AUTHOR: **Ms. Anna Robak**

Co-authors: **Dr Henning Bjornlund (University of South Australia and University of Lethbridge)**

Presenter: **Anna Robak**

Title of Paper: **Trade-offs between public health and environmental protection in a potable water supply context: Drinking Water Standards New Zealand vs resource consent conditions**

Anna Robak
Environmental Engineer (Opus International Consultants)/ PhD candidate (UniSA)
PO Box 5848, Auckland
Phone: 09 355 7148
Email: Anna.robak@opus.co.nz

ABSTRACT

Water suppliers face significant financial pressure because of ageing infrastructure, increasing demand, and increasingly stringent legislative requirements. Their funds are generally insufficient to meet all of these requirements; it is therefore necessary to begin considering alternative approaches for providing safe, secure drinking water.

One of the most important opportunities for achieving public health, environmental, and economic targets is a more collaborative approach involving 'soft' options. Water suppliers tend to select engineering options for compliance even when soft path options are available – partially because they lack the quantitative assessment to back up the softer options. If water suppliers quantitatively assessed and therefore understood the costs and benefits of their options, they could use this insight to pressure legislators to justify or amend standards and conditions, as well as to expand the range of permissible compliance options. In New York, over nine million people drink unfiltered water thanks to catchment protection initiatives. Filtration plants would have incurred significant costs and produced significant volumes of sludge that would need to be disposed of in an environmentally responsible manner, which would incur further costs. The DWSNZ require filtration plants for any surface water, thereby producing sludge and requiring discharge consents. To comply with discharge consent conditions, water suppliers build costly sludge handling facilities that can use significant energy and chemicals. New York City has avoided all of these financial and environmental costs using a soft path approach. The Ministry of Health and regional councils should consider more collaborative approaches in New Zealand.

KEYWORDS

Drinking water standards, discharge consent conditions, soft path

INTRODUCTION

Aproximately 90% of New Zealanders drink water that is provided through centralised potable water supply systems (MoH 2010). The purpose of these potable water supply systems is to protect public health and ensure a continuous supply of water. As such, water suppliers' activities are subject to a number of pieces of legislation. Ironically, water suppliers' investments to meet these pieces of legislation may negatively affect public health and environmental welfare, and increase ongoing costs in order to comply with the Health (Drinking Water) Amendment Act 2007 (HDWAA) (MoH 2008b), and the Resource Management Act 1991 (RMA) (MfE 1991). Although these pieces of legislation do not explicitly require new infrastructure, water suppliers and regulators appear to express a preference for 'hard' solutions. In this paper we propose that there are 'softer' ways of complying with legislation.

The HDWAA requires that, as of 2016, water suppliers take all practicable steps to comply with the Drinking Water Standards for New Zealand 2005 (DWSNZ) (MoH 2008a). The DWSNZ prescribe maximum acceptable values (MAVs) for chemical, cyanotoxin and radiological determinands, as well as for *E. coli* and protozoa; monitoring requirements for bacteria; and treatment process barriers for protozoa compliance. Typically, a protozoa barrier is the most expensive compliance component. In practice, the HDWAA has directed the installation of new protozoa removal / inactivation equipment, which is accompanied by power consumption, other consumables, and ongoing costs.

The DWSNZ use a 'log credit' system for protozoa compliance, where the level of treatment (log credit) required increases according to the catchment's protozoa risk category. In a catchment with intensive animal farming, for example, the highest level of treatment (5 log) is required. Surface waters require a minimum of 3 log treatment, which typically implies filtration.

The RMA delegates power to regional councils to set conditions on discharge to surface waters, among other powers. Water treatment plants (WTP) that take from surface waters are likely to require a form of filtration for protozoa compliance. The filtration process produces a sludge by-product because it captures contaminants, particulates, and chemical coagulants. Regional councils set conditions such that the sludge cannot be returned to the surface water. In practice, therefore, the RMA has directed the installation of sludge handling facilities, which are accompanied by power consumption, other consumables, and ongoing costs.

