* and *Cryptosporidium* concentrations is a topic of continuing interest in light of periodic outbreaks in community water systems, (Balderson & Karanis, 2011). This is particularly true of works of small treatment capacity and serving small communities having limited resources for maintenance and operation of reasonably complex systems. In recent years several reports have been published describing removal of these organisms in a variety of small but full-scale operating treatment plants serving communities of populations from a few hundred to a few thousand (Ongerth 1990, Ongerth & Pecoraro, 1995, Nieminski & Ongerth, 1995, Hutton et al, 1995, Hutton & Ongerth, 1997). Treatment types tested include: slow sand; package direct and pressure filters; direct filtration and complete conventional filtration; and diatomaceous earth filtration.

Measuring the removal of *Cryptosporidium* oocysts and *Giardia* cysts presents special problems for the investigator. Ambient concentrations of both organisms are most commonly near or below the normal limit of detection for accepted methods of analysis, Ongerth, 2013a. 2013b. Also, removal of particles in the size range of these organisms by typical water treatment processes is 2-3 logs placing treated water concentrations 100 to 1000 times below the normal limit of detection from ambient concentrations. Thus, to enable measurement of removal efficiency for these organisms requires producing large numbers of oocysts and/or cysts that can be seeded into the treatment system. The requirements for producing or obtaining and for manipulating seed stocks has led to the use of surrogates e.g. particles, latex beads, *C. perfringens* cysts, as a means of inferring removal capabilities. However, as described below, the investigations summarized here were conducted exclusively using *Cryptosporidium* oocysts and *Giardia* cysts carefully produced in the chief investigators laboratory to have native organism characteristics. In some cases measured organism removal was compared to measures of surrogate removal.

Previous findings indicate that removal efficiency for both *Giardia* and *Cryptosporidium* typically ranges from 2 to 3 logs, influenced by factors related to design and operation. In the last decade or so several additional investigations have focussed on the design and operation of specific treatment processes including settling, filtration, and solids recirculation. Previously unpublished results are compiled here shedding further light on their effects on treatment performance for control of these pathogens. The compiled results are illustrated in this abstract by one of the investigations focussed on the effect of backwash water reclamation and recirculation on overall removal performance for the subject organisms.

MATERIALS AND METHODS

Fifteen separate investigations of water treatment capability for removing *Cryptosporidium* oocysts and/or *Giardia* cysts between 1985 and 2002. Locations included the northwest of the USA and southeastern Australia. Treatment system types on which organism removals were measured included both full-scale operating ones and pilot scale facilities individually tailored to the specific design and operating characteristics of the full-scale facility. Included were slow sand, pressure filters, conventional treatment both with settling ponds and basins, direct filtration, and diatomaceous earth filters, with design and operating characteristics typical of small community installations, Table 1.

Table 1. Treatment facilities included in investigations of *Cryptosporidium* oocysts and/or *Giardia* cyst removal characteristics.

Location	Filtration Type	Capacity mgd	Seed Organism *Giardia*	Seed Organism *Crypto.*	Ref.
100 Mi. House, B.C. Canada	Slow sand	1		+	1
Northern Idaho, USA	Slow sand	0.07-0.29	+	+	2
Darrington, WA, USA	Package, direct	0.57	+		3
Grey Eagle CA, USA	Pressure, auto	4.0	+		3
Huntington UT, USA	Complete & direct	0.9		+	4
Seattle WA, USA	Complete & direct, pilot	1 (gpm)	+	+	5
Orchard Hills, NSW, Aust.	Complete conventional	15		+	6
Wellington NSW, Aust.	Complete conventional	5	+	+	U*
Guerie NSW, Australia	Complete conventional, auto	0.2	+	+	U
Macarthur, NSW, Aust.	Direct, pilot	19.6		+	U
E. Gippsland, VIC, Aust.	Complete conventional	4		+	U
Crystal Mtn, WA, USA	Diatomaceous earth	0.016			3
UNSW, Sydney NSW, Aust.	Diatomaceous earth, pilot	1ft^2			7,8

