An Evaluation of Hygienic Barriers at Oset Water Treatment Plant at Different Operational Modes

(En vurdering av Osets vannbehandlingsanleggs hygieniske barrierer under ulike driftsforhold)

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Abstract

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Abstract of Master's Thesis, Submitted December 2014

An Evaluation of Hygienic Barriers at Oset Water Treatment Plant at Different Operational Modes

The aim of this thesis is to determine the raw water quality level of Oset drinking water treatment plant, the hygienic barrier level required in the treatment plant based on the raw water quality level and number of consumers, and the final hygienic barrier levels in the different operational situations. The risk and vulnerability analysis done for the treatment plant states that the backup drinking water treatment operation does not meet the requirements and the water must be cocked before use. But there is no analysis done in situations of combining chemically treated and UV disinfected water is mixed with UV disinfected raw water and chlorine disinfection after the two types of water are mixed.

Types of data used in this thesis are secondary data collected and analyzed by ALS laboratory group Norway AS. Data of microbial and chemical raw water quality were extracted from the plant's data base for five years to determine the raw water quality. The hygienic barrier level required in the treatment plant was determined depending on the raw water quality level and the number of people using the drink inking water produced in the plant. The Norwegian water report 170_2009 was used as a standard tool to determine the hygienic level of the different operations in the plant.

This thesis shows that the chemically treated and UV disinfected water has enough hygienic barrier. But if UV disinfection is replaced by chlorine disinfection, level of barriers against parasites and viruses is not enough. The backup operation has not enough hygienic barriers. Both planned and high demand driven combination of operations have enough hygienic barrier level.

The results show that combining chemically treated water and UV disinfected raw water with final chlorine disinfection has enough hygienic barriers. The chemical treatment followed by chlorine disinfection has no enough hygienic barrier against parasites and the chlorine concentration is not enough for virus inactivation.

Sammendrag

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En vurdering av Osets vannbehandlingsanleggs hygieniske barrierer under ulike driftsforhold

Målet for denne masteroppgaven var for å bestemme Oset drikkevannbehandlingsanlegget sitt rå vannskvalitet, nødvendig hygieniske barrierer I anlegget og finale hygieniske barrierer nivå under ulike driftssituasjon. En risiko og sårbarhetsanalyse gjort for anlegget kommenterte at det vannet som produseres i reserve anlegget har ikke tilfredsstillende barriere høyde og vannet må kokes før den brukes. Men det finnes ikke noe analyse gjort for driftssituasjonen hvor en kjemiskbehandlet og UV desinfisert vann blandes med en UV desinfisert rå vann.

Det er sekundær data som er samlet og analysert av ALS laboratory group Norway AS som brukt i denne oppgaven. Mikrobiologiske og kjemiske data hentet fra anleggetsdatabase for fem år, og analysert for å bestemme rå vannets kvalitetsnivå. Nødvendig hygieniske barrierer nivå anlegget må ha er bestemt basert på nummer av brukere og vannkvalitetsnivå. Norsk vann rapport 170_2009 er brukt som en standard verktøy for å bestemme drikkevannets hygieniske barrierer nivå under de drifts situasjoner anlegget har.

Denne oppgaven viser at kjemisk behandlet og UV desinfisert drikkevann har nok hygienisk barrierer. Men om UV desinfeksjonen erstattes av klor desinfeksjon, skal anlegget ha bare en hygienisk barriere mot parasitter og klor konsentrasjonen er ikke nok mot virus. Hvis anlegget må produsere drikkevann i reserve anlegget, blir ikke nok hygieniske barrierer mot bakterier og virus og ingen barriere mot parasitter, derfor må brukere varsles til å koke vannet før de bruker vannet.

Resultatene viser at blanding av et kjemisk behandlet og UV desinfisert vann sammen med et UV desinfisert rå vann, samt med et finalt klor desinfeksjon av blandingen har nok hygienisk barrierer. Et kjemisk behandlet vann med klor desinfeksjon har bare en hygienisk barriere mot parasitter og det klor konsentrasjonen er ikke tilfredsstillende mot virus.

1. Introduction

The history of drinking water treatment is as old as a human history itself. However, our ancestors' knowledge about hygienic barrier is not fully documented. Among others, it took thousands of years before Anton van Leeuwenhoek observed microorganisms in water under a microscope in 1676 (Random History, 2007). But that does not mean our ancestors were happy with every type of water they were drinking. Drinking water treatment goes back to at least 2000 B.C.(EPA, 2000, APEC Water Systems, 2013, Random History, 2007). According to United States Environmental Protection Agency, EPA fact sheet, the ancient drinking water treatments were intended to improve physical quality of the water such as taste, odor, and appearance(EPA, 2000). According to the water office of US Environmental Protection agency (EPA), historical Sanskrit and Greek writings suggested different water treatment methods like filtration of the water through charcoal, exposing the water to sunlight, boiling and straining (EPA, 2000, APEC Water Systems, 2013, Random History, 2007).

The discovery of microscope in the seventeenth century led to the design of the first municipal water treatment plant. It was designed and built in Scotland by Robert Thom and distribution pipes were then installed in 1804 (Hardy Services, 2013, Random History, 2007). The connection between drinking water contamination and infectious diseases became obvious after Dr. John Snow was able to show that cholera was spreading because of contaminated drinking water pump in 1854 (Hardy Services, 2013, EPA, 2000). This became a reason for disinfecting contaminated water and water regulations by the government of UK (Hardy Services, 2013). John Snow added chlorine to the contaminated water to kill the cholera bacteria prompting water chlorination afterwards. After his findings were known, many cities started to treat the water with slow sand filter and chlorine disinfection before it was distributed to the consumers (Random History, 2007).

In short, the drinking water history shows us that there were three main focuses of the people who were concerned about the safety of drinking water (Trussell, 2005). 1. Source protection, once the impact of polluted water on human health was known, the first measure found to be sound was to find non contaminated drinking water source. As Trussel mentioned on his lecture(Trussell, 2005), this method showed some dramatic effects in some cities like New York City. 2. Water pipe pressure, Thomas Hawksley recommended pressurizing the water continuously instead of the intermittent pressurizing as it was the case at that time. His argument is still working that in case of leakage, polluted water cannot enter to the drinking water if the piped water has enough pressure. 3. And still valid action is treating the water. Since it is impossible to find uncontaminated water all the time and everywhere, treating the water is one of the actions necessary to secure public health. The Belgian town of Middelkerke became the first town in the world to use chlorine disinfection of drinking water in 1902(Johansen, 2001).

1.1.Back ground

1.1.1. Oset drinking water treatment plant

The raw water of Oset drinking water treatment plant is mainly from Maridalsvannet (Lake Maridalen). The Lake has a catchment area of 252 km^2. Average yearly flow to the lake is 184 million cubic meter water (Oslo Kommune vann- og avløpsetaten, 2014a). The catchment area is very suitable for recreational purposes. But due to fear of contamination to the drinking water from human activities, the municipality imposes three main restrictions from Gjerdingen in the north to lake Maridalen in south of about 30km length (Oslo Kommune vann- og avløpsetaten, 2012). The following activities are not allowed in the vicinity of the lake and in it:

a) Swimming, dog walking, fishing, jigging, or accessing the lake with boat or polluting the water by any other means,

b) Partying and feasting within 50 meters distance from the lakes, rivers or streams, and

c) Camping on the hill side of the lake, rivers or streams.

There is a sign posted in the restriction areas so that everybody who sees the sign knows these three activities are not allowed.(see Fig. 1.1).

Fig. 1.1 Notice board to the public about activities not allowed in the catchment area and in the lake.

Source: (Oslo Kommune vann- og avløpsetaten, 2012)

Kart restriksjoner
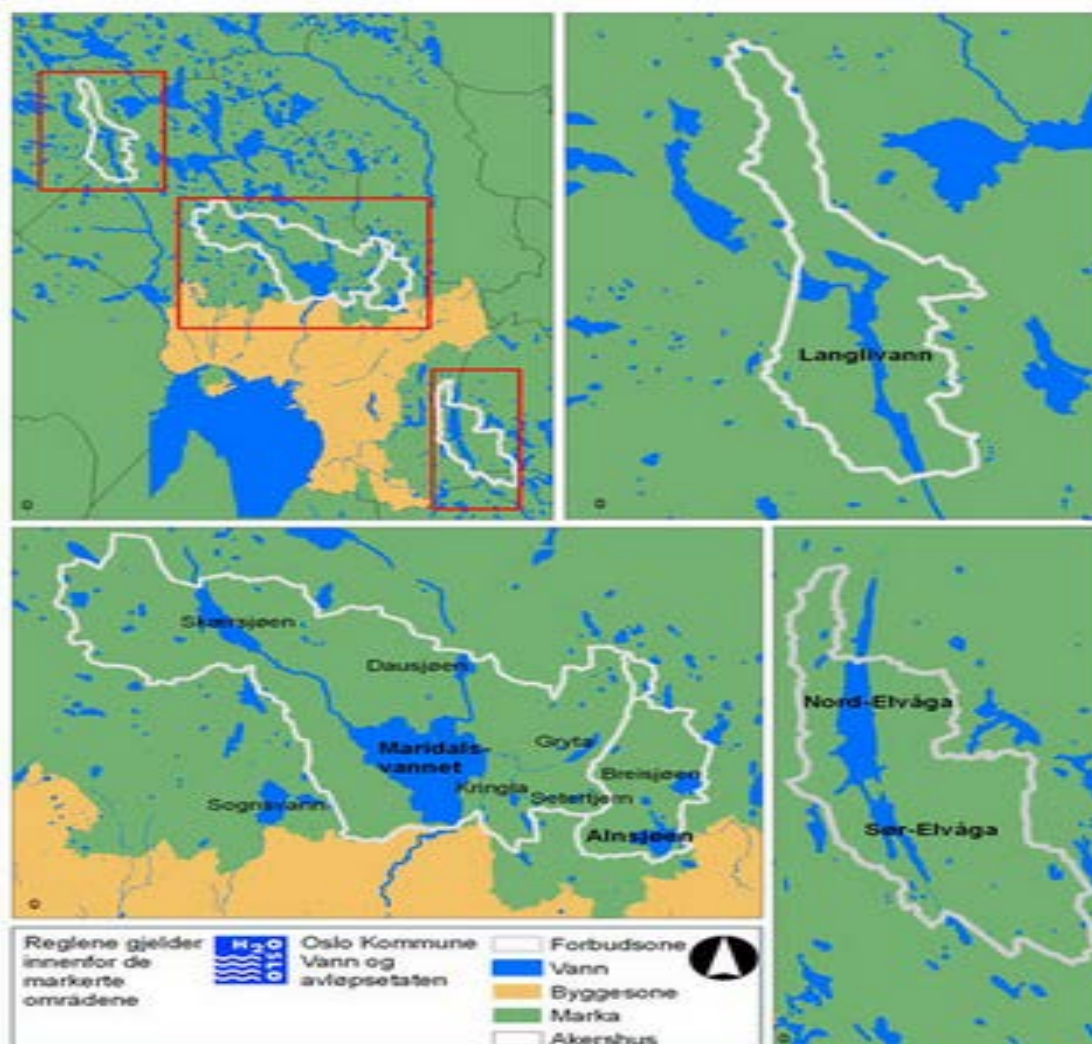
Fig. 1.2 Map of restricted areas in the catchment area of the raw water

Source: (Oslo Kommune vann- og avløpsetaten, 2012).

The new Oset drinking water treatment plant is completed in 2008. The drinking water treatment plant supplies drinking water to about 90% of Oslo city population which is estimated to be 623, 966 in 2013 (SSB, 2014). According to Kruger (total contractor), Oset drinking water treatment plant has two parallel independently working units with a total capacity of producing 390, 000 m^3 water per day. The plant's water treatment process combines Actiflo process with high velocity dual filtration (TGV) and UV disinfection (it also has sodium hypochlorite as an emergency or backup) (Kruger, 2009).

As Kruger (Kruger, 2009) states on its homepage, the treatment process has the following components:

1. Alkalization,

2. Coagulation, flocculation, and sedimentation,

3. Filtration in dual media filter,

4. UV treatment,

5. pH adjustment.

The stages 1 - 3 have one hygienic barrier effect and the UV disinfection is a second hygienic barrier. The treatment plant has two parallel water works each consisting of two Actiflo lines and seven filter units (see Fig. 1.3). The water works are designed for a color of 45 mgPt/l and turbidity of 1.4 NTU. And with a reduced capacity the water works can treat a water of color up to 70mgPt/l. The disinfection chamber is designed for 400 J/m^2 with one additional stand by UV chamber in each water work. The UV dose is calculated on biodosimetric basis, UV intensity and UV transmission, hydraulic load and life of the lamps (Kruger, 2009).
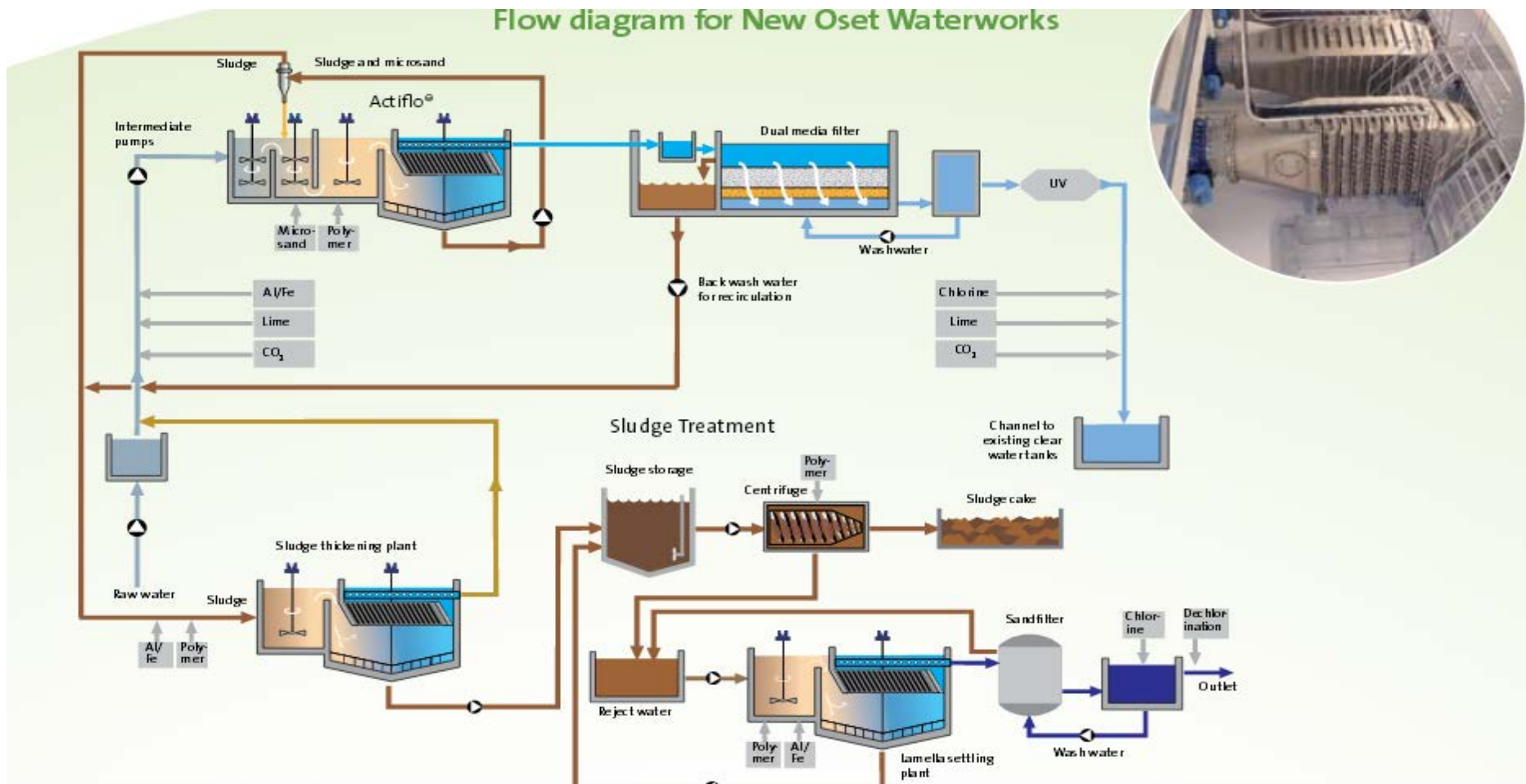
Fig. 1.3 Flow diagram of Oset drinking water treatment plant.

Source: (Kruger, 2009)

Actiflo® is a ballasted flocculation process which uses polymer to attach coagulated particles to micro sand for rapid settling in a lamella tube settler system. The micro sand is separated from the sludge in hydro cyclones and recycled to the process for reuse. The resulting sand ballasted flocs display unique settling characteristics, which allow for clarifier designs with high overflow rates and short retention times. (Kruger, 2009).

