COSTS AND BENEFITS OF COMPLIANCE: NEW ZEALAND DRINKING WATER STANDARDS

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ABSTRACT

In New Zealand, water suppliers are required to take all practicable steps to comply with the Drinking Water Standards 2005 (DWSNZ), published by the Ministry of Health (MoH). For many smaller communities, the costs of upgrading water supply infrastructure to comply with DWSNZ are substantial, but water suppliers do not estimate the benefits.

In this paper we propose a method for calculating the public health benefits associated with DWSNZ compliance. Our calculations suggest that for a catchment with high protozoal risk, the benefit cost ratio for upgrading to a compliant plant could be between 0.5 and 7.1. Furthermore, the number of illnesses could be reduced by 100 times.

The benefits of protozoal compliance due to cost of illness avoided depend on the number of infectious *Cryptosporidium* oocysts in the source water. We recommend that water suppliers are familiar with their catchment risks in order to understand the level of public health risks inherent in their water supplies.

KEYWORDS

Drinking water standards, compliance, benefit, water quality, cost of illness

1 INTRODUCTION

In an effort to reduce public health risks, governments in many parts of the world have adopted drinking water quality standards. The World Health Organisation (WHO) has developed two guideline documents for managing water supplies quality and risks, *Guidelines for Drinking-water Quality* (WHO 2008), along with a *Water Safety Plan Manual* (Bartram et al 2009), which many countries worldwide have at least partially adopted.

The current style and format of the New Zealand drinking water standards (DWS) (MoH 2008), which adopt many of the water quality parameters from the WHO guidelines, have been under development since 1992. These standards prescribe maximum acceptable values (MAVs) for chemical, cyanotoxin and radiological determinands, as well as for *E. coli* and pathogenic bacteria; monitoring requirements for bacteria; and treatment process barriers for protozoa compliance. The DWS use a 'log credit' system for protozoa compliance, which means the level of treatment (log credit) required increases according to the source's protozoal catchment risk category. In a catchment with intensive animal farming, for example, the highest level of treatment (5 log) is required.

A 1989 survey (Taylor 2002) suggested that at least 45% of water supplies in New Zealand did not properly monitor chlorine dosage, and 28% did not test for bacteria in the reticulation, which suggests water suppliers did not fully understand the public health risks associated with a substandard water supply. In addition, most of the substandard water supplies were managed by small water suppliers in communities with little available funding. Since that time, the DWS have developed substantially and their application will soon become a legal requirement. As at 2007, 6% of registered water supplies serving 75 % of the New Zealand population complied with the protozoal requirements of the DWS (MoH 2009b).

In New Zealand, as of 2016, water suppliers will be required to take all practicable steps to comply with the Drinking Water Standards for New Zealand 2005 (DWSNZ), published by the Ministry of Health (MoH). The costs of upgrading water supply infrastructure to comply with DWSNZ are substantial for many smaller communities, as they would require more sophisticated instrumentation, dosing equipment, and monitoring equipment. In many cases, whole new processes such as UV treatment or membrane filtration are also required in order to fulfill the log credit requirements. Various estimates of recently completed projects and budgeted capital expenditure associated with DWSNZ compliance have reported capital expenditures ranging from 0.8 to 20 million dollars per local authority (Cumming 2009); the MoH (2009a) have reported New Zealand-wide estimates of 50 to 275 million dollars. The MoH provides capital funding for small communities that have difficulty in funding capital improvements themselves, but there are also long-term operation and maintenance costs associated with these new upgrades.

The authors have been unable to find project feasibility benefit-cost analyses that suggest the benefits of investing in a higher quality drinking water justify the expense – particularly in developed countries where water quality is generally good and water related diseases and outbreaks are infrequent. However, a number of major disease outbreaks in the developed world since the early 1990's have shown the costs of poorly managed drinking water quality can be in the order of hundreds of millions of dollars, even for small towns, and result in human fatalities (Livernois 2002, Corso et al 2003).

In an effort to assess practicability of complying with DWSNZ from an affordability perspective, this paper makes an initial attempt at evaluating the costs and benefits associated with compliance with the protozoal and bacterial criteria in the drinking water standards by (1) examining the capital costs and the longer term operation and maintenance costs associated with some of these upgrades using recent water treatment plant upgrade works, including additional energy and raw material use, and (2) estimating the costs of illness avoided by complying with the drinking water standards.

2 BACKGROUND

2.1 WATERBORNE DISEASE IN NEW ZEALAND

The main purpose of water treatment is to protect the public from waterborne illness. Notifiable waterborne diseases affected an estimated 14,100 people in New Zealand between June 2008 and June 2009 and cost the New Zealand economy an estimated $18M (Table 1) (*adapted from MfE 2007 and updated to 2009 dollars*). Other estimates have suggested annual costs of $27M (MfE 2007). Table 1 shows that protozoa and bacteria contribute the largest share of the costs at 39% and 61% respectively. Norovirus, although a prominent waterborne disease in New Zealand, is one not notifiable, and is not included in the table.

Table 1: Estimated number of notifiable waterborne illness cases 2008-09

(adapted from MfE 2007 and updated to 2009 dollars)

Pathogen	Cases reported (2008-09)	% reported (NZ Med J, 2000)	Proportion waterborne (MfE 2007)	Estimated total waterborne cases per annum	Cost per case (2009 $) (MfE 2007)	Total cost ($000)	Percentage of total cost
Protozoa							
Cryptosporidiosis	813	10	30	2,439	1266	3,088	17.3
Giardiasis	1,717	10	20	3,434	1107	3,801	21.3
Bacteria							
Campylobacteriosis	6,828	13	10	5,252	690	3,624	20.3
E. coli O157 (VTEC)	156	35	20	89	77,671	6,924	38.8

Pathogen	Cases reported (2008-09)	% reported (NZ Med J, 2000)	Proportion waterborne (MfE 2007)	Estimated total waterborne cases per annum	Cost per case (2009 $) (MfE 2007)	Total cost ($000)	Percentage of total cost
Salmonellosis	1,296	31	5	209	681	142	0.8
Shigellosis	130	26	10	253	328	16	<0.1
Yersiniosis	493	20	10	247	1153	284	1.6
Viruses							
Virus (including Hepatitis A)	81	15	2	11	264	3	<0.1
Total							
Total	11,384			14,119		17,855	

DWSNZ prescribes six main criteria to manage the risks associated with drinking water: bacterial, protozoal, cyanotoxin, chemical, and radiological. Viral barriers are not prescribed at this stage because the effectiveness of treatment processes in removing viruses is not well understood. This paper focuses on bacterial and protozoal compliance, as these compliance criteria tend to drive the more significant investments. They appear to have the greatest economic and public health effects, and the effectiveness of different treatment types of these two categories are better understood.

