WHAT IS GOOD DISINFECTION PRACTICE?

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ABSTRACT

Since the early nineteen hundreds, chlorine has been applied to disinfect drinking water. However, chlorination has its constraints and research has demonstrated a prevailing risk from pathogens such as viruses and protozoa, which have proved to be partly resistant to chlorine, which promotes the concept of a multi-barrier protection. Consequently, more advanced technologies and operation procedures potentially have to be implemented in our Water Treatment Plants. New Zealand consists of many small to medium sized communities, which is also the case for Scandinavia, and as such, is comparable with Sweden. The prevailing risk of protozoa and viruses encouraged Water BA and Swedish Water AB to support a study on Good Disinfection Practice. The objective was to get an understanding of disinfection practices in different countries and to develop a pragmatic approach to a good disinfection practice for the conditions in Scandinavia. The study resulted in a proposed model based on a microbiological multi-barrier approach, considering the water safety from source to tap in terms of removal requirements for bacteria, protozoa and viruses. This paper presents findings in the report and guideline, and the developed model, and compares the approach to the New Zealand Drinking Water Standards 2005 (rev 2008).

KEYWORDS

disinfection, disinfection practice, drinking water standards, DWSNZ, pathogens, barrier, UV, ozone, chlorination, chlorine dioxide

1 INTRODUCTION

Since the early nineteen hundreds, chlorine has been applied to disinfect drinking water. Looking back, the positive impact has been huge and the practice has saved many people from becoming ill from waterborne diseases. However, chlorination has its constraints and research has demonstrated a prevailing risk from pathogens such as viruses and protozoa, which have proved to be partly resistant to chlorine. One disinfection method is not enough to provide safe drinking water, which promotes the concept of a multi-barrier protection. Consequently, more advanced technologies and operation procedures potentially have to be implemented in our Water Treatment Plants, not only to provide the required removal but also to provide redundancy in case of failure.

The perception in Sweden and Norway was that the risk was very small as the main source of water originated from the mountainous rivers and lakes. This has been proven to be wrong with parasitic protozoa outbreaks in Bergen, Norway (2004; 3,500 sick , one deceased) (Tveit, Søbstad, Kalland, Seim, Arnesen, & Fennell, 2005) and in Ostersund, Sweden (2010; 2,500 people sick) (Pedersen, 2010). Also New Zealand has had some smaller outbreaks (2009-2010, 37 outbreaks causing 154 cases of disease) (MoH, 2011).

This requires Councils in Scandinavia and in New Zealand to carefully plan for the high capital and operation expenditure involved in meeting compliance with the national drinking water standards. New Zealand consists of many small to medium sized communities, which is also the case for Scandinavia. In Norway 75% of 1600 WTPs provide water to population less than 10,000 people. Larger Councils such as Auckland can afford advanced and long-term sampling procedures followed by extensive risk analysis such as Quantative Microbiological Risk Analysis (QMRA) and Hazard Analysis and Critical Control Points (HACCP), while smaller and medium councils call for more pragmatic approaches.

The prevailing risk of protozoa and viruses escaping current water treatment and a generic need for a balanced but robust disinfection practice encouraged the equivalent to Water New Zealand in Sweden and Norway; Norwegian Water BA and Swedish Water AB, with similar conditions to New Zealand, to support a study on Good Disinfection Practice. The objective was to get an understanding of disinfection practices in different countries and to develop a pragmatic approach to a good disinfection practice for the conditions in Scandinavia.

The study resulted in a proposed model based on a microbiological multi-barrier approach, considering the water safety from source to tap in terms of removal requirements for bacteria, protozoa and viruses.

The initial reports (Odegaard, Fiksdal, & Osterhus, 2006) (Odegaard, Osterhus, & Melin, 2009a) were developed into a guideline for developing a good disinfection practice (Odegaard, Osterhus, & Melin, 2009b) here referred to as the GDP-guidelines.

This paper presents findings in the report and guideline, and the developed model, and compares the approach to the New Zealand Drinking Water Standards (DWSNZ2005, rev 2008).