Sludge handling options typically include disposal to land on the water treatment site; transfer to the wastewater treatment plant (WWTP) by pumping or sucker truck; and treatment on site with transfer to landfill by carting. Disposal to land on site is often not feasible due to site constraints, including a high water table or a small footprint. The WWTP and landfill options both require sludge handling facilities on site due to the large instantaneous volumes of sludge produced during filter cleaning. Very large pump stations, pipes, and sludge treatment infrastructure would be required to treat the large instantaneous flows, so a balance tank or holding basin is required to allow sludge treatment over a longer period. In addition to the balance tank, the WWTP option may require a pump station, an increase in capacity of the existing wastewater reticulation, and an increase in treatment capacity, including power consumption, chemicals, and other consumables, at the WWTP. The water treatment sludge may also dilute the wastewater, reducing WWTP efficiency. The landfill option would include a sludge thickening or bagging system which consume power and require chemical dosing and other consumables, and carting to landfill produces further emissions.

In addition to these extra financial and environmental costs, it is debatable that this sludge diversion activity is economically efficient or even achieves the desired outcome. Sludge handling facilities may cost in the order of $0.5M for a WTP serving 5000 people, yet compared to runoff from farms, WTP sludge may have negligible impact on stream health. Catchment protection measures might be more cost effective.

The additional infrastructure installed for DWSNZ and discharge consent condition compliance consumes additional power, chemicals, and materials; and produce additional wastes and emissions. These wastes and emissions affect public health and the environment, which the HDWAA and RMA set out to protect. The typical response to DWSNZ and discharge consent conditions has been to construct new infrastructure; however, the spirit of the HDWAA and RMA allow for broader consideration of options, which the authors highlight in this paper.

HOW TO COMPLY WITH DWSNZ FOR PROTOZOA

There are three simple steps to complying with the DWSNZ for protozoa: (1) assess catchment risk (log credit required); (2) assess existing protozoa treatment (log credit provided); and (3) make log credit provided ≥ log credit required. For Step 1, water suppliers may monitor cryptosporidium counts over a 12-month period, or use Table 1 as a qualitative lookup table. Step 2, assessing the log credit provided by the existing treatment plant, is explained in the DWSNZ. Step 3, provide log credit ≥ log credit required, requires either a reduction in log credit required or an increase in log credit provided.

Table 1. Log credit requirements, supplies serving < 10,000 people
(source: Table 5.1a DWSNZ2005)

Catchment or groundwater protozoal risk category	**Log credits required**
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	2
Secure, interim secure, and provisionally secure bore water	0

PROBLEMS WITH CURRENT DWSNZ COMPLIANCE APPROACHES

DWSNZ compliance is economically and environmentally inefficient for the following reasons:

1. Water suppliers do not assess the practicability of complying with the DWSNZ
2. There is a focus on protozoa risks, when there may be more significant bacteria risks

    a. Protozoa risks may be more costly to reduce than bacteria risks
    b. Protozoa risk categories from Table 1 may be more conservative than 'measured' risk
3. Protozoa compliance by installing barriers rather than by reducing catchment risks
    a. Barriers are costly and produce additional wastes, by-products, and emissions
    b. Opportunities for environmental protection may be missed

Problem 1: Practicability of DWSNZ compliance

The HDWAA requires that water suppliers 'take all practicable steps to comply with the drinking-water standards' (MoH 2008b), where practicability is in terms of affordability relative to potential harm and risk of illness (clause 69H). Yet water suppliers generally do not quantify the environmental impacts or public health benefits of compliance. This lack of analysis makes it difficult to decide whether to invest in improved compliance or alternative projects with public health, economic, or other benefits. In theory, compliance with DWSNZ should be an absolute requirement; but even local authority water suppliers have other public health related risks such as structural vulnerabilities to seismic events (addressed through the Building Act 2004) and traffic black spots. Water suppliers need to assess and prioritise these competing demands.

Problem 2: Focus on protozoa risks
Protozoa risks more costly to reduce than bacteria/reticulation risks?