1.1.2. Different operational scenarios

Oset drinking water treatment plant has four different operational scenarios: normal, backup, two types of combination of the two operational processes.

a. Normal operation:

According to Oslo municipality's department of water and wastewater (City of Oslo Water and Sewerage Works, 2008) and Kruger (Kruger, 2009), the newly established treatment process has two separate and identical but independent treatment plants. Each treatment plant has the following five steps (see Fig.1.4).

a) coagulation: after carbon dioxide and lime are added to increase the pH up to about 8, aluminum base coagulant is added which binds itself to the loose organic matter (humus matter),

b) micro sands of grain size about 0.1 mm is added to the formed flocs. The aluminum flocs and the micro sand are mixed,

c) to attract the flocs by making them larger, stronger and heavier, polymer is added

d) after sedimentation of the flocs and micro sand, the clarified water undergoes through high velocity dual media filter of fine grained sand and plastic granulates,

e) UV disinfection (it is the second hygienic barrier), if any microorganisms survive the first hygienic barrier (steps a -c), the UV light penetrates the microorganisms' cells and damages their DNA so that they cannot reproduce, and

f) finally before the water is sent to the consumers via the distribution net, lime is added to adjust the pH, and post chlorine disinfection with minimum of 0.05 mg/l after 30minutes contact time dose finalizes the process.
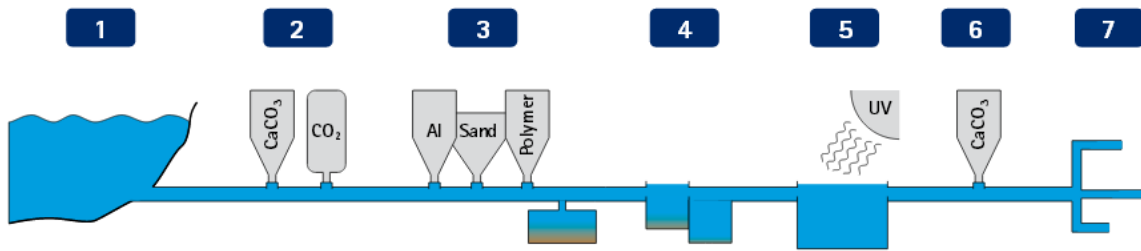
Fig. 1.4 Process line of the normal treatment line

Source: (Oslo Kommune vann- og avløpsetaten, 2014a).

  a) water intake from 30 m depth,

  1. alkalization

  2. coagulation flocculation

  3. dual media filtration

  4. UV disinfection

  5. pH adjustment

  6. distribution

b. Back up operation:

The second scenario is a back up treatment or production line which has the capacity of total production of (520, 000 m^3/day). The backup drinking water production is used only in a situation of emergency if both normal operation lines fail. This back up treatment has three main steps prior to high tank for distribution (See Fig. 1.5).

  a) water intake at 15 m depth,

  b) sieving through 5 µm wide mesh strainer, and

  c) sodium hypochlorite disinfection.
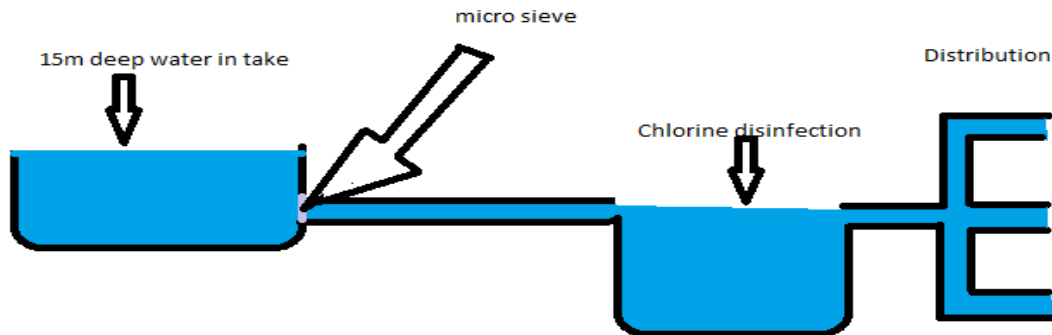
Fig. 1.5 Production line of the backup system.

Though it is not quantified how much the micro sieve removes, in the risk and vulnerability analysis done for the treatment plant showed that with annual production of 100 million m^3/yr water removed about 5 tones of suspended solids (Berge et al., 2011).

c. Combination of the two operations:

The combined operation is not a normal or routine drinking water production process. But it is used if one of the Actiflo production lines or components of the lines fails or when the drinking water demand exceeds the normal water production. This operation has two different forms . According to Lars J. Hem(personal communication), Oset drinking water treatment plant uses one of the following forms of combination:

a) **Planned combination of operations,**

When maintenance in one of Actfilo production lines is required or if one of the production lines fails, the combination process will be set when a production of 3.25 m^3/s is enough to cover the demand. 2.25 m^3/s water will be produced from one of the normal Actiflo production lines and 1 m^3/s water comes passing through 5 µm wide opening sieve and UV disinfection before it is mixed with the 2.25 m^3/s water of the normal operation and chlorine disinfection. Fig. 1.6.
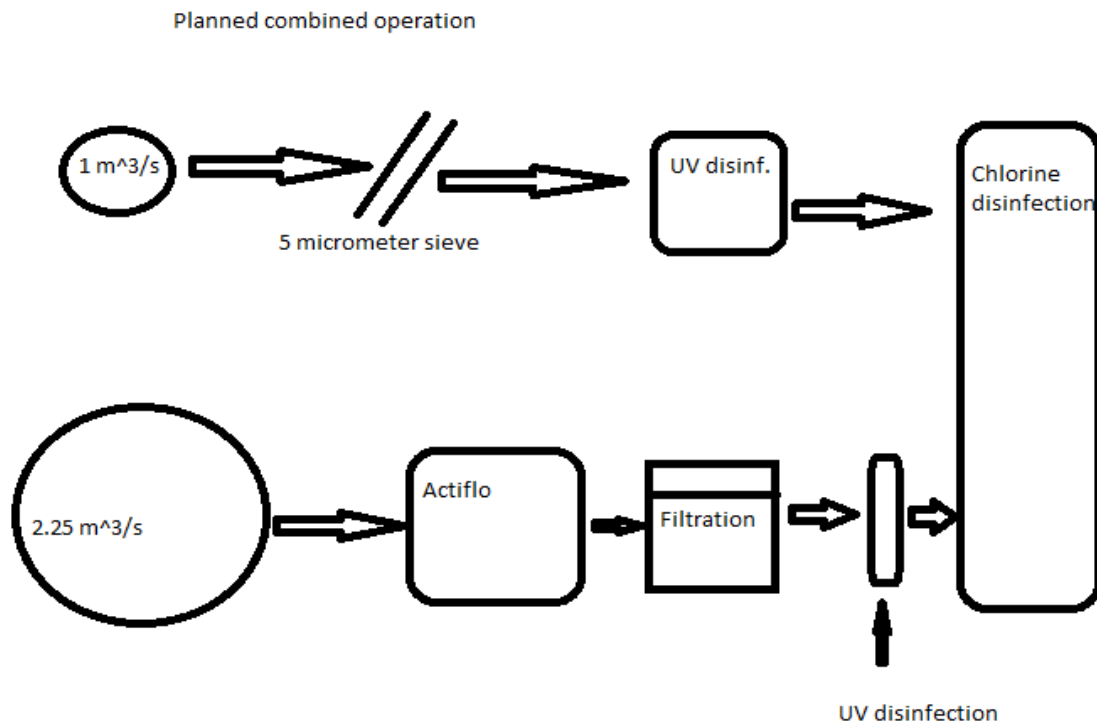
Fig. 1.6 Planned combined operation.

b) **Combination due to high demand,**

this operation starts if the normal operation cannot match the high demand that may occur because of high leakage, fire extinguishing water or any other reason that causes high water demand. When the demand is beyond the normal operation of 4.5 m^3/s , 1m^3/s raw water will be added by passing it through 5 µm wide sieve and UV disinfection so that the total drinking water production will be 5.5 m^3/s. The mixed water will be chlorine disinfected before the tank. The process flow is sketched in Fig. 1.7.
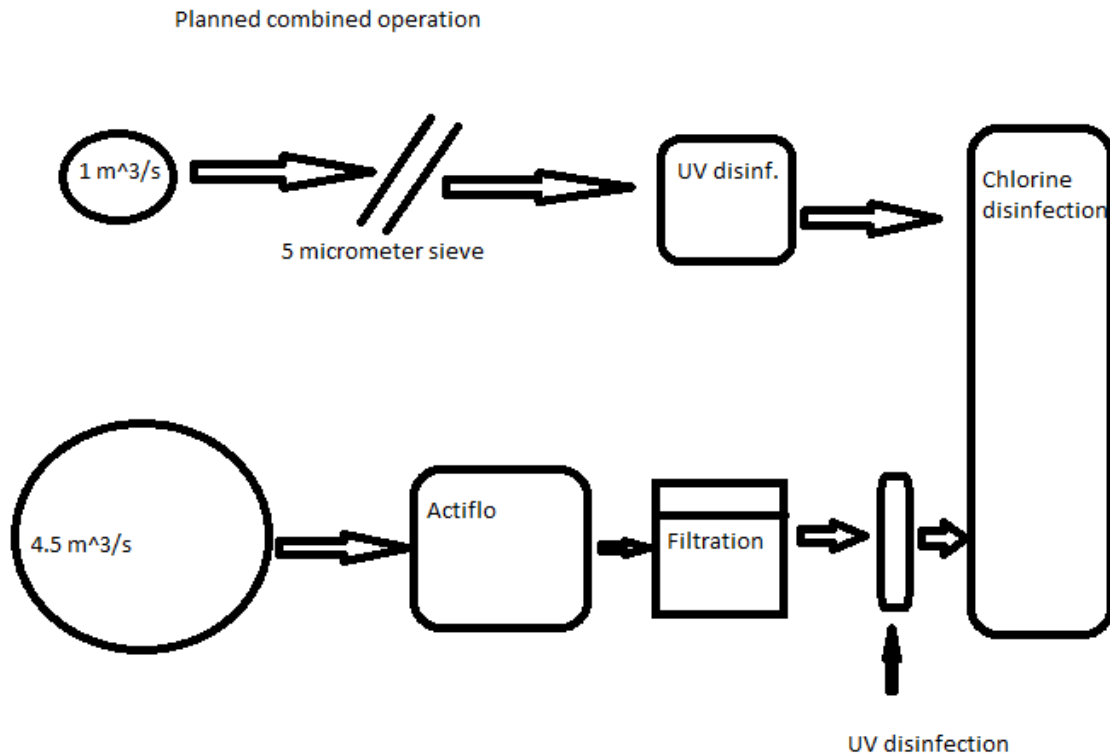
Fig. 1.7 Combined operation because of high demand.

Now we know that water quality may mean physical, chemical and micro biological quality. It is beyond the scope of this paper to deal with every quality aspect of drinking water . Therefore, this thesis will focus on evaluating the microbial hygienic barriers of Oset drinking water treatment plant. The evaluation mainly focuses on the methods suggested by Norwegian Water Report 170_2009 (Norsk Vann Rapport 170_2009).

1.2. Terms and definisjons

The guideline for good disinfection practices (or the microbial barrier analyses, as it is called in the English version) gives the following definitions to the terms used in the guideline and in this thesis (Ødegård, 2014):

1.2.1. Water Work or Water utility size

the guideline divides water works into three size groups depending on the number of people the water work is supplying drinking water to, as follows:

    (1) small, less than 1,000,

    (2) medium, 1,000 - 10,000, and

    (3) large, more than 10,000 people.

1.2.2. Type of water source

    a) surface water: which is divided into **lakes** and **rivers**

    b) ground water: this is also divided into:

- **ground water in unconsolidated sediments (in soil)** that is water transported through unsaturated zone of the soil for at least 60 days,

- **ground water in bed rocks from bore holes (bed rock ground water)** is water from drilled or blasted well with or without soil cover at the top, if the soil layer at the top is less than 3 m, it will be considered as surface water and if the top soil layer is more than 3 m, it is considered as ground water. Unless local hygienic or hydrological conditions indicate otherwise.

- **artificially recharged ground water** (produced by infiltration surface water through the soil), and

- **ground water influenced by surface water** is surface water treated by infiltration through soil**.**

1.2.3. Raw water quality level

The guideline for microbial barrier analyses (good disinfection practices) suggests two levels of surveying to determine the level of raw water quality:

1) the mandatory routine analysis survey for over the last three years,

2) an extended survey through a risk based sampling program over one year.

The survey time may differ from the guideline's suggestion based on the quality of the data one can have and the local conditions. Depending on the results of the routine analysis, one can determine whether risk based analysis is necessary. If the data are insufficient about raw water quality, one can directly go to risk based analysis.

The guideline recommends using the following indicators to determine a raw water quality:

➢ *E.coli* both for survey level 1 and 2.

> *Clostridium perfringens* for survey 1 and for survey 2, if it is necessary to carry out level 2 surveys.

> *Giardia* and *Cryptosporidium* for level 2 (risk based survey).

1.2.4. Barrier level required

is defined as the log reduction of the microorganisms (virus, bacteria and parasites) that has to be achieved by the barrier actions in the water works in the whole process (in the catchment area, and/or water source, in the treatment steps before the disinfection step. Required barrier level is determined based on the water quality level and the water work size. It depends on the size of the utility because the higher the number of people is consuming the treated water the higher will be the consequences of contamination.

1.2.5. Log credit

is the quantification of the various barrier actions implemented in the catchment, source, treatment and disinfection. It is log reduction of the various microorganism groups (virus, bacteria and parasites). They are called log credits because they will be subtracted from the required barrier level to determine the general barrier status. By subtracting the log credits given to the actions taken in the catchment, at source, and in the treatment steps before disinfection step, it is possible to calculate the barrier level the disinfection step must achieve to determine the treated water is safe in terms of hygienic barriers.

1.3. Raw water quality level determination

The raw water quality level will be categorized depending on the presence or absence of indicator and/or index microorganisms, and number of *E. coli, Clostridium perfringens/*100 ml. According to the guideline for microbial barrier analysis (good disinfection practice) it is done in two steps.

a) determination of the raw water quality based on the routine sampling program for the indicators *E. coli* and *Clostridium perfringens* over the last 3 years. If data for *Clostridium perfringens* not available, only *E. coli* data may be used. If neither *E. coli* nor *C. perfingens* is registered during the routine analysis in the last three years (<0/100ml), the raw water quality level will be categorized as level A. If *E. coli* was found in one or more of the samples during the routine sampling program over the last 3 years and the number of *E. coli* was <3/100 ml, and there was no *C. perfringens* or parasites in all the samples, the raw water quality will be categorized as level B.

b) If the number of *E. coli* in one or more of the samples over the last 3 years is >=3 or/and the number of *C. perfringens* is >= 1, it indicates that the raw water quality is poor and therefore it requires a thorough extended risk based sampling program. If the number of *E. coli* per 100 ml is more than or equal to (>=) 10, the extended risk based sampling program is directed to parasites (Giardia and *Cryptosporidium*).

The raw water quality determination procedure can be summarized as follows:

- Neither *E. coli* nor *C. perfringens* is found, nor no parasites detected in the last three years routine analysis: **Level A.**

- *E. coli* was found in one or more of the samples in the last three years. But in all of the samples the number of **E. coli** was < 3. And neither *C. perfringens* nor parasites detected: **Level B.**

- If the number of *E. coli* $\leq$ 10 and or *C. perfringens* per 100ml, the water quality will fall in categories of B, Ca, Cb, and Cc.

- If there is a waste water discharge to the water source, the water quality will be category D regardless of the analysis result.

- If average number of E. coli >10/100 ml, or number of C. perfringens > 3/100 ml; or any single sample has > 20 E. coli or > 6 C. perfringens/100 ml, parasites shall be included as indicators.

- One may avoid the extended risk based sampling by categorizing the raw water as the poorest possible level. In this evaluation, there is data for routine sample analysis, but the time and scope of the thesis does not allow running risk based sample analysis. Therefore, the evaluation is done based on the routine sample analysis.

1.4. Problem statement

The Norwegian drinking water regulation requires two mutually independent hygienic barriers from drinking water works if they are supplying water to 50 or more people or 20 or more households (Mattilsynet, 2011). Oset drinking water treatment plant is designed to satisfy the drinking water regulation in Normal operation (Oslo Kommune vann- og avløpsetaten, 2014a, Kruger, 2009). However the treatment plant has two additional treatment operations. In case of emergency or failure of normal operation, the water work runs backup operation which does not comply with the drinking water regulation. The other operation is in case of failure in one of the normal Actiflo lines of the normal operation and/or maintenance in one of the Actiflo lines, or when the drinking water demand exceeds the normal production capacity. In this case, micro sieve strained raw water is UV disinfected and mixed with the normally produced drinking water.

There is a risk and vulnerability analysis done for the water plant (Berge et al., 2011). The risk and vulnerability analysis among others, commented on the backup operation that the chlorine disinfection has a barrier effect against bacteria, partial barrier effect on virus and no barrier effect on parasites and the report recommended increasing the chlorine dose leaving the actual dose determination to further analysis. The risk and vulnerability analysis says nothing about the combined operations or what would the water quality be if the chemically treated and UV disinfected water is mixed with micro sieve strained and UV disinfected water.