2 PATHOGENIC MICROORGANISMS AND INDICATOR ORGANISMS

Currently efficient ways of determining all pathogens do not exist and the water practice is to monitor indicator organisms instead of the actual pathogens. *E.coli* is accepted as the best (we have) organism to track faecal contamination, even though the use of the bacteria have quite severe limitations. *E.coli* is less resistant than some of the viruses and protozoa, and thus a non-detection of *E.coli* does not necessarily mean the water is free from contamination. Moreover, *E.coli* is not very resistant to disinfection, skewing the understanding of treatment efficiency.

The viruses are the smallest of "microorganisms"[1] that can cause disease. They are typically <0.1 µm. The group Noroviruses causes most of the outbreaks due to viruses but there are many other groups that can cause outbreaks. Viruses can significantly vary in resistance to disinfection but in general they are inactivated reasonably well with chlorine. A bacterium is slightly bigger than a virus, typically about 1 µm. As in many other countries, *Campolybacter* is the bacterium that is causing most outbreaks in Norway and Sweden. In general chlorination is efficient against bacteria. However, some spore-developing bacteria can resist chlorination, such as *Bacillus* and *Clostridium*. Protozoa are bigger than bacteria, typically 3-10 µm and can be very resistant to disinfection. Focus is on *Giardia* and *Cryptosporidium*; two protozoa that can cause severe outbreaks.

In Norway the requirements call for sampling of heterotrophic plate count (22°C), *Coliform bacteria*, *E.coli*, *Enterococci* and *Clostridium perfringens* (including spores). *E.coli* bacteria is utilised to indicate fresh faecal contamination as well as an indicator of processes efficiency in inactivating pathogenic bacteria. *E.coli* is however not a good indicator for viruses, *Cryptosporidium* or *Giardia* (oo) cysts in the drinking water after disinfection.

Clostridium perfringens is included in the Norwegian drinking water standard as an indicator for viruses and protozoa. Whether it is a good indicator is still to be determined. The World Health Organisation (WHO) guidelines for drinking water quality does not advice routine monitoring of *Clostridium perfringens* in finished drinking water as the spores will survive much longer than pathogens from the intestinal, including viruses and protozoa. However, for raw water there is a strong opinion in the water community that *Clostridium perfringens* has a good indicator value together with *E.coli*. While *E.coli* indicates fresh faecal contamination, *Clostridium* will indicate old faecal contamination. Thus the GDP-guidelines incorporate *Clostridium perfringens* as one of the quality indicators for the water source.

In Norway and Sweden there is no routine monitoring of viruses despite the general acceptance that they are a common cause for outbreaks. The report does however suggest that monitoring of colifags (viruses that infect bacteria but not humans) is not only possible but advisable. The GDP-guidelines recommend that E.coli and Clostridium perfringens, possibly together with a time-extended mapping of the protozoa risk in terms of Cryptosporidium and Giardia, will constitute the evaluation of the water quality in the water source, with monitoring methods for viruses to be added when they are verified as representative and cost efficient. The report also suggests that protozoa monitoring is only necessary when there are indication of faecal contamination.

[1] Virus is strictly not a life form

3 PATHOGEN SEPARATION AND INACTIVATION EFFICIENCIES.

The dominating disinfection methods utilised in Norway is now UV-irradiation although chlorination is still used, often in combination with UV. UV has been used for many years for small waterworks but the incident in Bergen caused the large waterworks (including Oslo, Bergen, Trondheim, Stavanger) to install UV-plants. Other methods that are used in the world are disinfection with chlorine dioxide and ozone. The different methods have different inactivation efficiency on different microorganisms. The Ct-value (Concentration x turn over time x hydraulic factor) is essential in designing a disinfection process as there is a direct relationship between the Ct-value and the inactivation rate. A qualitative comparison of the inactivation efficiency on pathogens is given in Table 1.