Giardia and *Cryptosporidium parvum* are the main waterborne protozoa of concern in drinking water in New Zealand, costing an estimated $6.9M per annum (Table 1). Both protozoal types can cause severe diarrhoeal illness through giardiasis and cryptosporidiosis, resulting in time away from work and school, as well as direct medical costs. For immunocompromised individuals, death may result.

A single giardia cyst can cause disease. ESR (2009) reported 1,717 cases of giardiasis and 813 cases of cryptosporidiosis in New Zealand. New Zealand's reported morbidity rates are between 30% and 800% higher than in Australia, UK, Germany, and USA (reference).

2.1.1 PROTOZOAL REMOVAL

Risebro et al (2007) examined the causative agents in 61 outbreaks in 14 countries across Europe and found that half (31) of the outbreaks were due to protozoa. Twenty-nine of these were *Cryptosporidium* outbreaks and two were due to *Giardia*. Giardia is several times larger than *Cryptosporidium* and is therefore more likely to be removed from the drinking water through a filtration process. Furthermore, *Cryptosporidium* oocysts are more resistant to disinfection. As a result, the DWSNZ protozoa compliance focuses on removal of *Cryptosporidium.* According to DuPont et al (1995), the median infectious dose (ID_{50}) for *Cryptosporidium* is 10 to 30 oocysts, while infection may occur from a single oocyst.

In a study involving 23 protozoa outbreaks, Risebro et al (2007) found that 90% of the events were due to filtration deficiencies. The importance of filtration in removing protozoa highlights the need to provide robust treatment processes and monitor appropriately.

In the DWSNZ, protozoal compliance is expressed in terms of a log removal requirement – which is, in effect, the level of filtration and/or disinfection required to provide a 1 in 10,000 risk of infection. The log removal is the percentage removal of *Cryptosporidium* oocysts, which follows a log scale, as shown in Table 2. For each unit increase in log removal, ten times more *Cryptosporidium* oocysts are removed.

Table 2: Relationship between log removal and percentage removal (Source: MoH 2008)

Log removal	Percentage removal (%)
1	90
2	99
3	99.9
4	99.99
5	99.999

The source water supply is assigned a log removal requirement between 0 and 5 based on the catchment's assessed risks where 0 is extremely low risk and 5 is very high risk. The level of risk is based on an expected range of *Cryptosporidium* oocysts depending on the catchment activities. We aim for a maximum risk of infection of 1 in 10,000. Figure 1 shows that if we have 0.027 infectious oocysts, a 4-log treatment will provide a 1 in 10,000 risk of infection. Using the percentage removal for 4-log removal of 99.99% shown in Table 2, we expect to find 0.027 x (1-0.9999) = 0.000027 infectious *Cryptosporidium* oocysts in the treated water. Similarly, if we have 0.27 oocysts, a 5-log treatment will provide a 1 in 10,000 risk of infection. Since there are ten times more infectious oocysts in the source water we want to remove ten times more, and we will again expect to find 0.27 x (1-0.99999) = 0.000027 infectious *Cryptosporidium* oocysts in the treated water.

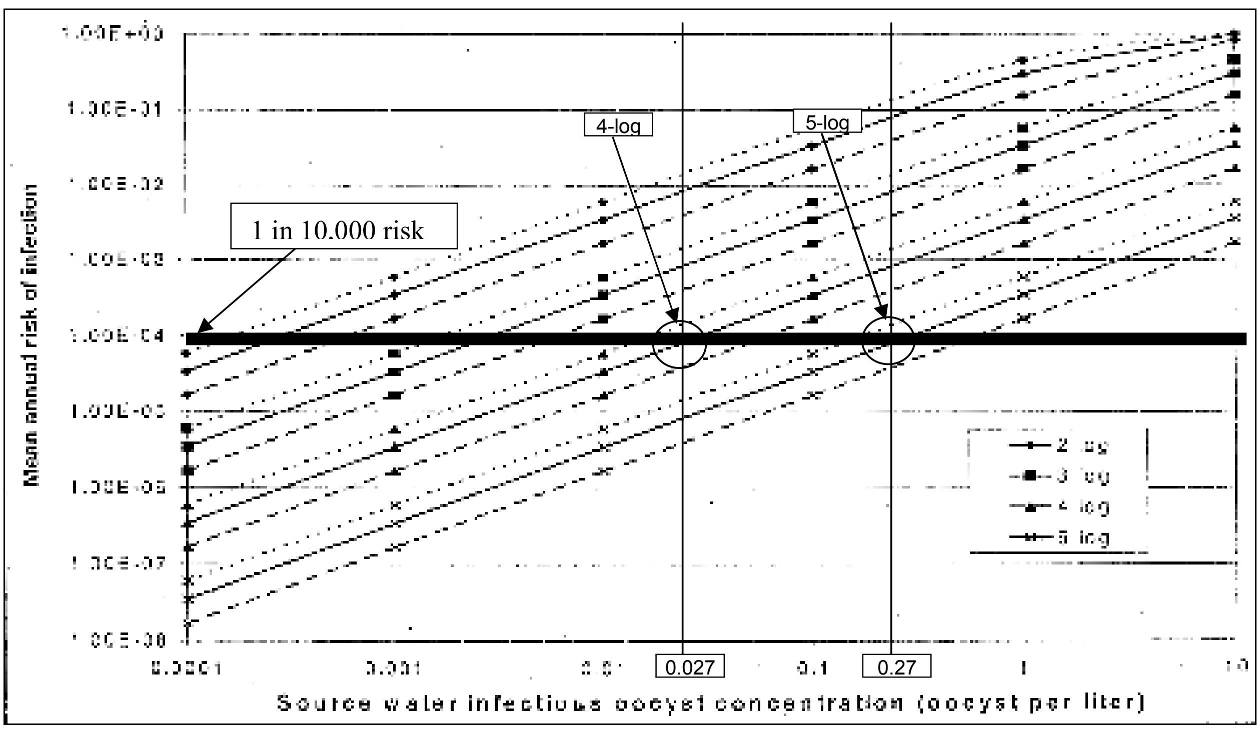

Figure 1: Annual risk of Cryptosporidium infection as a function of source water infectious oocyst concentration for treatment plants achieving 2-log, 3-log, 4-log, or 5-log removal of oocysts (adapted from USEPA 2006)

The catchment risk for water supplies serving fewer than 10,000 people is assigned according to the catchment activity, as shown in Table 3. For supplies serving more than 10,000 people, however, *Cryptosporidium* monitoring is required, and catchment risk is assigned as shown in *Table 4*.