1.5. Objectives:

Using the Norwegian Water Report 170_2009, "Guideline for Good Disinfection Practices, GDP" (Ødegaard et al., 2009), as a standard measuring tool to determine the barrier levels of Oset drinking water at different operations. This thesis attempts to determine the microbial hygienic barrier level of the drinking water after each operation.

The specific objectives are:

1) To determining the raw water quality level of Oset drinking water treatment plant,

2) To determine the hygienic barrier level required in the treatment plant based on number of consumers and raw water quality,

3) To determine whether the treated water in the treatment plant is hygienically safe at different operations based on the Norwegian drinking water regulation and the guideline for microbial analysis.

2. Literature Review

2.1. History of water in drinking Norway

Building of water works where it was possible to take water for drinking and for fire extinguishing in Norwegian cities started in 16th and 17th century (Blystad, 2010). Oslo (Christiania) inhabitants were enjoying wooden pipe transported water from Akerselva to the city through down town and to Akershus fortress starting from as early as 17th century (Johansen, 2001, Oslo Kommune vann- og avløpsetaten, 2014b). Johansen described that it was Akershus fortress who enjoyed the wooden piped water first and they had enough capacity to establish public water posts on crossroads and gradually started to have access to individual front yards, first to the officers and then, to the rest of the inhabitants against payment (Johansen, 2001). According to Finn Johansen, in 1814 Christiania became Norway's capital city and the population size tripled in the first half of 19th century making it necessary to increase the water supply. The first modern water work with cast iron pipes was opened in 1855 in Bergen (Blystad, 2010, Byrkjeland and Hammerborg, 2006). Though the cast iron pipes were more expensive than the wooden pipes, it was possible to produce larger dimensions and the pipes were more durable (Byrkjeland and Hammerborg, 2006).

As (Johansen, 2001) wrote, a new water supply system for providing water to individual estates against pre-payment was decided. In 1860 Oslo (Christiania) city found a new cast iron pipes and the last wooden pipe was replaced in 1879 (Johansen, 2001). Bergen was the first city to have drinking water distribution net in Norway in 1855 (Byrkjeland and Hammerborg, 2006). Because of industrial pollution of Akerselva, the drinking water intake was transferred to Maridalsvannet in 1867 (Johansen, 2001). Since the micro bacteriological test showed that the water was safe enough, it took the gastroenteritis outbreak of 1888 which affected thousands of Christiania inhabitants to start the discussion whether to only filter the water or to chlorinate it. And that debate led to establishment of the first water treatment plant. The treatment method was chlorine disinfection (Johansen, 2001). In 1929 the first water chlorination apparatus was installed at Maridalsvannet and at Sognsvannet in Norway (Johansen, 2001).

2.2. Microbial drinking water quality

As the saying "prevention is better than cure" goes, selecting the best possible raw drinking water quality source is very important in drinking water works. The quality of drinking water is often expressed in whether the water has fecal indicators or not (Figueras and Borrego, 2010). Thus, the method to categorize a water quality depends on the absence or presence of some microorganisms (Ødegaard et al., 2009, Snozzi, 2001). The microorganisms which are used to determine a microbial quality level of water are grouped in three: general microbial indicators, fecal indicators and index organisms (Snozzi, 2001, Ødegaard et al., 2009).

2.2.1. Indicators

are a group of microorganisms that show an effectiveness of a process for example total heterotrophic bacteria or total coliforms to assess a disinfection process (Payment et al., 2003).

2.2.2. Fecal indicators

are a group of organisms that indicate the water is contaminated with fecal excrement of an infected human or other warm blooded animals. Thermo tolerant coliforms or *E. coli* are the two examples that just show fecal contamination, meaning pathogens may be present (Ødegaard et al., 2009, Figueras and Borrego, 2010).

2.2.3. Index organisms

are a group or species that indicates presence of other pathogenic organisms. For example *E. coli* can be used as an index of *Salmonella*.

Indicator microorganisms should fulfill at least the following criteria (Ødegård, 2014):

- They should be easy to detect with the present methods,

- Their quantitative existence must be large enough for fair and reliable detection,

- They must give an indication of health risks.

The usual indicators used in Norway for drinking water microbial analyses are: Colony count (22^0C), *E. coli*, Intestinal enterococci, and *Clostridium perfringens* (Ødegaard et al., 2009, Helse- og omsorgsdepartementet, 2002). E. coli serves as an indicator of fresh fecal contamination. It also is used as an indicator of disinfection process effectiveness. But it is not a reliable indicator for the presence or absence of viruses and parasites (*Cryptosporidium* and *Giardia* (oo) cysts) in drinking water after disinfection. It is not a reliable indicator for the presence of *Campylobacter*, fecal contamination from birds either. *Clostridium pefringens* is used as an indicator of old fecal contamination because its spores can survive longer in the environment than E. coli does. As parasites and viruses have longer survival time in the environment than bacteria (for example, *E. coli*), *Clostridium perfringens* is considered to be better indicator for viruses and protozoa than *E. coli* for raw water. Based on the microbial analyses guideline and the data available, the presence of *E. coli* and *Clostridium perfringens* is used to determine the quality of the raw water.

The guideline to Norwegian drinking water regulation specifically focuses on the presence of *Clostridium perfringens (Mattilsynet, 2011, Ødegård, 2014)*. The guideline states that the requirement for treated drinking water before supply should be 0/100ml number of *C. perfringens*. This is not because *Clostridium perifringens* is so important to human health at such few number, but it is because *C. perifringens* is used as an indicator for human pathogens of long time survival outside human intestine (Ødegaard et al., 2009, Brynestad and Granum, 2002). Since this indicates an old fecal contamination, all other index organisms are long gone. Which also implies that may be true for viruses and bacteria. Because of this, Norwegian drinking water regulation states that if the number of *C. perifringens (*including its

spore*)* is more than 0/100 ml water after treatment, an investigation must be carried out to clarify if there is any human pathogenic health risk is associated (Mattilsynet, 2011).

2.3.Microbial Hygienic Barriers

Hygienic barriers are actions or measures used to eliminate or minimize the health risks related to chemical, physical and microbial quality of drinking water (Stanfield et al., 2003, Ødegaard et al., 2009). Microbial hygienic barriers remove, inactivate or kill microbial human pathogens. Microbial hygienic barriers can be achieved by physical and chemical removal of human pathogens together with particle removal in processes like filtration, coagulation and flocculation, sedimentation and/or inactivation or killing of the microorganisms by disinfection (Stanfield et al., 2003, LeChevallier et al., 2004). When microbial hygienic barriers are combined the result is synergetic, because the treatments upstream influence the efficiency of the disinfection process. For example UV or chlorine disinfection efficacy is dependent on the color and turbidity of the water and water turbidity itself is dependent on the particle removal processes (The Environmental Protection Agency of Ireland, 2011). Disinfection effectiveness with upstream water treatment is different from disinfection without any prior treatment. Environmental protection agency of Ireland explains that if there is upstream treatment (The Environmental Protection Agency of Ireland, 2011):

- Chlorine demand will be reduced (for example by organic matters) (LeChevallier et al., 1981), paving the way to have higher chlorine concentration with less byproduct formation (The Environmental Protection Agency of Ireland, 2011). LeChevallier and his co - authors (LeChevallier et al., 1981) concluded that surface water chlorine demand was positively correlated with both turbidity and total organic carbon. Thus, if turbidity and total organic carbon is reduced in upstream treatments, the chlorine demand in chlorine disinfection will be reduced. Because the particles are removed in the upstream treatment, there will be less natural organic matter to react with the chlorine to form the byproducts (Gallard and von Gunten, 2002, Chu et al., 2011).

- the water quality variability will be reduced, more reliable control over chlorine residual (The Environmental Protection Agency of Ireland, 2011). Since the water quality level will be increased to a certain level, the variability becomes less allowing use of known dose of chlorine (Chu et al., 2011)

- turbidity of the water will be reduced and as a result, there will be less shield for the microorganisms from the effects of UV or chemical disinfection (The Environmental Protection Agency of Ireland, 2011), and

- The microorganisms pose less challenge to the disinfection process since upstream processes are effective in removing part of the microorganisms (Copes et al., 2008). And the microorganisms will have less shield to from the inactivation of chlorine disinfection(The Environmental Protection Agency of Ireland, 2011).

2.4.Multiple Barriers

Multiple barriers are the main focus of every modern water treatment plant (Copes et al., 2008, Ødegaard et al., 2009). The multiple barrier idea is a historical development of drinking water treatment from thousands of years before Christ to our modern era (Random History, 2007, Hardy Services, 2013). It is somewhat a combination of selected proven water treatment techniques during the course of our history (Trussell, 2005, Copes et al., 2008). The barriers are selected water treatment methods in order to magnify pathogen removal capacity of each technique in the treatment process (LeChevallier et al., 2004). Having multiple hygienic barrier means that if one of the stages in the process fails or weakens due to operational failure or any other reason, the other steps in the process will prevent the probability of pathogenic organisms passing through the process and reaching the consumer, reducing the health risk (LeChevallier et al., 2004). Usually multiple barrier principle combines five basic methods in drinking water work plants. Selecting the best possible drinking water quality source and protecting it from contamination, removal of the dissolved contaminants or particles in the water with the help of chemicals (coagulation, flocculation and sedimentation), filtration, disinfection, and finally protecting the distribution network (LeChevallier et al., 2004, Helse- og omsorgsdepartementet, 2002).

The Norwegian drinking water regulation defines hygienic barrier as natural or manmade physical or chemical protective measure to remove, deactivate or kill bacteria, viruses and parasites and/or diluting, disintegrating or removing any chemicals and physical substances to a level so low that they no longer can create any human health risks (Helse- og omsorgsdepartementet, 2002).

 Norwegian drinking water regulations (drikkevannsforskriften kap. 4 §14.) requires from drinking water treatment plants to have at least two hygienic barriers in their raw water source and treatment plant in order to be authorized as a drinking water treatment plant (Mattilsynet, 2011). And one of the barriers should ensure that the drinking water is disinfected or treated in such a way that it removes, deactivates or kills infectious substances in the water(Helse- og omsorgsdepartementet, 2002). Determination of the hygienic barriers is considered based on the overall activities and measures taken starting from catchment area and drinking water source selection, and protection of the catchment and the source, water treatment and distribution (Mattilsynet, 2011).

According to (Ødegård, 2014) the microbial hygienic barriers are measures or methods taken to avoid or minimize the pathogenic microorganisms causing human illnesses categorized into three main groups: viruses, bacteria and parasites. A brief description of each group will be mentioned as follows:

   a) **Viruses:** are the smallest pathogenic microorganisms less than 0.1µm in size. They are infectious agents which can replicate themselves only inside living cells of other organisms. Norovirus are known to cause human water borne disease in Norway. There are many other variety of viruses to cause human disease (The National Academy of Sciences, 2014, Ødegaard et al., 2009).

b) **Bacteria:** are a large group of unicellular microorganisms without a cell nucleus. Not all bacteria are harmful to humans, some are beneficial and some have no effect at all. They are a little more than viruses in size, about 1µm, and the bacteria most known to cause abdominal and intestinal diseases in Norway are *Campylobacter*, *Escherichia coli* (*E. coli*) and *Salmonella* also belongs to the pathogenic bacteria group. *Escherichia coli* (*E. coli*) have different types and some of them are pathogenic like *E. coli O177:H7*. Some bacteria species form survival protecting spores. These spores help them resist extreme conditions (Ødegaard et al., 2009, The National Academy of Sciences, 2014).

c) **Parasites**: are living organisms which are living on the expenses of other organisms. But in drinking water pathogenic parasites, we are talking about protozoa which are bigger than bacteria in size, about 3 - 10µm. They are more resistant than bacteria and viruses to chlorine disinfection *Giardia* and *Cryptosporidium* are known to be highly pathogenic in this group. The Bergen 2004 fall epidemics was because of Giardia (Ødegaard et al., 2009, The National Academy of Sciences, 2014).

3. Materials and Methods

3.1. *Data source*

The types of data used in this thesis are secondary data. Raw water samples for microbial and chemical analysis were taken and analyzed by ALS laboratory group Norway AS once a week at the in late starting from the new Oset drinking water treatment plant was established in 2008, but total organic carbon content (TOC) of the raw water sample was analyzed quarterly (four times a year). ALS laboratory group Norway AS is accredited by Norwegian authorities to carry out some limited analysis on its own laboratories (ALS Laboratory Group Norway AS, 2013). The samples were analyzed in ALS laboratories and analyzed according to the Norwegian drinking water regulations reference methods, *E. coli, Clostridium perfringens,* and Coliforms, number of organisms in 100ml were extracted. Turbidity, color, pH, and total organic carbon were extracted from the data and analyzed with descriptive statistics in excel. The analyzed data were kept in the water works data base. From the data base for five years data, microbial and chemical data were extracted for five years and analyzed with the help of descriptive statistics in excel sheet.

The procedures described in the guideline for good disinfection practices (Ødegaard et al., 2009) was used. Raw water quality level was determined by analyzing maximum number of microorganisms in the five years of the data period. Number of consumers was taken from SSB. After the raw water quality level was determined, the hygienic barrier level of Oset drinking water treatment plant needs to achieve was determined. The hygienic barrier levels every operation in the treatment plant can achieve were determined. By subtracting the sum of the hygienic barrier levels the treatment plant has in the different operations from the hygienic barrier level the treatment plant should achieve, the hygienic barrier level of the plant in different operations was calculated. Based on the guideline for good disinfection practices (Ødegaard et al., 2009), the minimum temperature for the raw water at 30 meter depth was assumed to be 4^0C.

Using maximum number of the microorganisms in 100ml sample, the raw water quality level was determined. And the procedures used are summarized in table 3.1.

Table 3-1 The steps of the optimum disinfection practices (Microbial Analysis, MBA).

Step	Determination of	Dependent on
1	Raw water quality	• historic data for raw water quality • New data from risk-based sampling program
2	Required barrier level	• Water quality conditions • Size of water work
3	Catchment area and water source barriers	• Barrier actions in catchment area/water source • Surveillance of raw water quality
4	Water treatment barriers (before final disinfection)	• Water treatment methods • Surveillance of water treatment
5	Final disinfection barriers	• Disinfection methods • Dosage in disinfection processes
6	Overall barrier status (Total protection provided)	• Barrier level required ÷barrier credits • Step2 ÷step3 ÷step4 ÷step5

Source: (Ødegård, 2014)

3.2. Barrier effect in the catchment and at the source:

As it is mentioned in the guideline, it is difficult to quantify the effects of protective measures and the measures taken are already contributing to the present water quality. Therefore no log credit is given to the protective activities taken in the Maridalsvannet catchment and at the lake itself or the water intake place. The raw water quality level was categorized using the criteria shown in Figure 3.1.

Detection of indicator organisms through the routine sampling program during the last 3 years

| 0 EC[1] and 0 CP[1] and/or 0 P[1] | > 0 EC[1] and >0 CP[1] and/or 0 P[1] | If wastewater discharge to water source |

< 3 EC[1] and < 1 CP[1] or 0 P1

3< EC[1] < 10 and 1 < CP[1] or 0< P[1] <0,01

≥ 10 EC[1] and > 3 CP[1] or > 0,01 P[1]

Survey through a risk-based sampling program

Survey through a risk-based sampling program

| < 10 EC[2] ≤ 0,01 P[2] | ≥ 10 EC[2] ≤ 0,01 P[2] | > 0,01 P[2] |

| ≤ 3 EC[2] and ≤ 3 CP[2] | 3 - 5 EC[2] and ≤ 3 CP[2] | 6 - 7 EC[2] and ≤ 3 CP[2] | 8 - 10 EC[2] and ≤ 3 CP[2] | >10 EC[3] and < 3 CP[3] |

| 0.01 - 0.1P[2] | >0.1 - 0.3 P[2] | > 0.3P[2] |

A **B** **B** **Ca** **Cb** **Cc** **Da** **Da** **Db** **Dc**

Fig. 3.1 Raw water quality determination procedure.

Source: (Ødegård, 2014) p. 18.

[1]Once or more than many times;

[2]average concentration in more than 1/6 (16.7%) of the samples. For parasites (*Giardia* and *Cryptosporidium*), it is the sum/100ml.

[3] >20 *E. coli* or > 6 *C. perfringens*/100ml in any single sample during the sampling period.

EC = *E. coli*

CP = *Clostridium perfringens*

P = parasites (*Giardia* and/or *Cryptosporidium*).