Table 1 Qualitative comparison of the efficiency of disinfection methods. Green is when the method works well and red means the method should be applied with caution, making sure it will meet expectations (Odegaard, Osterhus, & Melin, 2009a)

Disinfection Method	Bacteria	Viruses	Protozoa
Chlorination	Very Efficient	Fairly Efficient	Inefficient
Ozone	Very Efficient	Very Efficient	Partly Efficient[1]
UV-radiation	Very Efficient	Efficient[2]	Very Efficient

[1]Efficient for Giardia, less efficient against Cryptosporidium, [2] More efficient against some than others

Pathogens are also removed in processes removing particles (filters) as they are small particles. This approach was the first step towards a water treatment practice during the plagues in Europe in the 1900-hundreds. As for the disinfection methods, the different separation methods have different efficiencies (Table 2).

Table 2 Qualitative comparison of the efficiency of pathogen separation methods. Green is when the method works well and red means the method should be applied with caution, making sure it will meet expectations (Odegaard, Osterhus, & Melin, 2009a)

Separation Method	Bacteria	Viruses	Protozoa
Rapid Sand Filter (RSF)	Inefficient	Very Inefficient	Rather Inefficient
Coagulation + RSF	Very Efficient	Efficient	Very Efficient
Membranes			
Rev. Osmosis / Nano Filtration	Very Efficient	Very Efficient	Very Efficient
Ultra Filtration (UF)	Efficient	Rather Efficient	Very Efficient
Micro Filtration (MF)	Rather Efficient	Less Efficient	Very Efficient
Coagulation + UF/MF	Very Efficient	Very Efficient	Very Efficient

4 THE NORWEGIAN SITUATION 2006

The population in Norway in 2010 was 4,850,440 people served by approximately 1,600 WTPs. The Norwegian disinfection practice, as it was sitting when the study was performed in 2006, was based on either chlorination or UV-radiation. There were more UV facilities than chlorination facilities but the larger plants utilised chlorination; 312 plants utilised chlorination, 528 plants utilised UV and 204 plants utilised both chlorination and UV. A great number of plants (31%) did not have disinfection at all and among them were also surface water plants. Only in a few places (4 registered) utilised ozone and those were in combination with bio-filtration to oxidise organic matter as well as disinfecting the water. Among the plants that utilised some form of disinfection, most of them did not utilise any other treatment such as particle separation or two-step disinfection. 26% of the membrane plants had no disinfection. A remarkable number of plants had been delivering drinking water with *E.coli* detection. The study also state that the disinfection facilities were poorly operated and monitored, causing a notable number of incidents.

5 THE NEW ZEALAND SITUATION 2009/2010

In June 2010 New Zealand had a population of 4,393,500 people and 91% were provided with water from 2,258 registered WTPs (MoH, 2011). Chlorination, ozonation and UV-radiation were the common disinfection methods utilised in New Zealand in 2009/2010. Chlorination remained the most popular method and served 78% of the people connected to registered drinking water supplies, or 26% of the treatment plants. The reason for disinfection non-compliance (including chlorination, ozonation and UV-radiation) was generally flaws in

monitoring, although about 70 plants had actual *E.coli* detection. 23 plants used ozonation and 784 used UV-radiation. 16% of the population was provided drinking water from registered secure groundwater.

6 INTERNATIONAL OUTLOOK

In 2006 many countries including New Zealand were updating or were about to update their drinking water standards to reflect the risk from protozoa contamination. As for most of the other countries that were investigated, Norway has the ambition that all drinking water delivered to the consumer will be disinfected. A few countries (Netherlands, Germany, and Switzerland) are of the opinion that the treatment of the water should be so advanced that the need for disinfection and maintaining chlorine residual in the network is eliminated. In any case, there is a general strong trend in many countries to reduce the required chlorine concentration to disinfect the finished water and achieve a sufficient residual. In terms of securing a sufficient microbiological barrier with disinfection there were two prevailing strategies; Design Verification or Safe Design. The first requires a chosen method to be demonstrated as sufficient to comply while the second strategy utilises the available scientific information on the inactivation efficiencies of methods together with safety factors so that there is a very high probability that the chosen design is adequate. The basis for the Norwegian model is based on the latter method used in USA and Canada, utilising the Ct-value and the multiple barrier concept.