In New Zealand, the most prominent public health risks in drinking water supplies are due to protozoa and bacteria. We assume protozoa risks are in the catchment, and therefore address them at the WTP; whereas the bacteria risks are both in the catchment and in the reticulation. Low and negative pressures in the distribution systems may suck in contaminated soil and water adjacent to the pipes through cracks in the pipes or flooded air valves (Besner et al. 2010). According to DWSNZ, we can only reduce protozoa risks through catchment protection or treatment infrastructure, but we can reduce bacteria risks through chlorination and rapid response to monitoring. Protozoa risks therefore get more attention, yet reviews of waterborne disease outbreaks disagree on which factor contributes most significantly to these outbreaks.

In a review of 288 Canadian drinking water related waterborne disease outbreaks between 1974 and 2001, Schuster et al. (2005) found that protozoa and bacteria contributed equally to the number of waterborne disease outbreaks; they did not, however, consider whether the problem was with the source / treatment or with the distribution system. In a review of 126 US drinking water related waterborne disease outbreaks between 1991 and 1998, Craun, Calderon & Nwachuku (2003) found that distribution system deficiencies contributed to the largest number of outbreak events. Finally, in a review of 61 drinking water related waterborne disease outbreaks in the European Union, Risebro et al. (2007) found that distribution system failures contributed to about one third of outbreaks and, importantly, noted that while source and treatment failures contributed to a larger number of events, they also had, on average, four causal factors. Distribution system failures had only two. As Risebro et al. note, "Events occurring in the distribution system are likely to be more catastrophic as there are fewer barriers between the incident and the consumer, leaving less time and opportunity for remediation." Although these three studies indicate the importance of distribution failures to waterborne disease outbreaks, they do not compare the magnitude of consequences caused by different types of system failures.

A back of the envelope estimate –

To compare the protozoa and bacteria risks, let us analyse a theoretical water supply serving 7500 people. For the protozoa risk, let us assume that the treatment provides one log credit less than required. For the bacteria risk, let us assume that each customer is affected twice each year by a low pressure event caused by a break or maintenance event in the distribution system.

Robak & Bjornlund (2009) find that we can expect between 3 and 30 annual illnesses due to protozoa in a town of 7500 people, where the catchment has a 4-log requirement and only 3-log treatment is provided. By providing a 4-log treatment, the number of illnesses will reduce ten-fold, to between 0.3 and 3 annual illnesses. The gains in providing an extra log credit are therefore between 2.7 and 27 protozoa illnesses annually.

One study in Norway suggested that each time there is a low pressure event caused by a mains break or maintenance, the risk of gastrointestinal illness (GII) increases by between 10% and 130% (Nygård et al. 2007). In New Zealand, we can roughly estimate the incidence of GII as 86,000 cases per year, based on MfE (2007) (Table 2). New Zealand's population is approximately 4.4 million (StatsNZ 2010), implying an average GII rate of 86,000/4,400,000 = 2% per year, or, because GIIs tend to last approximately one week, 0.038% of the population affected by illness per week. If two low pressure events occur in a distribution system in a year, then we can expect between 6 and 13 illnesses annually attributable to distribution system 'failures' (# events x endemic illness rate x distribution system relative risk x population = 2 x 0.00038 x 1.1 x 7500 = 6; at upper end, relative risk is 2.3 and we expect 13 illnesses). Our uncertainties include the endemic GII rate and the causal relationship between New Zealand maintenance practices and GII. In the Norwegian study, the endemic GII rate was 8%, which is much higher than our assumption. Furthermore, Hunter et al (2005) found that consumers who had experienced low pressure events at the tap were 12 times more likely to become ill.

Table 2. Estimated annual number of gastrointestinal illness cases in New Zealand 2008-09
(adapted from MfE 2007 and updated to 2009 dollars)

Pathogen	Cases reported (2008-09)	% reported (NZ Med J, 2000)	Total cases	Cost per case (1999 $) (MfE 2007)	Cost per case (2009 $)	Total cost ($000)
Protozoa						
Cryptosporidiosis	813	10	8130	978	1266	10,293
Giardiasis	1,717	10	17,170	855	1107	19,004
Bacteria						
Campylobacteriosis	6,828	13	52,523	533	690	36,240
E. coli O157 (VTEC)	156	35	446	60,000	77671	34,619
Salmonellosis	1,296	31	4181	526	681	2,847
Shigellosis	130	26	500	253	328	164
Yersiniosis	493	20	2465	891	1153	2,843
Viruses						
Virus (including Hepatitis A)	81	15	540	204	264	143