3.3. Determination of hygienic barrier level

After the raw water quality level was determined, the hygienic barrier level required was determined based on the guidelines criteria for number of consumers and raw water quality level (See figure 3.2).

```
┌─────────────────────────────────┐
│ Routine sampling raw water data │
│ for the last 3years             │
│                                 │
│ And/or data from risk based     │
│ sampling data                   │
└─────────────────────────────────┘
                │
                ▼
┌──────────────────────┐   ┌──────────────────────────┐
│ Raw Water quality    │   │ Water utility size       │
│ level                │   │                          │
│                      │   │ (number of people        │
│                      │   │ connected)               │
└──────────────────────┘   └──────────────────────────┘
        │                           │
        ▼                           ▼
┌────────────────────────────────────────────────────┐
│            Barrier level required                   │
└────────────────────────────────────────────────────┘
```
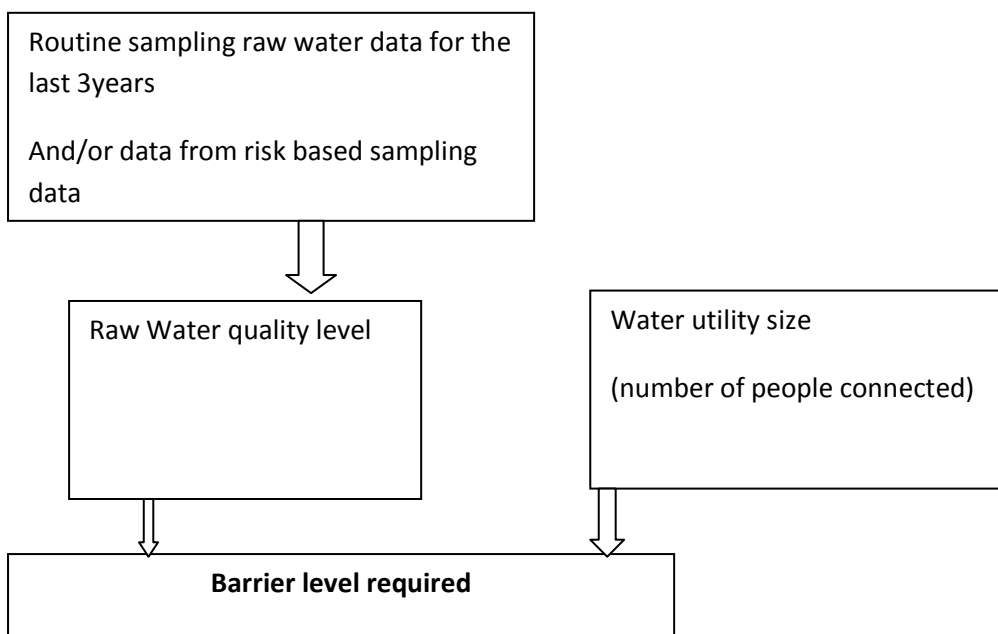
Fig. 3.2 Required barrier level determination

Adapted from (Ødegård, 2014).

The required barrier level means that the sum of log reductions the actions and processes in the water work must achieve for the given raw water quality level and number of people who get their drinking water from the water work so that to say the drinking water has enough microbial hygienic barrier.

The guideline for good disinfection practices summarizes the barrier level required according to the raw water quality and the person equivalent size of the water work was used to determine the hygienic barrier level required in Oset drinking water treatment plant (see table 3.2).

Table 3-2 . Barrier level required depend raw water quality and size of water utility.

Size of Water work		Raw water quality level			
		A	**B**	**C**	**D**
< 1000pe	Barrier level required	3.0b+3.0v+2.0p	4.0b+4.0v+2.0p	a. 4.5b+4.5v+2.5p b. 4.5b+4.5v+3.0p c. 4.5b+4.5v+3.5p	a. 5.0b+5.0v+3.0p b. 5.0b+5.0v+3.5p c. 5.0b+5.0v+4.0p
1000 - 10,000pe		3.5b+3.5v+2.5p	4.5b+4.5v+2.5p	a. 5.0b+5.0v+3.0p b. 5.0b+5.0v+3.5p c. 5.0b+5.0+4.0p	a. 5.5b+5.5v+3.5p b. 5.5b+5.5v+4.0p c. 5.5b+5.5v+4.5p
>10000pe		4.0b+4.0v+3.0p	5.0b+5.0v+3.0p	a. 5.5b+5.5v+3.5p b. 5.5b+5.5v+4.0p c. 5.5b+5.5v+4.5p	a. 6.0b+6.0v+4.0p b. 6.0b+ 6.0v+4.5p c. 6.0+6.0v+5.0p

Source: (Ødegård, 2014) p. 19

Table 3.2. abbreviations: b = bacteria, v = virus and p = parasites. The numbers before the abbreviations are log reductions required for the respective microorganism. For example the barrier level required for raw water quality level Dc and for the size of more than 10,000pe is 6.0b+6.0v+5.0p. That means the water must have treatment process and/or disinfection step for at least 6 log bacteria reduction, 6 log virus reduction and 5 log parasite reduction so that the treated water to be considered as hygienically safe.

3.4. Log credit assignment for barrier actions

The following barrier actions in three main steps in the water work from the rain fall in the catchment to the water supplied to the consumer was examined. For those actions that serve as hygienic barriers were given log credits depending on the values given in the guideline.

I.   Barrier actions in the catchment area and at the source

- physical barrier actions

- restrictions of activities in the catchment area and at the water source

- monitoring and surveillance in the catchment and at the source

II.   Barrier actions in water treatment plant before the final disinfection

- treatment actions (for example, coagulation, flocculation, sedimentation and filtration)

- monitoring and surveillance in the treatment plant

III.   Barrier actions in the final disinfection

- chemical or physicochemical disinfection

- advanced particle separation

The guideline for microbial barrier analysis advices to be careful in assigning log credit to catchment area and to the source, because there are many unforeseen events that can happen for example fecal material from birds or wild animals may be difficult to control all the time. And the efficiency of the actions incurs uncertainties. In every case, log credit for actions in the catchment and at the source was given only to the planned and new actions. It was not assigned any log credit to existing actions in the catchment or at the source. Because these actions already contributed in the categorization of the raw water quality level.

In the case of Oset drinking water work, it is an existing plant and though there are actions taken to protect the catchment area and the source, it was not given any log credit for those actions. Because the plant is serving drinking water to more than 500,000 people which makes it important for any case of contamination may have a huge consequence. Therefore conservative approach was used in assigning log credits.

The guideline for microbial barrier analysis (or good disinfection practices) summarizes the process of assigning log credit in table3.3.

Table 3-3 . Maximum log credit for various barrier actions. Source: (Ødegård, 2014)p. 21.

Barrier action	Maximum log credit
New actions in catchment area and at source - Lakes • Maximum log credit for physical and restrictive actions, of which • maximum log credit for raw water monitoring actions	2.0b + 2.0v + 1.25p 0.75b + 0.75v + 0.5p
New actions in catchment area and at source - Ground water • Maximum log credit for actions in various wells, of which • Maximum log credit for raw water monitoring action	2,0b + 2.0v + 1.25p 0.75b + 0.75v + 0.5p
New actions in catchment area and at source - Rivers and Brooks • Maximum log credit for raw water monitoring actions only, provided that auto closing raw water supply if control parameter limits are exceeded	0.75b + 0.75v + 0.5b
Water treatment actions prior to final disinfection	3.0b + 3.0v + 3.0p

Maximum log reduction in final disinfection
 	
• Chemical disinfection methods
 	
• UV disinfection
 	
   ➢ Dose 40mJ/cm^2 (Biodosimetrically determined)
 	
   ➢ Dose 30mJ/cm^2 (Biodosimetrically determined)
 	
   ➢ Dose 25mJ/cm^2 (Biodosimetrically determined)
 	
• Particle separation methods
	
	4.0b + 4.0v + 3.0p
	
	4.0b + 3.5v + 4.0p
	
	4.0b + 3.5v +4.0p
	
	3.5v + 3.0v +3.5p
	
	3.0b + 2.5v + 3.0p
	
	3.0b +3.0v + 3.0p

3.5. Calculating the Ct value

The Ct theoretical concept is that degree of inactivation (log inactivation) is related to concentration, C, of the chemical and the time, t, in which the microorganism is exposed to the chemical. The Ct value varies depending on type of microorganism, temperature and pH (see Table 3.4.).

Table 3.4. Designing Ct value for (mgmin/l) for inactivation of bacteria, viruses and parasites.

	Bacteria (3 log)		Viruses (3 log)		Parasites of Giardia Group (2 log)		Parasites of Cryptosporidium group	
	4^0C	0.5^0C	4^0C	0.5^0C	4^0C	0.5^0C	4^0C	0.5^0C
chlorine pH < 7	1.0	1.5	4.0	6.0	75	*100*	N.G	N.G.
pH 7 - 8	1.5	2.0	6.0	8.0	100	150	N.G.	N.G.
pH > 8	2.0	3.0	8.0	12.0	175	250	N.G.	N.G.
Chloramines	100	200	1500	2000	1750	2500	N.G.	N.G
Chlorine dioxide	1.0	1.5	20	25	25	40	1000	1250
Ozone	0.5	0.75	1.0	1.5	1.5	2.0	30	45

N.G = not given, Ct value is so high that it is not important for any practical purpose.   Source: (Ødegaard et al., 2009).

3.5.1. Determination of oxidation concentration and coefficient of degradation

When chlorine dose is added to the disinfection the disinfection tank, the concentration drops to certain level immediately. The concentration lost in that short time is the chlorine used to oxidize the organic matter (Ødegaard et al., 2009). This quickly lost concentration is called initial consumption, C_c. The rate of the chlorine concentration degradation, k is a coefficient which shows chlorine concentration degradation in chlorine disinfection.

Initial chlorine consumption and the degradation coefficient were determined from the model given in the guideline for good disinfection practices:

$C_c = 0.06 *TOC + 0.36 * C_{dose} + 0.08 * (C_{dose} / TOC) – 0.12,$ **and**

$k = 0.013 * TOC – 0.040 * C_i – 0.010 * C_i / TOC + 0.022.$

Where: C_c = Chlorine concentration used for organic matter oxidation, k degradation coefficient, TOC = total organic carbon content of the water at disinfection, C_i = initial chlorine concentration available for disinfection.

The effluent concentration, C_e was assumed to be 0.05 mg Cl_2/L. The other relation between the concentrations was used as follows:

- $C_i = C_{dose} - C_c$; Where C_{dose} = the chlorine dose added to the disinfection tank. After the initial chlorine dose and the effluent chlorine dose were determined, the degradation coefficient was derived from the next formula,

- $k = -[\ln(C_e/C_i)]/t$; Where t = effective contact time.

- $C_i = C_e/e^{-k*t}$

- $C_{dose} = C_i + C_c$

In the Ct calculations, C_c was derived from the model given above and k was calculated using the formula.

3.5.2. Determination of effective time, t in Ct calculation

The effective disinfection contact time was assumed to be the product of theoretical contact time and hydraulic factor of the contact tank. The contact time used in the calculation of Ct was:

$T = Q/V * (t_{10}/T)$

Where: t = effective contact time (min), V = Volume of contact tank(m^3), Q = designing water flow (m^3/min), t_{10}/T = hydraulic factor (T = theoretical contact time = V/Q).

Hydraulic flow factor depends on the type of flow in the tank. The more plug like the flow is the more hydraulic factor it will have. The hydraulic factors for different flow types given in the guideline are shown in Table 3.5.

Table 3-4 Guideline hydraulic Values of $10_{10}/T$

Degree of plug flow	T_{10}/T
No plug flow (ideal mixing)	0.1
Bad plug flow	0.3
Medium plug flow	0.5
Fairley good plug flow	0.7
Very good plug flow	0.9
Perfect plug flow	1.0

Adapted from (Ødegaard et al., 2009).

3.5.3. Calculating the Ct value

The Ct value is the area under the chlorine concentration curve

The Ct value was calculated as:

Ct = (Ce / k) (e^{k*t} -1)
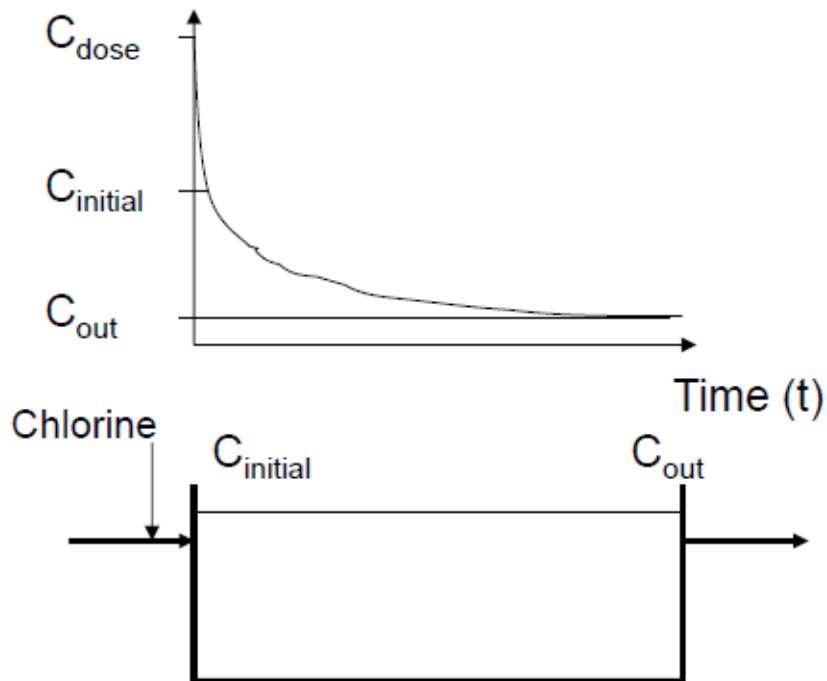
Fig. 3.3 Chlorine concentration change in disinfection tank.

Source: (Ødegård, 2014).

It is important to mention that there is a small dose of chlorine disinfection before distribution in the normal treatment operation. This chlorine disinfection is not used in the calculation because its purpose is to prevent any microorganism development and to inactivate any microorganism intrusion in the distribution system and it is in very small concentration that the Ct it has is almost negligible.

4. Results

4.1. The turbidity:

Turbidity was high in the week 29 of 2012 (see Table 4.1). In 2012 the turbidity was higher than the other 4 years starting from week 27 to week 48. In the year 2010, Oset raw water turbidity sharply increased through week 36 to week 38 (Fig. 4.1).

Table 4-1 Oset raw water turbidity (FTU) for the years 2009 - 2013

Year	2009	2010	2011	2012	2013
No. of samples	52	52	48	50	51
Max	0.47	1.15	0.44	1.64	0.88
min	0.20	0.25	0.21	0.33	0.34
Average	0.29	0.36	0.29	0.60	0.53
median	0.28	0.34	0.29	0.49	0.48
95%, percentile	0.429	0.4735	0.4	1.063	0.81
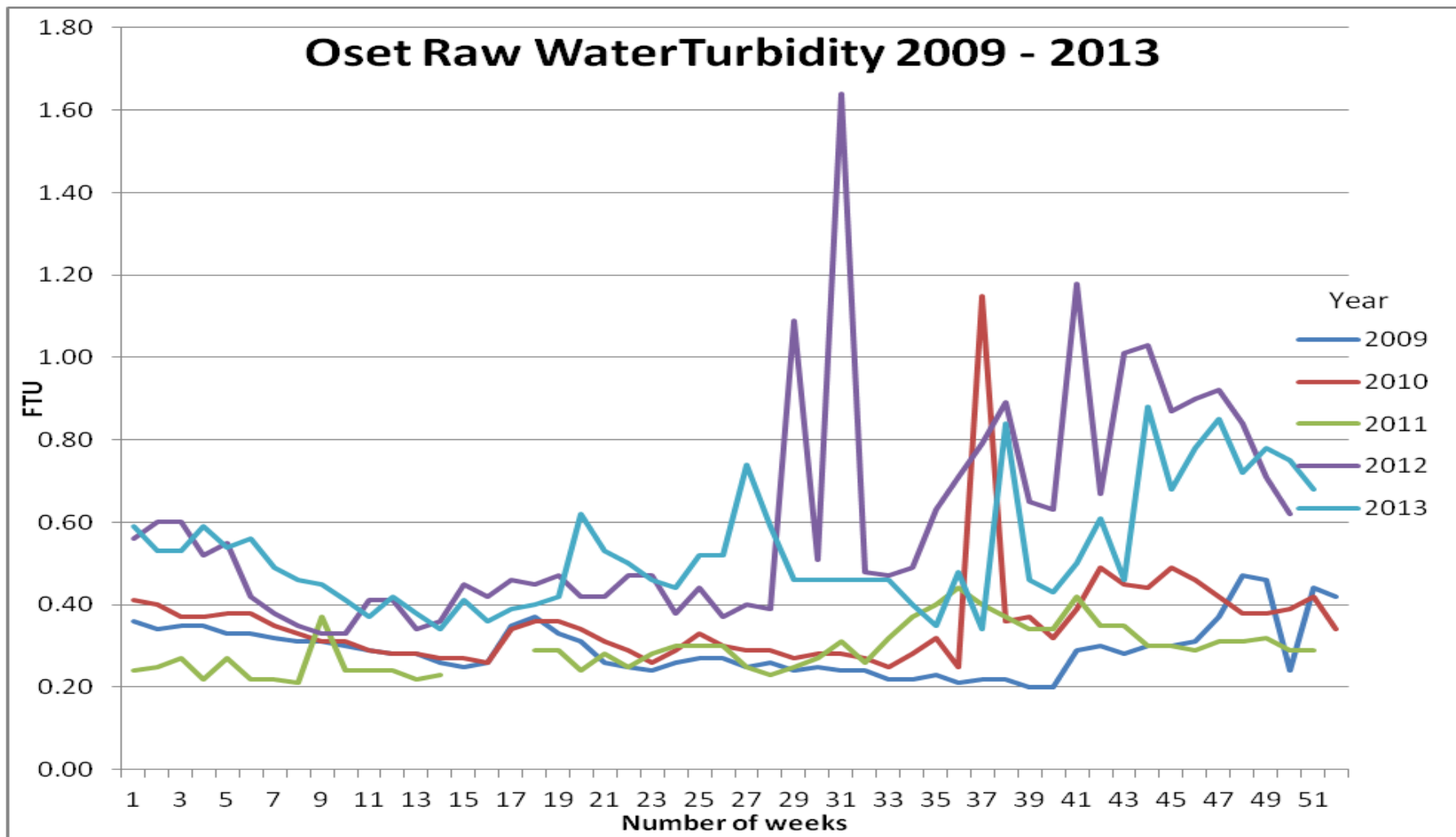
Fig. 4.1 Oset raw water turbidity for 2009 - 2013.