Table 3. Log credit requirements for different catchment and groundwater categories for supplies serving up to 10,000 people

(source: Table 5.1a DWSNZ2005)

Catchment or groundwater protozoal risk category	**Log credits**
Surface waters	
Waters from pastoral catchment with frequent high concentrations of cattle, sheep, horses or humans, or a waste treatment outfall nearby or upstream	5
Waters from pastoral catchment that always has low concentrations of cattle, sheep, horses or humans in immediate vicinity or upstream	4
Water from forest, bush, scrub or tussock catchments with no agricultural activity	3
Groundwaters	
Bore water 0 to 10 m deep and springs are treated as requiring the same log credit as the surface water in the overlying catchment	3–5
Bore water drawn from an unconfined aquifer 10 to 30 m deep, and satisfies groundwater security criteria 2	3
Bore water drawn from deeper than 30 m, and satisfies bore water security criteria 2	2
Secure, interim secure, and provisionally secure bore water	0

Table 4. Log credit requirement for surface waters, springs, and non-secure bore water 0-10m deep, based on Cryptosporidium monitoring (standard approach for supplies serving over 10,000 people)

(adapted from Table 5.1b DWSNZ2005)

***Cryptosporidium*, mean oocysts per 10 litres**	**Estimated mean infectious *Cryptosporidium* oocysts per 10 litres**	**Log credits**
>=10	>=3.7	5
0.75-9.99	0.28-3.69	4
<0.75	<0.27	3

DWSNZ provides guidance on treatment processes and upgrade pathways to achieve different log credits. Figure 2 through Figure 5 show which processes are required in order to achieve a particular log credit requirement. There are different options for compliance. It is expected that if existing treatment processes are in place, the lowest cost solution may be to add treatment processes to create a longer treatment chain. If the existing treatment plant is a coagulation / flocculation / filtration plant, then as shown in Figure 2, it achieves a 3 log credit. If the catchment requires greater than 3 log removal, the water supplier can select one treatment process from each of the rows below the main process to increase the plant's log credit. However, it is worth noting that many plants in New Zealand have no protozoal treatment at all (Ball 2009 pers. comm. 30 July).

Figure 2 shows that coagulation based processes followed by other treatment processes can achieve a maximum of 7.5 log credits. Figure 3 shows that single filtration processes followed by disinfection can achieve up to 8.0 log credits. Figure 4 shows that treatment plants providing two filtration processes can achieve up to 10.5 log credits. Figure 5 shows that disinfection-only processes can provide up to 3 log credits.

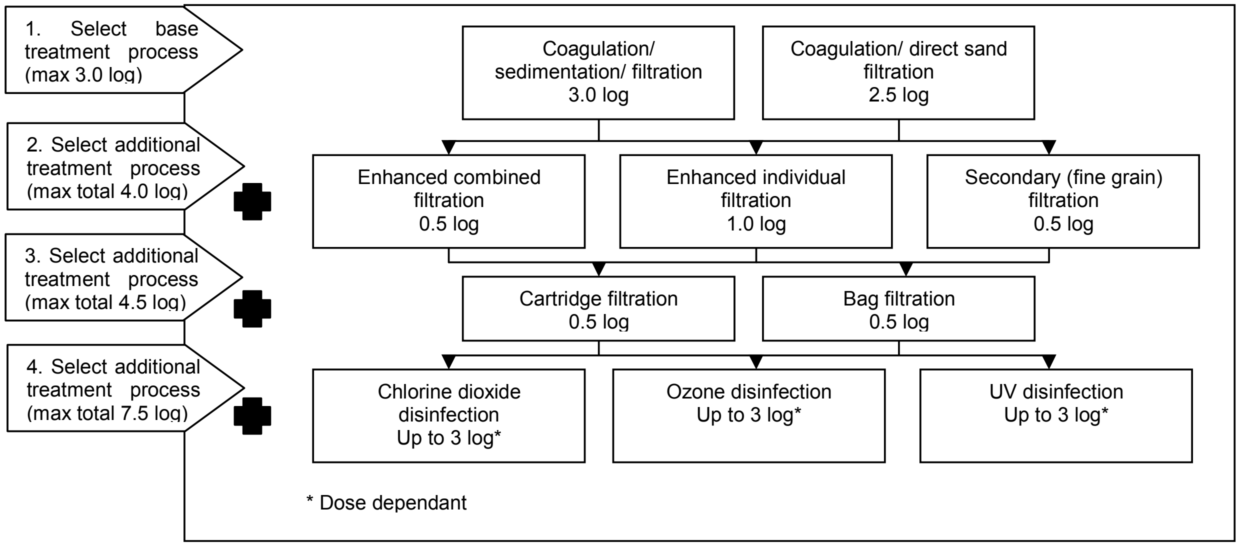

Figure 2. Log Credits for Protozoan Compliance – Coagulation based processes

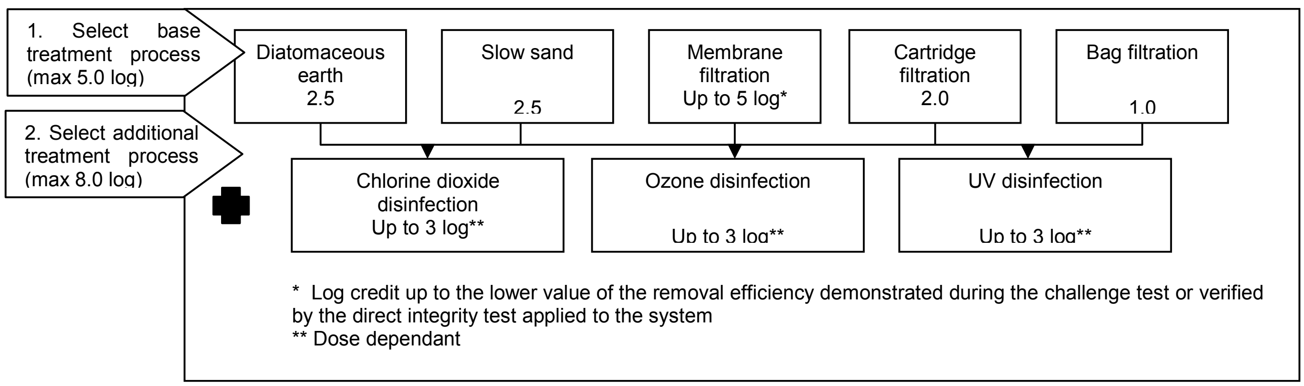

Figure 3. Log Credits for Protozoan Compliance – Single filtration process without coagulation