7 GOOD DISINFECTION PRACTICE

In the guideline (Odegaard, Osterhus, & Melin, 2009b) a good disinfection practice was defined as the establishment of a correct and sufficient barrier approach against microbial contamination in a water treatment plant (WTP), based on:

- **The size of the water treatment plant,** which is a correlation to the consequence a contamination in the water source or in the catchment, could have.
- **The circumstances around the water source and catchment** such as water quality and the contamination risk.
- **The surveillance of the water source and catchment** to enable a quick and adequate response in case of emergency that could negatively affect the water quality.
- **The water treatment process in addition to the disinfection,** which could be justified as a microbial barrier.
- **The surveillance in the water treatment plant** that will ensure an optimal operation and will enable a quick and adequate response to incidents in the plant.
- **The knowledge off the efficiency of disinfection methods** in regard to inactivation of pathogenic microorganisms, and a corresponding correct design and operation of utilised method.

The Good Disinfection Practice (GDP) Guidelines that was written in Norway (Odegaard et al, 2009b) are based on two elements:

1. A procedure by which one can determine the disinfection needed based on the barrier level needed and the possible barriers in the watershed and in the treatment processes
2. A “tool-box” by which one may design the disinfection method chosen in order to meet the disinfection requirement determined in the procedure mentioned above (not presented in this paper)

8 DETERMINING THE DISINFECTION BARRIER

The purpose of the procedure is to determine what inactivation efficiency is required for the different microorganisms in the post disinfection to arrive at satisfactory barrier efficiency for the WTP. The procedure is demonstrated in the flow chart in Figure 1.

The intention of the procedure is to answer the following questions:

1) What risk situation exist around the water treatment plant
2) What is the water quality in the water source/raw water
3) What measures to lower the contamination risk are planned in the catchment and in the water source
4) What water treatment is planned besides the disinfection

The procedure is built on the following steps:

1) The risk situation is evaluated based on:
   a) The water quality of the raw water
   b) The size of the WTP
   c) The characteristics of the water source
2) Step 1) then generates the barrier level that needs to be overcome to ensure a sufficient barrier effect in the whole WTP.
   a) Barrier level is defined as the reduction (in required Log-reduction) of a single group of pathogens; the groups being bacteria (b), viruses (v) and protozoa (p), which in total will have to be achieved.
3) The earned Log-credits can be awarded for:
   a) Barrier measures in the catchment or the water source
   b) Water treatment beside the disinfection
   c) Monitoring and control of water source and WTP.
4) The difference between required and awarded Log-credits determines the inactivation level for a single pathogen group, which the end disinfection will have to achieve.

Three groups of WTP sizes are categorised:

1) < 1000 p
2) 1000 – 10,000 p
3) >10,000 p

The water source has been grouped in following categories:

1) Surface water
   a) Lakes
   b) Streams
2) Groundwater
   a) Groundwater in soil
   b) Groundwater in mountains
   c) Artificial Recharge
   d) Groundwater affected by surface water

The water quality is based on collection in two levels:

- 3 years of common WTP-routine sampling
- 1 year targeted sampling based on estimated risk situation (directed by the 3-year-sampling)

As criterion of the water quality on the water source the indicator organisms *E.coli*, *Cl.perfringens* and Giardia and Cryptosporidium are used. The barrier level is defined as the reduction of the single group of organism (bacteria, viruses and protozoa) that in total must be achieved in WTP, which is dependent on the water quality in the raw water and an the size of the WTP. The barrier level is given as the Log-reduction necessary for bacteria, viruses and parasites:

$$Xb + Yv + Zp$$

X = Log-credits for bacteria (b), Y = Log-credits for Viruses (v), Z = Log-credits for protozoa (p)

Each group have to be treated separately and not summed together. Log-credits can be awarded for the existing barrier level, such as for measures that are done in the catchment and in the water source and for the treatment in the WTP on top of the disinfection. The required disinfecting barrier level is then the difference between the required and the existing barrier level, which becomes the inactivation efficiency that the disinfection will have to achieve.