4.2. The pH of Oset raw water:

The pH has no big difference though it slightly was low during summer times and higher in late autumn and winter (see Fig. 4.2). The highest being 6.82 in week 5 of 2013 and the lowest pH values recorded was 6.28 in week 23 of 2012, week 39 of 2009 and week 42 of 2013 (Table 4.2).

Table 4-2 pH of Oset drinking water raw water for years 2009 - 2013.

Year	2009	2010	2011	2012	2013
No. Of samples	52	52	51	50	51
Average	6.48	6.49	6.50	6.53	6.50
Max	6.64	6.69	6.79	6.67	6.82
min	6.28	6.29	6.29	6.28	6.28
median	6.50	6.50	6.50	6.56	6.52
95%, percentile	6.63	6.65	6.63	6.6555	6.675
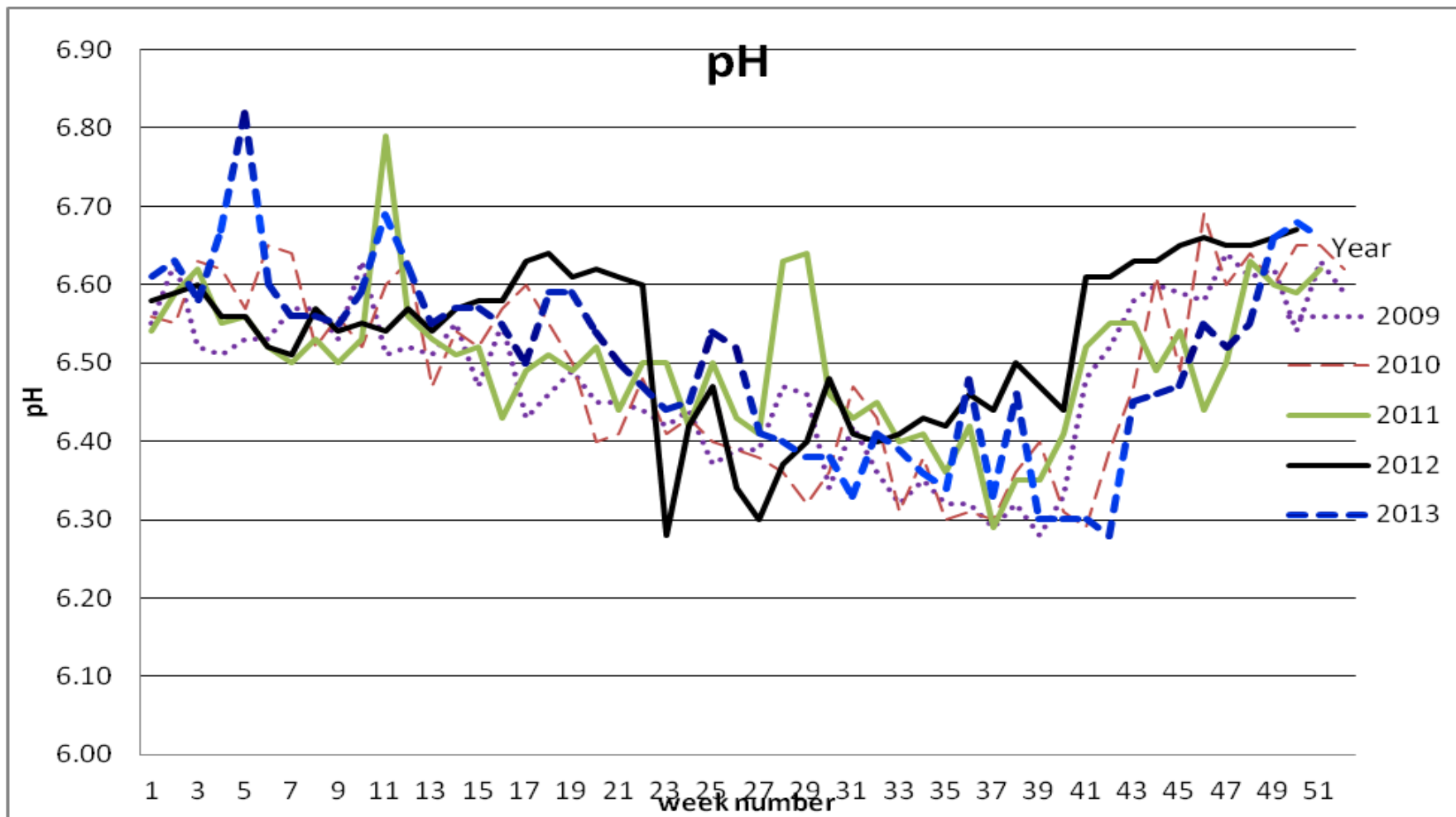
Fig. 4.2 Oset raw water pH, 2009 -2013

4.3.Color of the raw water:

Color also has somewhat higher numbers starting in the fall through the winter periods (see fig. 4.3). The highest being 33 mg Pt/L in week 44 of year 2011 and the minimum being in week 19 of year 2011 (see Table 4-3).

Table 4-3 Color of Oset Raw water (mgPt/L) for the year 2009 -2013

Year	2009	2010	2011	2012	2013
Number of samples	52	52	51	50	51
Average	22.9	23.2	24.0	26.4	25.6
Max	28	27	33	30	29
Minimum	20	20	19	23	21
Median	23	23	23	26	25
95% percentile	25	25	30	29	28
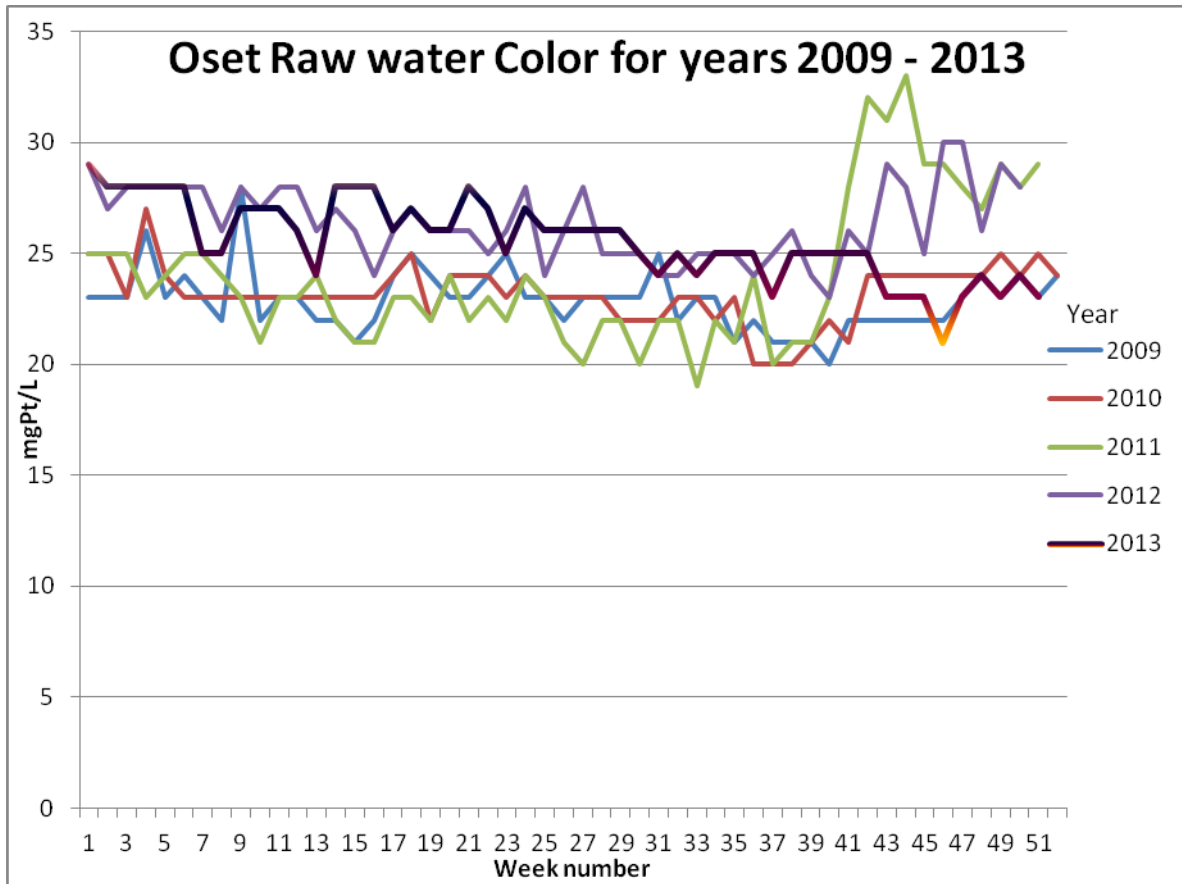
Fig. 4.3 Graph of 5 years raw water color for Oset drinking water treatment plant.

4.4. The total organic carbon content (TOC)

The total carbon content was in the range of 3.6 and 4.6 mg C/l for the years 2009 - 2013. The highest was in year 2011 and the lowest in year 2009 (see Table 4. 4). Averages of the years were between 3.8 and 4.4 mg C/l.

Table 4-4 Total Organic Carbon concentration (mg C/l) of Oset raw water for years 2009 - 2013.

Number of samples	2009	2010	2011	2012	2013
	4	4	4	4	4
max	4	4.3	4.6	4.4	4.5
average	3.78	4.03	4.05	4.25	4.38
min	3.6	3.9	3.7	4	4.2

4.5.E.coli

In the samples analyzed, the maximum number of E. coli found in a sample was in week 42 of year 2008. Which were 21E.coli bacteria per 100ml (see Table 4.5). The year 2008 was also a year of many samples containing the bacteria. 18 out of 52 samples were found to contain 1 or more *E. coli*/100ml. The five year average number of E. coli in 100ml is 13.2 (see Fig.4.5) .

Table 4-5 Summary of E. coli data for years 2008 - 2012.

Year	2008	2009	2010	2011	2012
No. of samples	52	53	52	52	52
Sum	47	21	15	20	13
Maximum	21	4	2	6	2
Minimum	0	0	0	0	0
Mean	0.90	0.40	0.29	0.38	0.25
Number of with *E. coli*	18	13	12	11	12
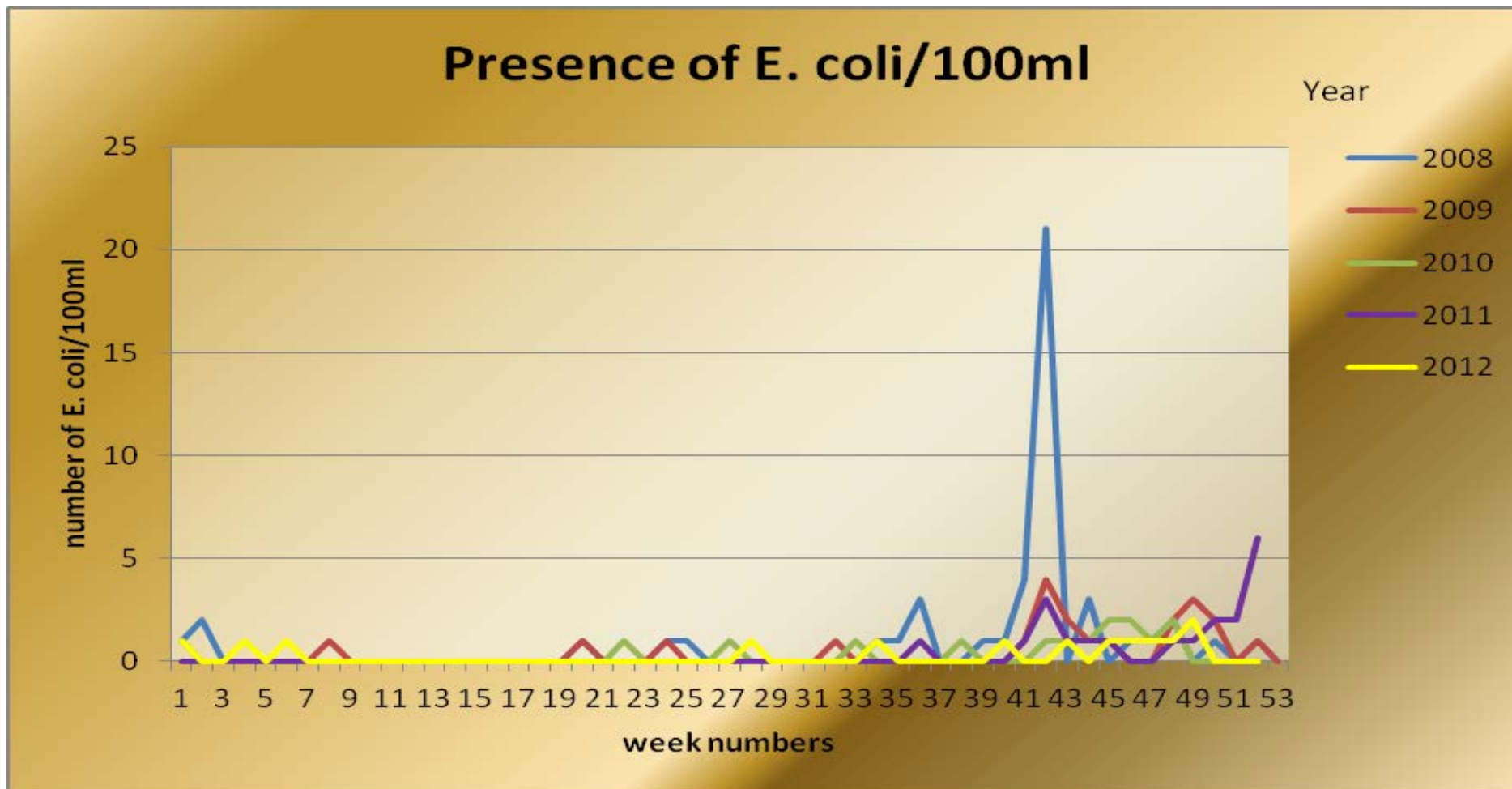
Fig. 4.4 Graphic presentation of E. coli concentration for years 2008 - 2012

4.6. Clostridium perfringens:

In the samples analyzed for *Clostridium perfringens*, the maximum number found per 100ml was 4 for the years 2009 and 2011 (see Table 4.6). The average number of samples found to contain one or more C. perfringens for the 5 years was 14.8. In the years both 2011 and 2012, 20 samples out 52 samples were containing at least one *C. perfringens* per 100ml. Maximum number of *C. perfringens*/100ml for the five years was 4 in week 49 of 2009 and in week 44 of year 2011.

Table 4-6 Data summary for *C. perfringens* in years 2008 - 2012.

Year	2008	2009	2010	2011	2012
Number of samples	51	53	52	52	52
Sum	16	13	23	40	26
Maximum	3	4	3	4	3
Minimum	0	0	0	0	0
Mean	0.31	0.25	0.44	0.77	0.5
Found	11	8	16	20	20

4.7. Coliforms

The maximum number of Coliforms for the years 2008 - 2012 was 200 number of coliforms per 100ml in week 32 and 33 respectively (see Fig. 4.7) , and the average for the five years number of samples found for C. forms present in the sample was 31.4 samples out of 52 were containing C. forms. The maximum number of samples with one or more C. forms during the five years was 34 in year 2012 (Table 4-7).

Table 4-7 Coliforms presence in the samples for the year 2008 -2012.