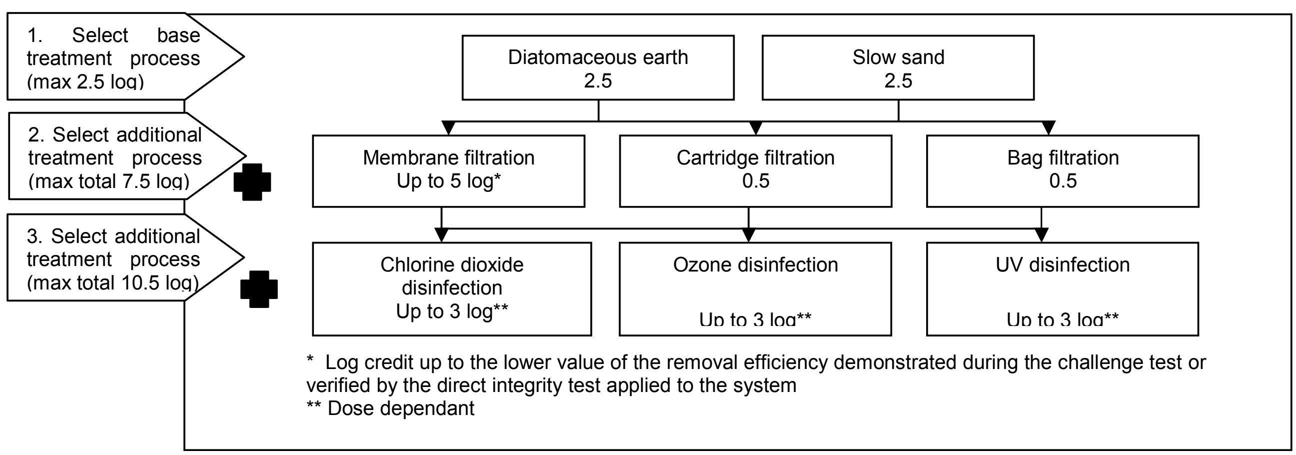

Figure 4. Log Credits for Protozoan Compliance – Two filtration processes

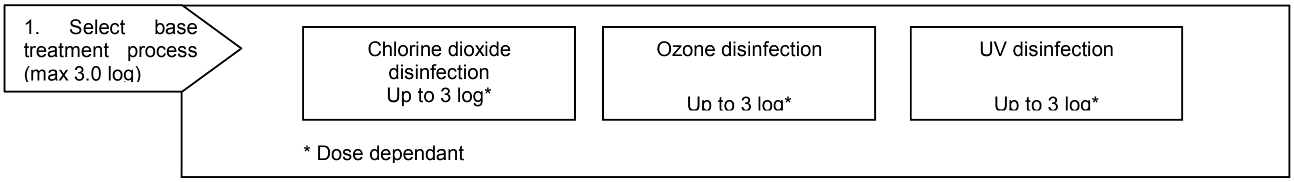

Figure 5. Log Credits for Protozoan Compliance – Disinfection only

The USEPA (2006) have estimated the annual risk of *Cryptosporidium* infection based on the source water concentration of infectious oocysts and the log reduction treatment, as shown in Figure 6. In the US, LeChevallier et al. (2003) found that approximately 37% of *Cryptosporidium* oocysts found in natural waters were infectious. Figure 6 suggests that for a particular infectious oocyst concentration, upgrading from a 3-log plant to a 5-log plant reduces the risk of infection by 100 times.

The log credit required is based on work by Haas et al (1996), which indicated that 1 in 10,000 is an acceptable annual risk for infection. *Table 4* prescribes that *Cryptosporidium* oocyst concentrations of up to 9.99 per 10 litres require a 4 log reduction. If 37% of oocysts are infectious, then infectious oocyst concentrations for a 4-log reduction are as shown in *Table 4*. The upper limit of the number of infectious oocysts for each log credit category shown in *Table 4* corresponds with the 1 in 10,000 risk shown in Figure 6.

Infection will occur when infectious oocysts are ingested, which means that infectious oocysts will be detected in the stool, but ingesting infectious oocysts does not guarantee illness. Haas et al (1996) estimate that the rate of becoming ill if infected, the morbidity rate, is 40%.

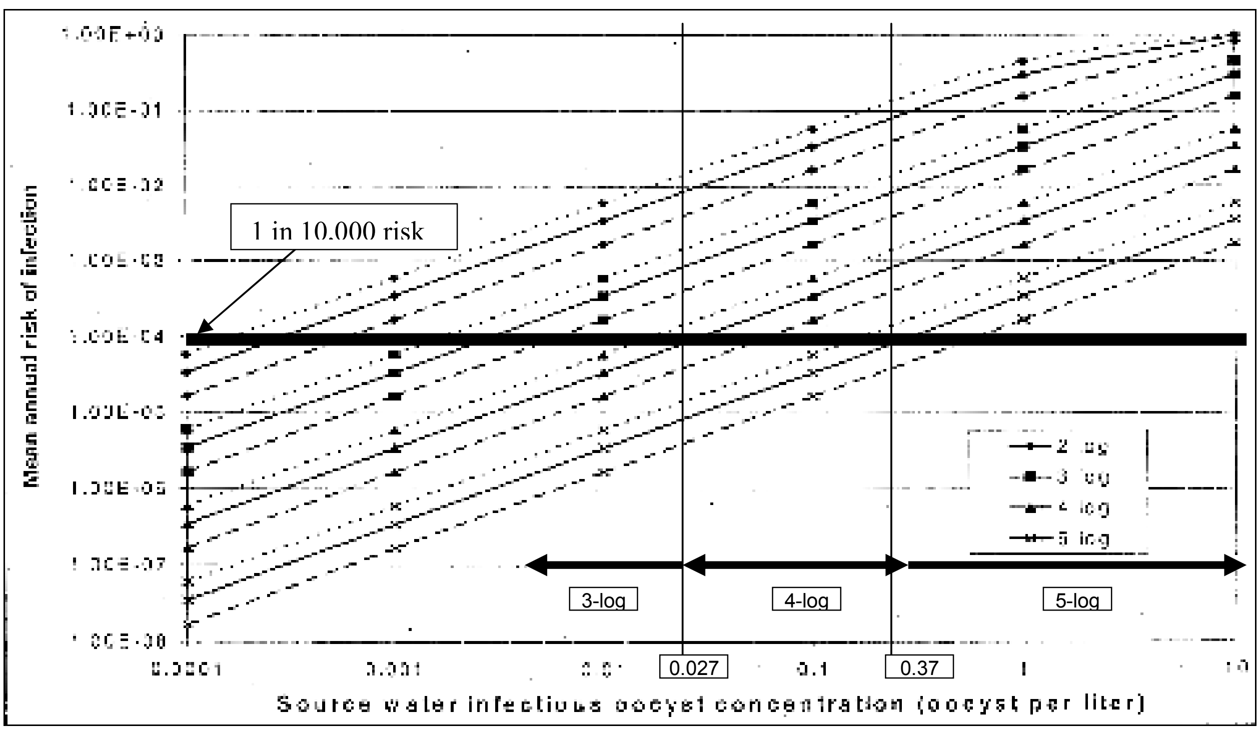

Figure 6: Annual risk of Cryptosporidium infection as a function of source water infectious oocyst concentration for treatment plants achieving 2-log, 3-log, 4-log, or 5-log removal of oocysts (adapted from USEPA 2006)

2.1.2 BENEFITS OF PROTOZOAL REMOVAL

The USEPA (2005) calculated the benefits of protozoa removal for the Long Term 2 Enhanced Surface Water Treatment Rule by estimating the cost of illness (COI) avoided due to an improvement in drinking water quality. Two estimate types were used: the traditional COI incorporates mainly direct medical costs and lost paid work days, while the enhanced COI incorporates lost productivity for time spent at work while unwell and lost leisure productivity for time spent on unpaid work or in leisure activities. Other studies that have evaluated the costs of drinking water outbreaks (Livernois 2002, Baker et al 2003, MfE 2007) have also valued lost productive and non-productive time.