* Unpublished

For seeding *Cryptosporidium* oocysts were isolated from fresh dairy calf feces as previously described; *Giardia* cysts were isolated from fresh gerbil feces as previously described, Ongerth et al, 1996. Oocysts and cysts were rinsed in dH2O, refrigerated without preservation, and used typically within 48 hours of isolation. Organism concentrations were measured by best-procedure at the time of each investigation, either by membrane filtration-IFA (as in Ongerth, 1995) or by USEPA Method 1622/1623. Recovery efficiency was always measured as described elsewhere, Ongerth, 2013c, and applied to provide strictly defined organism concentrations from which removals across individual treatment components or comprehensive treatment plant removals were calculated.

In some investigations modelling was included use an Excel spread-sheet mass balance model to describe plant components and interactions including: 1. influent conditions (flow and *Cryptosporidium* concentration); 2. clarifiers with sludge underflow to the sludge lagoon; 3. filtration with backwash disposal to the sludge lagoon; and 4. a sludge lagoon supernatant return filter for recycle to the plant influent. Mass balance spread-sheets were prepared for treatment schemes including the supernatant return filter and without the supernatant return filter.

Plant operating staff provided operating data including flow rates, turbidities, chemical doses, solids handling flow, and filtration cycles. Samples for *Giardia* and *Cryptosporidium* collected at process influent and effluent locations to describe process performance. All samples were analysed for *Cryptosporidium* and/or *Giardia* by USEPA Method 1623 or as described in individual references.

RESULTS

For the three plant flow configurations (Figure 1a, b, c), filtered water *Cryptosporidium* oocyst concentrations were calculated using the mass balance equations and compiled for each of the three performance levels, for each of the three influent flowrates, and for each of the three raw water *Cryptosporidium* oocyst concentrations. The number of conditions examined was 27 (3 x 3 x 3) for each plant flow configuration. For each condition, flowrates