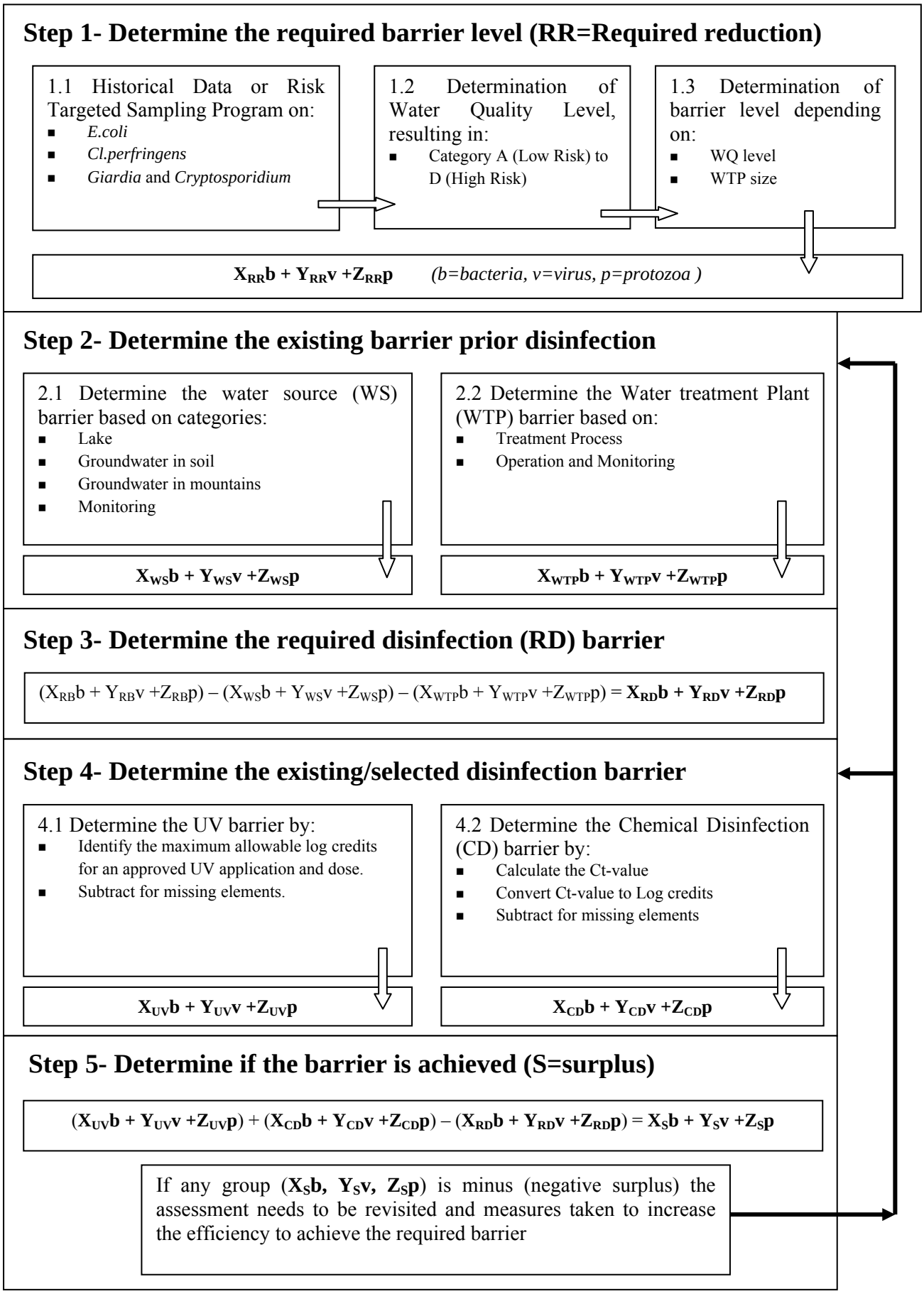

Figure 1 Guideline for achieving a safe drinking water according to the Norwegian GDP model (modified from (Odegaard, Osterhus, & Melin, 2009b)

The GDP-guidelines have listed all necessary information such as treatment units Log-credits, maximum allowable Log-credits for a treatment plant, water source risk level depending on type and catchment etc, that are necessary for the determination of disinfection barrier.