3 METHODOLOGY

In this section we propose a methodology for calculating the costs and benefits associated with upgrading a water supply to comply with the DWSNZ. If the existing treatment log credit is less than the catchment log removal requirement then an upgrade is required. The cost of a compliance upgrade is based on the capital and operating and maintenance costs associated with the additional equipment. The benefit of the compliance upgrade is based on the cost reductions associated with the expected reductions in illness, as shown in Figure 7.

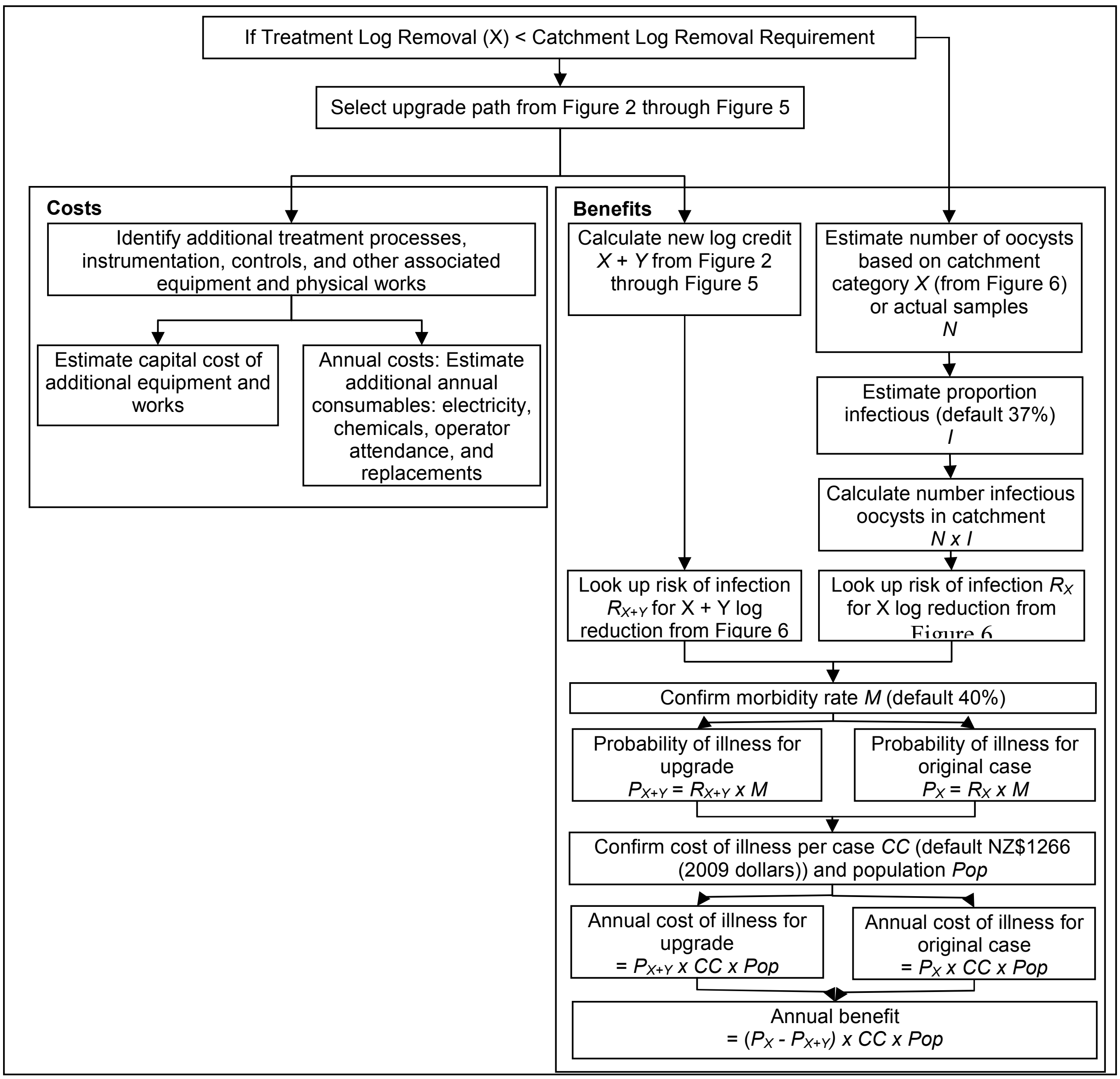

Figure 7: Methodology for calculating the costs and economic-health benefits of upgrading a water treatment plant for treatment of protozoa

We calculate the net present value (NPV) of costs and the NPV of benefits and divide the benefits by the costs to obtain the benefit-cost ratio. We use a real discount rate of 6.0% to calculate the NPV's, using the Weighted Average Cost of Capital method (WACC), a method accepted by the NZ Treasury, according to Vessey (2009, pers. comm. 30 July). To illustrate how these calculations can be applied, and to estimate whether or not there may be public health benefits in an economic sense, we provide two examples of theoretical compliance upgrades based on recent tender rates.

Table 5 shows three different water supply system sizes, each with two possible catchment log risks (4-log and 5-log). We assume the existing treatment plants provide only 3-log reduction through conventional coagulation / sedimentation / filtration, with an existing number of filters, control valves, and turbidity meters as shown in Table 5. The plant capacities are expressed in millions of litres per day (MLD), and are capable of serving the populations shown.

To estimate the cost of upgrade for each plant we assume the lowest cost upgrade path. Using Figure 2 through Figure 5 as a guide, Figure 2 shows the conventional coagulation / sedimentation / filtration processes we have assumed at the plant. We have therefore based our cost estimates on the upgrade path options in Figure 2. We examine the additional equipment that will likely be required for the compliance upgrade. The capital costs used in our calculations accrue due to the minimal expenditure required to comply with the DWSNZ and do not include deferred maintenance, capacity upgrade, or compliance with other standards.