Pathogen	Cases reported (2008-09)	% reported (NZ Med J, 2000)	Total cases	Cost per case (1999 $) (MfE 2007)	Cost per case (2009 $)	Total cost ($000)
Total						
Total	11,384		85,954			106,151

Our back-of-the-envelope analysis suggests that in a town of 7500 people, we can expect to reduce the number of protozoa illnesses by 2.7 to 27 annually by increasing from a 3-log to a 4-log protozoa barrier in a 4-log catchment. Assuming we could halve the number of illnesses through improved maintenance and repair practices, we can expect to reduce the number of illnesses attributable to distribution systems by 3 to 7 annually. We believe our distribution system illness estimate is very conservative, based on a reduction of only one low pressure event per year, and therefore believe the potential for illness reduction may be similar for both improved water treatment and improved distribution system management.

Assumed protozoa risk category more conservative?

The cost implications of using the quick reference in Table 1 may be high, as the log credit requirements may be conservative. Some high level decision makers in the Ministry of Health believe most places in New Zealand do not exceed a 4 log protozoa credit requirement (Michael Taylor, pers. comm. August 2009), yet many WTPs are currently being upgraded to a 5 log protozoa removal. Water suppliers should consider 12-month cryptosporidium testing, which costs approximately $20k. The catchment risks may be lower than Table 1 suggests.

Problem 3: Treatment over catchment protection
Protozoa barrier increases costs and wastes

For Step 3, most water suppliers build more infrastructure to ensure log credit provided ≥ log credit required; they consider plant upgrade options rather than reduce catchment risks. Yet by addressing only one side of the equation, water suppliers are missing opportunities to reduce broader public health and environmental risks through catchment protection options. Furthermore, providing a higher log credit treatment also typically increases the materials used; wastes, by-products, and emissions produced; and capital and operation and maintenance costs; and in essence increases catchment risk.

Opportunities for environmental protection

By providing more log credits, water suppliers increase the resources required to protect public health for the long term. An alternate way of making sure log credit provided ≥ log credit required, is to reduce catchment risks. Table 1 suggests that catchment risks can be reduced by reducing the intensity of farming or moving it out of the catchment altogether. Most water suppliers would avoid this alternative at all costs because it would likely involve negotiations and land purchase. Yet this move has been successful in other parts of the world.

In the US, every dollar invested in catchment protection saves several dollars in treatment expenditure (Pearce 2001). New York City (NYC) does not filter the surface water supplied to nine million people; it is one of the largest unfiltered drinking water systems in the world (DEC

2004). In 1995, New York State, upstate communities, NYC, and the Environmental Protection Agency (USEPA) committed $US250 million to avoid a $US6 billion WTP with annual costs of $US300 million (Mertz). The $US250 million was invested in 355,000 acres of land in the Catskills, providing incentives for catchment protection, and educating the public.

There may be additional environmental and economic benefits to reducing distribution risks relative to treatment risks. When a water supplier repairs pipes in the distribution system, the potential for contaminant intrusion reduces, thereby reducing public health risks. At the same time, the level of leakage in the network reduces, conserving water. When less water is abstracted, less water is treated and distributed. By reducing leakage, a water supplier can reduce public health risks, improve conservation, reduce chemical and power usage, reduce the volume of sludge by-products produced, and reduce ongoing operational costs.

HOW TO COMPLY WITH DISCHARGE CONSENT CONDITIONS

A typical WTP has two main options for sludge handling: (1) Send the sludge back to the source surface water; and (2) Capture the sludge on site and dispose of on or off site. Discharge consent conditions typically do not allow the first option. Within the second option, if enough land is available and the water table is sufficiently deep, sludge can be stored in large ponds, then applied to land or desludged after a number of years. However, if land is not available or the water table is shallow, the sludge can be stored in a balance tank and either desludged by sucker truck, thickened on site with the dry sludge carted to landfill, or piped to the WWTP.