9 NEW ZEALAND PROCEDURES

9.1 REGULATION

It is internationally accepted that a WTP should develop a Water Safety Plan (WSP that comprises system assessment and design, operational monitoring and management plans (including documentation and communication). This is described by WHO in the Framework for Safe Drinking Water (WHO, 2004). In New Zealand the WSP is called a Public Health Risk Management Plan (PHRMP), which is required for all water supplies in New Zealand, providing drinking water for more than 500 people (DWSNZ2005, rev 2008). Furthermore, WHO recommends within the framework for Safe Drinking Water that there are Health Based Targets, which is covered in the Drinking Water Standards New Zealand 2005 (Rev 2008), setting the Maximum Acceptable Value (MAV) for harmful contaminants, how they should be monitored and what remedial action should be taken in case of transgressions, and an Independent Surveillance, which covered by the role Drinking Water Assessor, appointed by the Ministry of Health, that inspects and assesses the water supply in terms of compliance to the Amendment Act, the PHRMP and the Drinking Water Standards.

9.2 Disinfection requirements in DWSNZ 2005 (rev 2008)

The requirements for disinfection are embedded in the compliance requirements. There are 2 compliance areas of microorganism; bacterial and protozoa.

There are no viral compliance requirements at the moment due to lack of confidence in our current knowledge regarding the risk of and how to monitor viruses. However, the standards do recommend that when the source is low-risk surface water and the overall treatment process does not include filtration, at least two disinfectants, one of which may be chlorine, should be used to provide adequate protection against viruses as well as protozoa.

Chlorination is not accepted as disinfection against protozoa, while chlorine dioxide, ozone and UV are. Therefore, when chlorine is used for bacterial compliance, an additional disinfection method is required to achieve protozoa compliance. Chlorine dioxoide, ozone and UV on the other hand, are accepted as sole measure for both bacterial and protozoa compliance, if protozoa compliance is met. The water source, catchment, separation and disinfection are only considered together when achieving protozoal compliance. For bacterial compliance there is no directives in the standards on measures in the catchment, water source and treatment train prior disinfection.

9.2.1 BACTERIAL COMPLIANCE

The bacterial compliance is achieved through achieving the required chlorine dose of 0.2 mg/l, achieving an actual contact time of 30 min, and monitoring E.coli, FAC, FACE (calc), chlorine dioxide, ozone, Ct (calc), pH and turbidity depending on situation and according to the DWSNZ specifications, and by applying the required remedial actions in case of a transgression. Five situations are managed with directives:

1) Drinking water leaving the treatment plant and E.coli monitoring is the only method of demonstrating compliance (Criterion 1)
2) Drinking water disinfected with chlorine leaving the treatment plant with chlorine residual (Criterion 2)
   a) Continuously monitored chlorine (E.coli monitoring is not required)
   b) Non-continuously monitored chlorine (WTP<5000 people)
3) Drinking water leaving the treatment plant disinfected with chlorine dioxide
4) Drinking water leaving the treatment plant disinfected with Ozone (Ct > 0.5)
5) Drinking water leaving the treatment plant disinfected with UV (bacterial compliance is achieved by meeting the requirements for protozoal compliance)

If disinfection with chlorine dioxide, ozone or UV meets the protozoal compliance criteria, also bacterial compliance is automatically achieved.

9.2.2 PROTOZOAL COMPLIANCE

Protozoa can be removed by filtration or inactivated by disinfection using ozone, chlorine dioxide or UV light. The compliance criteria for protozoa are based on the probability that the treatment process will have inactivated or removed any protozoa present. The assumption is that if the treatment process deals effectively with Cryptosporidium then it will also deal successfully with other pathogens. The principle is based on a cumulative log credit approach. Protozoal non-compliance occurs when:

- The treatment process does not satisfy the conditions to achieve the required barrier, or
- Monitoring or operational requirements are not meet or exceed the number allowed, or
- Incorrect monitoring procedures are used

The **first step** is to determine the level of required treatment. Up to 10,000 people served the water supplier can choose to take a risk category approach, evaluating the catchment or the groundwater based on 3 categories for surface water ranging from 3 to 5 log credits and 4 categories for groundwater ranging from 0 (secure bore) to 5 depending on contamination risk. If the served population is greater than 10,000 people a Cryptosporidium monitoring needs to be performed (26 samples over 12 month), categorising the required reduction from 3 to 5 depending on results (≥10 mean oocysts per 10L = 5 log credits, 0.75-9.99 = 4 log credits, ≤0.75= 3 log credits).