Table 5: Assumptions for cost and benefit calculations

Capacity (MLD)	**Population**	**Catchment log risk**		**Existing plant log credit**	**Existing number of**		
		Case I	**Case II**		**Filters**	**Control valves**	**Turbidity meters**
0.6	900	4	5	3	1	0	1
7	7,500	4	5	3	5	5	1
50	60,000	4	5	3	10	10	1

Once we have confirmed the additional equipment required to comply with the DWSNZ, we estimate the additional operating and maintenance costs associated with the additional requirements for energy use, chemical dosing, replacement parts, operator attendance, and monitoring and reporting.

We recognise the potential for significant variability between upgrades for different plants but provide these estimates based on actual costs and engineering cost estimates for projects Opus has been involved in. Operating and maintenance costs have been collected largely from suppliers and from best practice estimates conducted by the authors.

3.1 COST ESTIMATE

3.1.1 CASE I: CATCHMENT RISK: 4; PLANT EXISTING LOG CREDIT: 3.

In this example we assume Case I from Table 5, which refers to a catchment log risk of 4.0. The existing treatment plant, a conventional coagulation / sedimentation / filtration plant, provides a 3-log credit. We need to calculate the costs to upgrade to a 4-log plant by identifying the additional equipment required, estimating their costs, and estimating the annual costs associated with the operation and maintenance of the new equipment.

CAPITAL EXPENDITURE

Figure 2 suggests that the lowest cost method of upgrading from a coagulation / sedimentation / filtration plant that is already achieving a 3-log credit to a 4-log plant would likely be through enhanced filtration. Enhanced filtration requires that most water exceeding the specified turbidity parameters for filtered water is diverted to waste, as shown in Figure 8. We assume no additional storage is required for longer durations of elevated turbidity.

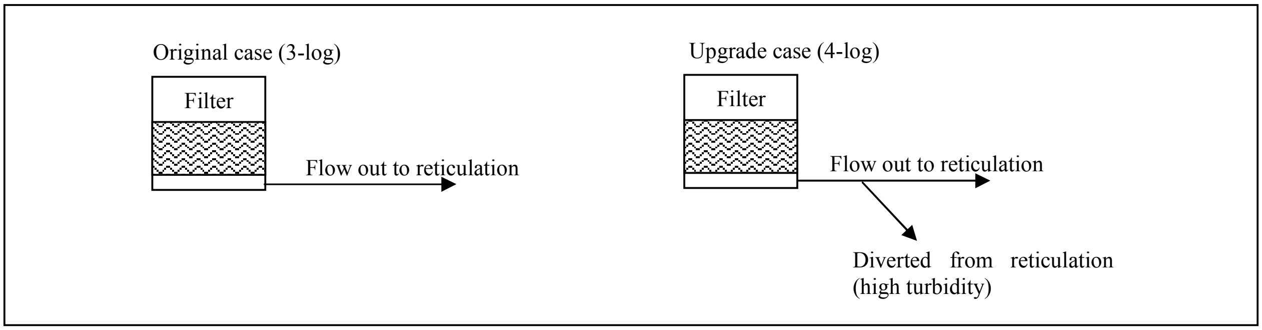

Figure 8: Enhanced filtration sketch (simplified)

The run to waste facility for enhanced filtration requires a turbidity meter on each filter; additional pipework to divert the filtered water to the source, to a holding pond, or back to the front of the plant; and control valves to automate this process. Figure 9 provides sketches of the assumed original and upgrade cases for a 0.6 and 7 MLD plant. The 50 MLD plant is simply an extension of the 7 MLD plant.

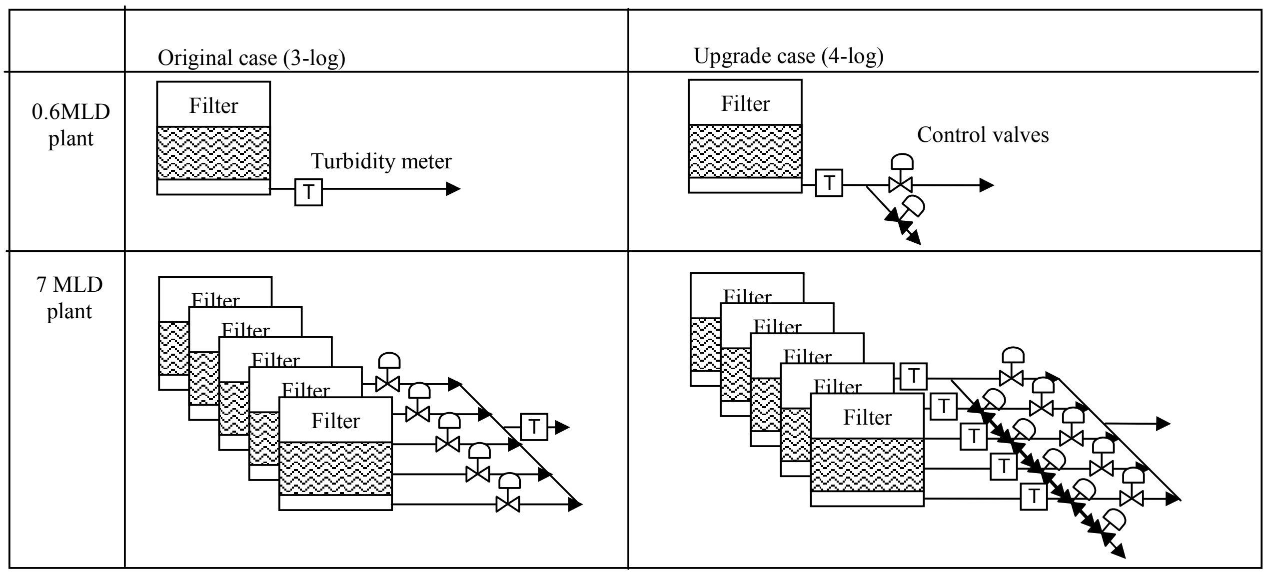

Figure 9: Enhanced filtration sketch for 0.6 and 7 MLD plants

Our capital cost estimates, shown in Table 6, assume the original treatment plant has only one turbidimeter for the total filtered water; that the 0.6MLD plant has no filtered water control valve and the larger plants have one control valve per filter, as depicted in Figure 9. Our pipe diameter estimates are based on equal flow out of all filters, with flow spread over a 23-hour operational day (to allow one hour for maintenance), and with a velocity of 1.5m/s in the pipes out of the filters, and our unit rates are based on recent tender prices.

The unit rates for supply, install and commissioning of the relevant equipment are based on recent tender rates and are shown in Table 7. The run to waste pipework for the 7MLD plant is based on a tender rate and the 0.6MLD and 50MLD run to waste pipework have been scaled down and up, respectively.