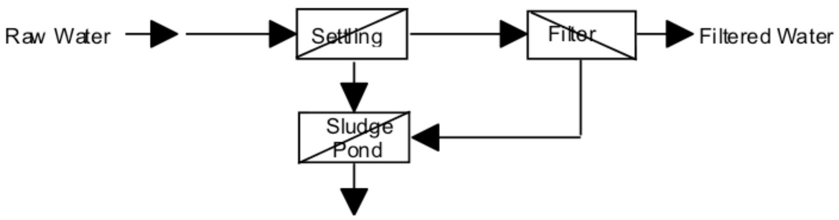

Figure 1a. Treatment Plant with No Sludge Lagoon Supernatant return

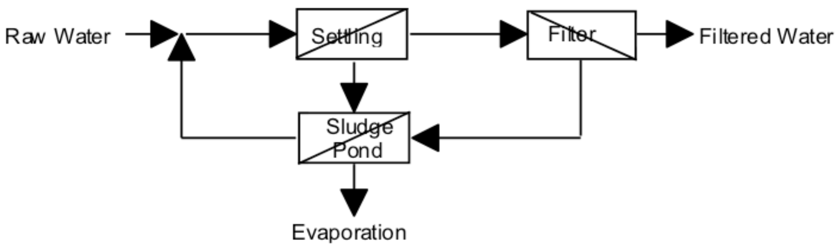

Figure 1b. Treatment Plant with Sludge Supernatant return, Without Filtration

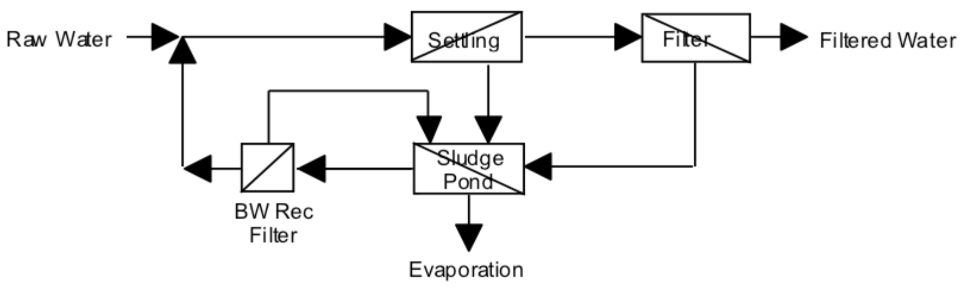

Figure 1c. Treatment Plant with Sludge Supernatant return, With Filtration

and concentrations at each point in the plant were calculated using the spread-sheets. Key components of the mass balance calculations that were used in this evaluation were: 1. filtered water *Cryptosporidium* oocyst concentration; 2. *Cryptosporidium* oocyst loading contribution of reclaimed sludge flow to the plant influent flow *Cryptosporidium* loading, expressed in terms of a concentration ratio (raw water oocyst concentration ÷ clarifiers influent oocyst concentration; and 3. accumulation of oocysts in the sludge lagoon. The results of each of the 81 mass balance runs are compiled separately in the appendix for reference.

Table 2. Treatment Evaluation, Process Performance Assumptions

Performance Level	Oocyst Removal Efficiency			
	Clarification	Filtration	Sludge Settling	BW Rec. Filter
Worst	50%	2-logs (99%)	50%	75%
Average	75%	2.5-logs (99.5%)	70%	75%
Best	90%	3-logs (99.9%)	90%	1-log (90%)

Details of plant operation needed for the mass balances included flowrates under typical operating conditions. Key flowrate conditions that affect the partitioning of Cryptosporidium in the plant include: 1. the clarifier sludge flow to the sludge lagoon; 2. backwash flowrates and frequency; and 3. flowrates and backwash details for the sludge lagoon supernatant return filter. Also, a typical value of evaporation from the sludge lagoon was required to provide a realistic estimate of overall plant operation. The flowrates and conditions used in the mass balances for each of the above process components were as listed below, Table 2. All flowrates were expressed in units of L/sec. Intermittent flows were expressed as continuous flows at reduced rates over 24 hrs.

Table 3. Summary of Treatment Treatment Plant Operating Conditions for Mass Balances

Treatment Component	**Condition**	**8 ML/day**	**16 ML/day**	**24 ML/day**
Clarifier underflow	<13 ML/day	0.202/8=0.025	- -	- -
	>13 ML/day	- -	0.403/16=0.025	0.403/24=0.0168
Backwash fraction	every 96 hrs	0.3105/8=0.0388	0.3105/16=0.0194	0.3105/24=0.0126
Sludge lagoon evaporation	2 or 6 mm/day	0 w/ rain	0.115 L/sec	0.346 L/sec
Supernatant return filter production	24 hr. average	6.48 L/sec	6.48 L/sec	6.48 L/sec
Supernatant return Filter BW rate	10 min. BW	6.4% (36000L)	6.4% (36000L)	6.4% (36000L)

The Evaluation of the contribution of the sludge lagoon supernatant return filter to overall plant performance for control of *Cryptosporidium* was the principal objective of this project. The effect of the filter and its performance can be seen from the percent change in concentrations summarised in Table 4. The comparison of treatment measured in terms of filtered water concentrations was expressed in terms of the percent change from the no supernatant return case to either the supernatant return without filtration or supernatant return with filtration case. These changes were summarised for all combinations of performance, flowrate, and influent oocyst concentration in Table 2.

For the three plant flow configurations (Figure 1), filtered water Cryptosporidium oocyst concentrations were calculated using the mass balance equations and compiled for each of the three performance levels, for each of the three influent flowrates, and for each of the three raw water Cryptosporidium oocyst concentrations. The number of conditions examined was 27 (3 x 3 x 3) for each plant flow configuration. For each condition, flowrates and concentrations at each point in the plant were calculated using the spreadsheets. Key components of the mass balance calculations that were used in this evaluation were: 1. the filtered water *Cryptosporidium* oocyst concentration; 2. the *Cryptosporidium* oocyst loading contribution of reclaimed sludge flow to the plant influent flow *Cryptosporidium* loading, expressed in terms of a concentration ratio (raw water oocyst concentration ÷ clarifiers influent oocyst concentration; and 3. the accumulation of oocysts in the sludge lagoon. The results of each of the 81 mass balance runs were compiled as summarized in Figure 3.