The **second step** is to determine the log credits that can be awarded for a certain treatment process, including the chosen disinfection method. The categories are:

- Coagulation-based processes using rapid granular media filtration
- Coagulation-based processes suing membrane filtration
- Filtration processes without coagulation using a single filtration process
- Filtration processes using two filtration processes
- Either option above followed by disinfection by ozone or chlorine dioxide or UV or in combination, with log credits for disinfection processes not exceeding 3 log
- Disinfection only by ozone or chlorine dioxide or UV or in combination, with log credits for disinfection processes not exceeding 3 log

To be allowed to count the allowed log credit for a certain process, it is required that the design, operation and monitoring comply with the specifications in the DWSNZ. Otherwise the process is considered to be non-compliant and remedial actions need to be initiated.

10 A BENCHMARK AGAINST THE GDP-GUIDELINES

A benchmarking of the Drinking Water Standards in New Zealand against the Norwegian guidelines for Good Disinfection Practice can be viewed below in Table 3.

Table 3 Benchmarking the DWSNZ against the Norwegian GDP-Guidelines

	Criteria	Comment	DWSNZ
1	The size of the water treatment plant,	which is a correlation to the consequence a contamination in the water source or in the catchment, could have.	Considered.
2	The circumstances around the water source and catchment	such as water quality and the contamination risk.	Directly considered in terms of protozoa, indirectly for bacteria, and not considered for viruses. Cl.perfringens monitoring is not required. DWSNZ allows medium (10,000 people) to small plants to use a risk category approach instead of water quality sampled data to estimate the required barrier. The Norwegian GDP-guidelines awards good water sources with a barrier value. DWSNZ assumes faecal contamination (incl. protozoa)

			in all surface waters, while Norway only requires protozoa protection if monitoring indicates faecal contamination.
3	The surveillance of the water source and catchment	to enable a quick and adequate response in case of emergency that could negatively affect the water quality.	Indirectly as the treatment has to be adequate to achieve monitored performance criteria and thus monitoring of e.g. E.coli and turbidity in the raw water is required to control the intake, dosing etc. DWSNZ lack raw water characterising requirement for both bacteria and viruses, which the GDP-model recommends, even though the GDP-guidelines acknowledge the lack of decent virus analysis methods.
4	The water treatment process in addition to the disinfection,	which could be justified as a microbial barrier.	Directly for protozoa, indirectly for bacteria as the treatment must achieve to comply with monitoring, not considered for viruses. The DWSNZ has no compliance requirements for viruses. Neither has Norway but the Norwegian GDP-guidelines incorporates the viruses in the determination of disinfection barrier efficiency.
5	The surveillance in the water treatment plant	that will ensure optimal operation and will enable a quick and adequate response to incidents in the plant.	Considered (e.g. requirements on pH, turbidity, disinfection dose, integrity tests etc)
6	The knowledge off the efficiency of disinfection methods	in regard to inactivation of pathogenic microorganisms, and a corresponding correct design and operation of utilised method.	Considered

11 CONCLUSION

The significant differences between the two approaches are the consideration of viruses and the surveillance in the water source, which is lacking in the DWSNZ. Requirements for viruses are yet to be determined both in Norway and in New Zealand (and in the rest of the world). In regard to surveillance, however, in order to be able to operate the plant and achieve the compliance, the management of the plant is forced to understand and monitor the raw water. So, indirectly, the compliance requirements also require quite advanced surveillance. Overall, the disinfection practice in New Zealand could be regarded as good when benchmarked against the Norwegian GDP-Guidelines.

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