Table 6: Capital cost estimate for upgrading from 3-log conventional coagulation / sedimentation / filtration plant to 4-log plant

Capacity	Original					Additional for run to waste		Estimate upgrade			
	Filters	Control valves	Turbidity meters	Pipe diam estimate	Q (m3/s) per filter	Control valves	Turbidity meters	Turbidity meters	Control valves	Pipework	Total
0.6MLD	1	0	1	78	0.0072	2	0	$ -	$ 10,000	$ 16,000	$ 26,000
7MLD	5	5	1	120	0.0169	5	4	$ 60,000	$ 27,500	$ 80,000	$ 167,500
50MLD	10	10	1	226	0.0604	10	9	$ 135,000	$ 60,000	$ 800,000	$ 995,000

Table 7: Unit rates

Item	Unit cost (installed)
Turbidity meter	$ 15,000
Control valve 100mm	$ 5,000
Control valve 150mm	$ 5,500
Control valve 200mm	$ 6,000
Run to waste pipework (0.6MLD plant)	$ 16,000
Run to waste pipework (7MLD plant)	$ 80,000
Run to waste pipework (50MLD plant)	$ 800,000

OPERATING EXPENDITURE

Annual operation and maintenance costs for the run to waste pipework would mainly include replacement costs associated with the control valves and turbidity meters, and increased operator attendance time associated with calibrating the turbidity meters, as shown in Table 8. We have assumed control valves have an expected life of 25 years, and turbidity meters have an expected life of 10 years. Site verification for turbidity meters is based on a weekly 15-minute verification, and calibration is based on a quarterly 30-minute calibration exercise. Operators' time is based on a rate of $55/hour. Our estimates for O&M costs do not take into account any reduced attendance requirements due to increased plant automation, control, or optimisation. Furthermore, we believe the additional energy costs associated with the control valves and turbidity meters are minimal.

Table 8: Annual operational cost estimate for upgrading from 3-log conventional coagulation / sedimentation / filtration plant to 4-log plant

Capacity	Control valves	Turbidity meters				Annual O&M
			Operator attendance (hours per week)			
	Replacements	Replacements	Site verification	Calibration	Operator time	
0.6MLD	$ 240	$ -	0.00	0.00	$ -	$ 240
7MLD	$ 700	$ 3,200	1.00	0.15	$ 3,300	$ 7,200
50MLD	$ 1,600	$ 7,200	2.25	0.35	$ 7,425	$ 16,225

3.1.2 CASE II: CATCHMENT RISK: 5; PLANT EXISTING LOG CREDIT: 3.

In this example we assume Case II from Table 5, which refers to a catchment log risk of 5.0. The existing treatment plant, a conventional coagulation / sedimentation / filtration plant, provides a 3-log credit. We need to calculate the costs to upgrade to a 5-log plant by identifying the additional equipment required, estimating their costs, and estimating the annual costs associated with the operation and maintenance of the new equipment.

CAPITAL EXPENDITURE

Figure 2 suggests that the lowest cost method of upgrading from a 3-log coagulation / sedimentation / filtration plant to a 5-log plant would likely be through UV disinfection. When using UV disinfection, the DWSNZ restrict the turbidity that may enter the UV units; thus, run to waste pipework is likely to be required in addition to the UV units.

In addition to the run to waste pipework associated with an upgrade from log 3 to 4 (Table 6), the UV disinfection facility requires interconnecting pipework between existing process units and cabling and communications to the existing control system. We assume a duty-standby or 50-50 duty-duty setup. We also assume the plant has adequate hydraulic head to drive the UV units, and that the existing electrical and controls system is adequate to control the UV system with minimal modifications. Finally, we assume a new building is required to house the UV units, and that a simple timber frame building is adequate. Because a new building is required, the interconnecting pipework is significant for the larger plants.

Our capital cost estimates, shown in Table 9, are based on recent tender prices and adjusted for inflation. We believe these estimates are conservative.

Table 9: Capital cost estimate for upgrading from 3-log conventional coagulation / sedimentation / filtration plant to 5-log plant

Capacity	Additional for run to waste*	UV units				Pipework				Building estimate			Total upgrade estimate
		Number units	Q (m3/s) per UV unit	Rate	Cost estimate	Pipe diam estimate (mm)	Length (m)	Rate	Cost estimate	Footprint (m^2)	Rate ($/$m^2$)	Cost estimate	
0.6MLD	$ 26,000	2	0.0036	$ 40,000	$ 80,000	78	16	$ 100	$ 1,600	7.5	$2,200	$ 16,500	$ 124,100
7MLD	$ 167,500	2	0.0423	$ 70,000	$ 140,000	268	50	$ 500	$ 25,000	30	$2,200	$ 66,000	$ 398,500
50MLD	$ 995,000	3	0.2013	$412,000	$1,236,000	716	130	$1,100	$ 143,000	210	$1,000	$ 210,000	$2,584,000

* From Table 6: Capital cost estimate for upgrading from 3-log conventional coagulation / sedimentation / filtration plant to 4-log plant

OPERATING EXPENDITURE

Annual operation and maintenance costs for the UV units would mainly include replacement costs associated with the UV lamps, and increased power requirements associated with running the UV units, as shown in Table 8. We have assumed the UV lamps have an expected life of 1.5 years. Our estimates for O&M costs do not take into account any reduced attendance requirements due to increased plant automation, control, or optimisation.

Table 10: Annual operational cost estimate for upgrading from 3-log conventional coagulation / sedimentation / filtration plant to 5-log plant

Capacity	Run to waste pipework	UV units				Annual O&M costs
		Replacements (lamps)	Power usage kW	Power rate $/kWh	Annual power costs	
0.6MLD	$ 240	$ 3,000	1.00	0.15	$ 1,259	$ 4,499
7MLD	$ 7,200	$ 5,000	1.50	0.15	$ 1,889	$ 14,089
50MLD	$ 16,225	$ 14,000	3.00	0.15	$ 3,778	$ 34,003

3.2 BENEFITS

In this paper we only consider the benefits that can be reliably quantified. There may be other significant benefits through tourism opportunities or avoidance of tarnished reputation; improvements in innovation and technology; and employment opportunities, but in this paper we focus on the public health benefits.

The public health benefits of protozoa removal are estimated by first calculating the expected number of cases of illness for both the original plant and the upgraded or compliant plant. Figure 7 shows the steps required to calculate the benefits due to cost of illness avoided.

3.2.1 COST OF ILLNESS DUE TO ORIGINAL PLANT

To estimate the number of cases of illness for the original plant we first estimate the number of infectious *Cryptosporidium* oocysts. If the water supply's catchment has a 5-log reduction requirement and we have not sampled for *Cryptosporidium*, to conservatively estimate the benefits we can assume there are ten

Cryptosporidium oocysts in ten litres of water, based on *Table 4*, which indicates 3.7 infectious oocysts in ten litres of water. Figure 1 is based on one litre of water, so we assume 0.37 infectious oocysts per litre.