PROBLEMS WITH CURRENT DISCHARGE CONSENT COMPLIANCE

Water suppliers' discharge consent compliance results in a lack of economic and environmental efficiencies for the following reasons:

1. Water suppliers do not assess the environmental benefits of complying with discharge consent conditions and therefore do not know if they will improve overall environmental health.
    a. Diverting sludge from the river to a WWTP or landfill may require significant capital and operational expenditures, and producing additional wastes, by-products, and emissions.
    b. By avoiding soft path or collaborative options we may be missing opportunities for enhanced environmental protection.
2. There is a focus on point source pollution, which may be negligible relative to non-point source pollution

Problem 1: Understanding of overall environmental health
Discharge consent compliance increases costs and wastes

When sludge is stored in a balance tank and either desludged by sucker truck, thickened on site and carted to landfill, or piped to a WWTP, the environment is affected in the following ways:

1. Desludged by sucker truck. Sucker trucks use fuel and produce emissions.
2. Thickened and carted to landfill. This option requires power and chemical dosing for a thickener, and the trucks that cart away the dried sludge use fuel and produce emissions.

3. Piped to WWTP. This option may require power in pumping to the WWTP, and additional power and chemicals will be consumed at the WWTP.

To date no one has compared the environmental effects of various sludge handling approaches.

Opportunities for environmental protection

Constructing and running sludge handling facilities can be costly. Even for small towns, sludge handling facilities can cost in the hundreds of thousands of dollars. For those sums, there are likely to be more cost effective environmental protection initiatives, yet no analysis to investigate which initiatives could produce equivalent benefits. In New York, for example, the governor committed US$1.25 million to nine water quality projects (DEC 2004), including phosphorous reduction through natural dairy cattle feed management plans; pharmaceuticals monitoring; and research and school education programs correlating land use to drinking water contaminants .

Problem 2: Point source pollution relative to non-point source pollution

Although it is practical to control point source pollution through discharge consents, there has been little analysis in New Zealand that compares the effect of point source pollution, such as water treatment sludge by-products, on stream health, relative to the effect of non-point source pollution, such as agricultural runoff.

DWSNZ-DISCHARGE CONSENT: UNSUSTAINABLE VICIOUS CYCLE?

Implicitly, DWSNZ compliance for surface water supplies triggers the need for discharge consents. From my own experience, many low-turbidity surface waters in New Zealand serving small communities do not comply with DWSNZ. According to Table 1, surface waters should be treated to a minimum 3-log protozoa removal. Water suppliers generally select filtration processes for 3-log protozoa removal because they perceive the alternatives to have unacceptable safety risks. Filtration processes produce sludge by-products, which regional councils typically do not allow in waterways. In addition to the new filtration processes, water suppliers must install sludge handling processes. Table 3 shows the basic treatment options for surface waters according to DWSNZ. Only the 3-log catchment has treatment options (disinfection) that do not produce sludge. Soon many small communities will attempt to comply with DWSNZ; they will also need to build sludge handling facilities. Figure 1 shows a preliminary decision tree for water suppliers to comply with DWSNZ (protozoa) and discharge consent conditions.

Table 3. DWSNZ treatment options for surface waters

Basic treatment options	3 log	4 log	5 log	Sludge produced?
1	Filtration	Filtration (enhanced)	Filtration plus disinfection	Y
2	Disinfection			N

RECOMMENDATIONS

To ensure efficient public spending and environmentally sustainable solutions in New Zealand, the Ministry for the Environment should promote research, and collaboration between regional councils and water suppliers, to identify more cost effective environmental improvements. We recommend the following to water suppliers and the wider community:

Water suppliers:

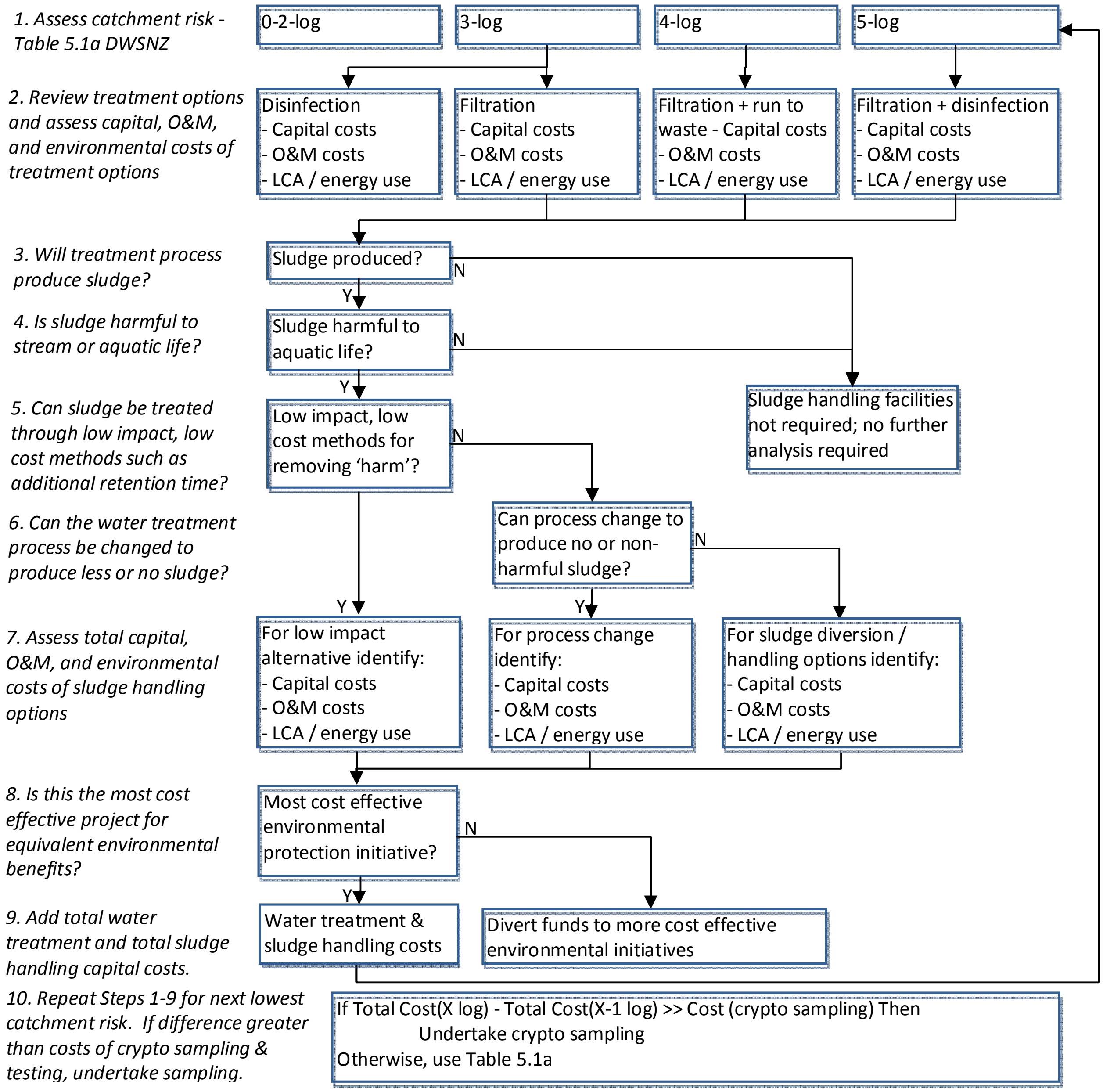

Figure 1. Sludge treatment decision tree

1. Confirm catchment risk category by sampling for cryptosporidium. Lab test costs of $20,000 compare favorably to the costs of most 1-log protozoa barrier increases.

2. Assess the capital and operational costs and environmental life cycles associated with UV, ozone, and chlorine dioxide disinfection as alternatives to filtration.
3. Explore cost-sharing frameworks with other catchment users. Many water suppliers' sources are polluted by upstream catchment activities so must treat water, and then divert treatment by-products to protect downstream users. Catchment users affecting water quality should contribute to water suppliers' capital and running costs.

Regional councils: Allow cost-sharing options from water suppliers and upstream polluters.

1. Identify non-point source polluters and non-compliant discharges and estimate the loads and effects on downstream water quality.
2. Prioritise asset and non-asset catchment protection measures according to economic and environmental benefits.

Ministry of Health: Provide guidance on the level of catchment protection required to assess surface waters at less than 3-log protozoa risk.