The filtered water *Cryptosporidium* oocyst concentrations predicted by the mass balances for the conditions described above are summarised in Table 4. The overall pattern that can be seen is that the filtered water concentrations are insensitive to flowrate, and directly proportional to the performance level and the influent oocyst concentration. For the plant flow scheme with no sludge lagoon recycle, for the lowest assumed influent oocyst concentration, 1 oocyst/ L, under worst performance conditions the maximum filtered water

Table 4. *Cryptosporidium* removal summary for varied treatment performance at selected plant flows, raw water oocyst concentrations, and recycle system effectiveness.

w/o BW Rec				w/ BW Rec w/o Filter				w/ BW Rec w/ Filter			
Worst Performance				Worst Performance				Worst Performance			
Flow, L/s	92.6	185.1	277.8	Flow, L/s	92.6	185.1	277.8	Flow, L/s	92.6	185.1	277.8
1 Oocy/L	0.00502	0.00501	0.00501	1 Oocy/L	0.00999	0.00997	0.00996	1 Oocy/L	0.00627	0.00625	0.00625
10 Oocy/L	0.0502	0.05009	0.05006	10 Oocy/L	0.0999	0.0997	0.0996	10 Oocy/L	0.0627	0.06254	0.0625
100 Ocy/L	0.502	0.50094	0.50063	100 Ocy/L	0.999	0.997	0.996	100 Ocy/L	0.627	0.62539	0.625
Average Performance				Average Performance				Average Performance			
Flow, L/s	92.6	185.1	277.8	Flow, L/s	92.6	185.1	277.8	Flow, L/s	92.6	185.1	277.8
1 Oocy/L	0.00125	0.00125	0.00125	1 Oocy/L	0.00179	0.00179	0.00179	1 Oocy/L	0.00139	0.00138	0.00138
10 Oocy/L	0.0125	0.0125	0.0125	10 Oocy/L	0.0179	0.0179	0.0179	10 Oocy/L	0.0139	0.0139	0.0138
100 Ocy/L	0.125	0.125	0.125	100 Ocy/L	0.179	0.1786	0.179	100 Ocy/L	0.139	0.138	0.138
Best Performance				Best Performance				Best Performance			
Flow, L/s	92.6	185.1	277.8	Flow, L/s	92.6	185.1	277.8	Flow, L/s	92.6	185.1	277.8
1 Oocy/L	0.0001	0.0001	0.0001	1 Oocy/L	0.00011	0.00011	0.00011	1 Oocy/L	0.0001	0.0001	0.0001
10 Oocy/L	0.0010	0.0010	0.0010	10 Oocy/L	0.0011	0.0011	0.0011	10 Oocy/L	0.0010	0.0010	0.0010
100 Ocy/L	0.010	0.010	0.010	100 Ocy/L	0.011	0.011	0.011	100 Ocy/L	0.010	0.010	0.010