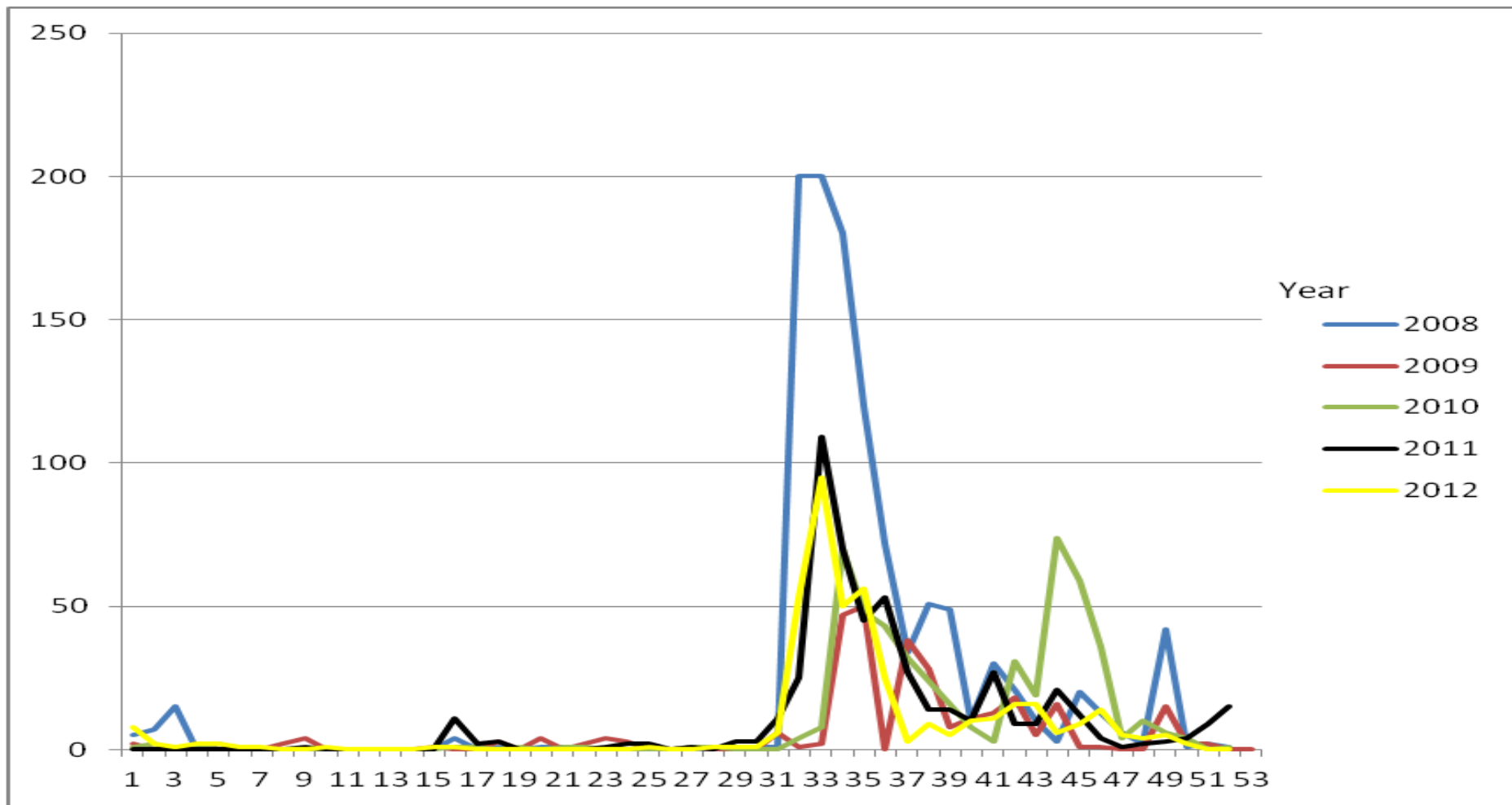| Year	2008	2009	2010	2011	2012
No. of samples	51	53	52	52	52
Sum	1104	292	513	523	424
Maximum	200	50	74	109	95
Minimum	0	0	0	0	0
Average	22	6	10	10	8
Found	31	29	31	32	34

Fig. 4.5 Graphic representation of Coliform concentration in the Oset raw water for the year 2008 - 2012

4.8.Raw water Quality level of Oset drinking water

The raw water of Oslo drinking water work had a maximum of 6 *E. coli* per 100ml of the routine sampling in year 2011. And the maximum number of *Clostridium perfringens* per 100ml was 4 in the year 2011. According to the guideline having maximum of *E. coli* of 6 per 100ml in one of the samples leads to looking at the number of C. perfringens per 100ml, which also leads to examine further, the presence of the more thermo tolerant *Intestinal enterococci* in any of the samples. The maximum number of *I. enterococus* in one of the samples was 5 in year 2012 per 100ml. There was at least one per 100ml *I. enterococus* in 8 out of 52 (15%) samples. Therefore the raw water quality level falls in category D. This is a poor raw water quality level. This raw water quality level also is what the maximum number of 21 *E. coli*/100ml in week 42 of year 2008 confirms the category (Table 4.5). The guideline recommends to categorize the raw water quality level in D if any single sample has more than or equal to 20 *E. coli*/100ml.

4.8.1. Oset drinking water hygienic barrier level required

For the raw water quality level D and the number of people ,more than 10,000 is 6 log virus removal, 6 log bacteria removal, and 5 log parasite removals according to the microbial barrier analysis. Oset drinking water raw water was categorized in quality level Dc because of the big number of people the water work must supply drinking water to.

The hygienic barrier level required for the raw water quality level of Oset drinking water work according to the guideline for good disinfection practices was:

- 6 log virus reduction,

- 6 log bacteria removal and

- 5 log parasite removal.

4.8.2. Log credit

The water treatment before final disinfection in Oset drinking water work included: alkalization, Actfilo (a ballasted flocculation process which uses polymer to attach coagulated particles to micro sand for rapid settling in a lamella tube settler system) followed by filtration with dual media filter. This process is very efferent and can be one hygienic barrier. The maximum log credit can be given to a treatment process, no matter how efficient it is, is 3 log as virus reduction, 3 log for bacteria reduction and 3 log parasite reduction. But as it is given in the guideline for microbial analysis (Ødegård, 2014), for coagulation, sedimentation and filtration is 2.75 log reduction for bacteria, 2.25 log reduction for viruses and 2.75 log reduction for parasites (provided that turbidity is less than 0.2 FNU).

Therefore the log credit for the drinking water treatment before final disinfection was:

> ➢ 2.75 log bacteria reduction,

> ➢ 2.25 log virus reduction, and

> ➢ 2.75 log parasite reduction.

4.9. Hygienic barrier levels of Oset drinking water treatment plant operations

4.9.1. Normal operation

a) Normal operation with UV disinfection

In the normal operation, the log credit given for the Actiflo treatment process was 2.75 log bacteria, 2.25 log virus and 2.75 log parasites from the hygienic barrier of 6 log viruses, 6 log bacteria and 5 log parasite removal requirements (only hygienic process).

Surveillance and monitoring in the treatment plant

Oset drinking water treatment plant uses SCADA (Supervisory Control And Data Acquision) system. There is a real time follow up and reporting system. If the turbidity, for example, is equal to or more than 0.2 FNU, an alarm goes off and the valve closes the flow of water to the UV chamber. And if the dosimetric dose of the UV is less than 400 J/m^2, The warning alarm goes off and the chlorine disinfection starts automatically. The operational surveillance and control is satisfactory and according to the latest recommendations. But by considering this surveillance as part of the chemical treatment, no log credit is given to the surveillance and mentoring system in the treatment plant.

The final disinfection method in normal operation in Oset drinking water work is UV disinfection with biodosimetric dose of 400J/m^2. According to the guideline for microbial barrier analysis, UV dose of 400J/m^2 removes 4.0 log bacteria, 3.5 log virus, and 4.0 log parasites. The final barrier level was determined and given in Table 4.9.

Final barrier level = barrier level required - (log credit in the catchment and at the source + log reduction at the water treatment + log reduction of operational surveillance and control+ log reduction at the final disinfection). See Table 4-8.

- ➢ 6 log bacteria - (2.75 log bacteria + 4.0 log bacteria) = - 0.75 log bacteria

- ➢ 6 log virus - (2.25 log virus + 3.5 log virus) = 0.25 log virus

- ➢ 5 log parasites - (2.75 log parasites + 4.0 log parasites) = -1.75 log parasite reduction.

Table 4-8 Hygienic barrier level of normal operation with UV disinfection

Barrier level log removal	Bacteria	Viruses	parasites
Required	6.0 log	6.0 log	5.0 log
Actiflo treatment	-2.75 log	-2.25 log	-2.75 log
Final disinfection	-4.0 log	-3.5 log	-4.0 log
Final hygienic barrier level	**-0.75 log**	**0.25 log**	**-1.75 log**

b) Normal operation with chlorine disinfection

In normal operation, if dosimetric UV dose is below $400J/m^2$, chlorine disinfection (sodium hypochlorite) automatically starts. In this case, the water treatment barrier level and the log credit for surveillance and monitoring at the treatment plant are in place and the disinfection shifts from UV to chlorine disinfection.

The Ct principle was used to calculate the log reduction level of the chlorine disinfection. The Ct principle is based on the concentration of the disinfecting chemical, C and the period of time the microorganisms are exposed to the chemical, t. In the Ct concept, four types of concentrations are used to calculate the dose: added dose, C_{dose}; initial oxidation concentration, C_c; initial disinfection concentration, C_i and effluent concentration, C_e.

Relationships of the concentrations can be explained in the following formula:

$C_{dose} = C_c + C_i$, Where $C_{dose} = Cl_2$ dose added, $C_c = Cl_2$ concentration used to oxidize the organic matters in the water, $C_i =$ initial Cl_2 concentration available for disinfection.

The chlorine dose is 0.4mg Cl_2/L, the effluent chlorine concentration is adjusted to be 0.05 mgCl_2/L, and it is designed in such a way that the effective contact time to be 30 minutes.

In the Risk and Vulnerability analysis done for Oset water work, it is stated that the contact tank has a fairly good plug flow (Berge et al., 2011). That means the hydraulic factor according to the guideline is 0.7.

Effective contact time, t = T* hydraulics factor of the tank.

Effective time, t = 0.7*30 min = 21.0 min.

Since we have the chlorine dose and effluent concentration, we can determine the initial chlorine concentration based on the formula **C_i = Cdose - Cc,** where:

Ci = initial concentration

Cdose = the chlorine dose added

Cc = the chlorine concentration used for oxidizing the organic matters in the water before the actual disinfection starts.

And: $Ce = Ci*e^{-k*t}$, where Ce = effluent concentration, k is chlorine degradation coefficient, and t = effective contact time between the microorganism and chlorine .

Models are given in the guideline for good disinfection practices to calculate initial (oxidation consumption) and degree of degradation for chlorine depending on organic carbon content and chlorine dose:

The organic carbon content in Actiflo treated and filtered water is much reduced in relation to that of raw water organic carbon content of the raw water, 4.6 mg TOC/l. According to Norwegian public health institute data of Oslo drinking water treatment plant in year 2013(Folkehelseinstituttet, 2014), total carbon concentration of Oslo drinking water in mg C/l was:

Average = 2.0

Median = 2.0,

Maximum = 2.4

Minimum = 1.5.

For the sake of conservative Ct calculation, TOC of maximum concentration, 2.4 mg C/l is used.

Cc= 0.06 * TOC + 0.36 * Cdose + 0.08 * (Cdose / TOC) – 0.12, and

k = 0.013 * TOC – 0.040 * C_i – 0.010 * C_i / TOC + 0.022. Where TOC is total organic carbon.

According to the model,

Cdose = 0.4 mg Cl_2/l

Effluent chlorine concentration, C_e = 0.05 mg Cl_2/l

TOC = 2.4 mg C/l, (Folkehelseinstituttet, 2014)

Hence, Cc = (0.06*2.4) + (0.36*0.4) + 0.08*(0.4/2.4) - 0.12 = **0.181mg/l**

Ci = Cdose - Cc = 0.400 - 0.181 = **0.219 mgCl$_2$/l**.

The degradation coefficient, k, for the treatment plant therefore will be:

k = 0.013*2.4 - 0.04*0.219 - 0.010*(0.219/2.4) + 0.022 = **0.044**

the other way to determine k is by the following formula: k = -[ln(Ce/Ci)]/t;

k = -[ln(0.05/0.219)]/21 = **0.07.** The guideline recommends using k value from the formula rather than the model. That is because the uncertainty in the model for k is higher than that of concentration of oxidation consumption, C_c.The guideline recommends using Cc (chlorine concentration of oxidation) from the model and calculating k from the formula because the uncertainty of Cc from the model is less than that of k. Thus, we will use k calculated, 0.07 and Cc from the model, 0.219 to calculate Ct value of our chlorine dose of 0.4mg/L for 30 minutes.

Ct = (Ce/k) * (e^{k*t} - 1) = (0.05/0.07)* (e$^{0.07*21}$ -1) = **2.39 mgCl$_2$.min/l.**

The chemically treated water pH is increased by adding lime and it has a pH of 7 - 8. Required Ct value of chlorine disinfection for 3 log virus reduction at temperature of 4^{0}C and pH of 7 - 8 in the guideline is 6. Ct value of chlorine disinfection for 3 log removal of bacteria for the same temperature and pH is 1.5.

According to the MBA guideline tool box, the Ct dose of 2.39 mgCl$_2$.min/l removes:

Calculated log reduction = nlog*Ct $_{calculated}$/Ct $_{required,}$ where: nlog = the log reduction at Ct required.

Acquired virus log reduction (Calculated log reduction)

= 3log * (2.39 mgCl$_2$.min/l)/6 mgCl$_2$.min/l = 1.20 log.

And acquired bacteria reduction = 3 log*(2.39 mgCl$_2$min/l)/1.5 mgCl$_2$min/l = 4.78 log bacteria reduction. Though the calculation gives high bacteria log reduction, the maximum log reduction can be assigned is 3.0 log bacteria reduction.

This means the dose, the log credit assigned to the Ct is only **1.2 log virus** and **3.0 log bacteria** reduction (see Table 4.10).

- log bacteria removal calculated = 6.0 - (2.75 + 3.0) = **0.25 log**

- log virus removal calculated = 6.0 - (2.25 + 1.2) = **2.55 log**

- log parasite removal calculated = 5.0 - (2.75 + 0) **= 2.25 log**

The final hygienic barrier level for this operation is summerized in Table 4-9.

Table 4-9 Hygienic barrier level of normal operation with chlorine disinfection

Barrier level log removal	Bacteria	Viruses	parasites
Required	6.0 log	6.0 log	5.0 log
Actiflo treatment	-2.75 log	-2.25 log	-2.75 log
Final disinfection	-3.0	-1.2 log	-0 log
Final hygienic barrier level	**0.25 log**	**2.55 log**	**2.25 log**

4.9.2. The backup treatment

The raw water quality is the same. That means the hygienic barrier level required is similar in all operations. In the back up treatment process we only have one hygienic barrier, chlorine disinfection. Though the micro sieve removes some of the microorganisms with the particle size of greater than their openings, no log credit is given to the straining. Therefore the final hygienic barrier being expected to achieve by the chlorine disinfection is as high as the total hygienic barrier level required based on the raw water quality and number of people the water work is supplying water to. In our case, it is 6 log bacteria, 6 log virus and 5 log parasite removal.

To determine the log inactivation of chlorine disinfection of the water, Ct concept is used. Ct concept is a concept that stems from the theoretical principle that an effect(log reduction) of disinfectant depends on the concentration, C, of the disinfectant and the time, t, the microorganism is exposed to the chemical (Ødegård, 2014).

Using the Ct concept, the inactivation effect of the two disinfectants was determined as follows:

The chlorine dose is 0.9mg Cl_2/L, the effluent chlorine concentration is adjusted to be 0.05mgCl_2/l, and it is designed in such a way that the contact time to be 30 minutes.

Effective contact time, t = T* hydraulics factor of the tank. The tank has no chambers and assumed to fairly good plug flow, which has t_{10}/T value of 0.7, and since there is no chamber, it is assumed the hydraulics factor to be 1. Therefore effective contact time will be 30min*0.7 = 21 min.

Since we have the chlorine dose and effluent concentration, we can determine the initial chlorine concentration based on the formula C_i = **Cdose - Cc,** where:

Ci = initial concentration

Cdose = the chlorine dose added

Cc = the chlorine used for oxidizing the organic matters in the water before the actual disinfection starts.

And: $Ce = Ci*e^{-k*t}$, where Ce = effluent concentration, k is chlorine degradation coefficient, and t = effective contact time between the microorganism and chlorine .

Models are given in the guideline for good disinfection practices to calculate initial (oxidation consumption) and degree of degradation for chlorine depending on organic carbon content and chlorine dose:

Cc= 0,06 * TOC + 0,36 * Cdose + 0,08 * (Cdose / TOC) – 0,12, and

k = 0,013 * TOC – 0,040 * C_i – 0,010 * C_i / TOC + 0,022. Where TOC is total organic carbon.

According to the model,

Cdose = 0.9 mg/l

TOC = 3.6 - 4.6 (five years data summary), The highest TOC value, 4.6 is used.

Hence, Cc = (0.06*4.6) + (0.36*0.9) + 0.08*(0.9/4.6) - 0.12 = **0.496mg/l**

Ci = Cdose - Cc = 0.9 - 0.5 = 0.4mg/l.