Use Figure 1 to estimate the risk of infection based on the existing / original treatment processes. If the existing treatment processes provide a 3-log reduction, then from Figure 1 the annual risk of infection for a source water of 0.37 infectious oocysts per litre is approximately 1%. The risk of morbidity given infection is 40%, so for the existing plant, given the catchment risk, we expect 0.4% (1% x 40%) of the population to become ill.

3.2.2 COST OF ILLNESS DUE TO COMPLIANT/UPGRADED PLANT

To estimate the annual number of illnesses for the compliant or upgraded plant, we again use Figure 1, with the same source water concentration of 0.37 infectious oocysts, but using the log credit line for the upgraded plant. If we consider upgrading the treatment plant to provide a 5-log reduction then, from Figure 1, the annual risk of infection is approximately 1 in 10,000 (0.01%). With this level of treatment we expect 0.004% (0.01% x 40%) of the population to become ill.

3.2.3 UPGRADE / COMPLIANCE BENEFITS

The benefits of the upgrade are the reduced percentage of the population we expect to become ill times the expected cost per case times the population served by the water supply.

$Annual\ Benefits = (P_X - P_{X+Y}) \times CC \times Pop$

Where

P_X is the risk of morbidity given the existing protozoa barrier with X-log credits,

P_{X+Y} is the risk of morbidity given the proposed protozoa barrier with X+Y log credits,

CC is the cost per case of illness, and

Pop is the population served by the water supply

We use a cost per case of $1266, from Table 1, which includes estimates from time off work, medical fees, and disability-adjusted life years (DALYs). These benefits do not account for the added security consumers may feel or the longer term benefits or productivity that may be associated with a higher level of public welfare.

3.2.4 CASE I: CATCHMENT RISK: 4; PLANT EXISTING LOG CREDIT: 3.

To estimate the benefits in upgrading from a 3-log to a 4-log plant given a 4-log catchment, we calculate values at both the low and high end of the number of expected infectious *Cryptosporidium* oocysts in the catchment: 0.28 and 3.7 infectious oocysts per 10 litres. From Figure 1, the mean annual risk of infection following 3-log treatment is 0.1% to 1.0%, and the mean annual risk of infection following 4-log treatment is 0.01% to 0.1%. By upgrading from a 3-log plant to a 4-log plant, the percentage of infections will therefore reduce by approximately 0.09% to 0.9%. Assuming a morbidity ratio of 40%, the percentage of illnesses will reduce by 0.036% to 0.36%. The estimated benefits of the upgrade are shown in Table 11. The annual benefits for our 4-log upgrades are up to $274k.

Table 11: Estimated benefits in upgrading from 3-log to 4-log plant

Capacity	Population	COI per case	Expected cases of illness following 3-log treatment		Cost of illness with 3-log treatment		Expected cases of illness following 4-log treatment		Cost of illness with 4-log treatment		Mean annual cost of illness avoided	
			Low	High	Low	High	Low	High	Low	High	Low	High
0.6MLD	900	$ 1,266	0.36	3.6	456	4,558	0.036	0.36	46	456	$ 410	$ 4,102
7MLD	7500	$ 1,266	3	30	3,798	37,981	0.3	3	380	3,798	$ 3,418	$ 34,183
50MLD	60000	$ 1,266	24	240	30,385	303,847	2.4	24	3,038	30,385	$ 27,346	$ 273,463

To estimate the benefits in upgrading from a 3-log to a 5-log plant given a 5-log catchment, we calculate values at both the low and expected high end of the number of expected infectious *Cryptosporidium* oocysts in the catchment: 3.7 and 7 infectious oocysts per 10 litres. From Figure 1, the mean annual risk of infection following 3-log treatment is 1.0% to 5.0%, and the mean annual risk of infection following 5-log treatment is

0.01% to 0.05%. By upgrading from a 3-log plant to a 5-log plant, the percentage of infections will therefore reduce by approximately 0.09% to 0.9%. Assuming a morbidity ratio of 40%, the percentage of illnesses will reduce by 0.036% to 0.36%. The estimated benefits of the upgrade are shown in Table 12. The annual benefits for our 5-log upgrade of a 50MLD plant are up to $1.5M.

Table 12: Estimated benefits in upgrading from 3-log to 5-log plant

Capacity	Population	COI per case	Expected cases of illness following 3-log treatment		Cost of illness with 3-log treatment		Expected cases of illness following 5-log treatment		Cost of illness with 5-log treatment		Mean annual cost of illness avoided	
			Low	High	Low	High	Low	High	Low	High	Low	High
0.6MLD	900	$ 1,266	3.6	18	4,558	22,789	0.036	0.18	46	228	$ 4,512	$ 22,561
7MLD	7500	$ 1,266	30	150	37,981	189,905	0.3	1.5	380	1,899	$ 37,601	$ 188,006
50MLD	60000	$ 1,266	240	1200	303,847	1,519,237	2.4	12	3,038	15,192	$ 300,809	$1,504,045

3.3 BENEFIT-COST RATIO

Our benefit cost analysis suggests the BCR may be as high as 7.8 for treatment plants serving large populations, as shown in Table 13. “Low” and “high” refer to the likely lowest and highest number of *Cryptosporidium* oocysts in the source water based on the catchment categories. The analysis is highly sensitive to the number of infectious *Cryptosporidium* oocysts in the source water. Our analysis used a real discount rate of 6%.

Table 13: Benefit-cost ratios for upgrades to 5-log plants from 3- and 4-log plants

Capacity (MLD)	Population	3 log to 4 log		3 log to 5 log	
		Low	High	Low	High
0.6	900	0.41	1.93	0.46	1.67
7	7,500	0.32	1.76	0.88	4.73
50	60,000	0.53	3.09	1.19	7.18

4 CONCLUSIONS

The public health benefits of complying with the protozoal requirements of the DWSNZ vary significantly with the actual concentration of infectious *Cryptosporidium* oocysts in the source water. We believe water suppliers should become familiar with their catchment risks in order to understand and attempt to quantify the public health risks associated with their supplies.

Although protozoal compliance tends to require more significant investments than other compliance elements of the DWSNZ, the benefits due to cost of illness avoided, based on our six cases (three supply sizes for two catchment cases), may be as high as 7 to 1. The compliance benefits for small water supplies with no existing protozoal treatment may be even more significant.

Compliance may yield additional benefits due to increased employment opportunities associated with the construction, operation and maintenance of the new system; improved general welfare and productivity in the community due to a higher quality drinking water; the innovation benefits that may arise from a greater familiarity with advanced water treatment technologies and subsequent development of our own treatment technologies nationally; the benefits arising from confidence in our water supplies; or the tourism benefits arising from confidence in the water quality (and tarnished reputation costs avoided).

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