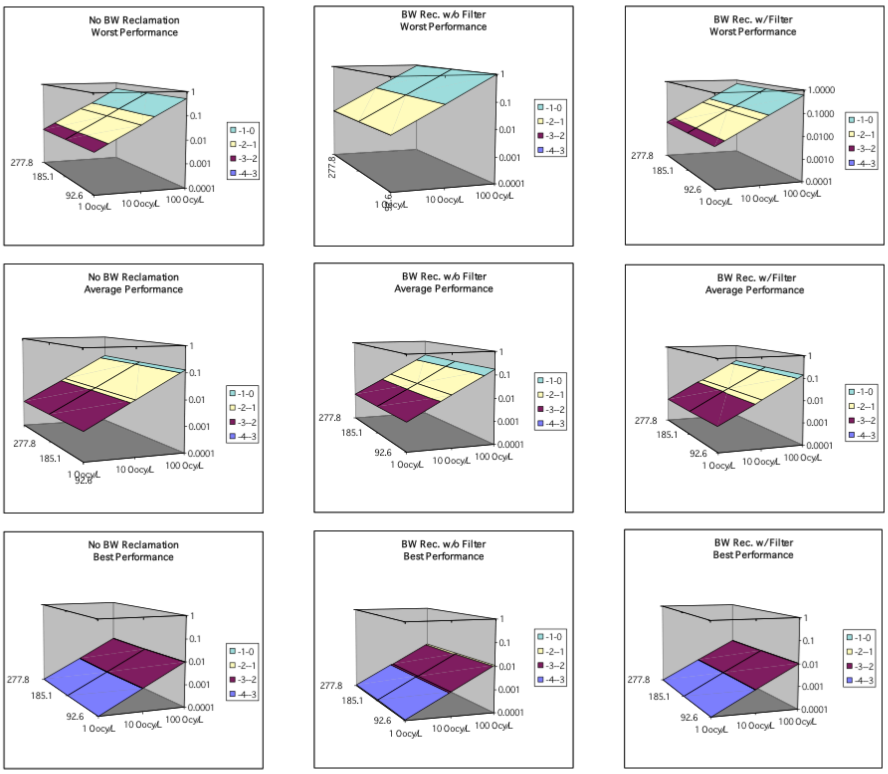

Figure 2. Treatment plant *Cryptosporidium* oocyst removal performance based on plant flow

rate, raw water oocyst conc., and recycle system effectiveness

DISCUSSION

Evaluation of the contribution of the sludge lagoon supernatant return filter to overall plant performance for control of *Cryptosporidium* was the principal objective of this project. The effect of the filter and its performance can be seen from the percent change in concentrations summarised in Table 4. The comparison of treatment measured in terms of filtered water concentrations was expressed in terms of the percent change from the no supernatant return case to either the supernatant return without filtration or supernatant return with filtration case. These changes were summarised for all combinations of performance, flowrate, and influent oocyst concentration in Table 4.

Effect of Supernatant Return with and without the Filter.

The effect of sludge lagoon supernatant return on filtered water *Cryptosporidium* oocyst levels can be compared for the treatment schemes with supernatant return but no filter (Figure 1b) and with supernatant return including the filter. As described above (see **RESULTS**) for any selected case defined by influent oocyst concentration, flowrate, and performance level, use of the filter can be seen to reduce the degree of effect of supernatant return by a significant margin. For worst and average performance cases, using the filter would reduce the effect of supernatant return by a factor of ca. 4: from -99% to -24% for worst performance; and from -42% to -11% for average performance. For best treatment performance assumptions, use of the filter would reduce the effect of supernatant return from ca. -10% to ca. 1%.

Effect of Performance of the Supernatant Return Filter

The relative importance of the performance level of the backwash filter can be examined through the comparisons of Table 3 and by simple manipulation of any of the mass balances. Operation of the plant including supernatant return and using the supernatant return filter, for example under worst treatment performance conditions would produce a filtered water concentration ca. 24% higher than if no supernatant return was included. The effect is reduced to ca. 10% if average treatment performance is assumed. Under best treatment performance conditions the effect would be unmeasurable. Approximately 60% of the difference in treatment performance for this case would be due to performance in the supernatant return filter alone. Comparing the average and worst performance results as just noted above, if the removal of the supernatant return filter used in the average case, 75%, were reduced to 50%, without altering performance of the other treatment components, the filtered water concentrations would be 0.00152 oocysts/ L instead of 0.00139 oocysts/ L, in comparison to 0.00627 for the worst performance case (for 1 oocyst/ L in raw water at a plant flowrate of 8 ML/day (92.6 L/sec), Table 3.

CONCLUSIONS

Compiled results from examination of small treatment systems shows performance at levels comparable to previously published information on large systems. Removal of *Cryptosporidium* and *Giardia* depends on treatment system type with slow sand least effective, conventional and direct filtration with generally effective removals but significantly dependent on both design and on operating details, and diatomaceous earth filtration capable of the most effective removals. Specific performance at individual treatment facilities is sensitive to operating conditions and in particular the consistency of operating conditions.

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