Ministry for the Environment: Promote research into cost effective catchment protection.

To the research community we offer the following topics:

1. Which drinking water supply system components contribute to the greatest number of outbreaks and endemic waterborne diseases in New Zealand?
2. Are there low cost, low impact ways of removing toxicity from alum sludge?
3. Is point source pollution significant relative to non-point source pollution?
4. Are 'soft-path' approaches more cost effective than asset-based solutions?

CONCLUSIONS

This paper has provided an initial discussion on the issue of increasing log-credits provided or reducing catchment log-credit required through changing management practices within the catchment following a soft-path approach to water management. We explore the potential viability of this solution and find that both in financial and environmental terms, reducing catchment log-credit requirement might be a more beneficial solution, low in capital outlay, operational costs, and environmental impact. One of the challenges of following this line of action is that the existing management structures, legal frameworks, as well as the people managing and designing them, are more comfortable with hard solutions. We believe that water suppliers, regional councils, the Ministry for the Environment, and the research community all have a role to play in exploring more sustainable options for providing safe drinking water.

REFERENCES

Besner, M, Broséus, R, Lavoie, J, Giovanni, G, Payment, P & Prévost, M 2010, 'Pressure Monitoring and Characterization of External Sources of Contamination at the Site of the Payment Drinking Water Epidemiological Studies', *Environmental Science & Technology*, pp. 703-708.

Craun, G, Calderon, R & Nwachuku, N 2003, 'Causes of waterborne outbreaks reported in the United States, 1991–1998', *Drinking Water and Infectious Disease, Establishing the Links, Hunter P, Waite M and Rochi E (eds.). CRC Press and IWA Publishing, Boca Raton, Florida*, pp. 105–117.

DEC 2004, *Governor announces funding for New York City watershed*, New York State Department of Environmental Conservation.

Hunter, Paul R, Chalmers, Rachel M, Hughes, S & Syed, Q 2005, 'Self-Reported Diarrhea in a Control Group: A Strong Association with Reporting of LowPressure Events in Tap Water', *Clinical Infectious Diseases,* vol. 40, no. 4, pp. e32-e34.

Mertz, T *New York City depends on natural water filtration*, RAND, viewed 4 July 2010, <http://www.rand.org/scitech/stpi/ourfuture/NaturesServices/sec1_watershed.html>.

MfE 2007, *Proposed national standard for sources of human drinking water, Resource Management Act Section 32, Analysis of the costs and benefits*, Ministry for the Environment Wellington.

MfE 1991, *Resource Management Act 1991*, New Zealand Parliament.

MoH 2010, *Annual Review of Drinking-Water Quality in New Zealand 2008/09*, Ministry of Health, Wellington.

MoH 2008a, *Drinking-water Standards New Zealand 2005 (Revised 2008)*, Ministry of Health, Wellington, New Zealand.

MoH 2008b, *Health (Drinking Water) Amendment Act 2007*, New Zealand Parliament.

Nygård, K, Wahl, E, Krogh, T, Atle Tveit, O, Bohleng, E, Tverdal, A & Aavitsland, P 2007, 'Breaks and maintenance work in the water distribution systems and gastrointestinal illness: a cohort study', *International Journal of Epidemiology,* vol. 36, pp. 873-880.

Pearce, D 2001, 'How valuable are the tropical forests?'.

Risebro, H, Doria, M, Andersson, Y, Medema, G, Osborn, K, Schlosser, O & Hunter, P 2007, 'Fault tree analysis of the causes of waterborne outbreaks', *Journal of Water and Health,* vol. 05.

Robak, A & Bjornlund, H 2009, *Costs and benefits of compliance: New Zealand Drinking Water Standards*, Rotorua, New Zealand.

Schuster, C, Aramini, J, Ellis, A, Marshall, B, Robertson, W, Medeiros, D & Charron, D 2005, 'Infectious disease outbreaks related to drinking water in Canada, 1974-2001', *Revue canadienne de santé publique,* vol. 96, no. 4.

StatsNZ 2010, *Estimated resident population of New Zealand*, Statistics New Zealand, viewed 5 July 2010, <http://www.stats.govt.nz/methods_and_services/population_clock.aspx>.