The degradation coefficient, k, for the treatment plant therefore will be:

k = 0.013*4.6 - 0.04*0.4 - 0.010*(0.4/4.6) + 0.022 = **0.065**

Other way to determine k is by the following formula: k = -[ln(Ce/Ci)]/t;

k = -[ln(0.05/0.4)]/21 = **0.10**. The guideline recommends using k value from the formula rather than the model. That is because the uncertainty in the model for k is higher than that of concentration of oxidation consumption, C_c. The guideline recommends using Cc (chlorine concentration of oxidation) from the model and calculating k from the formula because the uncertainty of Cc from the model is less than that of k. Thus, we will use k calculated, 0.139 and Cc from the model, 0.496 to calculate Ct value of our chlorine dose of 0.9mg/l for 30 minutes.

Ct = (Ce/k) * (e^{k*t} - 1) = (0.05/0.10)* ($e^{0.10*21}$ -1) = **3.58 mgCl$_2$.min/l.**

Required Ct value of chlorine disinfection for 3 log virus reduction at temperature of 4^0C and pH of less than 7 in the guideline is 4. Ct value of chlorine disinfection for 3 log removal of bacteria for the same temperature and pH is 1.

According to the MBA guideline tool box the Ct dose of 3.58 mgCl$_2$.min/l removes:

Calculated log reduction = nlog*Ct $_{calculated}$/Ct $_{required,}$ where: nlog = the log reduction at Ct required.

Acquired virus log reduction (Calculated log reduction)

$= 3\log * (3.58 \text{ mgCl}_2.\text{min/l})/4 \text{ mgCl}_2.\text{min/l} = 2.69 \log.$

And acquired bacteria reduction $= 3\log*(3.58 \text{ mgCl}_2\text{min/l})/1.0 \text{ mgCl}_2\text{min/l} = 10.74 \log$ bacteria reduction. Though the calculation gives high bacteria log reduction, the maximum log reduction can be assigned is 3.0 log bacteria reduction.

This means, the log credit assigned to the dose is **2.69 log virus** and **3.0 log bacteria** reduction.

Final barrier level if the drinking water treatment plant is forced to run the backup treatment process is shown in Table 4-10.

Table 4-10 The hygienic barrier level of the backup operation.

Barrier level log rem.	Bacteria	Virus	parasites
required	6.0 log	6.0 log	5.0 log
Treatment	0	0	0
Final disinfection	-3.0 log	-2.69 log	0.0 log
Final barrier level(sum)	3.0 log	2.31 log	5.0 log

4.10.   Combined operation of the treatment plant

In this operation we have two differently treated water types combined. One of the combined drinking water production process is a planned combination of the raw water and the chemically treated $2.25m^3/s$ water with $1m^3/s$ 5µm sieve strained raw water. The other combination occurs when drinking water demand is above $4.51m^3/s$. When the demand is more than the normal drinking water production, $1m^3/s$ 5µm sieve strained raw water will be UV disinfected and mixed with the $4.5m^3/s$ normally produced water and Chlorine disinfected.

4.10.1.   Planned combination of drinking water treatment operation

Two - third of it is chemically treated and UV disinfected water and one third of the water only strained through 5µm wide sieve and UV disinfected before the two water types are mixed. The two types are mixed and pass through post chlorine disinfection.

The raw water quality level is the same in all operations of the treatment plant. As a result of the same raw water quality and number of people the plant is serving, the hygienic barrier level is also the same in all operations. The problem with determining the disinfection efficiency of chlorine and UV is difficult because both UV and chlorine disinfection depends on the efficiency of upstream treatments. Therefore it is difficult to use the tool box in the guideline for the water which was barely strained upstream. Because color and turbidity of untreated water will be much higher than treated one. It is used dosimetric UV dose in both cases and the UV disinfection for the micro sieve strained raw water is designed for the raw water color and turbidity. Therefore its efficiency is assumed to be the same as that of UV disinfection process of the normal operation. We have two different hygienic barrier levels here:

1. The $1m^3/s$ micro sieve strained water has only one hygienic barrier, UV disinfection. The UV disinfection unit is designed for the raw water color and expected to inactivate 4 log bacteria, 3.5 log virus and 4 log parasites. Even if the micro sieve removes some of the microorganisms with particles of sizes greater than 5µm, no log credit is given to the micro sieve. Thus the final log inactivation for the micro sieve strained water is: 4 log bacteria, 3.5 log virus and 4 log parasites. Therefore, the final hygienic barrier of the micro sieve strained and UV disinfected water is given in Table 4.12.

Table 4-11 Hygienic barrier of the micro sieve strained and UV disinfected water.

Barrier level log rem.	Bacteria	Virus	parasites
required	6.0 log	6.0 log	5.0 log
Actions at catchment and source	0	0	0
Treatment	0	0	0
Surveillance and monitoring	0	0	0
Final disinfection	-4.0 log	-3.5 log	-4.0 log
Final barrier level(sum)	2.0 log	2.5 log	1.0 log

2. $2.25m^3/s$ volume of the water in the combined operation is chemically treated in the Actiflo lines and passes through filtration and UV disinfection. The chemical treatment of the Actiflo line removes 2.75 log bacteria, 2.25 log virus and 2.75 log parasites. Log credit is given to surveillance and monitoring in the treatment plant. Since the plant uses SCADA system, warning alarms and automatic correction systems the maximum credit of 1 log for bacteria removal, 1 log for virus removal and 0.75 log for parasite removal is given (see Table 4.13). The UV disinfection in activates 4.0 log bacteria, 4.0 parasites and 3.5 log viruses as it is mentioned in Table 3.3.

Table 4-12 Hygienic barrier level of chemically treated 2.25m^3/s water.

Barrier level log removal	Bacteria	Viruses	parasites
Required	6.0 log	6.0 log	5.0 log
Actions in the catchment and at the source	0	0	0
Actiflo treatment	-2.75 log	-2.25 log	-2.75 log
Final disinfection	-4.0 log	-3.5 log	-4.0 log
Final barrier level	**-0.75 log**	**0.25 log**	**-1.75 log**

The hygienic barrier level of the combined water changes because of dilution effect as follows:

a) The effect of micro sieve strained and UV disinfected water on the total of 3.25m^3/s water:

  ➤ bacteria inactivation = 4 log*(1m^3/s/3.25ms^{-1}) = 1.23 log bacteria

  ➤ virus inactivation = 3.5log*(1m/s/3.25m/s) = 1.08 log virus

  ➤ parasite inactivation = 4 log*(1m^3/s/3.25m^3/s) = 1.23 log parasite inactivation.

b) The effect of the chemically treated water on the total 3.25m^3/s of water:

  i. Chemical treatment the Actiflo line:

    ✓ 2.75 log*(2.25m^3/s/3.25m^3/s) = 1.90 log bacteria inactivation

    ✓ 2.25 log*(2.25m^3/s/3.25m^3/s) = 1.56 log virus inactivation

    ✓ 2.75 log*(2.25m^3/s/3.25m^3/s) = 1.90 log parasite inactivation

ii. UV disinfection:

- ✓ 4.0 log *(2.25m^3/s/3.25m^3/s) = 2.77 log bacteria inactivation,

- ✓ 3.5 log *(2.25m^3/s/3.25m^3/s) = 2.42 log reduction of viruses and

- ✓ 4.0 log *(2.25m^3/s/3.25m^3/s) = 2.77 log bacteria.

Chlorine disinfection of the combined water: After these two differently treated water types are combined, the combined water will chlorinate before distribution. To determine the hygienic barrier level of the combined water, the Ct concept is used here also. The chlorine dose used is 0.9mg Cl_2/l. The chlorine disinfection unit is designed so that the effluent concentration, C_e will be 0.05 mg Cl_2/l. Using the model given by the guideline for microbial analysis, the chlorine consumption concentration, C_c, the initial chlorine concentration, C_i available for the disinfection and the chlorine degradation coefficient were determined as it is shown in the following lines. The effective time is 21 minutes as it was determined in section 4.10.2. The minimum temperature is supposed to be the same which is 4^0C.

The model:

Cc= 0,06 * TOC + 0,36 * Cdose + 0,08 * (Cdose / TOC) – 0,12, and

Since the exact TOC of the combined water is not known, TOC of the raw water was taken for conservative reason. Maximum TOC of the raw water in section 4.4 is 4.6 mg C/l giving us:

C_c = (0.06*4.6)+(0.36*0.9)+(0.08*(0.9/4.6))-0.12 = 0.496 ~ 0.5 mg Cl_2/l

C_i = C_{dose} - C_c = 0.9 mg Cl_2/l - 0.5 mg Cl_2/l = **0.4 mg Cl_2/l**. We use the formula k = -[ln(Ce/Ci)]/t.

k = -[ln(0.05/0.4)]/21 = 0.099 ~ 0.1

Ct dose of chlorine disinfection of the planned combination is:

Ct = (C_e/k) *(e^{k*t}-1) = (0.05/0.1)*($e^{0.1*21}$ - 1) = **3.58 mg Cl_2 min/l.** To determine the inactivation of the Ct value the formula:

Calculated log reduction = nlog*Ct $_{calculated}$/Ct $_{required,}$ where: nlog = the log reduction at Ct required. The Ct value expected to inactivate 3 log bacteria and 3 log virus at minimum temperature of 4^0C and pH between 7 and 8 is 1.5 mg Cl_2 min/ and 6 mgCl_2 min/l respectively.

Log inactivation:

Bacteria: 3 log*(3.58 mgCl_2 min/l/1.5mg Cl_2 min/l) = 7.16 log, Only 3.0 log will be taken.

Virus: 3 log *(3.58 mg Cl_2 min/l/6 mg Cl_2 min/l) = 1.79 log.

Over all hygienic barrier level of the planned combination of operations is summarized in table 4-13.

Table 4-13 The hygienic barrier of the planned combined operation.

Barrier level log rem.		Bacteria	Virus	parasites
Required		6.0 log	6.0 log	5.0 log
Actions at catchment and source		0	0	0
Chemical treatment	($2.2m^3$/s)	-1.90 log	-1.56 log	-1.90 log
1. Final disinfection UV	($2.25m^3$/s)	-2.77 log	-2.42 log	-2.77 log
2. final disinfection UV	($1.0m^3$/s)	-1.23 log	-1.08 log	-1.23 log
Final Chlorine disinfection		-3.0 log	-1.79 log	0
Final barrier level(sum)		**-2.90**	**-0.85log**	**-0.90 log**

4.10.2. High demand driven combined drinking water production operation

$1m^3$/s micro sieve strained water is UV disinfected. As it is shown in section 4.11.1, no log credit is assigned to the micro straining and the UV disinfection is expected to have the same effect of inactivation of 4.0 log bacteria, 3.5 log viruses and 4.0 log parasite inactivation

In this operation, 4.5 m^3/s volume out of $5.5m^3$/s is normally produced and hygienically safe with two independent hygienic barriers. From our result in normal operation, the Actiflo and filtration removes 2.75 log bacteria, 2.25 log virus and 2.75 log parasites. The UV disinfection inactivates 4.0 log bacteria, 3.5 log viruses and 4.0 log parasites.

The effect of micro sieve strained and UV disinfected water on the total of 5.5 m^3/s water:

- ✓ bacteria inactivation = 4 log*($1m^3$/s/5.5ms^{-1}) = 0.73log bacteria

- ✓ virus inactivation = 3.5log*(1m/s/5.5m/s) = 0.64 log virus

- ✓ parasite inactivation = 4 log*($1m^3$/s/5.5m^3/s) = 0.73 log parasite inactivation.

a) The effect of the chemically treated water on the total $5.5m^3$/s of water:

  i. Chemical treatment the Actiflo line:

    - ✓ 2.75 log*($45m^3$/s/5.5m^3/s) = 2.25 log bacteria inactivation

✓ 2.25 log*(4.5m^3/s/5.5m^3/s) = 1.84 log virus inactivation

✓ 2.75 log*(4.5m^3/s/5.5m^3/s) = 2.25 log parasite inactivation

ii.   UV disinfection:

✓ 4.0 log *(4.5m^3/s/5.5m^3/s) = 3.27 log bacteria inactivation,

✓ 3.5 log *(4.5m^3/s/5.5m^3/s) = 2.86 log reduction of viruses and

✓ 4.0 log *(4.5m^3/s/5.5m^3/s) = 3.27 log bacteria.

Ct determination of the Chlorine disinfection: the water is chlorine disinfected before distribution just like in the case of planned combination of operations. The minimum temperature is the same 4^0C. Though the total carbon concentration may be much lower than the raw water concentration due to dilution effect of the chemically treated water, the TOC is determined to be the largest concentration of the raw water to be on the safest side. The TOC concentration used in this calculation is 4.6. Assuming hydraulic factor of the disinfection tank is the same, a factor of 0.7 is assigned. Therefore, effective time will be 30 minutes of contact time times the hydraulic factor is 21 minutes. The chlorine dose is 0.9 mg Cl_2/l and it is designed so that the effluent chlorine concentration will be 0.05 mg Cl_2/l after 30 minutes of contact. The model given by the guideline for microbial analysis was used in the determination of Ct value here also.

Cc= 0,06 * TOC + 0,36 * Cdose + 0,08 * (Cdose / TOC) – 0,12, where C_c is the chlorine concentration used for organic matter oxidation, TOC is total organic carbon content, and Cdose the chlorine concentration should be added.

C_c = (0.06*4.6)+(0.36*0.9)+(0.08*(0.9/4.6))-0.12 = 0.496 ~ **0.5 mg Cl_2/l**

C_i = C_{dose} - C_c = 0.9 mg Cl_2/l - 0.5 mg Cl_2/l = **0.4 mg Cl_2/l**, where C_i = initial concentration available for disinfection

We use the formula k = -[ln(Ce/Ci)]/t. C_e = effluent chlorine concentration.

k = -[ln(0.05/0.4)]/21 = 0.099 ~ 0.1

Ct dose of chlorine disinfection of the planned combination is:

Ct = (C_e/k) *(e^{k*t}-1) = (0.05/0.1)*($e^{0.1*21}$ - 1) = **3.58 mg Cl_2 min/l.** To determine the inactivation of the Ct value, the formula is used:

Calculated log reduction = nlog*Ct $_{calculated}$/Ct $_{required,}$ where: nlog = the log reduction at Ct required. The Ct value expected to inactivate 3 log bacteria and 3 log virus at minimum temperature of 4^0C and pH between 7 and 8 is 1.5 mg Cl_2 min/ and 6 mgCl_2 min/l respectively.

Log inactivation:

Bacteria: 3 log*(3.58 mgCl_2 min/l/1.5mg Cl_2 min/l) = 7.16 log, Only 3.0 log will be taken.

Virus: 3 log *(3.58 mg Cl_2 min/l/6 mg Cl_2 min/l) = 1.79 log.

The hygienic barrier level of high demand driven combination of operations is summarized in Table 4-14.

Table 4-14 Hygienic barrier level of high demand driven combined operation.

Barrier level log rem.		Bacteria	Virus	parasites
Required		6.0 log	6.0 log	5.0 log
Actions at catchment and source		0	0	0
Chemical treatment	($4.5m^3$/s)	-2.25 log	-1.84 log	-2.25 log
1. Final disinfection UV	($4.5m^3$/s)	-3.27 log	-2.86 log	-3.27 log
2. final disinfection UV	($1.0m^3$/s)	-0.73 log	-0.64 log	-0.73 log
Final Chlorine disinfection	(combined)	-3.0 log	-1.79 log	0
Final barrier level(sum)		**-3.25 log**	**-1.13 log**	**-1.25 log**

5. Discussion

5.1. *The normal operation system*

The Normal operation has Actiflo chemical treatment line, filtration and disinfection steps. Depending on turbidity of the water and UV dose the disinfection process may be UV disinfection or chlorine disinfection depending on whether dossimetric UV dose is above 400 J/m^2. Though it is limited to one hygienic barrier level in the microbial guideline and in the result and discussion because of the Norwegian drinking water regulation requirement of "two independent hygienic barriers", the Actiflo coagulation and flocculation line and the filtration lines can remove more than 2.75 log bacteria, 2.25 log viruses and 2.75 log parasites.

5.1.1. Normal operation with UV disinfection

The coagulation and flocculation of the Actiflo lines and filtration removes the microorganisms more than one hygienic barrier which is 3 log virus, 3 log bacteria and 2 log parasite removal. But the recommendation given by the guideline for good disinfection practices is not to assign a log credit for coagulation, sedimentation and filtration more than 2.75 for bacteria, 2.25 for parasites and 2.25 for viruses. The UV disinfection unit is designed for UV dosimetric dose of 400 J/m^2. The UV disinfection in normal operation inactivates more than required hygienic barrier level expected from final disinfection after upstream treatment and filtration. But the final hygienic barrier level against virus is positive 0.25 log, meaning the operation has not enough hygienic barrier against virus. The whole system is designed to the highest standard. As long as the treatment goes in the normal operation, the drinking water produced in the normal operation with UV disinfection meets the microbial barrier analysis guideline recommendation. The positive log number in the final hygienic barrier against virus can be because very conservative log credit assigning methods was used. For example no log credit was given to surveillance and control and the log credit assigned to the Actiflo plus filtration line is less than one hygienic barrier of 3.0 log for bacteria, 3.0 log for virus.

5.1.2. Normal operation with chlorine disinfection

In this operation, Actiflo chemical treatment and the filtration lines are the same as that of normal operation with UV disinfection. The difference is that if the turbidity is more than 0.2 FNU or if the UV dose is less than 400 J/m^2, the UV disinfection stops and chlorine disinfection sets in. The chlorine disinfection is effective in bacteria and virus removal but it is not effective against parasites. Therefore chlorine disinfection is expected to remove 0 log parasites. That means, from the hygienic barrier level of 5 log parasites the removal will be only that of Actiflo chemical treatment.

The final hygienic barrier level of the normal coagulation, sedimentation and filtration and chlorine disinfection unit is 0.25 log for bacteria, 2.55 log for viruses and 2.25 log for parasites. This shows that the normal operation with chlorine disinfection does not have the necessary hygienic barrier level for viruses and parasites and not enough against bacteria.

The suggestion may be to install additional membrane filtration or ozone disinfection unit. ozone disinfection unit may be an alternative. To improve the hygienic barrier level in respect to viruses and bacteria, increasing the chlorine dose may help. According to the model in the guideline chlorine dose may need to be as high as 2.0 mgCl$_2$/l, see Table 5.1. Though using high chlorine dose has serious health related risks, this operation is only temporary and the risk should be compared with that of the virus.

Table 5-1 Chlorine dose and relevant values for log inactivation of bacteria and viruses.

Cl$_2$ dose*	C$_c$	C$_i$	k	Ct	Log IA (pH 7-8)	
					Bacteria	Virus
0.900	0.378	0.522	0.112	4.226	8.451	2.113
1.000	0.417	0.583	0.117	4.555	9.111	2.278
1.100	0.457	0.643	0.122	4.877	9.755	2.439
1.200	0.496	0.704	0.126	5.193	10.386	2.596
1.300	0.535	0.765	0.130	5.503	11.005	2.751
1.400	0.575	0.825	0.134	5.807	11.614	2.904
1.500	0.614	0.886	0.137	6.107	12.214	3.054
1.600	0.653	0.947	0.140	6.403	12.805	3.201
1.700	0.693	1.007	0.143	6.695	13.389	3.347
1.800	0.732	1.068	0.146	6.983	13.966	3.491
1.900	0.771	1.129	0.148	7.268	14.536	3.634
2.000	0.811	1.189	0.151	7.550	15.099	3.775

*Table 5.1. is made in excel sheet assuming TOC = 2.4 mg Cl$_2$/l, minimum temperature = 4^{0}C.

5.2. The Backup treatment

According to the guideline for good disinfection practices, the final barrier level is expected to be negative values. Because the final barrier level is what is found after subtracting the total log reduction in the form of log credit from the total hygienic barrier level required. If the treatment plant is to produce drinking water using the backup operation, the produced water will not fulfill the hygienic barrier level required.

As the name backup implies this operation is used only in case of failure in both Actiflo lines and emergency cases. There is only micro strainer and chlorine disinfection. The chlorine disinfection removes or inactivates bacteria and viruses but almost no effect on parasites. Therefore it is important to alert the consumers so that they cook the water before they use it.

The possible additional measure can be UV disinfection unit for the backup operation as in the case of planned operations. If the raw water is UV and chlorine disinfected after micro sieve straining, it will have two hygienic barriers against bacteria and virus, and one hygienic barrier against parasites. This may require relatively big initial cost but it may require limited running and maintenance cost. It will not be running all the time, therefore it will be functioning only temporarily when the normal operation fails and some routine testing. The high number of people using the water work makes it worth to invest a little more than chlorine disinfection. The consequences of having pathogenic parasites or any other microorganisms in the drinking water may be huge to ignore.

5.3. The combined drinking water treatment operation

This drinking water treatment operation combines the normal water treatment operation and 1 m^3/s flow of micro sieve strained raw water.

5.3.1. Planned combination of operations

The final hygienic barrier level of the planned combination of operations is - 2.90 log bacteria, - 0.85 log viruses and - 0.90 parasites inactivation. The Ct calculation shows that the dilution effect of the coagulation, sedimentation and filtration treated water on the UV disinfected raw water gives a good result. The operation has two barriers UV disinfection before mixing and chlorine disinfection after mixing. Therefore, if one of the Actiflo lines stops for maintenance or other reason, mixing $1m^3$/s micro sieve strained water with the water produced in one of the lines and chlorine disinfecting the mixture may give a water of required hygienic barrier level.

5.3.2. High demand driven combination of operations

It is expected the high demand driven combination of operations to produce even better final hygienic barrier level than the planned combination because the volume of treated water mixed with the $1m^3$/s micro sieve strained raw water is doubled. The dilution effect is higher in the case of this combination. The final hygienic barrier level of the high demand combination is - 3.25 log bacteria, - 1.13 log viruses and - 1.25 log parasites removal or inactivation. This operation seems to have hygienically safe drinking water.

6. Conclusion

This thesis aimed to determine the raw water quality level of Oset drinking water treatment plant, the hygienic barrier level the treatment plant need to achieve, and the final hygienic barrier level of the treatment plant at four different operational situations: normal (Actiflo and filtration lines) with UV disinfection operation; normal with chlorine disinfection operation; the backup, micro sieve straining and chlorine disinfection operation; and the combination of the normal chemically treated and UV disinfected water and micro sieve strained and UV disinfected water and finally chlorine disinfection of the mixed water.

Depending on the highest number of *E. coli* (21/100 ml in week 42 of year 2008), the level of the raw water was determined to be in category D . Using the guideline for Good Disinfection Practices (Ødegaard et al., 2009), the hygienic barrier level required for about 624 000 consumers (SSB, 2014) was 6.0 log bacteria, 6.0 log viruses and 5.0 log parasite removals or inactivation.

The final hygienic barrier level of the normal operation with UV disinfection shows the drinking water produced in this operation has enough barrier level against bacteria and parasites, but the barrier level is not enough against viruses. This is less than expected especially when it comes to viruses though that is what the treatment plant is designed for. That means as long as the treatment plant runs in normal operation with UV disinfection, the water produced in the plant is in accordance with the Norwegian drinking water regulation (Helse- og omsorgsdepartementet, 2002). This result is what was expected because assigning the log credit of 2.25 log virus inactivation in the Actiflo and filtration line shows that the process is not one hygienic barrier (3 log). This can be corrected by increasing the chlorine dose in the final polishing disinfection step.

Chlorine disinfection has almost no effect on parasites (Ødegaard et al., 2009). Therefore, the normal operation with chlorine disinfection has only one hygienic barrier against parasites and the final hygienic barrier level of this operation shows that the hygienic barrier level against viruses with chlorine dose of 0.9 mg Cl_2/l is not enough to inactivate the required log of viruses. Though this operation seems to have two hygienic barriers as the Norwegian drinking water requires, the operation does not achieve the required hygienic level. As it was shown in the risk and vulnerability analysis (Brynestad and Granum, 2002), the water produced in this operation may not be hygienically safe.

Both types of the combined operations seem to have satisfactory hygienic barrier level. The dilution effect of the chemically treated water on the micro strained and UV disinfected water and the chlorine disinfection after mixing shows a good result.

The thesis depended on secondary data of Oset drinking water treatment plant and calculations as it is recommended in the guideline for good disinfection practices (Ødegaard et al., 2009) but no samples were taken or analyzed for the water produced from the different operations. Therefore, the results of this paper should only be

considered as an additional source to the risk and vulnerability analysis and other safety plans the water work has or plans to have. Analyzing the water quality after each operation and determining the actual efficiency of each treatment operation and is future area of research.
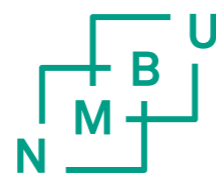
This thesis indicates that: 1. the treatment plant has enough hygienic barrier level required in the coagulation, sedimentation and filtration lines with UV disinfection operation against bacteria and parasites where as the barrier level against virus is not satisfactory, 2. the hygienic barrier level against bacteria and virus is not enough with a chlorine dose of 0.9 mgCl$_2$/l, and there is only one hygienic barrier against parasites. 3. the backup operation has only one hygienic barrier against bacteria and viruses but no hygienic barrier against parasites. Warning to consumers should be issued if the plant has to run the backup operation. 4. the combined operation has enough hygienic barrier level required both in the case of planned and high demand driven combination of operations.

7. References

ALS LABORATORY GROUP NORWAY AS. 2013. *Om ALS Laboratory Group Norway AS* [Online]. OSLO: ALS. Available: http://www.labforum.no/wips/1573224145/smId/1029858619/smTemplate/Detaljer/templ ate/default/ 2014].

APEC WATER SYSTEMS. 2013. *THE HISTORY OF CLEAN DRINKING WATER* [Online]. S. Johnson Dr.: APEC Water Systems. Available: http://www.freedrinkingwater.com/resource-history-of-clean-drinking-water.htm [Accessed 23.09 2014].

BERGE, D., TRYLAND, I., TORULV, T., HEM, L. J. & STRÆM, J. 2011. ROS Maridalsvannet – Oset Forurensningsanalyse av Maridalsvannet med nedbørfelt Hygieniske barrierer ved Oset vannbehandlingsanlegg Beskyttelsestiltak i nedbørfeltet. Oslo: Norsk institutt for vannforskning.

BLYSTAD, H. 2010. *Vannhygiene - veileder for helsepersonell* [Online]. Oslo: Folkehelseinstituttet. Available: http://www.fhi.no/eway/default.aspx?pid=239&trg=Content_6493&Main_6157=6287:0:25,5 499&MainContent_6287=6493:0:25,6832&Content_6493=6441:82614::0:6446:8:::0:0 [Accessed 17.11 2014].

BRYNESTAD, S. & GRANUM, P. E. 2002. < i> Clostridium perfringens</i> and foodborne infections. *International journal of food microbiology,* 74**,** 195-202.

BYRKJELAND, M. & HAMMERBORG, M. 2006. *BYENS SKJULTE ÅRER: VANN OG AVLØP I BERGEN GJENNOM 150 ÅR* [Online]. Bergen: Bergen Kommune. Available: https://www.bergen.kommune.no/bk/multimedia/archive/00010/Byens_skjulte__rer___104 37a.pdf [Accessed 10.11 2014].

CHU, W., GAO, N., DENG, Y., TEMPLETON, M. R. & YIN, D. 2011. Impacts of drinking water pretreatments on the formation of nitrogenous disinfection by-products. *Bioresource technology,* 102**,** 11161-11166.

CITY OF OSLO WATER AND SEWERAGE WORKS 2008. New water treatment plant in Oslo. Oslo: City of Oslo Water and Sewerage Works.

COPES, R., HRUDEY, S. E., PAYMENT, P. & ACT, D. W. 2008. TURBIDITY AND MICROBIAL RISK IN DRINKING WATER.

EPA. 2000. *The History of Drinking Water Treatment* [Online]. EPA. Available: http://www.epa.gov/safewater/consumer/pdf/hist.pdf [Accessed 23.09 2014].

FIGUERAS, M. & BORREGO, J. J. 2010. New perspectives in monitoring drinking water microbial quality. *International journal of environmental research and public health,* 7**,** 4179-4202.

FOLKEHELSEINSTITUTTET. 2014. *Vannverksregisteret / Vannverksopplysninger* [Online]. Oslo: ved Folkehelseinstituttet. Available: http://www.fhi.no/eway/default.aspx?pid=239&trg=List_6212&Main_6157=6263:0:25,5901 &MainContent_6263=6464:0:25,6754&List_6212=6640:0:25,7055:1:0:0:::0:0 [Accessed 15.11 2014].

GALLARD, H. & VON GUNTEN, U. 2002. Chlorination of natural organic matter: kinetics of chlorination and of THM formation. *Water research,* 36**,** 65-74.

HARDY SERVICES. 2013. *A Brief History Of Water Treatment Techniques* [Online]. Hapton, Brnley. Available: http://hardyservices.co.uk/blog/brief-history-water-treatment-techniques/ [Accessed 25.08 2014].

HELSE- OG OMSORGSDEPARTEMENTET. 2002. *Forskrift om vannforsyning og drikkevann (Drikkevannsforskriften)* [Online]. Oslo: Helse- og omsorgsdepartementet. Available: http://lovdata.no/dokument/SF/forskrift/2001-12-04-1372 [Accessed 24.08 2014].

JOHANSEN, T. A. 2001. *Under byens gater* [Online]. Oslo: Vann- og avløpsetaten. Available: http://www.vann-og-avlopsetaten.oslo.kommune.no/getfile.php/vann-%20og%20avl%C3%B8psetaten%20%28VAV%29/Internett%20%28VAV%29/Dokumenter/stu die/historie/kap_1.pdf [Accessed 25.09 2014].

KRUGER. 2009. *The Design and Construction of Norway's New Oset Waterworks* [Online]. Sandefjord: KRUGER. Available: http://www.kruger.dk/krugeras/ressources/documents/2/2832,OSET-4s-2008_web.pdf [Accessed 30.09 2014].

LECHEVALLIER, M. W., EVANS, T. & SEIDLER, R. J. 1981. Effect of turbidity on chlorination efficiency and bacterial persistence in drinking water. *Applied and environmental microbiology,* 42**,** 159-167.

LECHEVALLIER, M. W., KWOKKEUNG, A. & AU, K.-K. 2004. *Water treatment and pathogen control: process efficiency in achieving safe drinking-water*, IWA Publishing.

MATTILSYNET. 2011. *Veiledning til Drikkevannsforskriften (Versjon 3)* [Online]. Brumunddal: Mattylsine. Available: http://www.mattilsynet.no/om_mattilsynet/gjeldende_regelverk/veiledere/veileder_til_drik kevannsforskriften.1334/binary/Veileder%20til%20drikkevannsforskriften [Accessed 30.09 2014].

OSLO KOMMUNE VANN- OG AVLØPSETATEN. 2012. *Restriksjoner* [Online]. Oslo: Oslo Kommmune. Available: http://www.vann-og-avlopsetaten.oslo.kommune.no/vannet_vart/drikkevann/vannkilder/restriksjoner/ [Accessed 18.10 2014].

OSLO KOMMUNE VANN- OG AVLØPSETATEN. 2014a. *Oset Water Treatment Plant* [Online]. Oslo: Oslo Kommune vann- og avløpsetaten. Available: http://www.vann-og-avlopsetaten.oslo.kommune.no/getfile.php/vann-%20og%20avl%C3%B8psetaten%20%28VAV%29/Internett%20%28VAV%29/Dokumenter/Ny e%20Oset/Oset-%20teknisk%20brosjyre%202008.pdf [Accessed 17.10 2014].

OSLO KOMMUNE VANN- OG AVLØPSETATEN. 2014b. *Water Supply in Oslo* [Online]. Oslo: Oslo Kommune vann- og avløpsetaten. Available: http://www.vann-og-avlopsetaten.oslo.kommune.no/getfile.php/vann-%20og%20avl%C3%B8psetaten%20%28VAV%29/Internett%20%28VAV%29/Pdf/Watersupply %20%20aug%20brosjyre%202008%20MTIxOTkxMjg0ODEwNjk0MTU1Mz.pdf [Accessed 17.10 2014].

PAYMENT, P., WAITE, M. & DUFOUR, A. 2003. Introducing parameters for the assessment of drinking water quality. *Assessing microbial safety of drinking water***,** 47.

RANDOM HISTORY. 2007. *A History of Drinking Water Treatment* [Online]. Available: http://www.randomhistory.com/1-50/001water.html [Accessed 23.08 2014].

SNOZZI, M. 2001. Nicholas J. Ashbolt, Willie OK Grabow and. *Water Quality Guidelines, Standards and Health: Assessment of risk and risk management for water-related infectious disease***,** 289.

SSB. 2014. *Population, 1 January 2014, estimated* [Online]. Oslo: SSB. Available: http://www.ssb.no/en/befolkning/statistikker/folkemengde/aar-berekna/2013-12-19 [Accessed 14.10 2014].

STANFIELD, G., LECHEVALLIER, M. & SNOZZI, M. 2003. Treatment efficiency. *Assessing microbial safety of drinking water***,** 159.

THE ENVIRONMENTAL PROTECTION AGENCY OF IRELAND. 2011. *Water Treatment Manual: Disinfection* [Online]. Wexford,: Office of Environmental Enforcement. Available: http://www.epa.ie/pubs/advice/drinkingwater/watertreatmentmanualdisinfection.html#.VE oI3xbdoXs [Accessed 24.10 2014].

THE NATIONAL ACADEMY OF SCIENCES. 2014. *What You Need To Know About Infectious Disease Glossary* [Online]. Available: http://needtoknow.nas.edu/id/glossary/ [Accessed 01.10 2014].

TRUSSELL, R. R. 2005. *Water Treatment: Where have we been and where are have we been and where are we going?* [Online]. Pasadena: Trussell Technologies, Inc. Available: http://www.trusselltech.com/uploads/media_items/historical-water-treatment-with-a-future-perspective.original.pdf [Accessed 26.09 2014].

ØDEGAARD, H., STEIN, Ø. & ESA, M. 2009. Veiledning til bestemmelse av god desinfeksjonspraksis. *Norsk Vann Rapport.* Hamar: Norsk Vann

ØDEGÅRD, H. 2014. Microbial barrier analysis (MBA)- a guideline. Hamar: Norsk Vann.